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Environmental Science 16e

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About the Cover

A major new theme for this edition of *Environmental Science* is *biomimicry* or *learning from nature*. In recent years, scientists have been studying nature in an effort to learn how a variety of life has existed on the earth for 3.8 billion years despite several catastrophic changes in the planet's environmental conditions. They include strikes by huge meteorites, long warming periods and ice ages, and five mass extinctions—each wiping out 30% to 90% of the world's species.

Examples of how life on the earth has sustained itself for 3.8 billion years are being used to help us develop technologies and solutions to the environmental problems we face and to learn how to live more sustainably. For example, the front cover of this book shows a humpback whale. These whales, which can be 12 to 15 meters (40 to 50 feet) long and weigh as much as 36,400 kilograms (80,000 pounds), can move swiftly and turn quickly as they swim in ocean water. Research, including wind-tunnel tests, shows that this dexterity is due to bumps called tubercles along the edges of their flippers (see photo at left), which somehow help whales move efficiently. A company called WhalePower is using this lesson from nature in designing the blades of wind turbines (see photo below) to be more efficient in producing electricity. Wind power is the world's second-fastest growing source of electricity, as discussed in detail in Chapter 13. Throughout this book, we provide a number of other examples of biomimicry, or learning from the earth.

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Brief Contents

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Preface

We wrote this book to help you achieve three important goals: *first*, to explain to your students the basics of environmental science; *second*, to help your students in using this scientific foundation to understand the environmental problems that we face and to evaluate possible solutions to them; and *third*, to inspire them to make a difference in how we treat the earth on which our lives and economies depend, and thus in how we treat ourselves and our descendants.

We view environmental problems and possible solutions to them through the lens of *sustainability*—the integrating theme of this book. We believe that most people can live comfortable and fulfilling lives and that societies will be more prosperous when sustainability becomes one of the chief measures by which personal choices and public policies are made. Our belief in a sustainable future is foundational to this textbook, and we consistently challenge students to work toward attaining it.

For this reason, we are happy to be continuing our partnership with *National Geographic Learning*. One result has been the addition of many stunning and informative photographs, numerous maps, and several stories of National Geographic Explorers—people who are making a positive difference in the world. With these tools, we continue to tell of the good news from various fields of environmental science, hoping to inspire young people to commit themselves to making our world a more sustainable place to live for their own and future generations.

What's New in This Edition?

- *An emphasis on learning from nature*: We establish this in the Core Case Study for Chapter 1, *Learning from the Earth*, which introduces the principles of biomimicry. We further explore the principles and applications of biomimicry in a Science Focus box and a feature article on biomimicry pioneer Janine Benyus later in the chapter. In our research, we have found that biomimicry presents a growing number of opportunities for using nature's genius, as Benyus puts it, to make our own economies and lifestyles more sustainable.
- A new feature called *Learning from Nature*—a set of brief summaries of specific applications of biomimicry in various industries and fields of research—appearing in most chapters.
- An *attractive and efficient new design* with visual elements inspired by National Geographic Learning to capture and hold students' attention.
- *New Core Case Studies* for 8 of the book's 17 chapters bring important real-world stories to the forefront for use in applying those chapters' concepts and principles.
- A *heavier emphasis on data analysis*, with new questions added to the captions of all figures that involve data graphs, designed to get students to analyze the data represented in the figure. These complement the exercises we provide at the ends of chapters.
- A new feature called *Econumbers*, which highlight key statistics that will be helpful for students to remember.
- *New treatment of the history* of environmental conservation and protection in the United States.

Sustainability Is the Integrating Theme of This Book

Sustainability, a watchword of the 21st century for those concerned about the environment, is the overarching theme of this textbook. You can see the sustainability emphasis by looking at the Brief Contents (p. v).

Six principles of sustainability play a major role in carrying out this book's sustainability theme. These principles are introduced in Chapter 1. They are depicted in Figure 1.2 (p. 6), Figure 1.7 (p. 9), and on the inside back cover of the book and are used throughout the book, with each reference marked in the margin by  (see pp. 47 and 314).

We use the following five major subthemes to integrate material throughout this book:

- ***Natural Capital.*** Sustainability depends on the natural resources and ecosystem services that support all life and economies. See Figures 1.3, p. 7, and 7.16, p. 152.
- ***Natural Capital Degradation.*** We describe how human activities can degrade natural capital. See Figures 6.3, p. 111, and 10.11, p. 236.
- ***Solutions.*** We present existing and proposed solutions to environmental problems in a balanced manner and challenge students to use critical thinking to evaluate them. See Figures 9.12, p. 202, and 13.23, p. 346.
- ***Trade-Offs.*** The search for solutions involves trade-offs, because any solution requires weighing advantages against disadvantages. Our Trade-Offs diagrams located in several chapters present the benefits and drawbacks of various environmental technologies and solutions to environmental problems. See Figures 10.18, p. 242, and 16.10, p. 458.
- ***Individuals Matter.*** Throughout the book, Individuals Matter boxes and some of the Case Studies describe what various scientists and concerned citizens

(including several National Geographic Explorers) have done to help us work toward sustainability (see pp. IM 1.1, p. 9, IM 7.1, p. 147, and IM 15.1, p. 430). Also, a number of What Can You Do? diagrams describe how readers can deal with the problems we face (see Figures 8.11, p. 178, and 11.20, p. 279). Eight especially important ways in which individuals can live more lightly on the earth are summarized in Figure 17.24 (p. 499).

Other Successful Features of This Textbook

- ***Up-to-Date Coverage.*** Our textbooks have been widely praised for keeping users up to date in the rapidly changing field of environmental science. Since the last edition, we have updated the information and concepts in this book using thousands of articles and reports published between 2013 and 2017. Major new or updated topics include biomimicry, fracking, the growing problem of lead poisoning in public water supplies, ocean acidification, and developments in battery technology. Other such topics include synthetic biology; threats to the Monarch butterfly; Chinese, Indian, and U.S. population trends; African Savanna; elephants as keystone species; climate change and species extinction; wildfires in the western United States; jellyfish populations explosion; marine protected areas and marine reserves; effects of overfertilization; aquaculture effects on mangroves; organic no-till farming; deep-sea mining; costs of producing heavy oil from tar sands; increased natural gas production in the United States; methane leaks from natural gas production; coal burning and air pollution in China; shared (community) solar power; C. diff superbug; Ebola virus; effects of smoking and e-cigarette use; deaths from air pollution in China and India; case study on climate change in Alaska; and the overall drop in coal use.
- ***Concept-Centered Approach.*** To help students focus on the main ideas, we built each major chapter section around a key question and one to three key concepts, which state the section's most important take-away messages. In each chapter, all key questions are listed at the front of the chapter, and each chapter section begins with its key question and concepts (see pp. 3 and 89). Also, the concept applications are highlighted and referenced throughout each chapter.
- ***Science-Based.*** Chapters 2–7 cover scientific principles important to the course and discuss how scientists work (see Brief Contents, p. v). Important environmental science topics are explored in depth in Science Focus boxes distributed among the chapters throughout the book (see pp. 19 and 76) and integrated throughout the book in various Case Studies (see pp. 76 and 83) and in numerous figures.
- ***Global Coverage.*** This book also provides a global perspective, first on the ecological level, revealing how all the world's life is connected and sustained within the biosphere, and second, through the use of information and images from around the world. This includes more than 30 maps in the basic text and available on the Learning Path. At the end of each chapter is a Global Environment Watch exercise that applies this global perspective.
- ***Core Case Studies.*** Each chapter opens with a Core Case Study (see pp. 28 and 90), which is applied throughout the chapter. These applications are indicated by the notation (**Core Case Study**) wherever they occur (see pp. 9 and 74). Each chapter ends with a *Tying It All Together* box (see pp. 64 and 163), which connects the Core Case Study and other material in the chapter to some or all of the principles of sustainability.
- ***Case Studies.*** In addition to the 17 Core Case Studies, more than 40 additional Case Studies (see pp. 76, 83, and 110) appear throughout the book (and are listed in the Detailed Contents, pp. vi – xiv). Each of these provides an in-depth look at specific environmental problems and their possible solutions.
- ***Critical Thinking.*** The Learning Skills section (p. xxiv) describes critical thinking skills, and specific critical thinking exercises are used throughout the book in several ways:
  - In dozens of *Thinking About* exercises that ask students to analyze material immediately after it is presented (see pp. 31 and 121).
  - In all *Science Focus* boxes.
  - In dozens of *Connections* boxes that stimulate critical thinking by exploring often surprising connections related to environmental problems (see pp. 53 and 122).
  - In the captions of many of the book's figures (see Figures 1.11, p. 14, and 3.10, p. 53).
  - In end-of-chapter *Critical Thinking* questions (see pp. 41 and 164).
- ***Visual Learning.*** With a new design heavily influenced by material from National Geographic and new photographs, many of them from the archives of National Geographic, this is the most

visually interesting environmental science textbook available (see Figure 1.6, p. 8; chapter-opening photo, pp. 26-27; and Figure 5.10, p. 98). Add in the more than 130 diagrams, each designed to present complex ideas in understandable ways relating to the real world (see Figures 3.12, p. 54, and 7.8, p. 141), and you also have one of the most visually informative textbooks available.

- ***Flexibility.*** To meet these diverse needs of hundreds of widely varying environmental science courses, we have designed a highly flexible book that allows instructors to vary the order of chapters and sections within chapters without exposing students to terms and concepts that could confuse them. We recommend that instructors start with Chapter 1, which defines basic terms and gives an overview of sustainability, population, pollution, resources, and economic development issues that are discussed throughout the book. This provides a springboard for instructors to use other chapters in almost any order. One often-used strategy is to follow Chapter 1 with Chapters 2–7, which introduce basic science and ecological concepts. Instructors can then use the remaining chapters in any order desired. Some instructors follow Chapter 1 with Chapter 17 on environmental economics, politics, and worldviews, before proceeding to the chapters on basic science and ecological concepts. Instructors whose students have access to MindTap have a second level of flexibility in the supplemental information, maps, and graphs provided there. Examples include basic chemistry (Supplement 3), maps and map analysis (Supplement 4), and environmental data and data analysis (Supplement 5).
- ***In-Text Study Aids.*** Each chapter begins with a list of *Key Questions* showing how the chapter is organized (see p. 107). Wherever a new *key term* is introduced and defined, it appears in boldface type and all such terms are summarized in the glossary at the end of the book. In most chapters, *Thinking About* exercises reinforce learning by asking students to think critically about the implications of various environmental issues and solutions immediately after they are discussed in the text (see pp. 13 and 121). The captions of many figures contain similar questions that get students to think about the figure content (see pp. 14 and 53). In their reading, students also encounter *Connections* boxes, which briefly describe connections between human activities and environmental consequences, environmental and social issues, and environmental issues and solutions (see pp. 53 and 122). New to this edition is a set of *Learning from Nature* boxes that give quick summaries of biomimicry applications (see pp. 53 and 77). The text of each chapter concludes with three *Big Ideas* (see pp. 39 and 129), which summarize and reinforce three of the major take-away messages from each chapter. Finally, a *Tying It All Together* section relates the Core Case Study and other chapter content to the principles of sustainability (see pp. 22 and 85). These concluding features reinforce the main messages of the chapter along with the themes of sustainability to give students a stronger understanding of how they all tie together.

Each chapter ends with a *Chapter Review* section containing a detailed set of review questions that include all the chapter's key terms in bold type; *Critical Thinking* questions that encourage students to think about and apply what they have learned to their lives; *Doing Environmental Science*—an exercise that will help students experience the work of various environmental scientists; a *Global Environment Watch* exercise taking student to Cengage's GREENR site where they can use this tool for interesting research related to chapter content; and a *Data Analysis* or *Ecological Footprint Analysis* problem built around ecological footprint data or some other environmental data set (see pp. 102–105 and 256–259).

Supplements for Instructors

- ***MindTap.*** MindTap is a new approach to highly person-alized online learning. Beyond an eBook, homework solution, digital supplement, or premium website, MindTap is a digital learning platform that works alongside your campus Learning Management System (LMS) to deliver course curriculum across the range of electronic devices in your life. MindTap is built on an "app" model allowing enhanced digital collaboration and delivery of engaging content across a spectrum of Cengage and non-Cengage resources. Visit the Instructor's Companion Site for tips on maximizing your MindTap course.
- ***Instructor's Companion Site.*** Everything you need for your course in one place! This collection of book-specific lecture and class tools is available online via www.cengage.com/login. Access and download PowerPoint presentations, images, instructor's manual, videos, and more.
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Help Us Improve This Book or Its Supplements

Let us know how you think this book can be improved. If you find any errors, bias, or confusing explanations, please e-mail us about them at:

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Most errors can be corrected in subsequent printings of this edition, as well as in future editions.

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G. Tyler Miller

Scott E. Spoolman

Pedagogy Contributors

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School (Granada Hills, California); Anthony Weston, State University of New York at Stony Brook; Raymond White, San Francisco City College; Douglas Wickum, University of Wisconsin, Stout; Charles G. Wilber, Colorado State University; Nancy Lee Wilkinson, San Francisco State Univer-sity; John C. Williams, College of San Mateo; Ray Williams, Rio Hondo College; Roberta Williams, University of Nevada, Las Vegas; Samuel J. Williamson, New York University; Dwina Willis, Freed-Hardeman University; Ted L. Willrich, Oregon State University; James Winsor, Pennsylvania State University; Fred Witzig, University of Minnesota at Duluth; Martha Wolfe, Elizabethtown Community and Technical College; George M. Woodwell, Woods Hole Research Center; Peggy J. Wright, Columbia College; Todd Yetter, University of the Cumberlands; Robert Yoerg, Belmont Hills Hospital; Hideo Yonenaka, San Francisco State University; Brenda Young, Daemen College; Anita Závodská, Barry University; Malcolm J. Zwolinski, University of Arizona.

About the Authors

G. TYLER MILLER

G. Tyler Miller has written 64 textbooks for introductory courses in environmental science, basic ecology, energy, and environmental chemistry. Since 1975, Miller's books have been the most widely used textbooks for environmental science in the United States and throughout the world. They have been used by almost 3 million students and have been translated into eight languages.

Miller has a professional background in chemistry, physics, and ecology. He has a PhD from the University of Virginia and has received two honorary doctoral degrees for his contributions to environmental education. He taught college for 20 years, developed one of the nation's first environmental studies programs, and developed an innovative interdisciplinary undergraduate science program before deciding to write environmental science textbooks full time in 1975. Currently, he is the president of Earth Education and Research, devoted to improving environmental education.

He describes his hopes for the future as follows:

If I had to pick a time to be alive, it would be the next 75 years. Why? First, there is overwhelming scientific evidence that we are in the process of seriously degrading our own life-support system. In other words, we are living unsustainably. Second, within your lifetime we have the opportunity to learn how to live more sustainably by working with the rest of nature, as described in this book.

I am fortunate to have three smart, talented, and wonderful sons—Greg, David, and Bill. I am especially privileged to have Kathleen as my wife, best friend, and research associate. It is inspiring to have a brilliant, beautiful (inside and out), and strong woman who cares deeply about nature as a lifemate. She is my hero. I dedicate this book to her and to the earth.

SCOTT E. SPOOLMAN

Scott Spoolman is a writer with more than 30 years of experience in educational publishing. He has worked with Tyler Miller since 2003 as a contributing editor and lately as coauthor of *Living in the Environment*, *Environmental Science*, and *Sustaining the Earth*. With Norman Myers, he coauthored *Environmental Issues and Solutions: A Modular Approach*.

Spoolman holds a master's degree in science journalism from the University of Minnesota. He has authored numerous articles in the fields of science, environmental engineering, politics, and business. He has also worked as a consulting editor in the development of over 70 college and high school textbooks in the fields of the natural and social sciences.

In his free time, he enjoys exploring the forests and waters of his native Wisconsin along with his family—his wife, environmental educator Gail Martinelli, and his children, Will and Katie.

Spoolman has the following to say about his collaboration with Tyler Miller:

I am honored to be working with Tyler Miller as a coauthor to continue the Miller tradition of thorough, clear, and engaging writing about the vast and complex field of environmental science. I share Tyler Miller's passion for ensuring that these textbooks and their multimedia supplements will be valuable tools for students and instructors. To that end, we strive to introduce this interdisciplinary field in ways that will be not only informative and sobering but also tantalizing and motivational.

If the flip side of any problem is an opportunity, then this truly is one of the most exciting times in history for students to start an environmental career. Environmental problems are numerous, serious, and daunting, but their possible solutions generate exciting new career opportunities. We place high priorities on inspiring students with these possibilities, challenging them to maintain a scientific focus, pointing them toward rewarding and fulfilling careers, and in doing so, working to help sustain life on Earth.

From the Authors

My Environmental Journey— *G. Tyler Miller*

My environmental journey began in 1966 when I heard a lecture on population and pollution problems by Dean Cowie, a biophysicist with the U.S. Geological Survey. It changed my life. I told him that if even half of what he said was valid, I would feel ethically obligated to spend the rest of my career teaching and writing to help students learn about the basics of environmental science. After spending six months studying the environmental literature, I concluded that he had greatly underestimated the seriousness of these problems.

I developed an undergraduate environmental studies program and in 1971 published my first introductory environmental science book, an interdisciplinary study of the connections between energy laws (thermodynamics), chemistry, and ecology. In 1975, I published the first edition of *Living in the Environment*. Since then, I have completed multiple editions of this textbook, and of three, others derived from it, along with other books.

Beginning in 1985, I spent 10 years in the deep woods living in an adapted school bus that I used as an environmental science laboratory and writing environmental science textbooks. I evaluated the use of passive solar energy design to heat the structure; buried earth tubes to bring in air cooled by the earth (geothermal cooling) at a cost of about $1 per summer; set up active and passive systems to provide hot water; installed an energy-efficient instant hot water heater powered by LPG; installed energy-efficient windows and appliances and a composting (waterless) toilet; employed biological pest control; composted food wastes; used natural planting (no grass or lawnmowers); gardened organically; and experimented with a host of other potential solutions to major environmental problems that we face.

I also used this time to learn and think about how nature works by studying the plants and animals around me. My experience from living in nature is reflected in much of the material in this book. It also helped me develop the six simple principles of sustainability that serve as the integrating theme for this textbook and to apply these principles to living my life more sustainably.

I came out of the woods in 1995 to learn about how to live more sustainably in an urban setting where most people live. Since then, I have lived in two urban villages, one in a small town and one within a large metropolitan area.

Since 1970, my goal has been to use a car as little as possible. Since I work at home, I have a "low-pollute commute" from my bedroom to a chair and a laptop computer. I usually take one or two airplane trips a year to visit my sister and my publisher.

As you will learn in this book, life involves a series of environmental trade-offs. Like most people, I still have a large environmental impact, but I continue to struggle to reduce it. I hope you will join me in striving to live more sustainably and sharing what you learn with others. It is not always easy, but it sure is fun.

Cengage Learning's Commitment to Sustainable Practices

We the authors of this textbook and Cengage Learning, the publisher, are committed to making the publishing process as sustainable as possible. This involves four basic strategies: ■ *Using sustainably produced paper.* The book publishing industry is committed to increasing the use of recycled fibers, and Cengage Learning is always looking for ways to increase this content. Cengage Learning works with paper suppliers to maximize the use of paper that contains only wood fibers that are certified as sustainably produced, from the growing and cutting of trees all the way through paper production. ■ *Reducing resources used per book.* The publisher has an ongoing program to reduce the amount of wood pulp, virgin fibers, and other materials that go into each sheet of paper used. New, specially designed printing presses also reduce the amount of scrap paper produced per book. ■ *Recycling.* Printers recycle the scrap paper that is produced as part of the printing process. Cengage Learning also recycles waste cardboard from shipping cartons, along with other materials used in the publishing process. ■ *Process improvements.* In years past, publishing has involved using a great deal of paper and ink for the writing and editing of manuscripts, copyediting, reviewing page proofs, and creating illustrations. Almost all of these materials are now saved through use of electronic files. Very little paper and ink were used in the preparation of this textbook.

Learning Skills

Students who can begin early in their lives to think of things as connected, even if they revise their views every year, have begun the life of learning.
Mark Van Doren

Why Is It Important to Study Environmental Science?

Welcome to **environmental science**—an *interdisciplinary* study of how the earth works, how we interact with the earth, and how we can deal with the environmental problems we face. Because environmental issues affect every part of your life, the concepts, information, and issues discussed in this book and the course you are taking will be useful to you now and throughout your life.

Understandably, we are biased, but *we strongly believe that environmental science is the single most important course that you could take*. What could be more important than learning about the earth's life-support system, how our choices and activities affect it, and how we can reduce our growing environmental impact? Evidence indicates strongly that we will have to learn to live more sustainably by reducing our degradation of the planet's life-support system. We hope this book will inspire you to become involved in this change in the way we view and treat the earth, which sustains us, our economies, and all other living things.

You Can Improve Your Study and Learning Skills

Maximizing your ability to learn involves trying to *improve your study and learning skills*. Here are some suggestions for doing so:

Develop a passion for learning. This is a key to success.

Get organized. Planning is a key life skill.

Make daily to-do lists in writing. Put items in order of importance, focus on the most important tasks, and assign a time to work on these items. Shift your schedule as needed to accomplish the most important items.

Set up a study routine in a distraction-free environment. Develop a written daily study schedule and stick to it. Study in a quiet, well-lit space. Take breaks every hour or so. During each break, take several deep breaths and move around; this will help you stay more alert and focused.

Avoid procrastination. Do not fall behind on your reading and other assignments. Set aside a particular time for studying each day and make it a part of your daily routine.

Make hills out of mountains. It can be difficult to read an entire chapter or book, write a paper, or cram for a test within a short period of time. Instead, break these large tasks (mountains) down into a series of small tasks (hills). Each day, read a few pages of the assigned book or chapter, write a few paragraphs of the paper, and review what you have studied and learned.

Ask and answer questions as you read. For example, "What is the main point of a particular subsection or paragraph?" Relate your own questions to the key questions and key concepts addressed in each major chapter section and listed in the review section at the end of each chapter.

Focus on key terms. Use the glossary in your textbook to look up the meaning of terms or words you do not understand. This book shows all key terms in **bold** type and lesser, but still important, terms in *italicized* type. The *Chapter Review* questions at the end of each chapter also include the chapter's key terms in bold. Flash cards for testing your mastery of key terms for each chapter are available on the website for this book, or you can make your own.

Interact with what you read. You could mark key sentences and paragraphs with a highlighter or pen or with asterisks and notes in the margin. You might also mark important pages that you want to return to by adding notes or highlighting material or by folding down page corners.

Review to reinforce learning. Before each class session, review the material you learned in the previous session and read the assigned material.

Become a good note taker. Learn to write down the main points and key information from any lecture. Review, fill in, and organize your notes as soon as possible after each class.

Check what you have learned. At the end of each chapter, you will find review questions that cover all of the key material in each chapter section. We suggest that you try to answer each of these questions after studying each chapter section. Waiting to do this for the entire chapter after you complete it can be overwhelming.

Write out answers to questions to focus and reinforce learning. Write down your answers to the critical thinking questions found in the *Thinking About* boxes throughout the chapters, in many figure captions, and at the end

of each chapter. These questions are designed to inspire you to think critically about key ideas and connect them to other ideas and to your own life. Also, write down your answers to all chapter-ending review questions. The website for each chapter has an additional detailed list of review questions for that chapter. Save your answers for review and test preparation.

Use the buddy system. Study with a friend or become a member of a study group to compare notes, review material, and prepare for tests. Explaining something to someone else is a great way to focus your thoughts and reinforce your learning. Attend any review sessions offered by instructors or teaching assistants.

Learn your instructor's test style. Does your instructor emphasize multiple-choice, fill-in-the-blank, true-or-false, factual, or essay questions? How much of the test will come from the textbook and how much from lecture material? Adapt your learning and studying methods to this style.

Become a good test taker. Avoid cramming. Eat well and get plenty of sleep before a test. Arrive on time or early. Calm yourself and increase your oxygen intake by taking several deep breaths. (Do this also about every 10–15 minutes while taking the test.) Look over the test and answer the questions you know well first. Then work on the harder ones. Use the process of elimination to narrow down the choices for multiple-choice questions. For essay questions, organize your thoughts before you start writing. If you don't understand what a question means, make an educated guess. You might earn some partial credit and avoid getting a zero. Another strategy for getting some credit is to show your knowledge and reasoning by writing something like this: "If this question means so and so, then my answer is _____."

Develop an optimistic but realistic outlook. Try to be a "glass is half-full" rather than a "glass is half-empty" person. Pessimism, fear, anxiety, and excessive worrying (especially over things you cannot control) are destructive and lead to inaction.

Take time to enjoy life. Every day, take time to laugh and enjoy nature, beauty, and friendship.

You Can Improve Your Critical Thinking Skills

Critical thinking involves developing skills to analyze information and ideas, judge their validity, and make decisions. Critical thinking helps you distinguish between facts and opinions, evaluate evidence and arguments, and take and defend informed positions on issues. It also helps you integrate information, see relationships, and apply your knowledge to dealing with various problems and decisions. Here are some basic skills for learning how to think more critically.

Question everything and everybody. Be skeptical, as any good scientist is. Do not believe everything you hear and read, including the content of this textbook, without evaluating the information you receive. Seek other sources and opinions.

Identify and evaluate your personal biases and beliefs. Each of us has biases and beliefs taught to us by our parents, teachers, friends, role models, and our own experience. What are your basic beliefs, values, and biases? Where did they come from? What assumptions are they based on? How sure are you that your beliefs, values, and assumptions are right and why? According to the American psychologist and philosopher William James, "A great many people think they are thinking when they are merely rearranging their prejudices."

Be open-minded and flexible. Be open to considering different points of view. Suspend judgment until you gather more evidence, and be willing to change your mind. Recognize that there may be a number of useful and acceptable solutions to a problem, and that very few issues are either black or white. Try to take the viewpoints of those you disagree with to better understand their thinking. There are trade-offs involved in dealing with any environmental issue, as you will learn in this book.

Be humble about what you know. Some people are so confident in what they know that they stop thinking and questioning. To paraphrase American writer Mark Twain, "It's what we know is true, but just ain't so, that hurts us."

Find out how the information related to an issue was obtained. Are the statements you heard or read based on firsthand knowledge and research or on hearsay? Are unnamed sources used? Is the information based on reproducible and widely accepted scientific studies or on preliminary scientific results that may be valid but need further testing? Is the information based on a few isolated stories or experiences or on carefully controlled studies that have been reviewed by experts in the field involved? Is it based on unsubstantiated and dubious scientific information or beliefs?

Question the evidence and conclusions presented. What are the conclusions or claims based on the information you're considering? What evidence is presented to support them? Does the evidence support them? Is there a need to gather more evidence to test the conclusions? Are there other, more reasonable conclusions?

Try to uncover differences in basic beliefs and assumptions. On the surface, most arguments or disagreements involve differences of opinion about the validity or mean-

ing of certain facts or conclusions. Scratch a little deeper and you will find that many disagreements are based on different (and often hidden) basic assumptions concerning how we look at and interpret the world around us. Uncovering these basic differences can allow the parties involved to understand one another's viewpoints and to agree or disagree about their basic assumptions, beliefs, or principles.

Try to identify and assess any motives on the part of those presenting evidence and drawing conclusions. What is their expertise in this area? Do they have any unstated assumptions, beliefs, biases, or values? Do they have a personal agenda? Can they benefit financially or politically from acceptance of their evidence and conclusions? Would investigators with different basic assumptions or beliefs take the same data and come to different conclusions?

Expect and tolerate uncertainty. Recognize that scientists cannot establish absolute proof or certainty about anything. However, the goal of science is to provide a high degree of certainty (at least 90%) about its data and the scientific theories used to explain the data.

Check the arguments you hear and read for logical fallacies and debating tricks. Here are six of many examples of such debating tricks. *First*, attack the presenter of an argument rather than the argument itself. *Second*, appeal to emotion rather than facts and logic. *Third*, claim that if one piece of evidence or one conclusion is false, then all other related pieces of evidence and conclusions are false. *Fourth*, say that a conclusion is false because it has not been scientifically proven. Scientists never prove anything absolutely, but they strive to establish a high degree of certainty (at least 90%) about their results and theories. *Fifth*, inject irrelevant or misleading information to divert attention from important points. *Sixth*, present only either/or alternatives when there may be a number of options.

Do not believe everything you read on the Internet. The Internet is a wonderful and easily accessible source of information that includes alternative explanations and opinions on almost any subject or issue—much of it not available in the mainstream media and scholarly articles. Blogs of all sorts have become a major source of information, more important than standard news media for some people. However, because the Internet is so open, anyone can post anything they want to some blogs and other websites with no editorial control or review by experts. As a result, evaluating information on the Internet is one of the best ways to put into practice the principles of critical thinking discussed here. Use and enjoy the Internet, but think critically and proceed with caution.

Develop principles or rules for evaluating evidence. Develop a written list of principles to serve as guidelines for evaluating evidence and claims. Continually evaluate and modify this list on the basis of your experience.

Become a seeker of wisdom, not a vessel of information. Many people believe that the main goal of their education is to learn as much as they can by gathering more and more information. We believe that the primary goal is to learn how to sift through mountains of facts and ideas to find the few *nuggets of wisdom* that are the most useful for understanding the world and for making decisions. This book is full of facts and numbers, but they are useful only to the extent that they lead to an understanding of key ideas, concepts, connections, and scientific laws and theories. The major goals of the study of environmental science are to find out how nature works and sustains itself (*environmental wisdom*) and to use *principles of environmental wisdom* to help make human societies and economies more sustainable, more just, and more beneficial and enjoyable for all. As writer Sandra Carey observed, "Never mistake knowledge for wisdom. One helps you make a living; the other helps you make a life."

To help you practice critical thinking, we have supplied questions throughout this book, found within each chapter in brief boxes labeled *Thinking About*, in the captions of many figures, and at the end of each chapter. There are no right or wrong answers to many of these questions. A good way to improve your critical thinking skills is to compare your answers with those of your classmates and to discuss how you arrived at your answers.

Use the Learning Tools We Offer in This Book

We have included a number of tools throughout this textbook that are intended to help you improve your learning skills and apply them. First, consider the *Key Concepts* list at the beginning of each chapter section. You can use these to preview a chapter and to review the material after you've read it.

Next, note that we use three different special notations throughout the text. Each chapter opens with a **Core Case Study**, and each time we tie material within the chapter back to this core case, we note it in bold, colored type as we did in this sentence. You will also see two icons appearing regularly in the text margins. When you see the *sustainability* icon 

, you will know that you have just read something that relates directly to the overarching theme of this text, summarized by our six **principles of sustainability**, which are introduced in Figures 1.2, p. 6, and 1.7, p. 9, and summarized on the inside back cover of this book. The *Good News* icon 

appears near each of many examples of successes that people have had in dealing with the environmental challenges we face.

We also include several brief *Connections* boxes to show you some of the often surprising connections between environmental problems or processes and some of the products and services we use every day or some of the activities we partake in. These, along with the *Thinking About* boxes scattered throughout the text (both designated by the *Consider This* heading), are intended to get you to think carefully about the activities and choices we take for granted and about how they might affect the environment.

New to this edition is a third Consider This feature called *Learning from Nature*. Most chapters contain one or more of these, each of which gives an example of how scientists and engineers are applying nature's lessons through biomimicry (a major new theme of this edition) to solve a problem or to improve a technology.

At the end of the chapter, we list what we consider to be the *three big ideas* that you should take away from each chapter. Following that list in each chapter is a *Tying It All Together* box. This feature quickly reviews the Core Case Study and how key chapter material relates to it, and it explains how the principles of sustainability can be applied to deal with challenges discussed in the core case study and throughout the chapter.

Finally, we have included a *Chapter Review* section at the end of each chapter, with questions listed for each chapter section. These questions cover all of the key material and key terms in each chapter. In each chapter, they are followed by *Critical Thinking* questions that help you apply chapter material to the real world and to your own life; a *Doing Environmental Science* exercise to help you experience the work of scientists; a *Global Environment Watch* exercise, in which you can use the GREENR online global environmental database; and a *Data Analysis* or *Ecological Footprint Analysis* exercise to help you learn how to interpret and use scientific research data.

Know Your Own Learning Style

People have different ways of learning and it can be helpful to know your own learning style. *Visual learners* learn best from reading and viewing illustrations and diagrams. *Auditory learners* learn best by listening and discussing. They might benefit from reading aloud while studying and using a tape recorder in lectures for study and review. *Logical learners* learn best by using concepts and logic to uncover and understand a subject rather than relying mostly on memory.

This book and its supporting website material contain plenty of tools for all types of learners. Visual learners can benefit from using flash cards (available on the website) to memorize key terms and ideas. This is a highly visual book with many photographs and diagrams carefully selected to illustrate important ideas, concepts, and processes. Auditory learners can make use of our *ReadSpeaker app* in MindTap, which can read the chapter aloud in various voices and speeds. For logical learners, the book is organized by key concepts that are revisited throughout any chapter and related carefully to other concepts, major principles, and case studies and other examples. We urge you to become aware of your own learning style and make the most of these various tools.

This Book Presents a Positive, Realistic Environmental Vision of the Future

Our goal is to present a positive vision of our environmental future based on realistic optimism. To do so, we strive not only to present the facts about environmental issues but also to give a balanced presentation of different viewpoints. We consider the advantages and disadvantages of various technologies and proposed solutions to environmental problems. We argue that environmental solutions usually require *trade-offs* among opposing parties, and that the best solutions are *win-win* solutions where everyone benefits. We also present the good news as well as the bad news about efforts to deal with environmental problems.

One cannot study a subject as important and complex as environmental science without forming conclusions, opinions, and beliefs. However, we argue that any such results should be based on use of critical thinking to evaluate conflicting positions and to understand the trade-offs involved in most environmental solutions. To that end, we emphasize critical thinking throughout this textbook, and we encourage you to develop a practice of thinking critically about everything you read and hear, both in school and throughout your life.

Help Us Improve This Book

Researching and writing a book that covers and connects the numerous major concepts from the wide variety of environmental science disciplines is a challenging and exciting task. Almost every day, we learn about some new connection in nature. However, in a book this complex, there are bound to be some errors—some typographical mistakes that slip through and some statements that you might question, based on your knowledge and research. We invite you to contact us to correct any errors you find, point out any bias you see, and suggest ways to improve this book. Please e-mail your suggestions to Tyler Miller at mtg89@hotmail.com or Scott Spoolman at spoolman@tds.net.

Now start your journey into this fascinating and important study of how the earth's life-support system works and how we can leave the planet in a condition at least as good as what we now enjoy. Have fun.

Supplements for Students

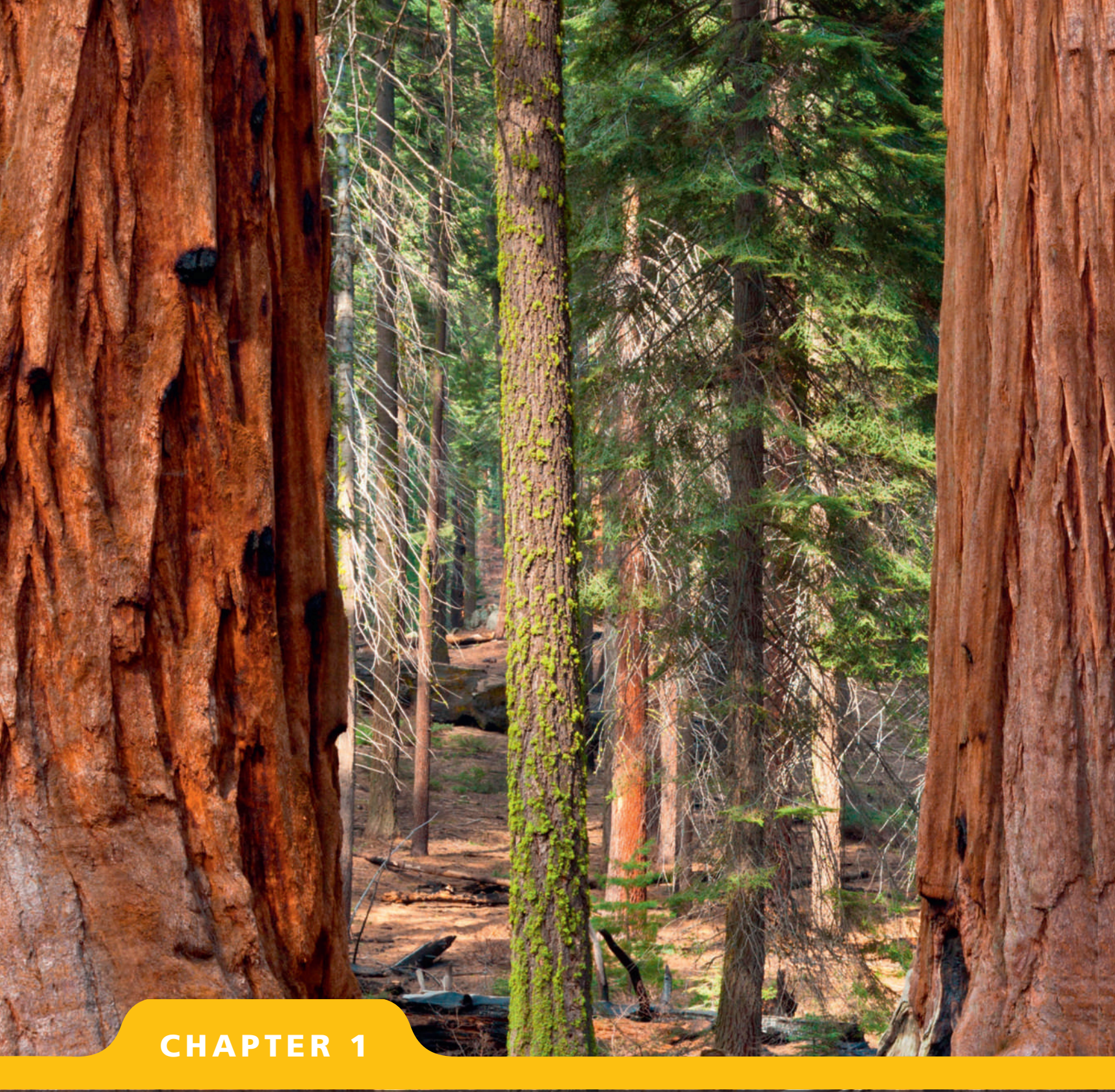
You have a large variety of electronic and other supplemental materials available to you to help you take your learning experience beyond this textbook:

- ***Environmental Science MindTap.*** MindTap provides you with the tools you need to better manage your limited time. You can complete assignments whenever and wherever you are ready to learn with course material specifically customized for you by your instructor and streamlined in one proven, easy-to-use interface. MindTap includes an online homework solution that helps you learn and understand key concepts through focused assignments, exceptional text-art integration, and immediate feedback. With these resources and an array of tools and apps—from note taking to flashcards—you'll get a true understanding of course concepts, helping you achieve better grades and setting the groundwork for your future courses.
- ***Global Environment Watch.*** Integrated within MindTap and updated several times a day, the Global Environment Watch is a focused portal into GREENR—the Global Reference on the Environment, Energy, and Natural Resources—an ideal one-stop site for classroom discussion and research projects. This resource center keeps courses up to date with the most current news on the environment. Users get access to information from trusted academic journals, news outlets, and magazines, as well as statistics, an interactive world map, videos, primary sources, case studies, podcasts, and much more.

Other student learning tools include:

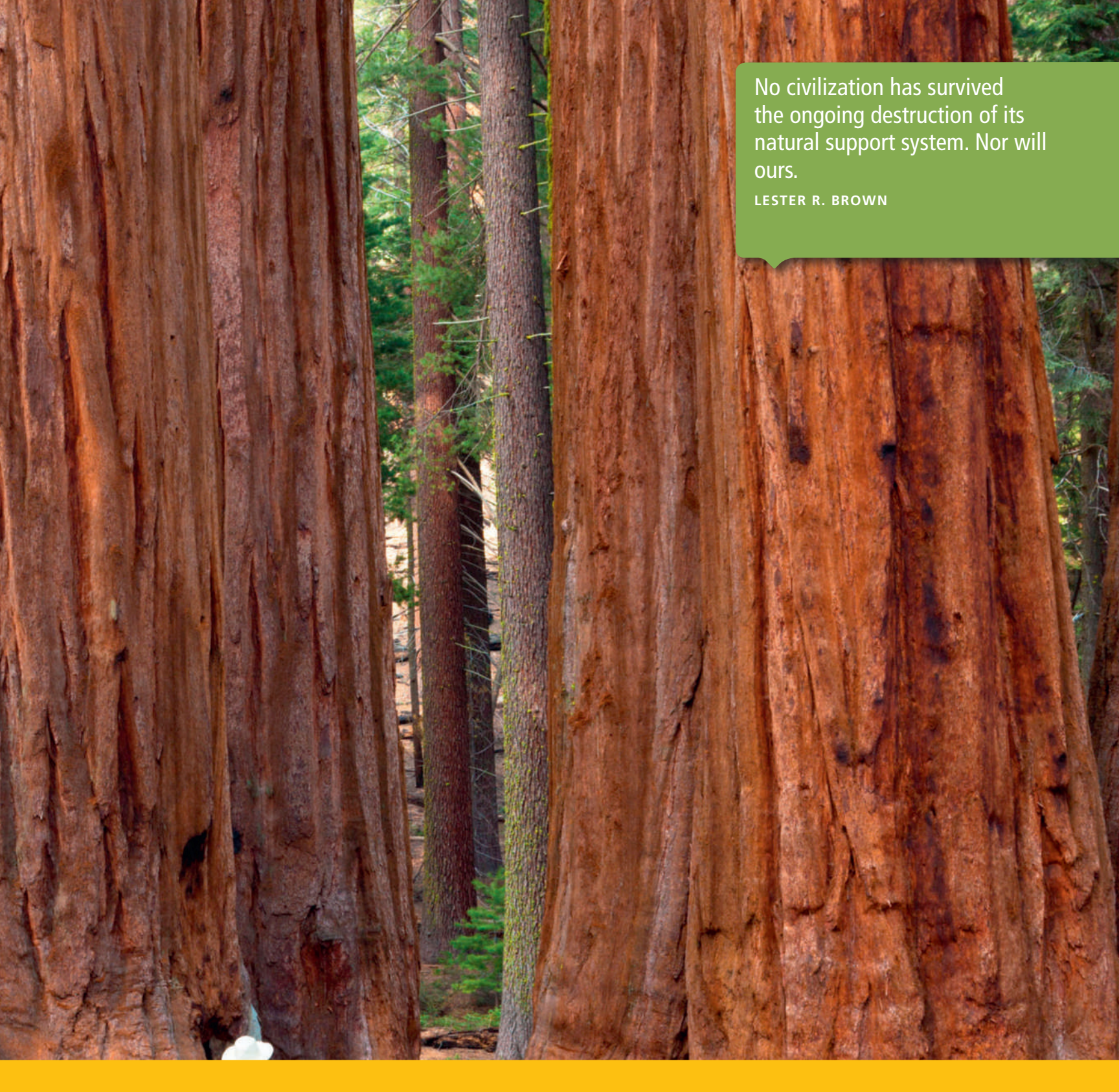
- ***Essential Study Skills for Science Students*** by Daniel D. Chiras. This book includes chapters on developing good study habits; sharpening memory; getting the most out of lectures, labs, and reading assignments; improving test-taking abilities; and becoming a critical thinker. Available for students on instructor's request.
- ***Lab Manual.*** Edited by Edward Wells, this lab manual includes both hands-on and data analysis labs to help your students develop a range of skills. Create a custom version of this Lab Manual by adding labs you have written or ones from our collection with Cengage Custom Publishing. An Instructor's Manual for the labs will be available to adopters.
- ***What Can You Do?*** This guide presents students with a variety of ways that they can affect the environment and shows them how to track the effect their actions have on their carbon footprint. Available for students on instructor's request.

Environmental Science 16e



CHAPTER 1

The Environment and Sustainability



No civilization has survived the ongoing destruction of its natural support system. Nor will ours.

LESTER R. BROWN

Key Questions

1.1 What are some key principles of sustainability?

1.2 How are we affecting the earth?

1.3 Why do we have environmental problems?

1.4 What is an environmentally sustainable society?

Forests such as this one in California's Sequoia National Park help to sustain all life and economies.

robertharding/Alamy Stock Photo

Core Case Study

Learning from the Earth

Sustainability is the capacity of the earth's natural systems that support life and human economic systems to survive or adapt to changing environmental conditions indefinitely. Sustainability is the big idea and the integrating theme of this book.

The earth is a remarkable example of a sustainable system. Life has existed on the earth for about 3.8 billion years. During this time, the planet has experienced several catastrophic environmental changes. They include gigantic meteorite impacts, ice ages lasting millions of years, long warming periods that melted land-based ice and raised sea levels by hundreds of feet, and five mass extinctions—each wiping out more than half of the world's species. Despite these dramatic environmental changes, an astonishing variety of life has survived.

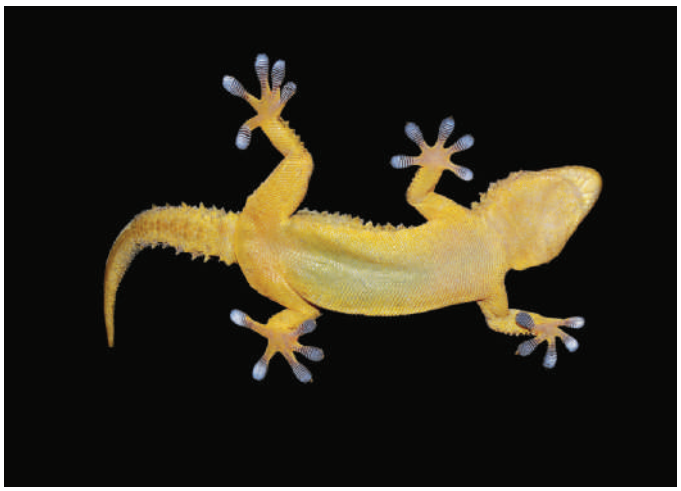
How has life survived such challenges? Long before humans arrived, organisms had developed abilities to use sunlight to make their food and to recycle all of the nutrients they needed for survival. Organisms also developed a variety of abilities to find food and survive. For example, spiders create webs that are strong enough to capture fast-moving flying insects. Bats have a radar system for finding prey and avoiding collisions. These and many other abilities and materials were developed without the use of the high-temperature or high-pressure processes or the harmful chemicals that we employ in manufacturing.

This explains why many scientists urge us to focus on learning from the earth about how to live more sustainably. Biologist Janine Benyus is a pioneer in this area. In 1997, she coined the term **biomimicry** to describe the rapidly growing scientific effort to understand, mimic, and catalog the ingenious ways in which nature has sustained life on the earth for 3.8 billion years. She views the earth's life-support system as the world's longest and most successful research and development laboratory.

How do geckos (Figure 1.1, left) cling to and walk on windows, walls, and ceilings? Scientists have learned that these little lizards have many thousands of tiny hairs growing in ridges on the toes of their feet and that each hair is divided into a number of segments that they use to grasp the tiniest ridges and cracks on a surface (Figure 1.1, right). They release their iron grip by tipping their foot until the hairs let go.

This discovery led to the development of a sticky, toxin-free "gecko tape" that could replace toxin-containing glues and tapes. It is an excellent example of biomimicry, or earth wisdom, and you will see many more of such examples throughout this book.

Nature can teach us how to live more sustainably on the amazing planet that is our only home. As Benyus puts it, after billions of years of trial-and-error research and development: "Nature knows what works, what is appropriate, and what lasts here on Earth." ●



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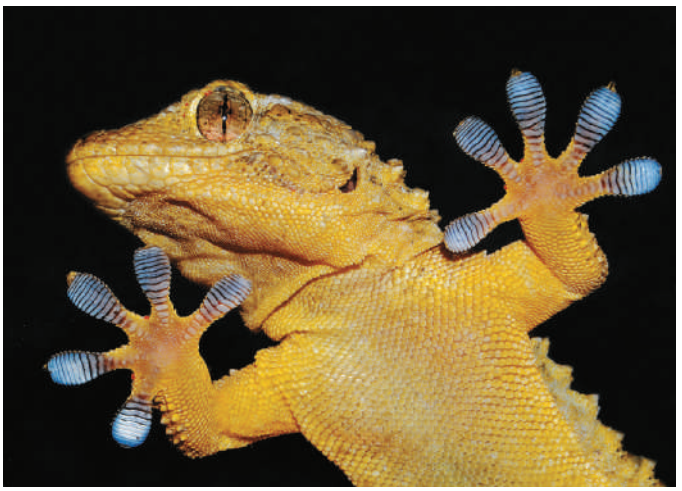

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FIGURE 1.1 The gecko (left) has an amazing ability to cling to surfaces because of projections from many thousands of tiny hairs on its toes (right).

1.1 WHAT ARE SOME KEY PRINCIPLES OF SUSTAINABILITY?

CONCEPT 1.1A Life on the earth has been sustained for billions of years by solar energy, biodiversity, and chemical cycling.

CONCEPT 1.1B Our lives and economies depend on energy from the sun and on natural resources and ecosystem services (*natural capital*) provided by the earth.

CONCEPT 1.1C We can live more sustainably by following six principles of sustainability.

Environmental Science Is a Study of Connections in Nature

The **environment** is everything around you. It includes energy from the sun and all the living things (such as plants, animals, and bacteria) and the nonliving things (such as air, water, and sunlight) with which you interact. Despite humankind's many scientific and technological advances, our lives depend on sunlight and the earth for clean air and water, food, shelter, energy, fertile soil, a livable climate, and other components of the planet's *life-support system*.

Environmental science is a study of connections in the natural environment nature. It is an interdisciplinary study of **(1)** how the earth (nature) works and has survived and thrived, **(2)** how humans interact with the environment, and **(3)** how humans can live more sustainably. It strives to answer several questions: What environmental problems do we face? How serious are they? How do they interact? What are their causes? How has nature solved such problems? How can we solve such problems? To answer such questions, environmental science integrates information and ideas from fields such as biology, chemistry, geology, engineering, geography, economics, political science, and ethics.

A key component of environmental science is **ecology**, the branch of biology that focuses on how living organisms interact with the living and nonliving parts of their environment. Each organism, or living thing, belongs to a **species**—a group of organisms having a unique set of characteristics that set it apart from other groups.

A major focus of ecology is the study of ecosystems. An **ecosystem** is a biological community of organisms within a defined area of land or volume of water that interact with one another and with the nonliving chemical and physical factors in their environment. For example, a forest ecosystem consists of plants, animals, and organisms that decompose organic materials, all interacting with one another and the chemicals in the forest's air, water, and soil.

Environmental science and ecology should not be confused with **environmentalism**, or **environmental activism**, which is a social movement dedicated to protecting the earth's life-support system for humans and other species.

Learning from the Earth: Three Scientific Principles of Sustainability

Modern humans have been around for about 200,000 years—less than the blink of an eye, relative to the 3.8 billion years that life has existed on the earth. During their short time on the earth, and especially since 1900, humans have expanded into and dominated almost all of the earth's ecosystems.

This large and growing human impact threatens the existence of many species and biological centers of life such as tropical rainforests and coral reefs. It also adds pollutants to the earth's air, water, and soil. Many environmental scientists warn that humans are degrading the earth's life-support system that supports all life and human economies.

Scientific studies of how the earth works reveal that three natural factors play key roles in the long-term sustainability of the planet's life, as summarized below and in Figure 1.2 (**Concept 1.1A**). Understanding these three **scientific principles of sustainability**, or major *lessons from nature*, can help us move toward a more sustainable future.

- **Solar energy:** The sun's energy warms the planet and provides energy that plants use to produce **nutrients**, the chemicals that plants and animals need to survive.
- **Biodiversity:** The variety of genes, species, ecosystems, and ecosystem processes are referred to as **biodiversity** (short for *biological diversity*). Interactions among species provide vital ecosystem services and keep any population from growing too large. Biodiversity also provides ways for species to adapt to changing environmental conditions and for new species to arise and replace those wiped out by catastrophic environmental changes.
- **Chemical cycling:** The circulation of nutrients from the environment (mostly from soil and water) through various organisms and back to the environment is called **chemical cycling**, or **nutrient cycling**. The earth receives a continuous supply of energy from the sun but it receives no new supplies of life-supporting chemicals. Through billions of years of interactions with their living and nonliving environment, organisms have developed ways to recycle the chemicals they need to survive. This means that the wastes and decayed bodies of organisms become nutrients or raw materials for other organisms. In nature, **waste = useful resources.**

Key Components of Sustainability

Sustainability, the integrating theme of this book, has several key components that we use as subthemes. One is **natural capital**—natural resources and ecosystem

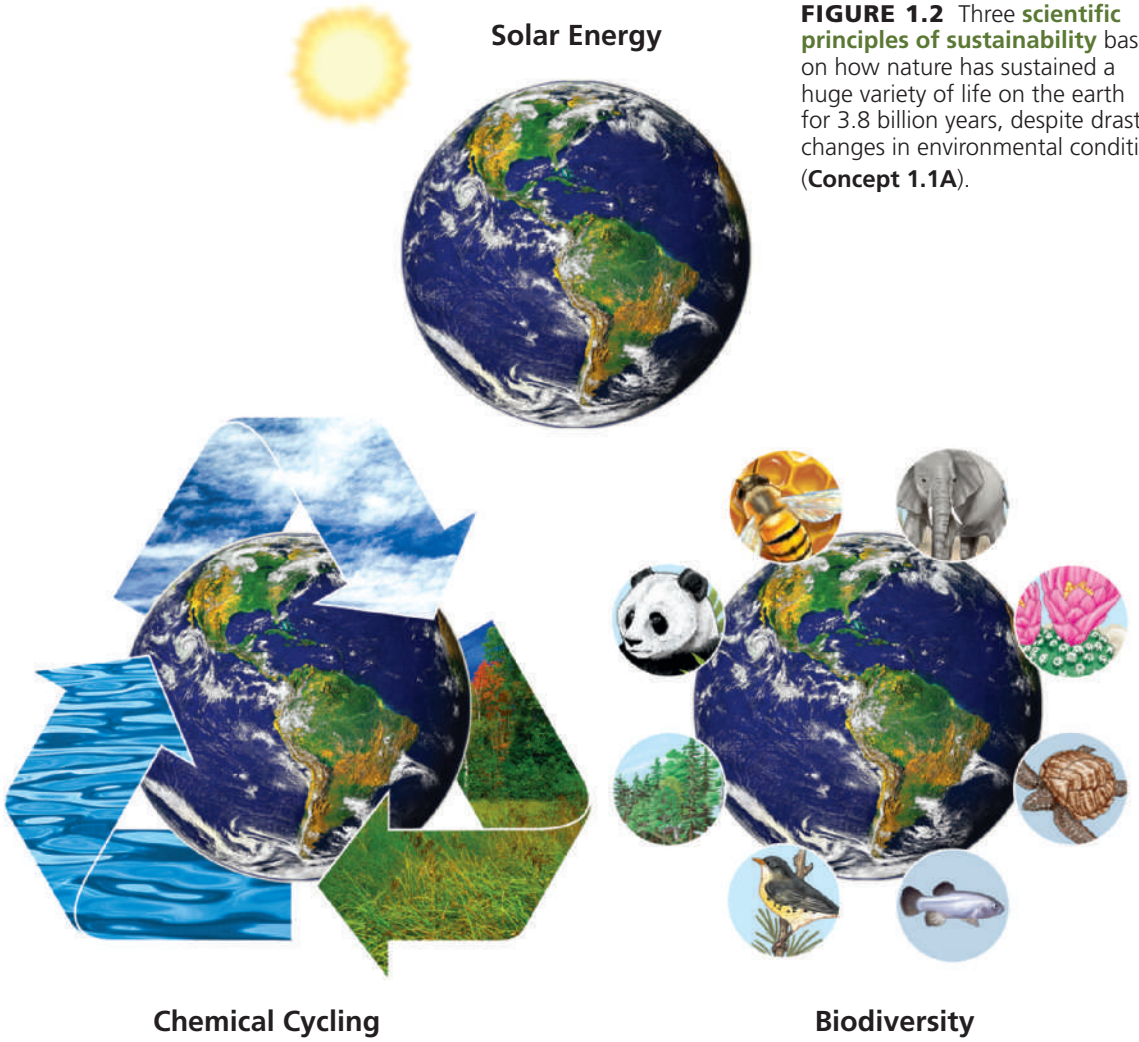

FIGURE 1.2 Three **scientific principles of sustainability** based on how nature has sustained a huge variety of life on the earth for 3.8 billion years, despite drastic changes in environmental conditions (**Concept 1.1A**).

services that keep humans and other species alive and that support human economies (Figure 1.3).

Natural resources are materials and energy provided by nature that are essential or useful to humans. They fall into three categories: *inexhaustible resources*, *renewable resources*, and *nonrenewable (exhaustible) resources* (Figure 1.4). An **inexhaustible resource** is one that is expected to last forever on a human timescale. **Solar energy** is such a resource, expected to last for at least 5 billion years until the death of the star we call the sun. A **renewable resource** is a resource that can be used repeatedly because it is replenished through natural processes as long as it is not used up faster than nature can renew it. Examples are forests, grasslands, fertile topsoil, fishes, clean air, and fresh water. The highest rate at which people can use a renewable resource indefinitely without reducing its available supply is called its **sustainable yield**.

Nonrenewable or **exhaustible resources** are those that exist in a fixed amount, or *stock*, in the earth's crust. They take millions to billions of years to form through geological processes. On the much shorter human timescale, we can use these resources faster than nature can replace them. Examples of nonrenewable resources are oil, natural gas, and coal (Figure 1.5), and metallic mineral resources such as copper and aluminum.

Ecosystem services are the natural services provided by healthy ecosystems that support life and human economies at no monetary cost (Figure 1.3). For example, forests help purify air and water, reduce soil erosion, regulate climate, and recycle nutrients. Thus, our lives and economies are sustained by energy from the sun and by natural resources and ecosystem services (natural capital) provided by the earth (**Concept 1.1B**).

Key ecosystem services include purification of air and water, renewal of topsoil, pollination, and pest control. Another important example is nutrient cycling, which is a **scientific principle of sustainability**. Without nutrient cycling in topsoil, there would be no land plants, no pollinators, and no food for us and other animals.

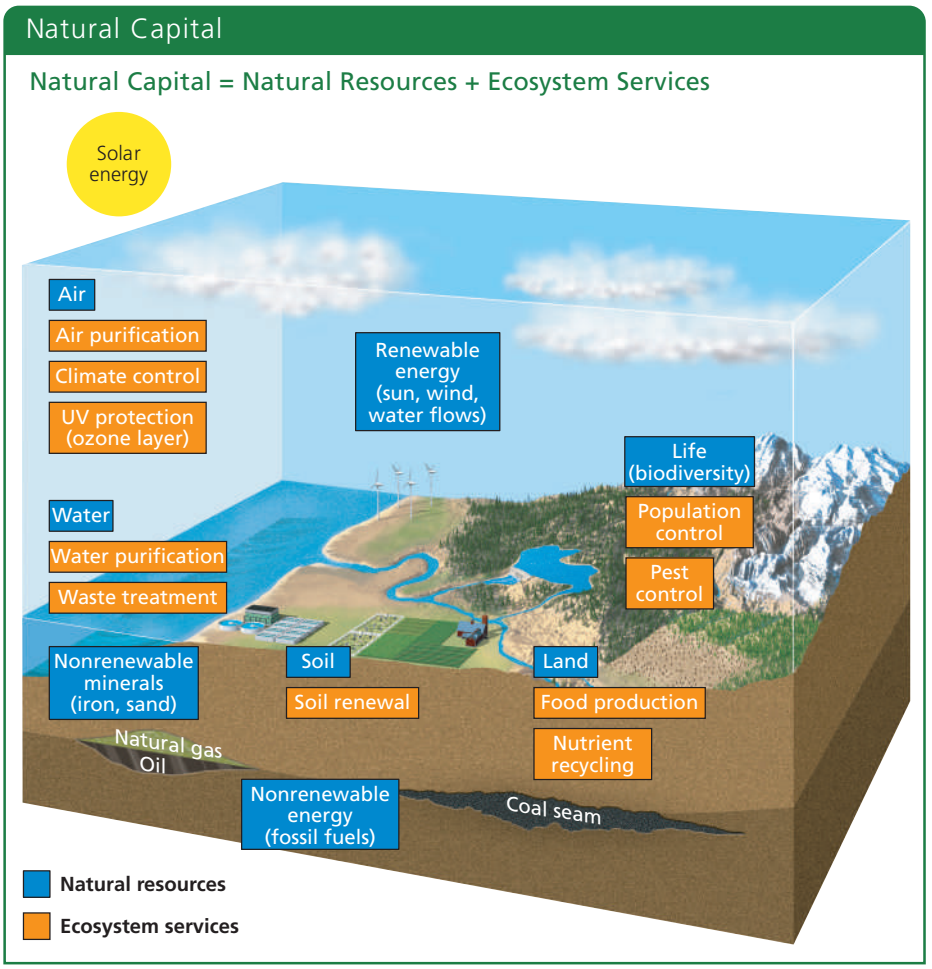

FIGURE 1.3 Natural Capital consists of natural resources (blue) and ecosystem services (orange) that support and sustain the earth's life and human economies (**Concept 1.1B**).

Inexhaustible
Solar energy
Wind energy
Geothermal energy

Renewable
Trees
Topsoil
Freshwater

Nonrenewable (Exhaustible)
Fossil fuels (oil, natural gas, coal)
Iron and copper

Left: Carole Castelli/Shutterstock.com. Center: Alexander Kalina/Shutterstock.com. Right: Karl Naundorf/Shutterstock.com.

FIGURE 1.4 We depend on a combination of inexhaustible, renewable, and nonrenewable (exhaustible) natural resources.

PETE MCBRIDE/National Geographic Creative

FIGURE 1.5 It would take more than a million years for natural processes to replace the coal that was removed from this strip mine in the U.S. state of Wyoming within a couple of decades.

A second component of sustainability—and another subtheme of this textbook—is that human activities can *degrade natural capital*. We do this by using renewable resources faster than nature can restore them and by overloading the earth's normally renewable air, water, and soil with pollution and wastes. For example, people in many areas of the world are replacing biologically diverse mature forests with simplified crop plantations (Figure 1.6) that require large and costly inputs of energy, water, fertilizer, and pesticides. Many human activities add pollutants to the air and dump chemicals and wastes into rivers, lakes, and oceans faster than they can be cleansed through natural processes. Many of the plastics and other synthetic materials people use can poison wildlife and disrupt nutrient cycling because they cannot be broken down and used as nutrients by other organisms.

A third component of sustainability involves people finding *solutions* to the environmental problems we face. People can work together to protect the earth's natural capital and to use it sustainably. For example, a solution to the loss of forests is to stop burning or cutting down mature forests faster than they can grow back (Figure 1.6). This requires that citizens become educated about the ecosystem services forests provide and work to see that forests are used sustainably.

Conflicts can arise when environmental protection has a negative economic effect on groups of people or certain industries. Dealing with such conflicts often involves both sides making compromises or *trade-offs*—the fourth component and subtheme of this book. For example, a timber company might be persuaded to plant and harvest trees in an area that it had already cleared or degraded instead of clearing an undisturbed area of a mature forest. In return, the government may subsidize (pay part of the cost of) planting new trees.

Each individual—including you—plays an important role in learning how to live more sustainably. Thus, *individuals matter*—the fifth component of sustainability and subtheme of this book.

Tom Koene/Visuals Unlimited, Inc.

FIGURE 1.6 Small remaining area of once diverse Amazon rain forest surrounded by vast soybean fields in the Brazilian state of Mato Grosso.

INDIVIDUALS MATTER 1.1

Janine Benyus: Using Nature to Inspire Sustainable Design and Living

ecowatch.com

Janine Benyus has had a lifelong interest in learning how nature works and how to live more sustainably. She realized that 99% of the species that have lived on the earth became extinct because they could not adapt to changing environmental conditions. She views the surviving species as examples of *natural genius* that we can learn from.

Benyus says that when we need to solve a problem or design a product, we should ask: Has nature done this and how did it do it? We should also think about what nature does not do as a clue to what we should not do, she argues. For example, nature does not produce waste materials or chemicals that cannot be broken down and recycled.

Benyus has set up the nonprofit Biomimicry Institute that has developed a curriculum for K–12 and university students and a two-year program to train biomimicry professionals. She has also established a network called Biomimicry 3.8, named for the 3.8 billion years during which organisms have developed what Benyus calls their *genius for surviving*. It is a network of scientists, engineers, architects, and designers who share examples of biomimicry.

Three Additional Principles of Sustainability

Our research in economics, politics, and ethics has provided us with three additional **principles of sustainability** (Figure 1.7):

- **Full-cost pricing** (from economics): Some economists urge us to find ways to include in market prices the harmful environmental and health costs of producing and using goods and services. This practice, called **full-cost pricing**, would give consumers information about the harmful environmental impacts of the goods and services that they use.
- **Win–win solutions** (from political science): Political scientists urge us to look for *win–win solutions* to environmental problems, based on cooperation and compromise, that will benefit the largest number of people as well as the environment.
- **Responsibility to future generations** (from ethics): Ethics is a branch of philosophy devoted to studying ideas about what is right and what is wrong. According to environmental ethicists, we have a responsibility to leave the planet's life-support systems in a condition as good as or better than what we inherited for the benefit of future generations and for other species.

These six **principles of sustainability** (see inside back cover of this book) can serve as guidelines to help us live more sustainably. This includes using biomimicry as a tool for learning from the earth about how to live more sustainably (**Core Case Study** and Individuals Matter 1.1).

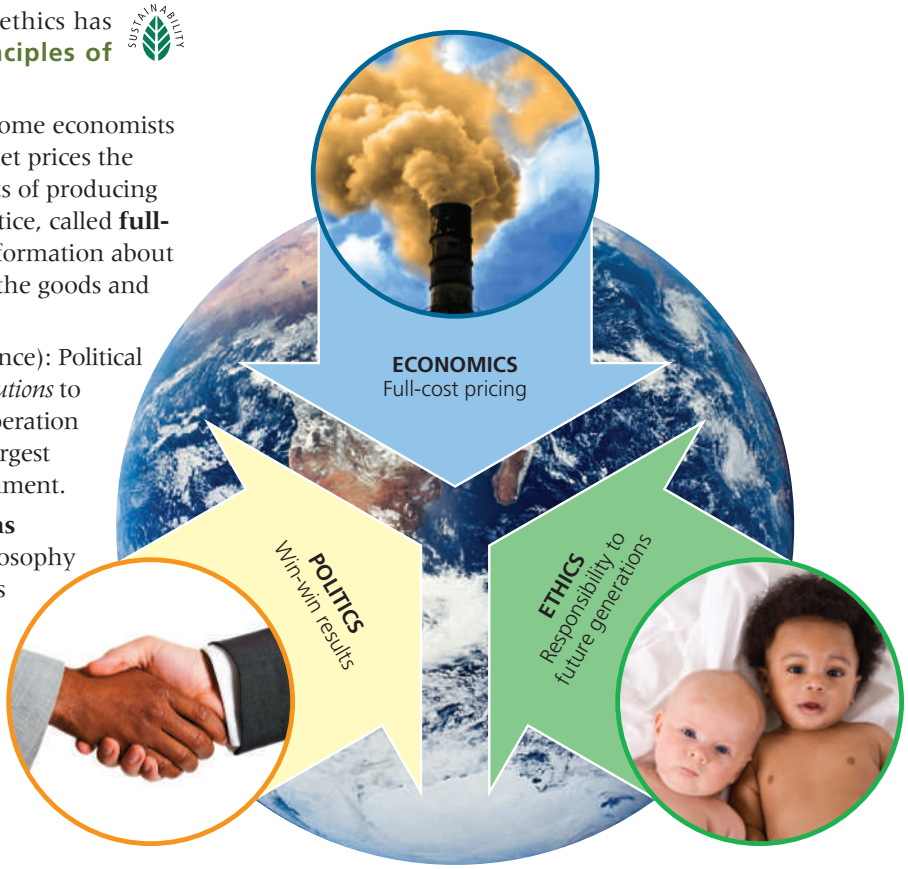

FIGURE 1.7 Three **principles of sustainability based on economics, political science, and ethics** can help us make a transition to a more environmentally and economically sustainable future.

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