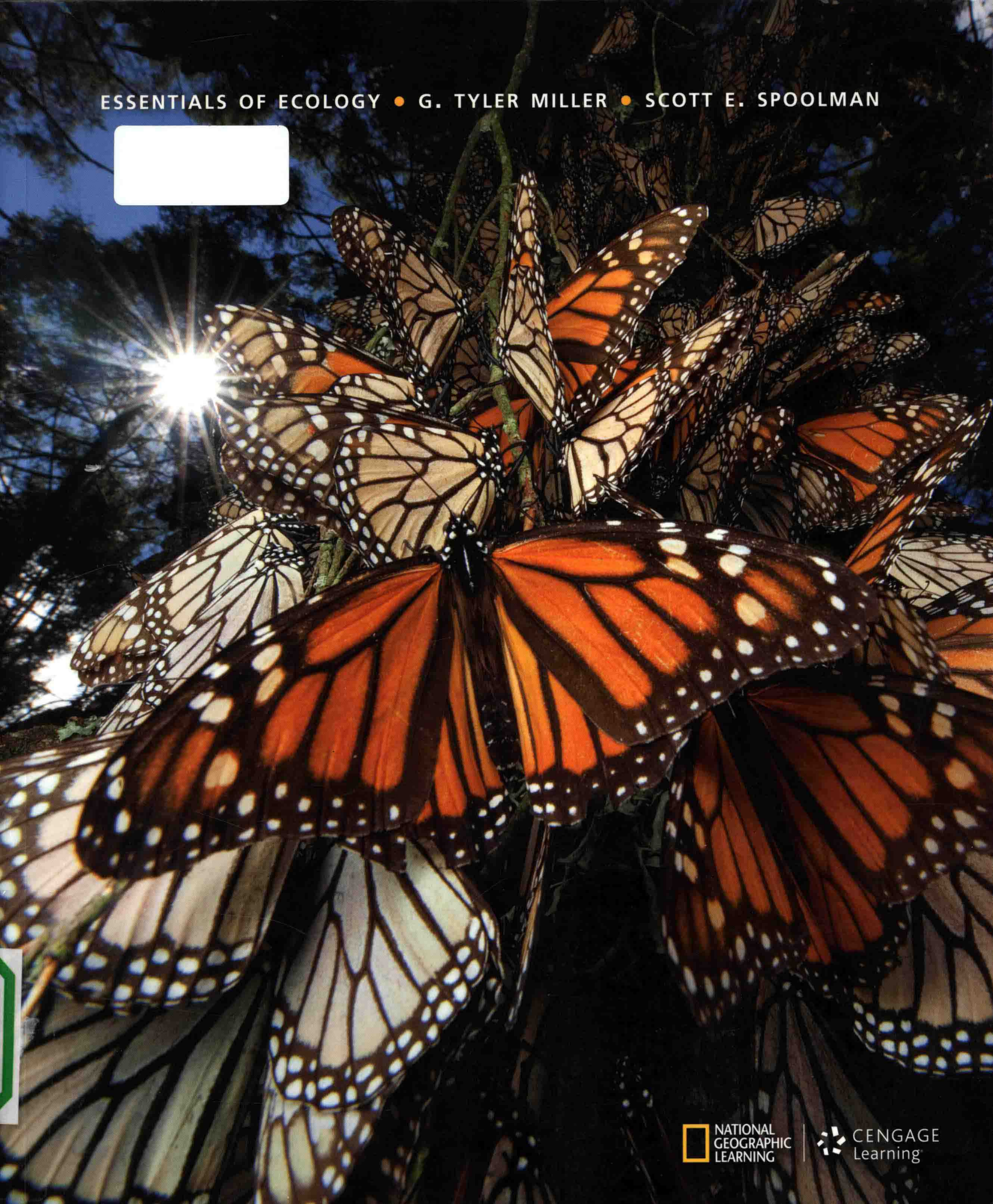
ESSENTIALS OF ECOLOGY • G. TYLER MILLER • SCOTT E. SPOOLMAN
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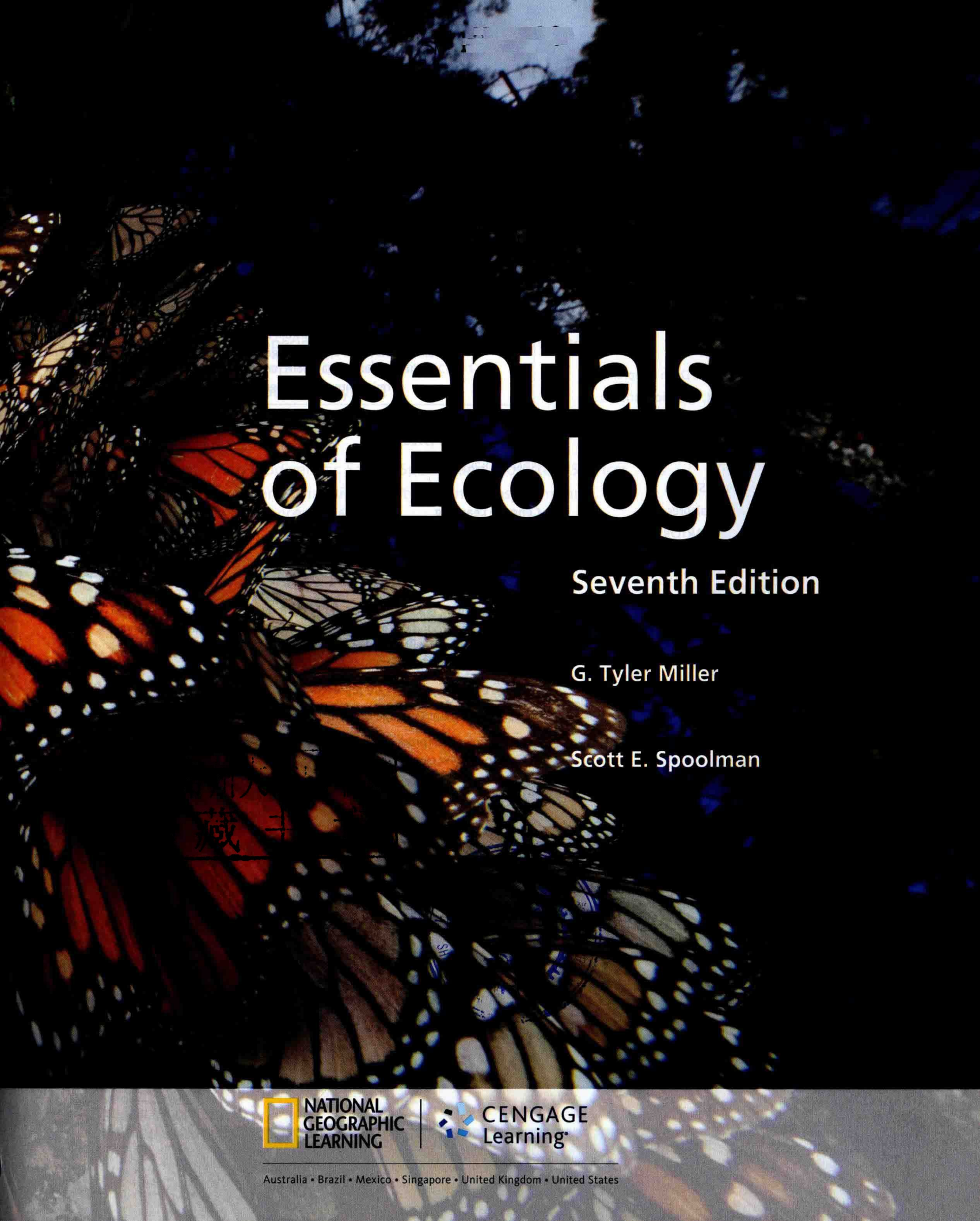

Essentials of Ecology

Seventh Edition

G. Tyler Miller

Scott E. Spoolman

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ABOUT THE COVER PHOTO

The beautiful monarch butterfly is one of North America's best-known butterfly species. Because monarchs cannot survive cold winters, they migrate south to a warmer climate during the fall to hibernate in dense colonies in certain types of trees (as in the photo, right). Monarchs that live west of the Rocky Mountains migrate to the area around Pacific Grove, California where they cluster in groves of eucalyptus trees. Monarchs that live east of the Rockies migrate as far as 4,000 kilometers (2,500 miles) to live in oyamel fir trees in Mexico.

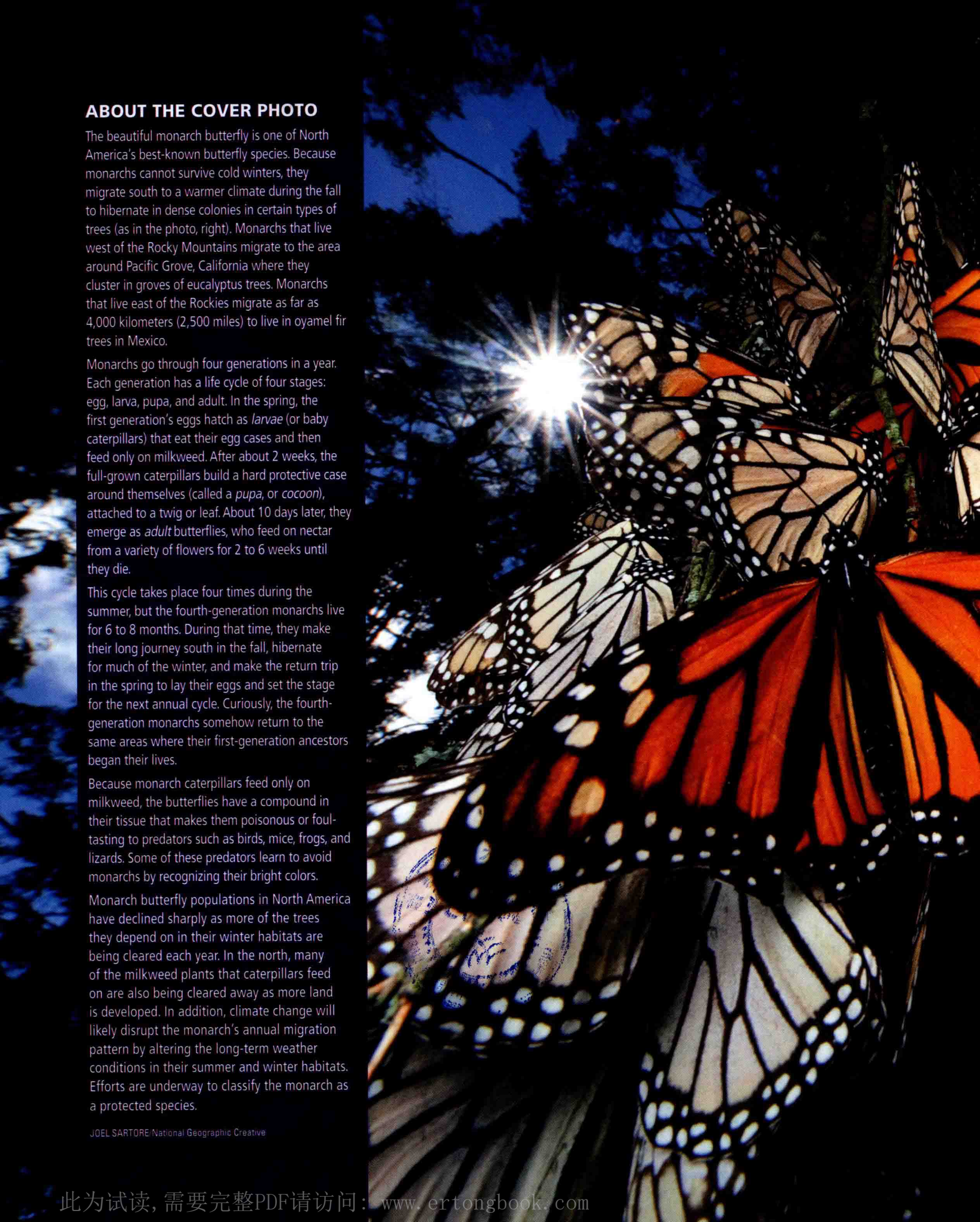
Monarchs go through four generations in a year. Each generation has a life cycle of four stages: egg, larva, pupa, and adult. In the spring, the first generation's eggs hatch as *larvae* (or baby caterpillars) that eat their egg cases and then feed only on milkweed. After about 2 weeks, the full-grown caterpillars build a hard protective case around themselves (called a *pupa*, or *cocoon*), attached to a twig or leaf. About 10 days later, they emerge as *adult* butterflies, who feed on nectar from a variety of flowers for 2 to 6 weeks until they die.

This cycle takes place four times during the summer, but the fourth-generation monarchs live for 6 to 8 months. During that time, they make their long journey south in the fall, hibernate for much of the winter, and make the return trip in the spring to lay their eggs and set the stage for the next annual cycle. Curiously, the fourth-generation monarchs somehow return to the same areas where their first-generation ancestors began their lives.

Because monarch caterpillars feed only on milkweed, the butterflies have a compound in their tissue that makes them poisonous or foul-tasting to predators such as birds, mice, frogs, and lizards. Some of these predators learn to avoid monarchs by recognizing their bright colors.

Monarch butterfly populations in North America have declined sharply as more of the trees they depend on in their winter habitats are being cleared each year. In the north, many of the milkweed plants that caterpillars feed on are also being cleared away as more land is developed. In addition, climate change will likely disrupt the monarch's annual migration pattern by altering the long-term weather conditions in their summer and winter habitats. Efforts are underway to classify the monarch as a protected species.

JOEL SARTORE/National Geographic Creative



For Instructors

With this new edition, we are happy to announce our new partnership with *The National Geographic Society,* which shares our goals, as reflected in its statement of purpose: *Inspiring people to care about the planet.* One result of this new collaboration is the addition of many stunning and informative photographs, numerous maps, and several new stories of National Geographic Explorers—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 new partnership with National Geographic* has given us access to hundreds of amazing photographs, numerous maps, and inspiring stories of *National Geographic Explorers*—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.
- *Campus Sustainability boxes:* short descriptions about what selected U.S. colleges and universities are doing to make their institutions more sustainable.
- *Three social science principles of sustainability.* These complement the three scientific principles of sustainability that we have long used to explain how life on Earth has sustained itself for billions of years, and they act as guidelines for making a possible transition to more sustainable economies and societies.
- *New Core Case Studies* for 6 of the book's 11 chapters that serve as an integrating theme throughout each chapter. They bring important real-world stories to the forefront for use in applying those chapters' concepts and principles.
- *Two new end-of-chapter exercises: Doing Environmental Science* and *Global Environment Watch* research projects give students challenging new ways to apply the material.

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. vii).

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), in Figure 1-5 (p. 9), and on the back cover of the student edition and are used throughout the book, with each reference marked in the margin by the symbol shown here at the right (see pp. 62 and 218).

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 10-4, p. 220.
- ***Natural Capital Degradation.*** We describe how human activities can degrade natural capital. See Figures 1-7, p. 11, and 7-17, p. 160.
- ***Solutions.*** We present existing and proposed solutions to environmental problems in a balanced manner and challenge students to use critical thinking to evaluate them.
- ***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.
- ***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. 82 and 240). Also, a number of What Can You Do? diagrams describe how readers can deal with the problems we face (see Figures 9-12, p. 202, and 10-30, p. 242).

Other Key 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 2010–2013 to update the information and concepts in this book. Major new or updated topics include planetary boundaries that indicate ecological tipping points (Science Focus 3.3, p. 72) and the rising threat of ocean acidification (Science Focus 11.2, p. 252), along with 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 or two 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. 29 and 31). Also, the concept applications are highlighted and referenced throughout each chapter.

- ***Science-Based Coverage.*** Chapters 2–8 cover scientific principles important to the course and discuss how scientists work (see Brief Contents, p. vii). Important environmental science topics are explored in depth in Science Focus boxes distributed among the chapters throughout the book (see pp. 94 and 203) and integrated throughout the book in various Case Studies (see pp. 238 and 256) and in numerous figures.
- ***Global Perspective.*** 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 dozens of maps in the basic text and in Supplement 6. Half of these maps are new and more than half of the new maps are from National Geographic. At the end of each chapter is a Global Environment Watch exercise that applies this global perspective (see p. 245).
- ***Core Case Studies.*** Each chapter opens with a Core Case Study (see pp. 78 and 190), which is applied throughout the chapter. These applications are indicated by the notation (**Core Case Study**) wherever they occur (see pp. 88 and 155). Each chapter ends with a *Tying It All Together* box (see pp. 96 and 213), 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 11 Core Case Studies, many additional Case Studies (see pp. 92, 200, and 238) appear throughout the book (and are listed in the Detailed Contents, pp. viii–xvi). Each of these provides an in-depth look at specific environmental problems and their possible solutions. We also have included very brief descriptions of efforts on several college campuses to study or apply principles of sustainability in our new *Campus Sustainability* stories that appear in several of the book's chapters (see pp. 210 and 270).
- ***Critical Thinking.*** The Preface for Students (p. xxiii) describes critical thinking skills, and specific critical thinking exercises are used throughout the book in several ways:
  - As more than 100 *Thinking About* exercises that ask students to analyze material immediately after it is presented (see pp. 35 and 264).
  - In all *Science Focus* boxes.
  - In dozens of *Connections* boxes that stimulate critical thinking by exploring the often surprising connections related to environmental problems (see pp. 18 and 195).
  - In the captions of many of the book's figures (see Figures 3-15, p. 63, and 9-8, p. 198).
  - In end-of-chapter questions (see pp. 97 and 214).
- ***Visual Learning.*** With a new design heavily influenced by material from National Geographic and hundreds of photographs, this is the most visually appealing environmental science textbook available (see Figures 3-21, p. 71; 7-16, p. 159; and 10-18, p. 229). Also included are many diagrams designed to present complex ideas in understandable ways relating to the real world (see Figures 3-3, p. 54; 3-17, p. 66; and 4-2, p. 79).
- ***In-Text Study Aids.*** Each chapter begins with a list of *Key Questions* showing how the chapter is organized (see p. 217). 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. More than 100 *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. 226). The captions of many figures contain similar questions that get students to think about the figure content (see Figure 10-28, p. 238). 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 p. 226). Finally, the text of each chapter wraps up with three *Big Ideas* (see p. 242), which summarize and reinforce three of the major take-away messages 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. 243). Again, this reinforces the main messages of the chapter along with the themes of sustainability to give students a stronger understanding of how it all ties 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 to experience the work of various environmental scientists; a *Global Environment Watch* exercise taking students 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. 243–245.) And at the end of the book, we have included a comprehensive glossary that includes definitions of all key terms as well as many other terms that are important to environmental science.

Supplements for Instructors

- ***Environmental Science MindTap.*** MindTap is a new personal learning experience that combines all your digital assets—readings, multimedia, activities, and assessments—into a singular learning path to improve student outcomes.
- ***Instructor 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.*** Cengage Learning Testing Powered by Cognero is a flexible, online system that allows you to do the following:
  - author, edit, and manage test bank content from multiple Cengage Learning solutions
  - create multiple test versions in an instant
  - deliver tests from your LMS, your classroom, or wherever you want
- ***Transparencies.*** Online Transparency Correlation Guide. This guide correlates the transparency set created for *Living in the Environment 17e, Environmental Science 13e, Sustaining the Earth 10e,* and *Essentials of Ecology 6e* to the new editions of these texts: *Living in the Environment 18e, Environmental Science 14e, Sustaining the Earth 11e,* and *Essentials of Ecology 7e.* To acquire the set of 250 printed transparencies and 250 electronic masters, please ask your local Cengage Learning Sales Representative or call 1-800-423-0563.
- ***Aplia.*** Aplia™ is a Cengage Learning online homework system dedicated to improving learning by increasing student effort and engagement. Aplia makes it easy for instructors to assign frequent online homework assignments. Aplia provides students with prompt and detailed feedback to help them learn as they work through the questions, and features interactive tutorials to fully engage them in learning course concepts. Automatic grading and powerful assessment tools give instructors real-time reports of student progress, participation, and performance, and Aplia's easy-to-use course management features let instructors flexibly administer course announcements and materials online. With Aplia, students will show up to class fully engaged and prepared, and instructors will have more time to do what they do best. . . teach.
- ***BBC Videos for Environmental Science.*** This large library of BBC clips are informative, short clips of 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 Companion Site and within MindTap.
- ***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.
- ***Virtual Field Trips in Environmental Issues.*** This supplement 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, the role of climate change in extinctions, invasive species, the evolution of a species in relation to its environment, and an ecosystem approach to sustaining biodiversity. Students are engaged, interacting with real issues to help them think critically about the world around them.

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.

Acknowledgments

We wish to thank the many students and teachers who have responded so favorably to the 17 previous editions of *Living in the Environment,* the 14 editions of *Environmental Science,* the 10 editions of *Sustaining the Earth,* and the 6 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 300 reviewers, who pointed out errors and suggested many important improvements in the various editions of these three books.

It takes a village to produce a textbook, and the members of the talented production team, listed on the copyright page, have made vital contributions. Our special thanks go to development editor Jake Warde, production editors Hal Humphrey and Dan Fitzgerald, designer Pam Galbreath, copy editor Chris DeVito, compositor Craig Beffa, photo researcher Christina Ciaramella, artist Patrick Lane, media developer Alexandria Brady, assistant editor Alexis Glubka, product assistant Kellie Petruzzelli, and Cengage Learning's hardworking sales staff. Finally, we

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G. Tyler Miller

Scott E. Spoolman

Guest Essayists

Guest essays by the following authors are available online: **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; **David Pimentel**, professor of insect ecology and agricultural sciences, Cornell University; **John Pichtel**, Ball State 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.

Dr. Dean Goodwin and his colleagues Berry Cobb, Deborah Stevens, Jeannette Adkins, Jim Lehner, Judy Treharne, Lonnie Miller, and Tom Mowbray provided excellent contributions to the Data Analysis and Ecological Footprint Analysis exercises. Mary Jo Burchart of Oakland Community College wrote the in-text Global Environment Watch exercises.

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Pelliam, Bureau of Land Management, U.S. Department of the Interior; Murray Paton Pendarvis, Southeastern Louisiana University; Dave Perault, Lynchburg College; Rodney Peterson, Colorado State University; Julie Phillips, De Anza College; John Pichtel, Ball State University; William S. Pierce, Case Western Reserve University; David Pimentel, Cornell University; Peter Pizor, Northwest Community College; Mark D. Plunkett, Bellevue Community College; Grace L. Powell, University of Akron; James H. Price, Oklahoma College; Marian E. Reeve, Merritt College; Carl H. Reidel, University of Vermont; Charles C. Reith, Tulane University; Erin C. Rempala, San Diego City College; Roger Revelle, California State University, San Diego; L. Reynolds, University of Central Arkansas; Ronald R. Rhein, Kutztown University of Pennsylvania; Charles Rhyne, Jackson State University; Robert A. Richardson, University of Wisconsin; Benjamin F. Richason III, St. Cloud State University; Jennifer Rivers, Northeastern University; Ronald Robberecht, University of Idaho; William Van B. Robertson, School of Medicine, Stanford University; C. Lee Rockett, Bowling Green State University; Terry D. Roelofs, Humboldt State University; Daniel Ropek, Columbia George Community College; Christopher Rose, California Polytechnic State University; Richard G. Rose, West Valley College; Stephen T. Ross, University of Southern Mississippi; Robert E. Roth, Ohio State University; Dorna Sakurai, Santa Monica College; Arthur N. Samel, Bowling Green State University; Shamili Sandiford, College of DuPage; Floyd Sanford, Coe College; David Satterthwaite, I.E.E.D., London; Stephen W. Sawyer, University of Maryland; Arnold Schecter, State University of New York; Frank Schiavo, San Jose State University; William H. Schlesinger, Ecological Society of America; Stephen H. Schneider, National Center for Atmospheric Research; Clarence A. Schoenfeld, University of Wisconsin, Madison; Madeline Schreiber, Virginia Polytechnic Institute; Henry A. Schroeder, Dartmouth Medical School; Lauren A. Schroeder, Youngstown State University; Norman B. Schwartz, University of Delaware; George Sessions, Sierra College; David J. Severn, Clement Associates; Don Sheets, Gardner-Webb University; Paul Shepard, Pitzer College and Claremont Graduate School; Michael P. Shields, Southern Illinois University at Carbondale; Kenneth Shiovitz; F. Siewert, Ball State University; E. K. Silbergold, Environmental Defense Fund; Joseph L. Simon, University of South Florida; William E. Sloey, University of Wisconsin, Oshkosh; Robert L. Smith, West Virginia University; Val Smith, University of Kansas; Howard M. Smolkin, U.S. Environmental Protection Agency; Patricia M. Sparks, Glassboro State College; John E. Stanley, University 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; 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.

For Students

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 and the learning opportunities available to you online 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.***
- ***Get organized.***
- ***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.*** 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 hills out of mountains.*** It is psychologically difficult to read an entire book, read a chapter in a book, write a paper, or cram to study for a test. Instead, break these large tasks (mountains) down into a series of small tasks (hills). Each day, read a few pages of a book or chapter, write a few paragraphs of a 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?" "How does it relate to the key question 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 MindTap online edition of this text provides direct links to definitions for all bold-type terms. 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 highlight key sentences and paragraphs and make notes in the margins. You might also mark important pages that you want to return to. The MindTap edition supports extensive note-taking features.
- ***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 using your own shorthand system. 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.
- ***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. Additional quizzes can be found online as well. 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 _____."
- ***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 and see relationships and to apply your knowledge to dealing with new and different problems, as well as to your own lifestyle choices. 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. Understand that there are trade-offs involved in dealing with any environmental issue, as you will learn in reading 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 reliable results of science have a high degree 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, even 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 especially 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, scientific laws, theories, concepts, and connections. 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 Questions* 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 which appear on the back cover of the student edition. 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 activities and choices we take for granted and how they might be affecting 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 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.

We have also 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. A variety of other exercises and projects follow this review section at the end of each chapter.

Finally, at the back of the book, we have included a comprehensive glossary. It includes definitions of all the book's key terms, as well as definitions of many other important terms.

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 online) to memorize key terms and ideas. This is a highly visual book with many carefully selected photographs and diagrams designed 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 different speeds and voices. 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. Such solutions are achieved when people with different viewpoints work together to come up with a solution that both sides can live with. 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 applying critical thinking to 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 our 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 is a new approach to highly personalized online learning. Beyond an eBook, homework solution, digital supplement, or premium website, MindTap is a digital learning platform that works alongside your campus 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.
- ***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/shop/isbn/9781423929444 to complete the exercises found at the end of each chapter.

- **New! *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.* Students are engaged, interacting with real issues to help them think critically about the world around them.

Visit www.cengagebrain.com for additional materials, including free resources, at www.cengagebrain.com/shop/isbn/9781133940135.

Other student learning tools include the following:

- *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.

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 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 on earlier editions of *Living in the Environment*, *Environmental Science*, and *Sustaining the Earth*. With Norman Myers, he also 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.