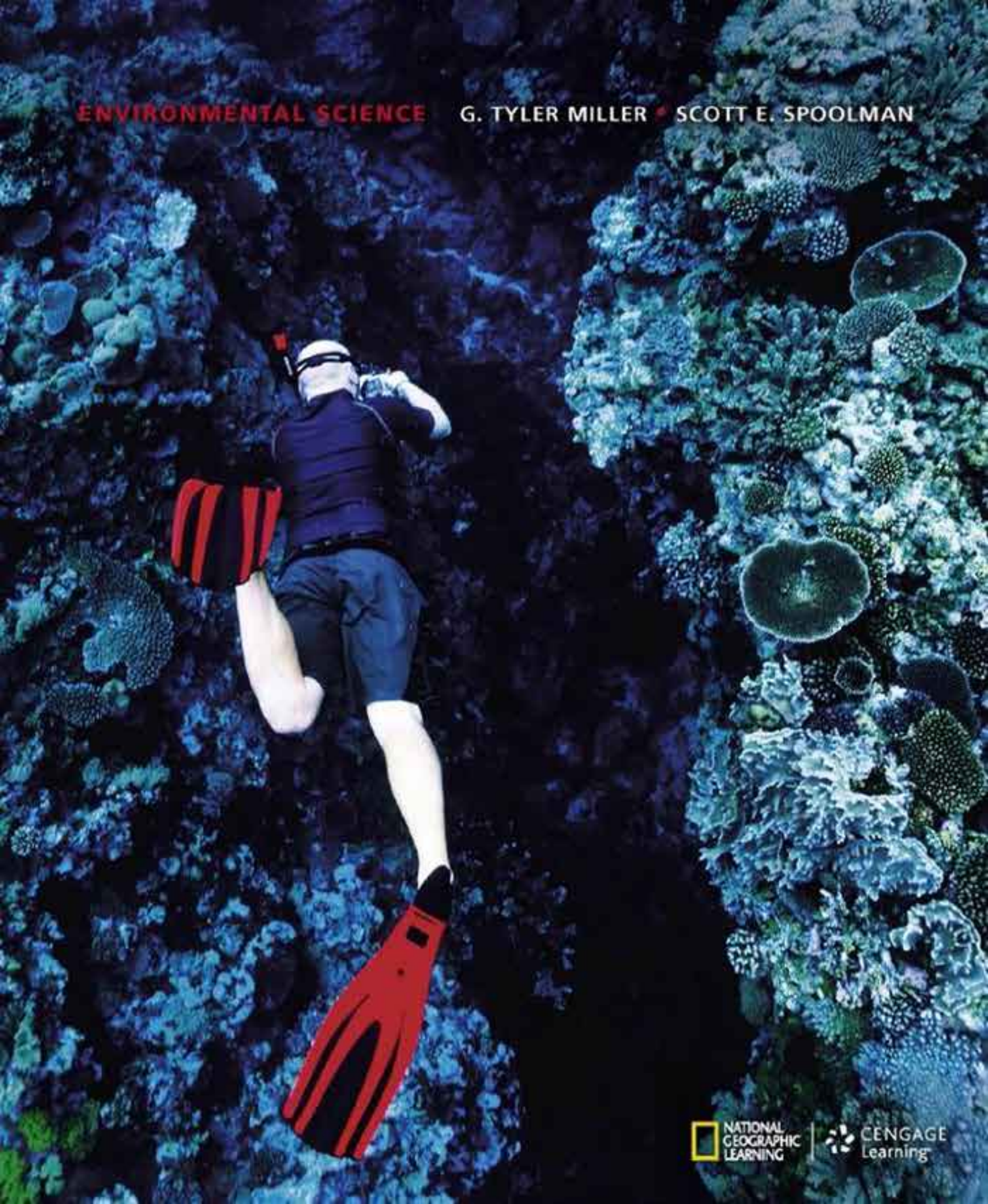
ENVIRONMENTAL SCIENCE

G. TYLER MILLER • SCOTT E. SPOOLMAN



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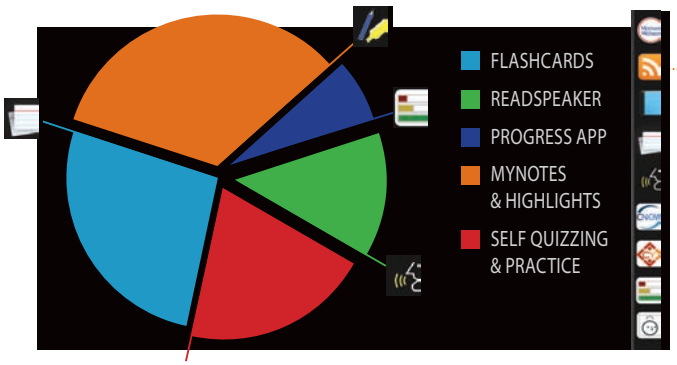

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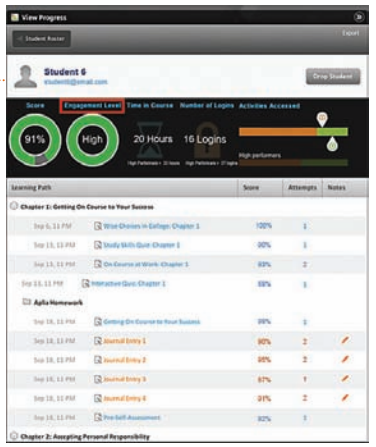

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ENVIRONMENTAL SCIENCE

FIFTEENTH EDITION

ABOUT THE COVER PHOTO

In 2005, nature journalist Richard Louv hypothesized that many people, especially children, have experienced *nature-deficit disorder,* a series of problems resulting from their spending increasingly less time in the natural world. Many children and young adults spend most of their free time indoors watching TV and using smart phones, computers, and other electronic devices. Evidence indicates that such isolation from nature could be contributing to stress, anxiety, depression, irritability, difficulty in dealing with change, and excessive body weight. In the United States, according to the Centers for Disease Control and Prevention, about 33% of all children and 69% of all adults over age 20 are overweight or obese. Also, the indoor air in U.S. homes and buildings is typically 2 to 5 times more polluted than outdoor air, according to the U.S. Environmental Protection Agency, which could be contributing to the increasing incidence of certain lung ailments.

Nature-deficit disorder is partly an effect of urbanization. More than half of the world's people now live in urban areas, many of which do not have enough parks and recreational areas to make it easy for people to get out. Cities also have higher crime rates than do rural areas, and the continuous news cycle along with social networking keep people hyper-informed about crime and other threats. Thus, many people are afraid to venture out.

Research indicates that children and adults can gain many benefits by playing and exploring outdoors, hiking, jogging, snorkeling (see cover photo), fishing, gardening, and bird-watching. Such activities can foster better health, reduce stress, improve mental abilities, and stimulate imagination and creativity. Experiencing nature can also provide a sense of wonder and connection to life on Earth, which keeps us alive and supports our economies.

Environmental scientists have identified this increasing isolation from nature as one of the five major causes of the environmental problems we face. Without an understanding of our utter dependence on nature for food, shelter, clean air, clean water, and many other natural resources and services, we become more likely to degrade our environment. With such an understanding, we will be more likely to reverse such degradation and to contribute positively to the environment and thus to our own well-being.

Jason Edwards/National Geographic Creative

ENVIRONMENTAL SCIENCE

FIFTEENTH EDITION

G. Tyler Miller

Scott E. Spoolman

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G. Tyler Miller, Scott E. Spoolman

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Text Researcher: Kavitha Balasundaram, PreMedia Global

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20 Channel Center Street
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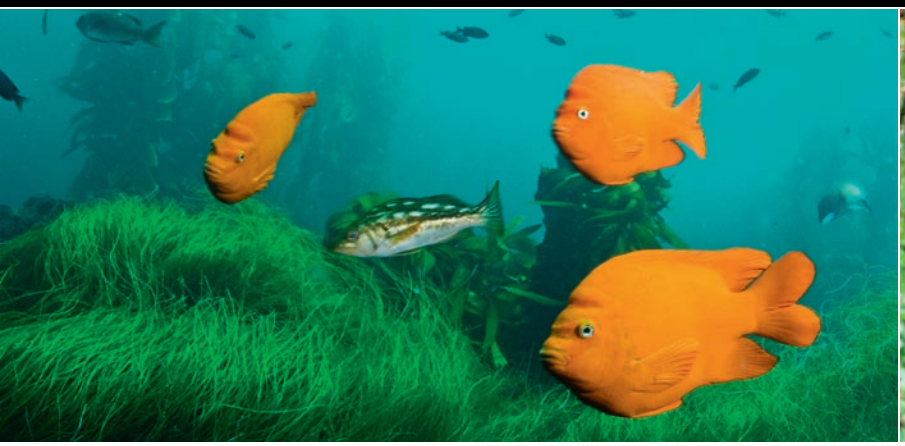

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SUSTAINING HUMAN SOCIETIES

SUPPLEMENTS

For Instructors

We wrote this book to help instructors achieve three important goals: *first,* to explain to their students the basics of environmental science; *second,* to help their 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 their students 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 will still be able to live comfortable and fulfilling lives, and that societies will be more prosperous and peaceful, when sustainability becomes one of the chief measures by which personal choices and public policies are made. We consistently challenge students to work toward attaining such a future.

For this reason, we are happy to be working with the National Geographic Society in the production of this book. This partnership has allowed us to include many stunning and informative photographs, numerous maps, and many new stories of National Geographic Explorers and other researchers who have received funding from National Geographic—people who are making a positive difference in the world. With these new 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?

- *Our partnership with National Geographic* has given us access to hundreds of amazing photographs, numerous maps, and inspiring stories of *National Geographic Explorers and grantees*—people who are leading the way in environmental science, education, or entrepreneurial enterprises.
- A *stunning new design* with a National Geographic look that enhances visual learning.
- *New Core Case Studies* for 10 of the book's 17 chapters bring important real-world stories to the forefront for use in applying those chapters' concepts and principles.
- New Supplement 6, Geologic and Biological Time Scale, that locates major developments related to life on Earth, including the mass extinctions, within the earth's geologic time scale.

Sustainability Is the Integrating Theme of This Book

Sustainability 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) and Figure 1.5 (p. 9) and summarized in Supplement 7 (pp. S50–S51), and we apply them throughout the book, with each reference marked in the margin as shown here (see pp. 50 and 219).

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 9.4, p. 189.
- ***Natural capital degradation.*** We describe how human activities can degrade natural capital. See Figures 1.7, p. 10, and 7.17, p. 146.
- ***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 9.14, p. 195, and 11.11, p. 257.
- ***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 13.9, p. 322, and 16.11, p. 439.
- ***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. 17, 209, and 237). Also, a number of What Can You Do? diagrams describe how readers can deal with the problems we face (see Figures 11.21, p. 267, and 13.44, p. 353). Eight especially important steps that people can take are summarized in Figure 17.21 (p. 478).

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. We have used thousands of articles and reports published in 2011–2014 to update the information in this book. Major new or updated topics include planetary bound-

aries and ecological tipping points (Science Focus 3.3, p. 58), hydraulic fracturing, or fracking (Science Focus 13.1, p. 318), and the rising threat of ocean acidification (Science Focus 9.3, p. 206), along with dozens of other important topics.

- ***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 lessons. 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. 187 and 262). Also, the concept applications are highlighted and referenced throughout each chapter.
- ***Science-Based Approach.*** 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. 206 and 408). We also integrate science coverage throughout the book in various Case Studies (see pp. 175 and 203) and in numerous figures.
- ***Global Coverage.*** This book 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 40 maps in the basic text and in Supplement 4. 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. 162 and 216), which is applied throughout the chapter. These applications are indicated by the notation **Core Case Study** wherever they occur (see pp. 171 and 240). Each chapter ends with a *Tying it All Together* box (see pp. 181 and 244) that 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, some 42 additional Case Studies (see pp. 220, 259, and 322) appear throughout the book (and are listed in the Detailed Contents, pp. vi–xiii). Each of these provides an in-depth look at specific environmental problems and their possible solutions.
- ***Critical Thinking.*** The Note to Students (p. xxiii) 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. 117 and 263).
  - 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. 166 and 396).
  - In the captions of many of the book's figures (see Figures 8.4, p. 166, and 11.13, p. 260).
  - In end-of-chapter *Critical Thinking* questions (see pp. 126 and 356).
- ***Visual Learning.*** With a new design heavily influenced by material from National Geographic and more than 440 photographs, many of them from the archives of National Geographic, this is the most visually arresting environmental science textbook available (see Figures 5.9, p. 92, 7.16, p. 145, and 9.13, p. 195). Add in the more than 130 diagrams, each designed to present complex ideas in understandable ways relating to the real world (see Figures 3.3, p. 44, and 4.2, p. 65), and you also have one of the most visually informative textbooks available.
- ***Flexibility.*** To meet the 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 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 the 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, respectively, before proceeding to the chapters on basic science and ecological concepts. We provide a second level of flexibility in seven Supplements (see p. xiii in the Detailed Contents), which instructors can assign as desired to meet their needs. Examples include Some Basic Chemistry (Supplement 3), Maps and Map Analysis (Supplement 4), Environmental Data and Data

Analysis (Supplement 5), and a new Supplement 6 showing a Geologic and Biological Time Scale.

- ***In-Text Study Aids.*** Each chapter begins with a list of *Key Questions* showing how the chapter is organized (see pp. 312–313). When a new *key term* is introduced and defined, it is printed 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 p. 320). The captions of many figures contain similar questions that get students to think about the figure content (see Figures 13.5, p. 320, and 13.34, p. 345). 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. 347 and 349). Finally, the text of each chapter wraps up with three *Big Ideas* (see p. 353), which summarize and reinforce three of the major take-away lessons from each chapter, and a *Tying It All Together* section that relates the Core Case Study and other chapter content to the principles of sustainability (see p. 354).

Each chapter ends with a *Chapter Review* section containing a detailed set of review questions that include all of 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 to 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. 127 and 357.)

Online Solutions and Resources

- ***MindTap.*** MindTap is a new approach to highly personalized online learning. Beyond an e-Book, 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.
- ***Aplia.*** Aplia™ for Environmental Science is an online interactive learning solution that improves comprehension and outcomes by increasing student effort and engagement. Aplia provides automatically graded assignments that were written to make the most of the web medium and contain detailed, immediate explanations on every question. Students come to class prepared and ready to participate. Diverse types of questions aim to reinforce, extend, and apply key concepts by focusing on case studies, data analysis, real-world applications, global perspectives, and more. Aplia homework is also available via MindTap.
- ***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.
- ***Cognero Test Bank.*** Available to adopters. Cengage Learning Testing Powered by Cognero is a flexible, online system that allows you to author, edit, and manage test bank content from multiple Cengage Learning solutions; create multiple test versions in an instant; and deliver tests from your LMS, your classroom, or wherever you want.
- ***BBC Videos for Environmental Science.*** These short, informative video clips cover current news stories on environmental issues from around the world. These clips are a great way to start a lecture or spark a discussion. Available on the Instructor's Companion Site and within MindTap.

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:

- **mtg89@hotmail.com**
- **spoolman@tds.net**

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

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ronment, the 11 editions of *Sustaining the Earth,* and the 7 editions of *Essentials of Ecology,* and who have corrected errors and offered many helpful suggestions for improvement. We are also deeply indebted to the more than 400 reviewers, who pointed out errors and suggested many important improvements in the various editions of these three books.

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G. Tyler Miller

Scott E. Spoolman

Guest Essayists

Guest essays by the following authors are available as assignable activities via MindTap: **M. Kat Anderson**, ethnoecologist with the National Plant Center of the USDA's Natural Resource Conservation Center; **Lester R. Brown**, president, Earth Policy Institute; **Alberto Ruz Buenfil**, environmental activist, writer, and performer; **Robert D. Bullard**, professor of sociology and director of the Environmental Justice Resource Center at Clark Atlanta University; **Michael Cain**, ecologist and adjunct professor at Bowdoin College; **Herman E. Daly**, senior research scholar at the School of Public Affairs, University of Maryland; **Lois Marie Gibbs**, director, Center for Health, Environment, and Justice; **Garrett Hardin**, professor emeritus (now deceased) of human ecology, University of California–Santa Barbara; **John Harte**, professor of energy and resources, University of California–Berkeley; **Paul G. Hawken**, environmental author and business leader; **Jane Heinze-Fry**, environmental educator; **Paul F. Kamitsuja**, infectious disease expert and physician; **Amory B. Lovins**, energy policy consultant and director of research, Rocky Mountain Institute; **Bobbi S. Low**, professor of resource ecology, University of Michigan; **John J. Magnuson**, Director Emeritus of the Center for Limnology, University of Wisconsin–Madison; **Lester W. Milbrath**, director of the research program in environment and society, State University of New York–Buffalo; **Peter Montague**, director, Environmental Research Foundation; **Norman Myers**, tropical ecologist and consultant in environment and development; **David W. Orr**, professor of environmental studies, Oberlin College; **Noel Perrin**, adjunct professor of environmental studies, Dartmouth College; **John Pichtel**, Ball State University; **David Pimentel**, professor of insect ecology and agricultural sciences, Cornell University; **Andrew C. Revkin**, environmental author and environmental reporter for the *New York Times;* **Vandana Shiva**, physicist, educator, environmental consultant; **Nancy Wicks**, ecopioneer and director of Round Mountain Organics; and **Donald Worster**, environmental historian and professor of American history, University of Kansas.

Pedagogy Contributors

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sity of Virginia; Mel Stanley, California State Polytechnic University, Pomona; Richard Stevens, Monroe Community College; Norman R. Stewart, University of Wisconsin–Milwaukee; Frank E. Studnicka, University of Wisconsin–Platteville; Chris Tarp, Contra Costa College; Roger E. Thibault, Bowling Green State University; Nathan E. Thomas, University of South Dakota; William L. Thomas, California State University–Hayward; Shari Turney, copy editor; John D. Usis, Youngstown State University; Tinco E. A. van Hylckama, Texas Tech University; Robert R. Van Kirk, Humboldt State University; Donald E. Van Meter, Ball State University; Rick Van Schoik, San Diego State University; Gary Varner, Texas A&M University; John D. Vitek, Oklahoma State University; Harry A. Wagner, Victoria College; Lee B. Waian, Saddleback College; Warren C. Walker, Stephen F. Austin State University; Thomas D. Warner, South Dakota State University; Kenneth E. F. Watt, University of California, Davis; Alvin M. Weinberg, Institute of Energy Analysis, Oak Ridge Associated Universities; Brian Weiss; Margery Weitkamp, James Monroe High 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 University; 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.

G. TYLER MILLER

G. Tyler Miller has written 62 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 and textbook editor 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 worked as an acquisitions editor on a series of college forestry textbooks. He has also worked as a consulting editor in the development of over 70 college and high school textbooks in 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 informative and sobering, but also tantalizing and motivational.

If the flip side of any problem is indeed 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 the earth.

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 ten 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 to 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 airplane trip 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.

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. A passion for learning will serve you well while studying environmental science and in whatever career you choose.

Get organized. Planning is a key life skill.

Make daily to-do lists. 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 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 to 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 molehills 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 (molehills). 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.

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 within MindTap, 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 or electronically if you are using MindTap (which may be synced with an Evernote account). You might also mark important pages that you want to return to by using Post-it notes 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. MindTap has additional questions for each 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 have no idea 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 to distinguish between facts and opinions, evaluate evidence and arguments, and take and defend informed positions on issues. It also helps you to integrate information, to see relationships, and to 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 in order 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 meaning 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 to 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 results of science have varying degrees of certainty.

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 can often establish high degrees of certainty.) *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 1.5, p. 9, and summarized in Supplement 7 (pp. S50–S51). 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.

At the end of each chapter, we list what we consider to be the *three big ideas* that you should take away from the 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 to 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 exciting 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 the related MindTap contain plenty of tools for all types of learners. Visual learners can benefit from the animations and videos in MindTap that support many of the concepts presented. In addition, features such as an easy-to-use note-taking feature and flash cards help you learn important terms and concepts. 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. Additionally, podcasts featuring interviews of National Geographic Explorers and grantees add context to many environmental issues. 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. And we 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 state-

ments 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 our planet in a condition at least as good as what we now enjoy. Have fun.

Online Learning Solutions and Resources 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:

MindTap Environmental Science. MindTap is a new approach to highly personalized online learning. Beyond an e-book, 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.

Aplia for Environmental Science. Aplia™ is an online interactive learning solution that helps you improve comprehension—and your grade—by integrating a variety of mediums and tools such as videos, tutorials, practice tests, and interactive e-books. Aplia provides automatically graded assignments with detailed, immediate feedback on every question, and innovative teaching materials. More than 2 million students like you have used Aplia at over 1,800 institutions. Aplia should be purchased only when assigned by your instructor as part of your course.

Global Environment Watch. 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. Log in or purchase access at www.cengagebrain.com to complete the exercises found at the end of each chapter. Links to GREENR for in-text activities are also provided via MindTap.

Virtual Field Trips in Environmental Issues. *Virtual Field Trips in Environmental Issues* brings the field to you, with dynamic panoramas, videos, photographs, maps, and quizzes covering important topics within environmental science. A case study approach covers the issues of *keystone species, climate change's role in extinctions, invasive species, the evolution of a species due to its environment,* and *an ecosystem approach to sustaining biodiversity.* Engage and interact with these real issues to help you think critically about the world.

ENVIRONMENTAL SCIENCE

FIFTEENTH EDITION

1 ENVIRONMENTAL PROBLEMS, THEIR CAUSES, AND SUSTAINABILITY

KEY QUESTIONS

1.1 What are some principles of sustainability?

1.2 How are our ecological footprints affecting the earth?

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

LESTER R. BROWN

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.

Robert Harding World Imagery/Alamy

CORE CASE STUDY

The Greening of American Campuses

Sustainability is the capacity of the earth's natural systems and human cultural systems to survive, flourish, and adapt to changing environmental conditions into the very long-term future. It is the overarching theme of this textbook.

Since the mid-1980s, there has been a boom in environmental awareness on college campuses and in public and private schools around the world. In the United States, hundreds of colleges and universities have now taken the lead in a quest to become more sustainable and to educate their students about sustainability.

For example, at Oberlin College in Ohio, a group of students worked with faculty members and architects to design a more sustainable environmental studies building (Figure 1.1) powered by solar panels, which produce 30% more electricity than the building uses. Closed-loop underground geothermal wells provide heating and cooling. In its solar greenhouse, a series of open tanks populated by plants and other organisms purifies the building's wastewater. The building collects rainwater for irrigating the surrounding grasses, gardens, and meadow, which contain a diversity of plant and animal species.

Berea College in Kentucky boasts an innovative environmental science curriculum including a Sustainable Appalachian Communities course. The school also features its Ecovillage, a 50-unit experimental residence complex that uses passive solar heating, solar panels, and filtered rainwater.

At the University of California, Santa Cruz, in 2012, students reused, recycled, or composted more than 70% of their solid waste with a goal of reaching 100% by 2020. And in Asheville, North Carolina, Warren Wilson College gets more than a third of its food from regional farms, including its own large on-campus organic garden.

In addition to making campuses greener, colleges are increasingly offering environmental sustainability courses and programs. At Pfeiffer University, many students have accompanied Professor Luke Dollar, a National Geographic Emerging Explorer, on trips to Madagascar to take part in his research on that country's endangered species and ecosystems. At the University of Wisconsin–Madison, the Nelson Institute for Environmental Studies seeks to integrate sustainability content throughout the academic departments, as well as to serve communities outside of the university.

These and many other institutions are educating students who will provide leadership in helping us to make our societies and economies more sustainable during the next few decades. Maybe you will join the ranks of such environmental leaders.

Robb Williamson/NREL

FIGURE 1.1 The Adam Joseph Lewis Center for Environmental Studies at Oberlin College in Oberlin, Ohio.

1.1 WHAT ARE SOME 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 could shift toward living more sustainably by applying full-cost pricing, searching for win-win solutions, and committing to preserving the earth's life-support system for future generations.

Environmental Science Is a Study of Our Interactions with the World

The **environment** is everything around us. It includes the living and the nonliving things (air, water, and energy) with which we interact in a complex web of relationships that connect us to one another and to the world we live in. Despite our many scientific and technological advances, we are utterly dependent on the earth for clean air and water, food, shelter, energy, fertile soil, and all other components of the planet's *life-support system*.

This textbook is an introduction to **environmental science**, an *interdisciplinary* study of how humans interact with the living and nonliving parts of their environment. It integrates information and ideas from the *natural sciences* such as biology, chemistry, and geology; the *social sciences* such as geography, economics, and political science; and the *humanities* such as ethics. The three goals of environmental science are **(1)** to learn how life on the earth has survived and thrived, **(2)** to understand how we interact with the environment, and **(3)** to find ways to deal with environmental problems and live more sustainably.

A key component of environmental science is **ecology**, the biological science that studies how living things interact with one another and with their environment. These living things are called **organisms**. Each organism belongs to a **species**, a group of organisms that has a unique set of characteristics that distinguish it from other groups of organisms.

A major focus of ecology is the study of ecosystems. An **ecosystem** is a set of organisms within a defined area of land or volume of water that interact with one another and with their environment of nonliving matter and energy. For example, a forest ecosystem consists of plants (especially trees; see chapter-opening photo), animals, and various other organisms that decompose organic materials, all interacting with one another, with solar energy, and with the chemicals in the forest's air, water, and soil.

We should not confuse environmental science and ecology with **environmentalism**, a social movement dedicated to trying to sustain the earth's life-support systems for all forms of life. Environmentalism is practiced more in the political and ethical arenas than in the realm of science. Environmentalism and environmental science are both being practiced vigorously on many college and university campuses (**Core Case Study**).

Three Scientific Principles of Sustainability

How has the incredible variety of life on the earth been sustained for at least 3.8 billion years in the face of catastrophic changes in environmental conditions? Such changes included gigantic meteorites impacting the earth, ice ages lasting for hundreds of millions of years, and long warming periods during which melting ice raised sea levels by hundreds of feet.

The latest version of our species has been around for only about 200,000 years—less than the blink of an eye, relative to the 3.8 billion years that life has existed on the planet (see the Geologic and Biological Time Scale in Supplement 6, p. S49). Yet, there is mounting scientific evidence that, as we have expanded into and dominated almost all of the earth's ecosystems during that short time, and especially since 1900, we have seriously degraded these natural systems that support all species, including our own, and our economies.

Our science-based research leads us to believe that three major natural factors have played the key roles in the long-term sustainability of life on this planet, as summarized below and in Figure 1.2 (**Concept 1.1A**). We use these three **scientific principles of sustainability**, or *lessons from nature*, throughout the book to suggest how we might move toward a more sustainable future.

- **Dependence on solar energy:** The sun's input of energy, called **solar energy**, warms the planet and provides energy that plants use to produce **nutrients**, the chemicals necessary for their own life processes and for those of most other animals, including humans. The sun also powers *indirect forms of solar energy* such as wind and flowing water, which we use to produce electricity.
- **Biodiversity:** The variety of genes, organisms, species, and ecosystems in which organisms exist and interact are referred to as **biodiversity** (short for *biological diversity*). The interactions among species, especially the feeding relationships, provide vital ecosystem services and keep any population from growing too large. Biodiversity also provides countless ways for life to adapt to changing environmental conditions, even catastrophic changes that wipe out large numbers of species.
- **Chemical cycling:** The circulation of chemicals necessary for life from the environment (mostly from soil and water) through organisms and back to the environment is called **chemical cycling**, or **nutrient**

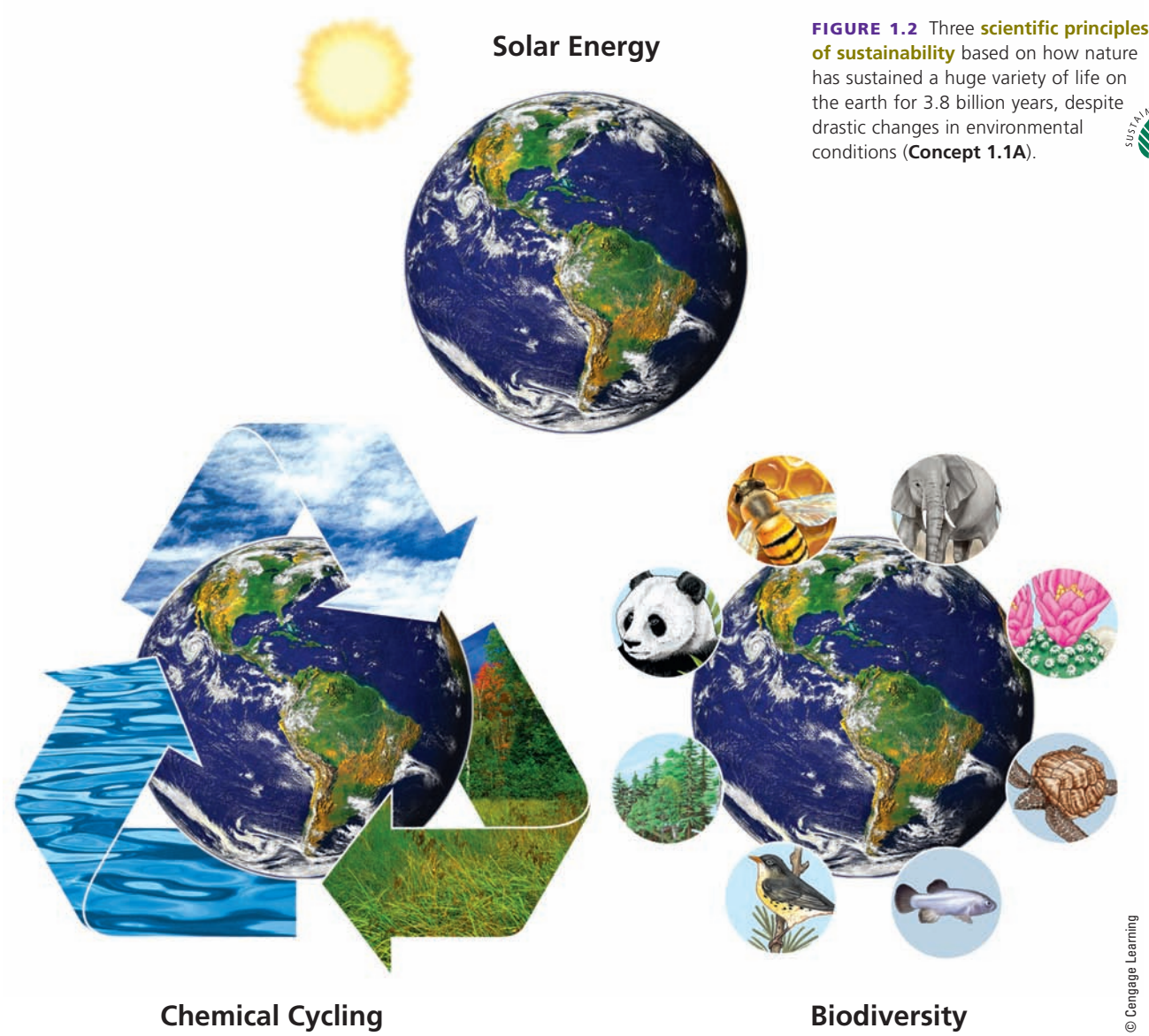


FIGURE 1.2 Three **scientific principles of sustainability** based on how nature has sustained a huge variety of life on the earth for 3.8 billion years, despite drastic changes in environmental conditions (**Concept 1.1A**).

cycling. The earth receives a continuous supply of energy from the sun, but it receives no new supplies of life-supporting chemicals. Thus through their complex interactions with their living and nonliving environment, organisms must continually recycle the chemicals they need in order to survive. This means that there is little waste in nature, other than in the human world, because the wastes and decayed bodies of any organism become nutrients or raw materials for other organisms. In nature,

waste = useful resources

Ecology and environmental science reveal that *interdependence, not independence, is what sustains life* and allows it to adapt to a continually changing set of environmental conditions. Many environmental scientists argue that understanding this interdependence is the key to learning how to live more sustainably.

Sustainability Has Certain Key Components

Sustainability, the central integrating theme of this book, has several critical components that we use as subthemes. One such component is **natural capital**—the natural resources and ecosystem services that keep us and other species alive and support human economies (Figure 1.3).

Natural resources are materials and energy in nature that are essential or useful to humans. They are often classified as *inexhaustible resources* (such as energy from the sun and wind), *renewable resources* (such as air, water, topsoil, plants, and animals) or *nonrenewable* or *depletable resources* (such as copper, oil, and coal). **Ecosystem services** are processes provided by healthy ecosystems that support life and human economies at no monetary cost to us. Examples include purification of air and water, renewal of topsoil, nutrient cycling, pollination, and pest control.

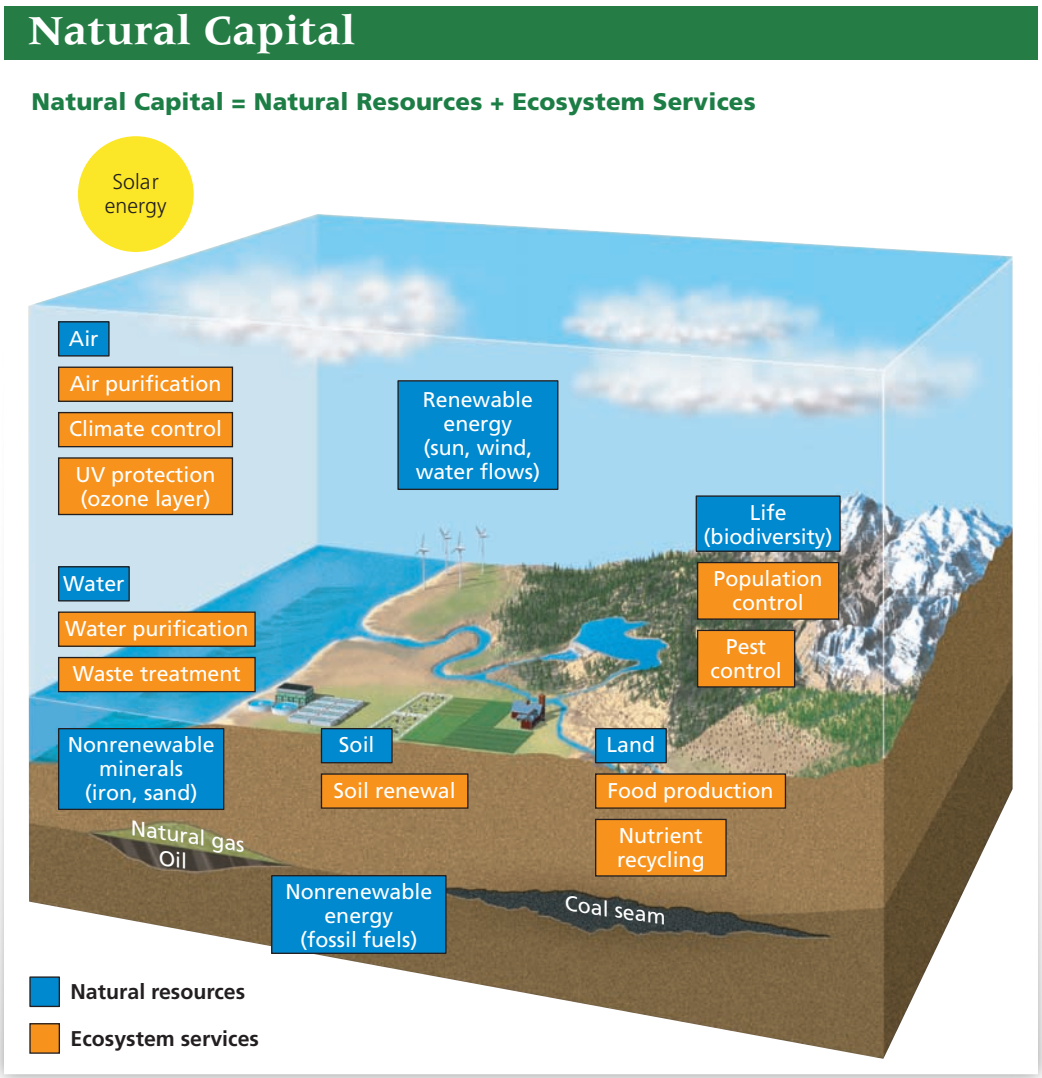


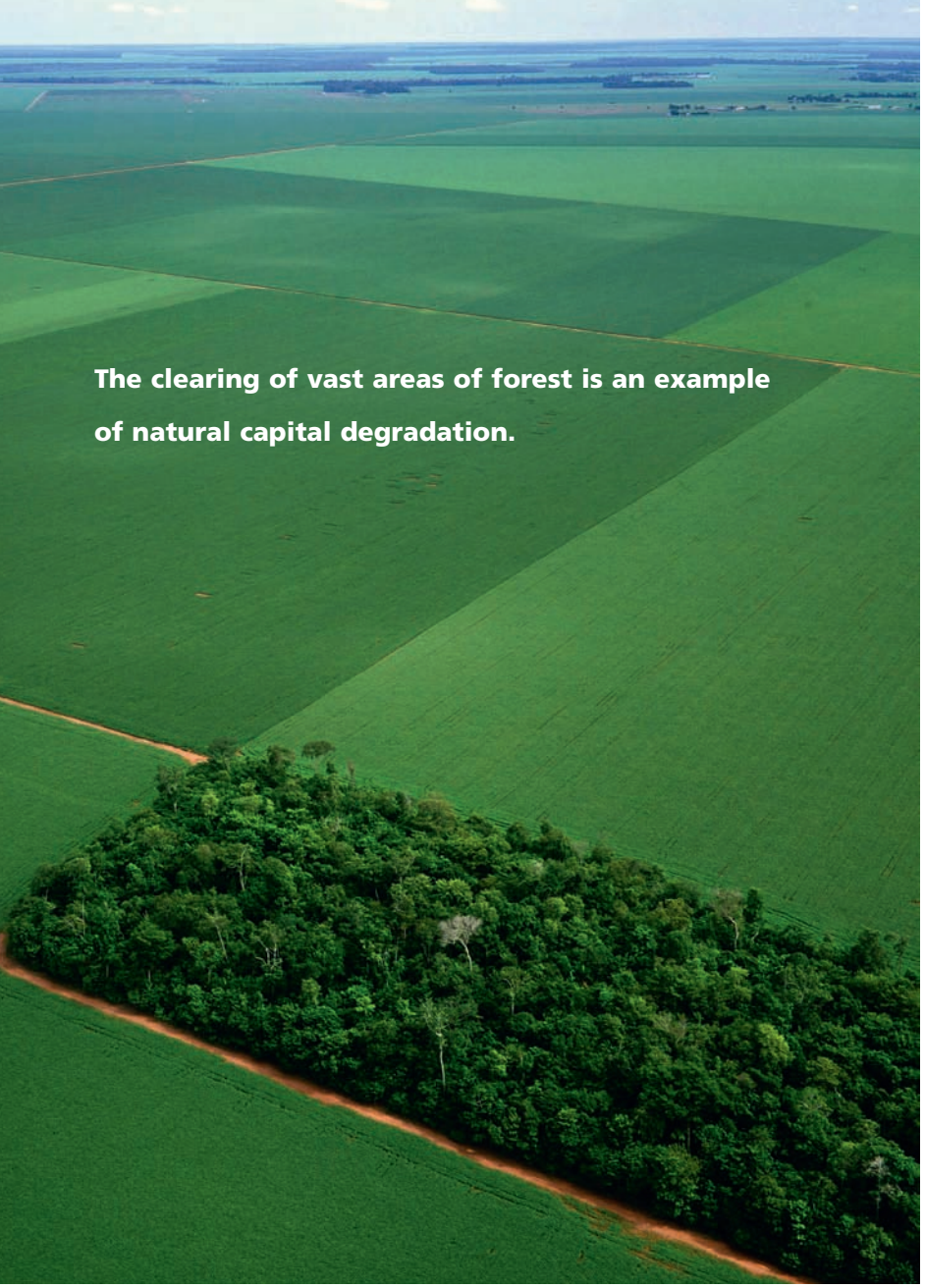
FIGURE 1.3 Natural capital consists of natural resources (blue) and ecosystem services (orange) that support and sustain the earth's life and human economies (**Concept 1.1B**).

One essential ecosystem service is chemical, or nutrient, cycling—the basis for one of the three **scientific principles of sustainability** (Figure 1.2). Chemical cycling helps to turn wastes into resources. An important component of nutrient cycling is *topsoil*—a vital natural resource that provides us and most other land-dwelling species with food. Without nutrient cycling in topsoil, life as we know it could not exist on the earth's land.

Natural capital is also supported by energy from the sun—the focus of another of the **scientific principles of sustainability** (Figure 1.2). Thus, our lives and economies depend on energy from the sun, and on natural resources and ecosystem services *(natural capital)* provided by the earth (**Concept 1.1B**).

A second component of sustainability—and another subtheme of this text—is to recognize that many human activities can *degrade natural capital* by using normally renewable resources such as trees and topsoil faster than nature can restore them and by overloading the earth's normally renewable air and water systems with pollution and wastes. For example, in some parts of the world, we are replacing diverse and naturally sustainable forests (Figure 1.4) with crop plantations that can be sustained only with large inputs of water, fertilizer, and pesticides. We are also adding harmful chemicals and wastes to some rivers, lakes, and oceans faster than these bodies of water can cleanse themselves through natural processes. In addition, we are disrupting the nutrient cycles that support life because many of the plastics and other synthetic materials that we have created cannot be broken down and used as nutrients by other organisms.

This leads us to a third component of sustainability: *solutions*. While environmental scientists search for scientific solutions to problems such as the degradation of forests and other forms of natural capital, social scientists are looking for economic and political solutions. For example,



John Lee/Aurora Photos

FIGURE 1.4 Small remaining area of once diverse Amazon rain forest surrounded by vast soybean fields in the Brazilian state of Mato Grosso.

a scientific solution to the problems of depletion of forests is to stop burning or cutting down biologically diverse, mature forests (Figure 1.4). A scientific solution to the problem of pollution of rivers is to prevent the excessive dumping of harmful chemicals and wastes into streams and to allow them to recover naturally. However, to implement such solutions, governments often have to enact and enforce environmental laws and regulations.

The search for solutions often involves conflicts. For example, when a scientist argues for protecting a long-undisturbed forest to help preserve its important biodiversity, the timber company that had planned to harvest the trees in that forest might protest. Dealing with such conflicts often involves making *trade-offs,* or compromises—another component of sustainability. For example, the timber company might be persuaded to plant and harvest trees in an area that it had already cleared or degraded, instead of clearing the undisturbed forest. In return, the government might give the company a *subsidy,* or financial support, to meet some of the costs for planting the trees.

In making a shift toward sustainability, the daily actions of each and every individual are important. In other words, *individuals matter*—another subtheme of this book. History shows that almost all of the significant changes in human systems that have improved environmental quality have come from the bottom up, through the collective actions of individuals and from individuals inventing more sustainable ways of doing things.

Other Principles of Sustainability Come from the Social Sciences

Our study of environmental problems, proposed solutions, and trade-offs has led us to propose three **social science principles of sustainability** (Figure 1.5), derived from studies of economics, political science, and ethics:

- **Full-cost pricing** (from economics): Many economists urge us to find ways to include the harmful environmental and health costs of producing and using goods and services in their market prices—a practice called **full-cost pricing**. This would give consumers better information about the environmental impacts of their lifestyles, and it would allow them to make more informed choices about the goods and services they use.
- **Win-win solutions** (from political science): We can learn to work together in dealing with environmental problems by recognizing our interdependent connections with others and with our life-support system. This means shifting from a *win-lose* approach based on competition and dominance of other humans and of ecosystems to *win-win* solutions that are based on compromise in light of our interdependence and that benefit both people and the environment.
- **A responsibility to future generations** (from ethics): We should leave the planet's life-support systems in at least as good a condition as that which we now enjoy, if not better, for future generations.

Other researchers have proposed additional sustainability principles, but we believe that our six **principles of sustainability** (Figure 1.2, Figure 1.5, and Supplement 7, pp. S50–S51) can serve as key guidelines for helping us live more sustainably.

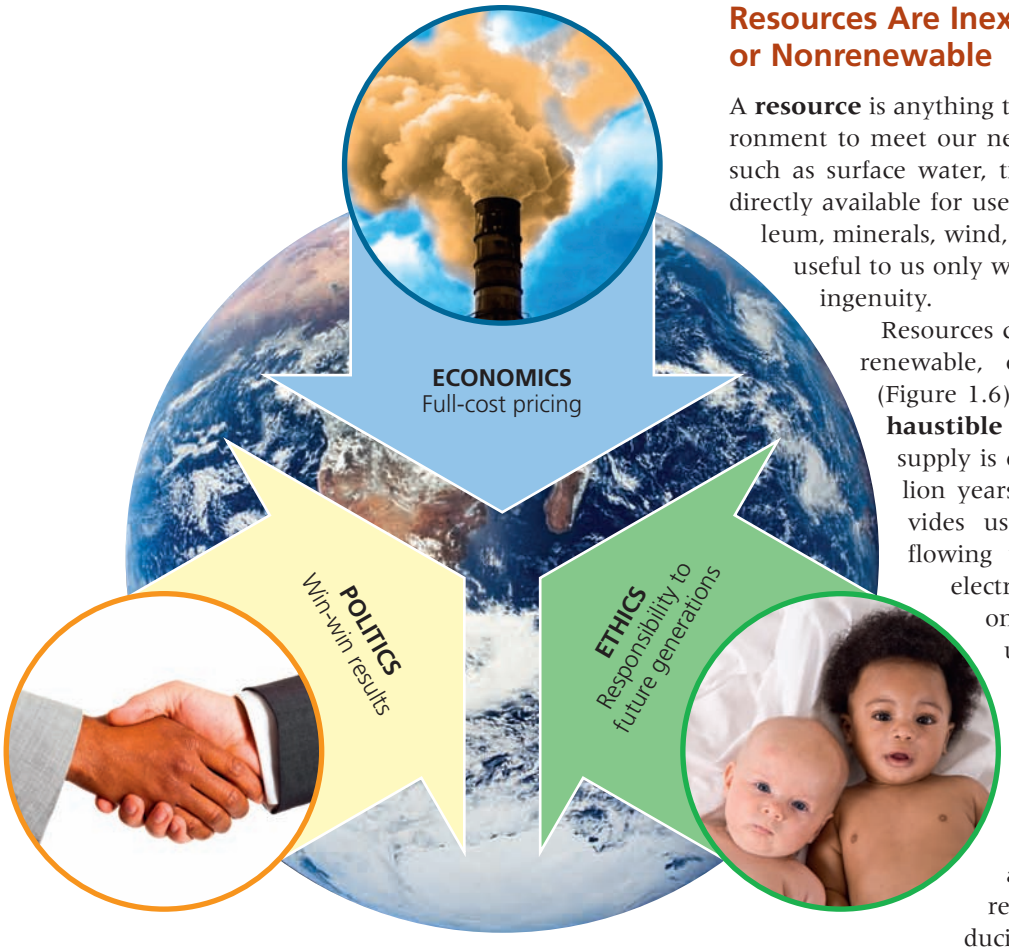


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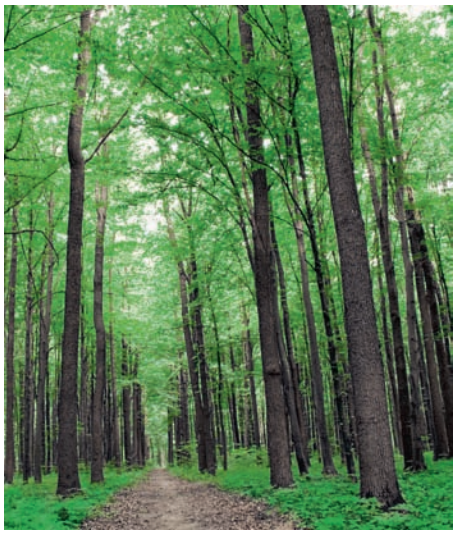
FIGURE 1.5 Three **social science principles of sustainability** can help us make a transition to a more environmentally and economically sustainable future.

Resources Are Inexhaustible, Renewable, or Nonrenewable

A **resource** is anything that we can obtain from the environment to meet our needs and wants. Some resources, such as surface water, trees, and edible wild plants, are directly available for use. Other resources, such as petroleum, minerals, wind, and underground water, become useful to us only with some effort and technological ingenuity.

Resources can be classified as inexhaustible, renewable, or nonrenewable (exhaustible) (Figure 1.6). Solar energy is called an **inexhaustible resource** because its continuous supply is expected to last for at least 6 billion years until the sun dies. It also provides us with inexhaustible wind and flowing water that we use to produce electricity. A **renewable resource** is one that can be replenished by natural processes within hours to centuries, as long as we do not use it up faster than natural processes can renew it. Examples include forests, grasslands, fishes, fertile topsoil, clean air, and freshwater. The highest rate at which we can use a renewable resource indefinitely without reducing its available supply is called its **sustainable yield**.

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. Center: Alexander Kalina/Shutterstock.com. Right: Karl Naundorf/Shutterstock.com.

FIGURE 1.6 We depend on a combination of inexhaustible, renewable, and exhaustible (nonrenewable) natural resources.