G. Tyler Miller · Scott Spoolman

EDITION 16

Environmental Science

NATIONAL GEOGRAPHIC | CENGAGE

Environmental Science 16e

G. Tyler Miller

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NATIONAL GEOGRAPHIC LEARNING | CENGAGE

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About the Cover

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

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

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Preface

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

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

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

What's New in This Edition?

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

Sustainability Is the Integrating Theme of This Book

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

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

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

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

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

Other Successful Features of This Textbook

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

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

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

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

Supplements for Instructors

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

Help Us Improve This Book or Its Supplements

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

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

Acknowledgments

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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 content developer Oden Connolly; production managers Hal Humphrey and Valarmathy Munuswamy; the copy editors of Editorial Services, Lumina Datamatics; compositor Lumina Datamatics; photo researcher Venkat Narayanan; artist Patrick Lane; development manager Lauren Oliveira; and Cengage Learning's hard-working sales staff. Finally, we are very fortunate to have the guidance, inspiration, and unfailing support of our Project Manager April Cognato and her dedicated team of highly talented people who have made this and other book projects such a pleasure to work on.

G. Tyler Miller

Scott E. Spoolman

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About the Authors

G. TYLER MILLER

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

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

He describes his hopes for the future as follows:

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

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

SCOTT E. SPOOLMAN

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

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

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

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

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

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

From the Authors

My Environmental Journey— *G. Tyler Miller*

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

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

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

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

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

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

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

Cengage Learning's Commitment to Sustainable Practices

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

Learning Skills

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

Why Is It Important to Study Environmental Science?

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

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

You Can Improve Your Study and Learning Skills

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

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

Get organized. Planning is a key life skill.

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

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

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

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

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

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

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

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

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

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

Write out answers to questions to focus and reinforce learning. Write down your answers to the critical thinking questions found in the *Thinking About* boxes throughout the chapters, in many figure captions, and at the end of each chapter. These questions are designed to inspire you to think critically about key ideas and connect them to other ideas and to your own life. Also, write down your answers to all chapter-ending review questions. The website for each chapter has an additional detailed list of review questions for that chapter. Save your answers for review and test preparation.

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

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

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

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

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

You Can Improve Your Critical Thinking Skills

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Use the Learning Tools We Offer in This Book

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

Next, note that we use three different special notations throughout the text. Each chapter opens with a **Core Case Study**, and each time we tie material within the chapter back to this core case, we note it in bold, colored type as we did in this sentence. You will also see two icons appearing regularly in the text margins. When you see the *sustainability* icon, you will know that you have just read something that relates directly to the overarching theme of this text, summarized by our six **principles of sustainability**, which are introduced in Figures 1.2, p. 6, and 1.7, p. 9, and summarized on the inside back cover of this book. The *Good News* icon GOOD NEWS appears near each of many examples of successes that people have had in dealing with the environmental challenges we face.

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

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

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

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

Know Your Own Learning Style

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

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

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

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

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

Help Us Improve This Book

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

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

Supplements for Students

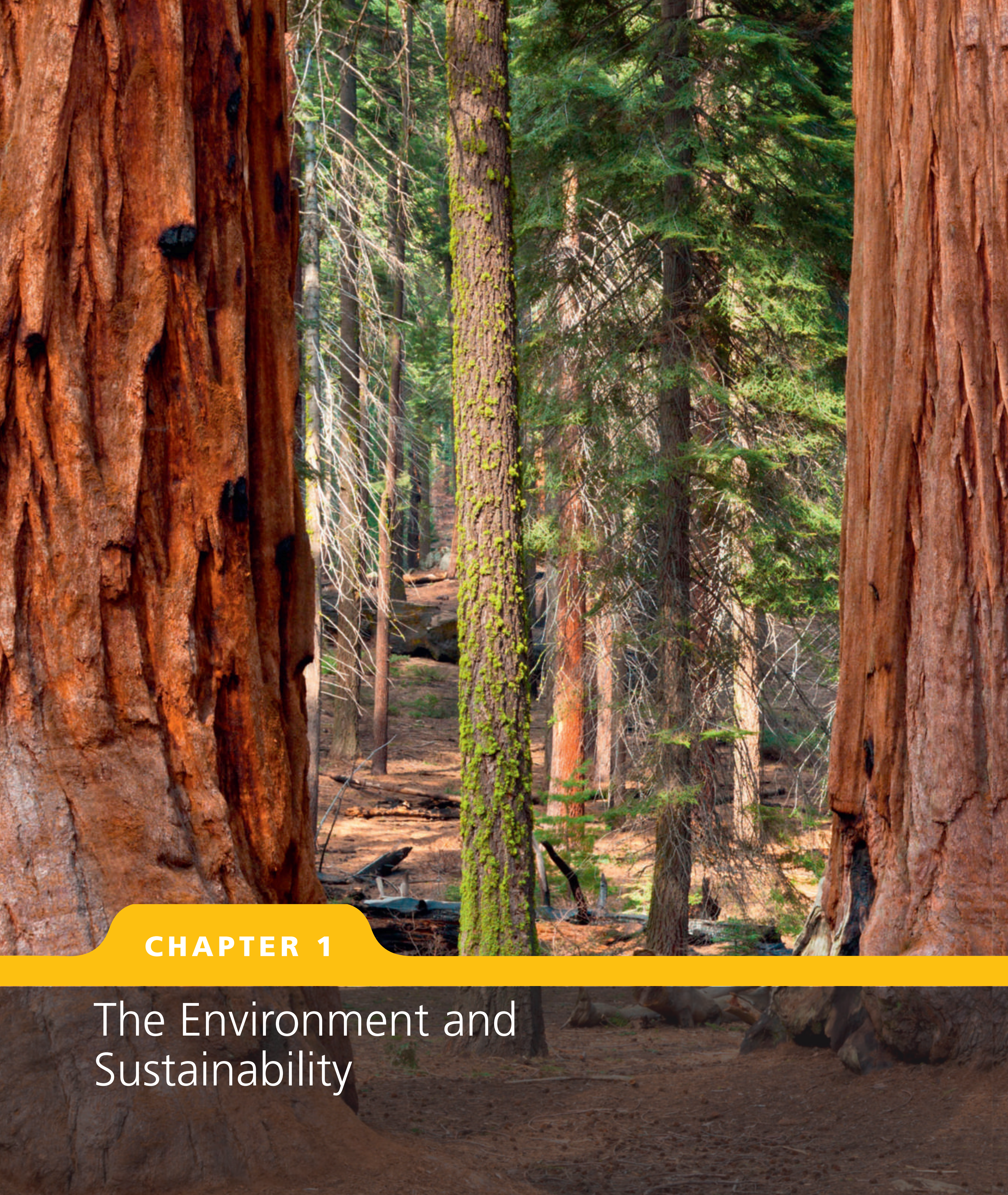
You have a large variety of electronic and other supplemental materials available to you to help you take your learning experience beyond this textbook:

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

Other student learning tools include:

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

Environmental Science 16e



CHAPTER 1

The Environment and Sustainability

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

LESTER R. BROWN

Key Questions

1.1 What are some key principles of sustainability?

1.2 How are we affecting the earth?

1.3 Why do we have environmental problems?

1.4 What is an environmentally sustainable society?

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

robertharding/Alamy Stock Photo

Core Case Study

Learning from the Earth

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

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

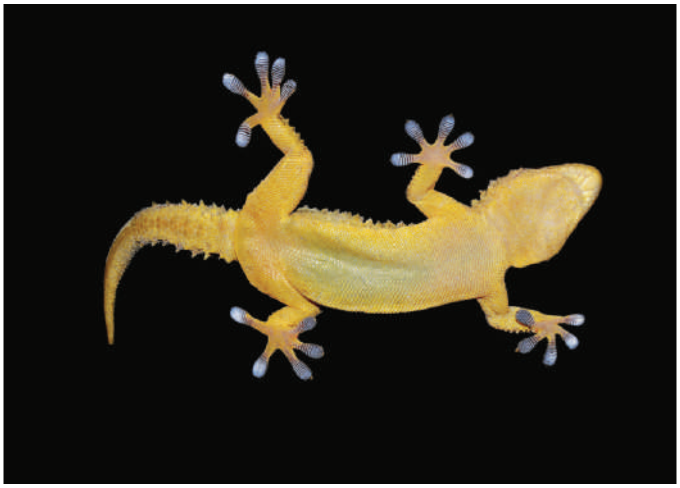
How has life survived such challenges? Long before humans arrived, organisms had developed abilities to use sunlight to make their food and to recycle all of the nutrients they needed for survival. Organisms also developed a variety of abilities to find food and survive. For example, spiders create webs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

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

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

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

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



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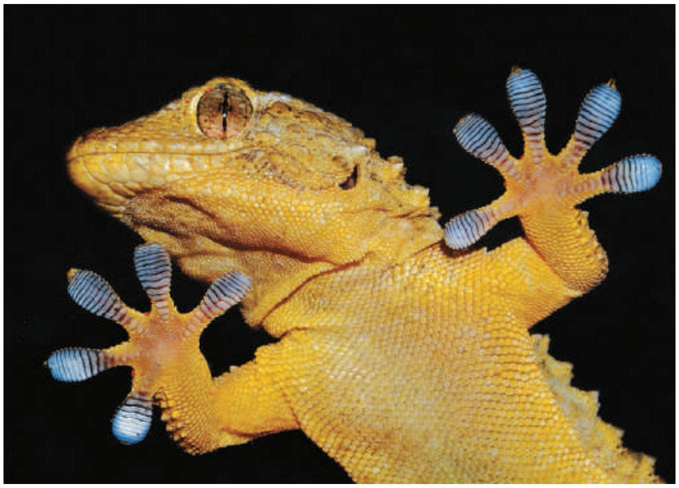


nico99/Shutterstock.com

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

1.1 WHAT ARE SOME KEY PRINCIPLES OF SUSTAINABILITY?

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

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

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

Environmental Science Is a Study of Connections in Nature

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

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

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

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

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

Learning from the Earth: Three Scientific Principles of Sustainability

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

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

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

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

Key Components of Sustainability

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

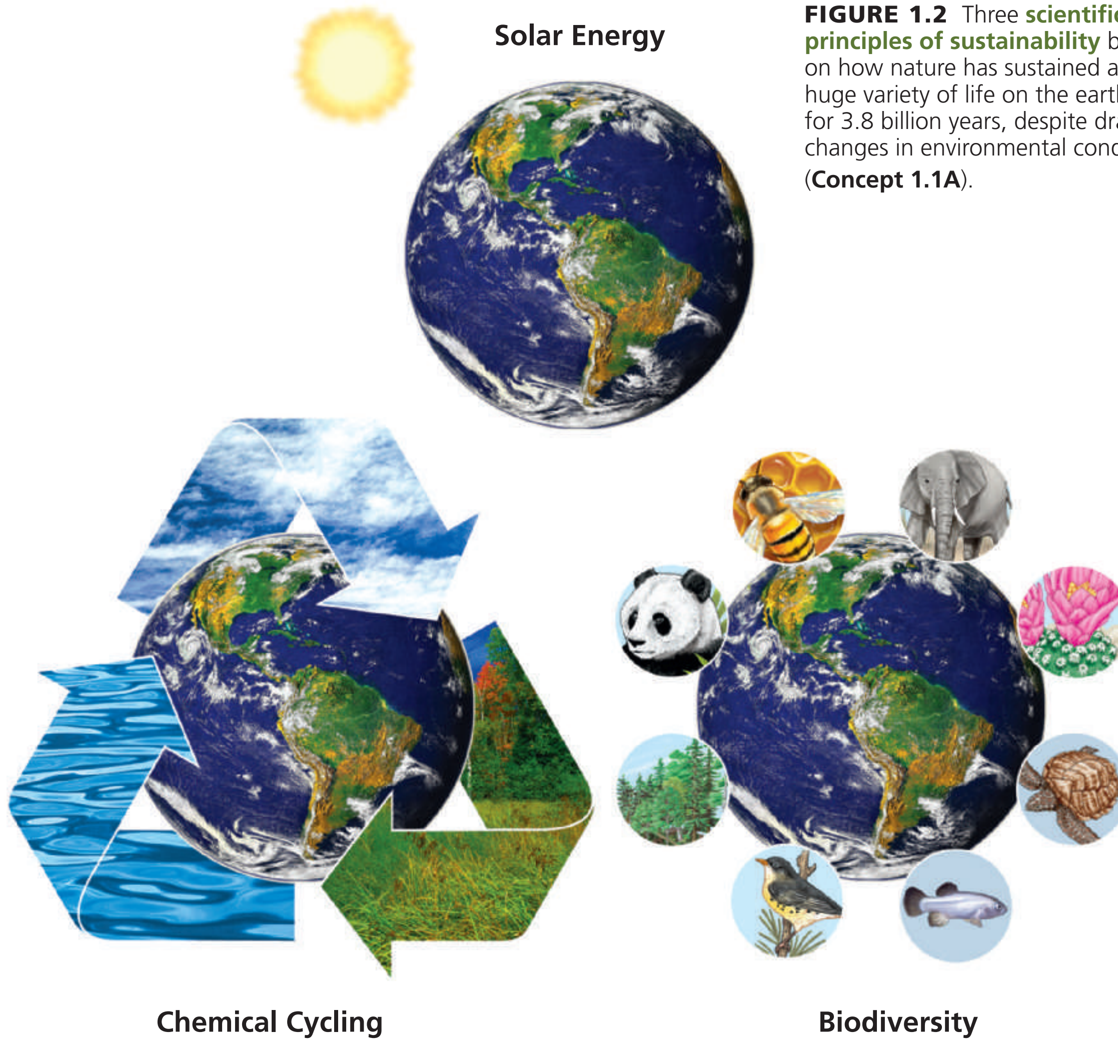


FIGURE 1.2 Three **scientific principles of sustainability** based on how nature has sustained a huge variety of life on the earth for 3.8 billion years, despite drastic changes in environmental conditions (**Concept 1.1A**).

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

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

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

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

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

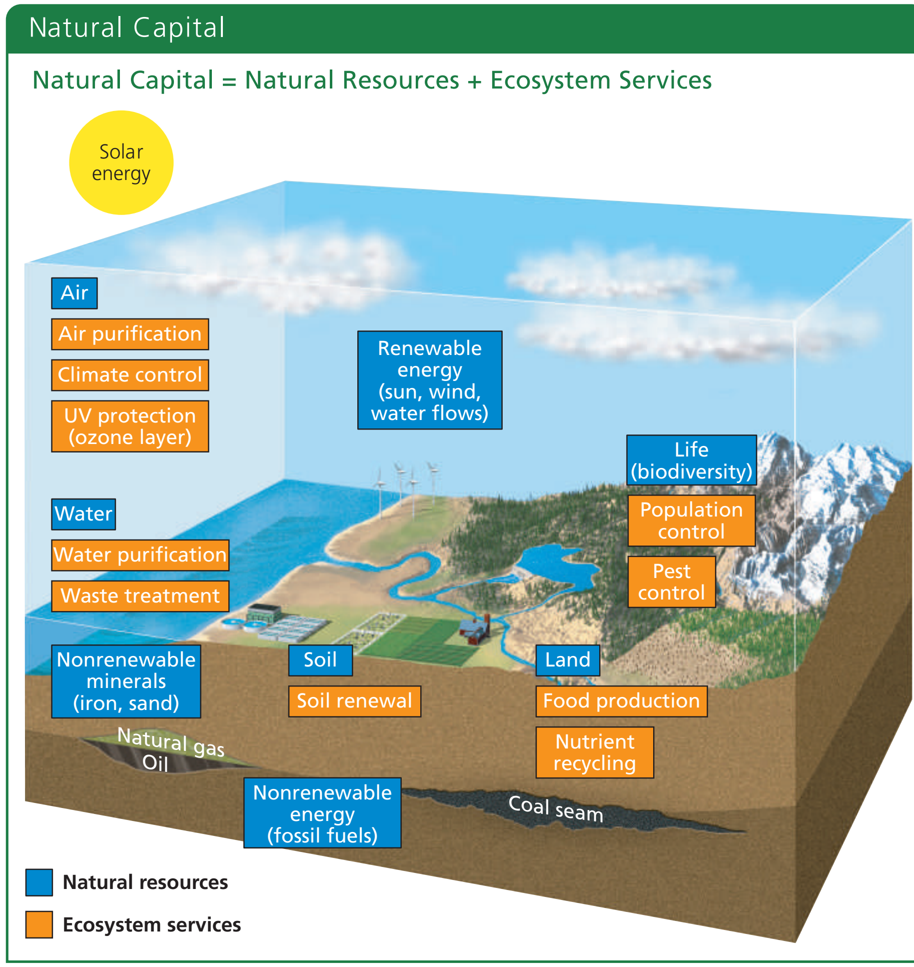


FIGURE 1.3 **Natural Capital** consists of natural resources (blue) and ecosystem services (orange) that support and sustain the earth's life and human economies (**Concept 1.1B**).

Inexhaustible
Solar energy
Wind energy
Geothermal energy

Renewable
Trees
Topsoil
Freshwater

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

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

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


PETE MCBRIDE/National Geographic Creative

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

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

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

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

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


Tom Koene/Visuals Unlimited, Inc.

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

INDIVIDUALS MATTER 1.1

Janine Benyus: Using Nature to Inspire Sustainable Design and Living


ecowatch.com

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

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

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

Three Additional Principles of Sustainability

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

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

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

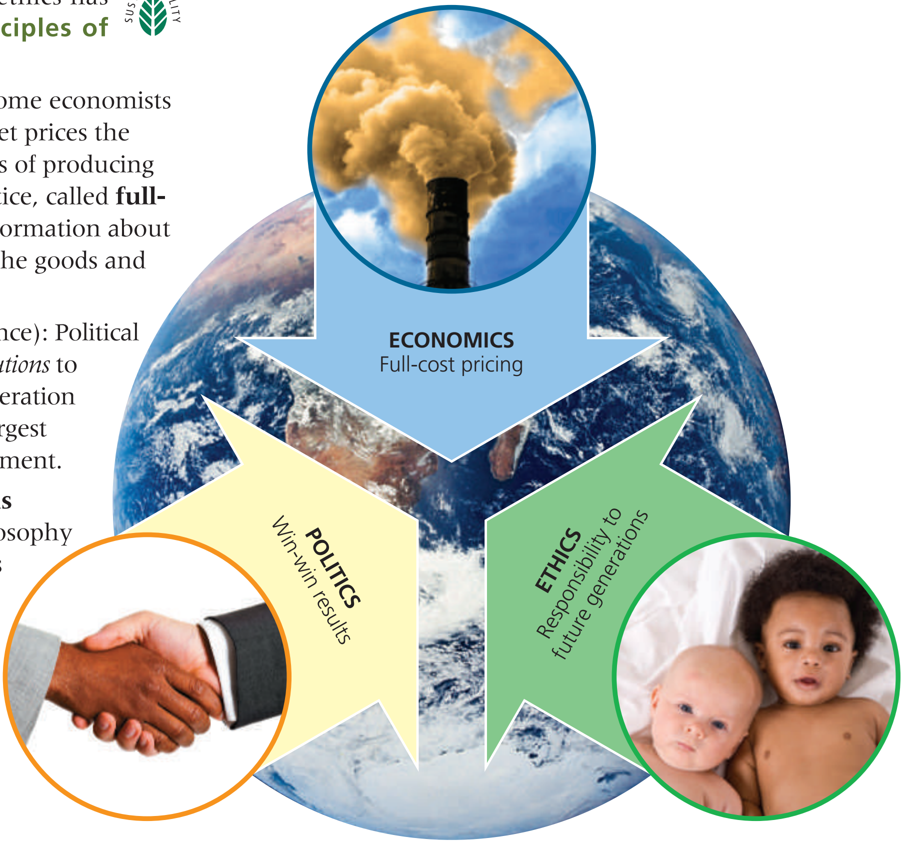


FIGURE 1.7 Three **principles of sustainability based on economics, political science, and ethics** can help us make a transition to a more environmentally and economically sustainable future.

Left: Minerva Studio/Shutterstock.com. Center: mikeledray/Shutterstock.com. Right: iStock.com/Kali Nine LLC

Countries Differ in Their Resource Use and Environmental Impact

The United Nations (UN) classifies the world's countries as economically more developed or less developed, based primarily on their average income per person. **More-developed countries** are industrialized nations with high average income per person. They include the United States, Japan, Canada, Australia, Germany, and most other European countries. These countries, with 17% of the world's population, use about 70% of the earth's natural resources. The United States, with only 4.4% of the world's population, uses about 30% of the world's resources.

All other nations are classified as **less-developed countries**, most of them in Africa, Asia, and Latin America. Some are *middle-income, moderately developed countries* such as China, India, Brazil, Thailand, and Mexico. Others are *low-income, least-developed countries* including Nigeria, Bangladesh, Congo, and Haiti. The less-developed countries, with 83% of the world's population, use about 30% of the world's natural resources.

1.2 HOW ARE WE AFFECTING THE EARTH?

CONCEPT 1.2A Humans dominate the earth with the power to sustain, add to, or degrade the natural capital that supports all life and human economies.

CONCEPT 1.2B As our ecological footprints grow, we deplete and degrade more of the earth's natural capital that sustains us.

Good News: Many People Have a Better Quality of Life

As the world's dominant animal, humans have an awesome power to degrade or sustain the earth's life-support system. For example, humans decide whether forests are preserved or cut down. Human activities affect the temperature of the atmosphere, the temperature and acidity of ocean waters, and which species survive or become extinct. At the same time, creative thinking, scientific research, political pressure by citizens, and regulatory laws have improved the quality of life for many of the earth's people, especially in the more-developed countries.

Humans have developed an amazing array of useful materials and products. We have learned how to use wood, fossil fuels, the sun, wind, flowing water, the nuclei of certain atoms, and the earth's heat (geothermal energy) to supply us with enormous amounts of energy. Most people live and work in artificial environments within buildings and cities. We have invented computers to extend our brainpower, robots to perform repetitive tasks with great precision, and electronic networks to enable instantaneous global communication.

Globally, life spans are increasing, infant mortality is decreasing, education is on the rise, some diseases are being conquered, and the population growth rate has slowed. While one out of seven people live in extreme poverty, we have witnessed the greatest reduction in poverty in human history. The food supply is generally more abundant and safer, air and water are getting cleaner in many parts of the world, and exposure to toxic chemicals is more avoidable. People have protected some endangered species and ecosystems and restored some grasslands and wetlands, and forests are growing back in some areas.

Scientific research and technological advances financed by affluence helped achieve these improvements in life and environmental quality. Education also spurred many citizens to insist that businesses and governments work toward improving environmental quality. We are a globally connected species with growing access to information that could help us to shift to a more sustainable path.

Bad News: On the Whole, We Are Living Unsustainably

According to a large body of scientific evidence, humans are living unsustainably. People continually waste, deplete, and degrade much of the earth's life-sustaining natural capital—a process known as **environmental degradation**, or **natural capital degradation** (Figure 1.8).

According to research by the Wildlife Conservation Society and the Columbia University Center for International Earth Science Information Network, human activities directly affect about 83% of the earth's land surface (excluding Antarctica) as human ecological footprints have impacted the earth (Figure 1.9). This land is used for important purposes such as urban development, growing crops, grazing livestock, mining, timber cutting, and energy production.

In many parts of the world, however, renewable forests are shrinking (Figure 1.6), deserts are expanding, and topsoil is eroding. The lower atmosphere is warming, floating ice and many glaciers are melting at unexpected rates, sea levels are rising, and ocean acidity is increasing. There are more intense floods, droughts, severe weather, and forest fires in many areas. In a number of regions, rivers are running dry, 20% of the world's species-rich coral reefs are gone, and others are threatened. Species are becoming extinct at least 100 times faster than in prehuman times. And extinction rates are projected to increase at least another 100-fold during this century, creating a 6th mass extinction caused by human activities.

In 2005, the United Nations released its *Millennium Ecosystem Assessment*, a four-year study by 1,360 experts from 95 countries. According to this study, human activities have overused about 60% of the earth's ecosystem services

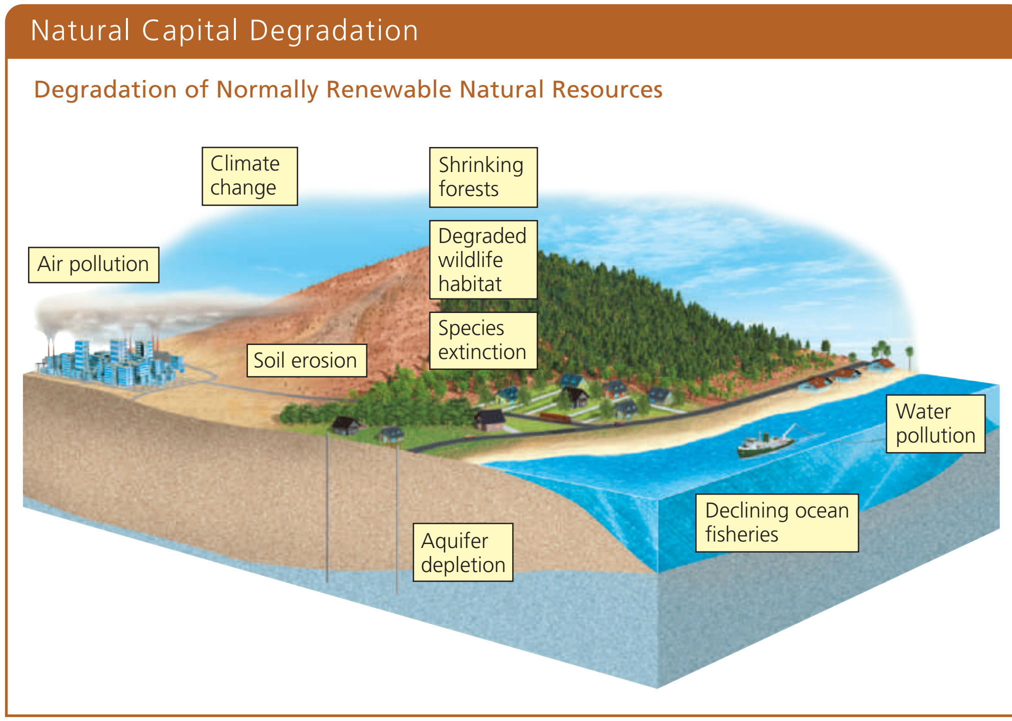


FIGURE 1.8 Natural Capital Degradation: Degradation of normally renewable natural resources and ecosystem services (Figure 1.3), caused by growing human ecological footprints mostly as a result of population growth and rising rates of resource use per person.

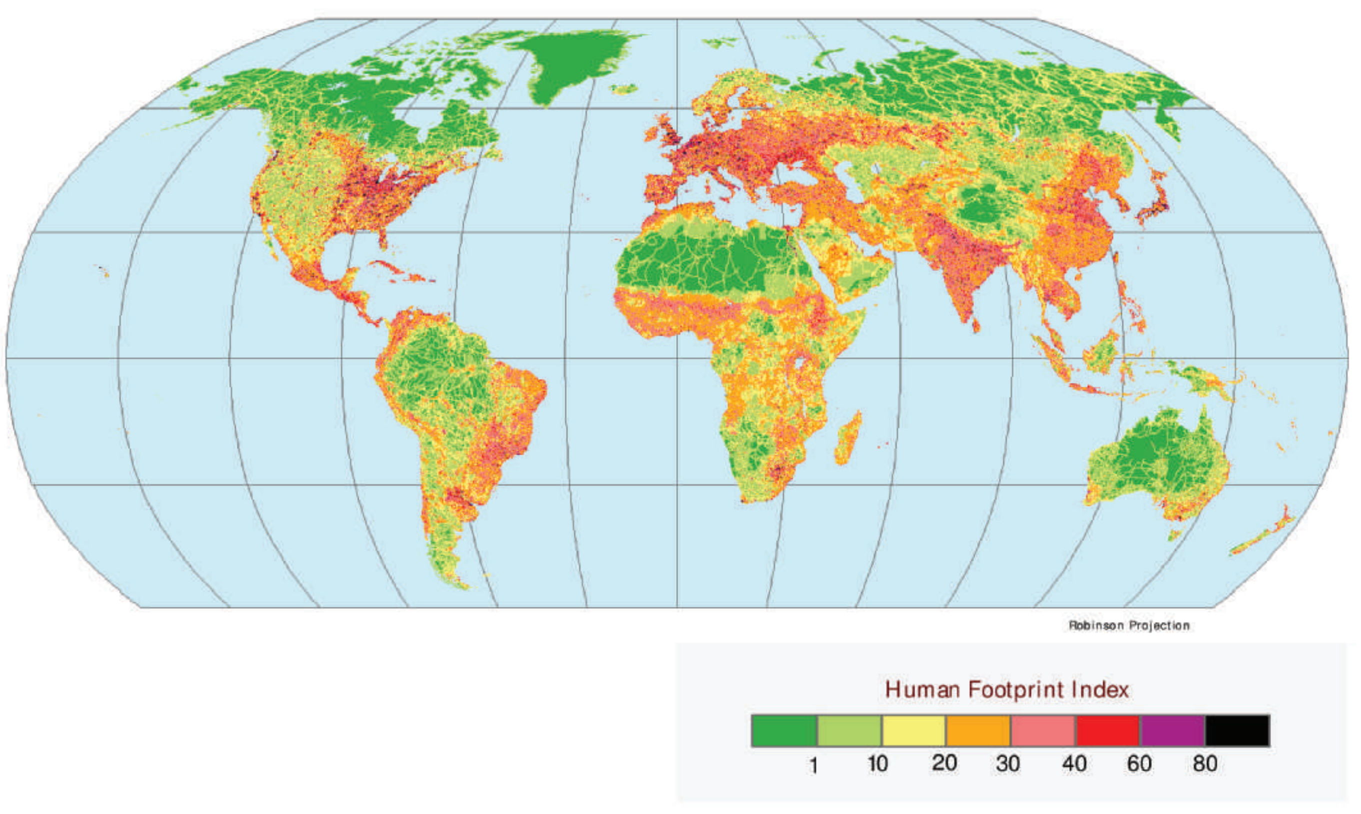


FIGURE 1.9 Natural Capital Use and Degradation: The human ecological footprint has an impact on about 83% of the earth's total land surface.

(see orange boxes in Figure 1.3), mostly since 1950. According to these researchers, "human activity is putting such a strain on the natural functions of Earth that the ability of the planet's ecosystems to sustain future generations can no longer be taken for granted." They also concluded that scientific, economic, and political solutions to these complex problems could be implemented within decades. Since that study, the harmful environmental and health impact of human activities on the planet's ecosystems has increased.

Degrading Commonly Shared Renewable Resources: The Tragedy of the Commons

Some renewable resources, called *open-access resources*, are not owned by anyone and can be used by almost anyone. Examples are the atmosphere and the open ocean and its fish. Other examples of less open, but often *shared resources,* are grasslands, forests, streams, and *aquifers*, or underground bodies of water. Many of these renewable resources have been environmentally degraded. In 1968, biologist Garrett Hardin (1915–2003) called such degradation the *tragedy of the commons.*

Degradation of such shared or open-access renewable resources occurs because each user reasons, "The little bit that I use or pollute is not enough to matter, and anyway, it's a renewable resource." When the level of use is small, this logic works. Eventually, however, the total effect of large numbers of people trying to exploit a widely available or shared renewable resource can degrade it, eventually exhausting or ruining it. Then no one benefits and everyone loses. That is the tragedy.

One way to deal with this difficult problem is to use a shared or open-access renewable resource at a rate well below its estimated sustainable yield. This is done by mutually agreeing to use less of the resource, regulating access to the resource, or doing both.

Another way is to convert shared renewable resources to private ownership. The reasoning is that if you own something, you are more likely to protect your investment. However, history shows that this does not necessarily happen. In addition, this approach is not possible for open-access resources such as the atmosphere, which cannot be divided up and sold as private property.

Our Growing Ecological Footprints

The effects of environmental degradation by human activities can be described as an **ecological footprint**—a rough measure of the total harmful environmental impacts of individuals, cities, and countries on Earth's natural resources, ecosystem services, and life-support system. A **per capita ecological footprint** is the average ecological footprint of an individual in a given population or defined area. Figure 1.9 shows that the human ecological footprint has impacted 83% of the earth's land surface, and Figure 1.10 shows the human ecological footprint in North America.

An important measure of sustainability is **biocapacity**, or **biological capacity—**the ability of an area's ecosystems to regenerate the renewable resources used by a population, city, region, country, or the world in a given time period and to absorb the resulting wastes and pollution. If the total ecological footprint in a defined area (such as a city, country, or the world) is larger than its biocapacity, the area is said to have an *ecological deficit.* Such a deficit occurs when people are living unsustainably by depleting natural capital instead of living off the renewable resources and ecosystem services provided by such capital. Figure 1.11 is a map of ecological debtor and creditor countries.

Ecological footprint data and models have been in use since the 1990s. Though imperfect, they provide useful rough estimates of individual, national, and global environmental impacts. In 2016, the World Wide Fund for Nature (WWF) and the Global Footprint Network estimate that we would need the equivalent of 1.6 planet Earths to sustain the world's average 2014 rate of renewable resource use per person far into the future. They estimated that by 2030, we would need the equivalent of two planet Earths and, by 2050, three planet Earths. The current and projected future overdraft of the earth's natural resources and ecosystem services and the resulting environmental degradation will be passed on to future generations.

1.6 Number of earths needed to sustain the 2014 global rate of renewable resource per person use indefinitely

Throughout this book, we discuss ways to use existing and emerging technologies and economic tools to reduce our harmful ecological footprints and to increase our beneficial environmental impacts by working with rather than against the earth. For example, we can replant forests on degraded land, restore degraded wetlands and grasslands, and protect species from becoming extinct.

IPAT Is Another Environmental Impact Model

Another environmental impact model was developed in the early 1970s by scientists Paul Ehrlich and John Holdren. This IPAT model shows that the environmental impact **(I)** of human activities is the product three factors: *population size* **(P)**, *affluence* **(A)** or resource consumption per person, and the beneficial and harmful environmental effects of *technologies* **(T)**. The following equation summarizes the IPAT model:

Impact (**I**) = Population (**P**) × Affluence (**A**) × Technology (**T**)

The **T** factor can be either harmful or beneficial. Some forms of technology such as polluting factories, gas-guzzling

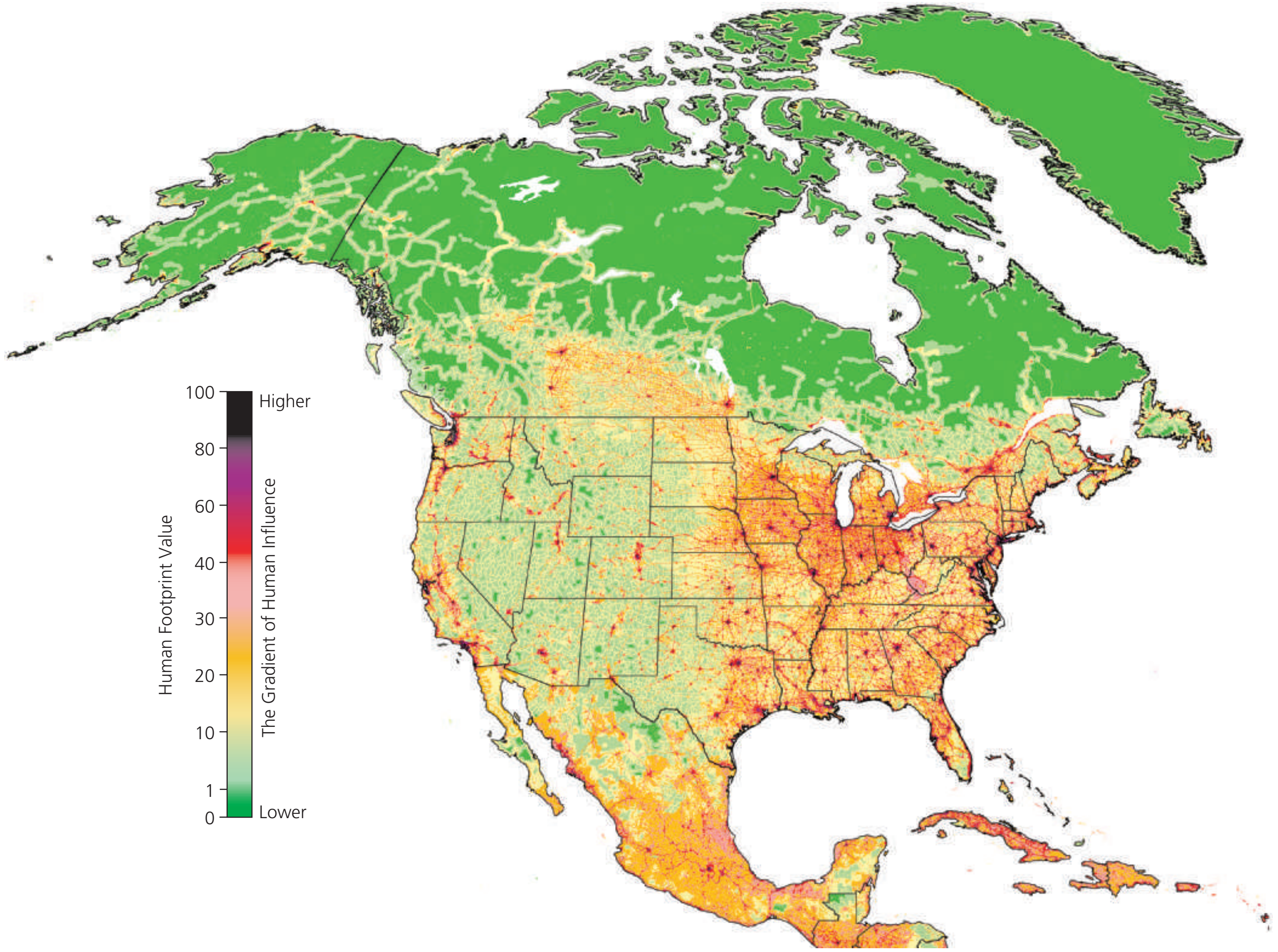


FIGURE 1.10 Natural Capital Use and Degradation: The human ecological footprint in North America. Colors represent the percentage of each area influenced by human activities.

Compiled by the authors using data from Wildlife Conservation Society and Center for International Earth Science Information Network at Columbia University.

motor vehicles, and coal-burning power plants increase our harmful environmental impact by raising the T factor. Other technologies reduce our harmful environmental impact by decreasing the T factor. Examples are pollution control and prevention technologies, fuel-efficient cars, and wind turbines and solar cells that generate electricity with a low environmental impact. By developing technologies that mimic natural processes (**Core Case Study**), scientists and engineers are finding ways to have positive environmental impacts, and we introduce such developments in biomimicry throughout this book.

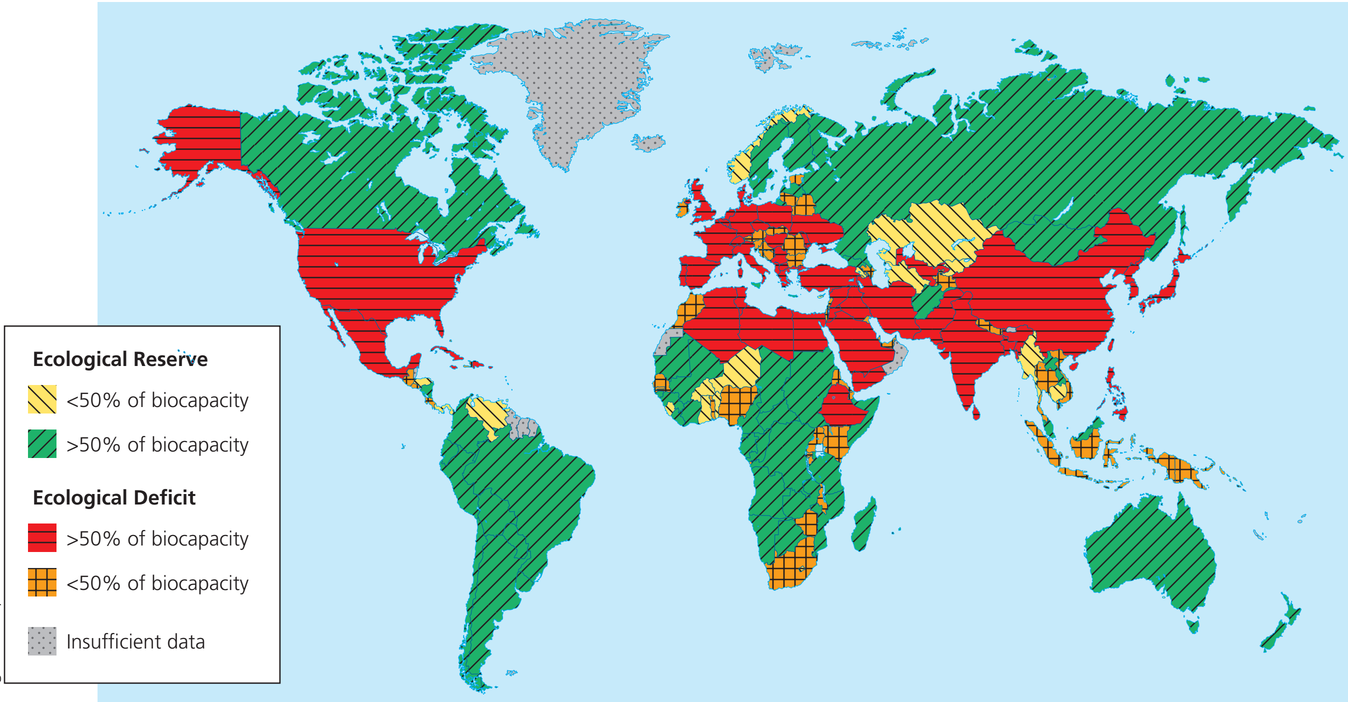
In a moderately developed country such as India, population size is a more important factor than affluence, or resource use per person, in determining the country's environmental impact. In a highly developed country such as the United States with a much smaller population, resource use per person and the ability to develop environmentally beneficial technologies play key roles in the country's environmental impact.

Cultural Changes Can Increase or Shrink Our Ecological Footprints

Until about 10,000 to 12,000 years ago, humans were mostly *hunter–gatherers* who obtained food by hunting wild animals or scavenging their remains, and gathering wild plants. Our hunter–gatherer ancestors lived in small groups, consumed few resources, had few possessions, and moved as needed to find enough food to survive.

Since then, three major cultural changes have occurred. *First* was the *agricultural revolution*. It began around 10,000 years ago when humans learned how to grow and breed plants and animals for food, clothing, and other purposes and began living in villages instead of frequently moving to find food. They had a more reliable source of food, lived longer, and produced more children who survived to adulthood.

Second was the *industrial–medical revolution*, beginning about 300 years ago when people invented machines for



Compiled by the authors using data from Global Footprint Network and WWF: *Living Planet Report 2014.*

FIGURE 1.11 *Ecological debtors and creditors*. The ecological footprints of some countries exceed their biocapacity, while other countries have ecological reserves. ***Critical thinking:*** Why do you think that the United States is an ecological debtor country?

the large-scale production of goods in factories. Many people moved from rural villages to cities to work in the factories. This shift involved learning how to get energy from fossil fuels (such as coal and oil) and how to grow large quantities of food. It also included medical advances that allowed a growing number of people to have longer and healthier lives.

Third, about 50 years ago, the *information–globalization revolution* began when we developed new technologies for gaining rapid access to all kinds of information and resources on a global scale.

Each of these three cultural changes gave us more energy and new technologies with which to alter and control more of the planet's resources to meet our basic needs and increasing wants. They also allowed expansion of the human population, mostly because of larger food supplies and longer life spans. In addition, these cultural changes resulted in greater resource use, pollution, and environmental degradation and expanding ecological footprints (Figures 1.9 and 1.10).

On the other hand, some technological leaps have enabled us to shrink our ecological footprints by reducing our use of energy and matter resources and our production of wastes and pollution. For example, the use of energy-efficient LED light bulbs, energy-efficient cars and buildings, recycling, sustainable farming, and solar energy and wind energy to produce electricity is on the rise.

Many environmental scientists and other analysts see such developments as evidence of an emerging fourth major cultural change: a **sustainability revolution**, in which we could learn to live more sustainably during this century. This would involve avoiding degradation and depletion of the natural capital that supports all life and our economies and restoring natural capital that we have degraded (Figure 1.3). Making this shift would involve learning how nature has sustained life for over 3.8 billion years and using these lessons from nature to shrink our ecological footprints and increase our beneficial environmental impacts. GOOD NEWS

1.3 WHAT CAUSES ENVIRONMENTAL PROBLEMS?

CONCEPT 1.3A Basic causes of environmental problems are population growth, wasteful and unsustainable resource use, poverty, avoidance of full-cost pricing, and increasing isolation from nature.

CONCEPT 1.3B Our environmental worldviews play a key role in determining whether we live unsustainably or more sustainably.

The Human Population Is Growing at a Rapid Rate

Exponential growth occurs when a quantity increases at a fixed percentage per unit of time, such as 0.5% or 2% per year. Exponential growth starts slowly, but after a few doublings, it grows to enormous numbers because each doubling is twice the total of all earlier growth. When we plot the data for an exponentially growing quantity, we get a curve that looks like the letter J.

For an example of the awesome power of exponential growth, consider a simple form of bacterial reproduction in which one bacterium splits into two every 20 minutes. Starting with 1bacterium, after 20 minutes, there would be 2; after an hour, there would be 8; 10 hours later, there would be more than 1,000; and after just 36 hours (assuming that nothing interfered with their reproduction), there would be enough bacteria to form a layer of 0.3 meters (1 foot) deep over the entire earth's surface.

The human population has grown exponentially (Figure 1.12) to the current population of 7.4 billion people. In 2016, the rate of growth was 1.21%. Although this rate of growth seems small, it added 89.7 million people to the world's 7.4 billion people. By 2050, the population could reach 9.9 billion—an addition of 2.5 billion people within your lifetime.

No one knows how many people the earth can support indefinitely. No one knows how much average resource consumption per person will seriously degrade the planet's natural capital. However, humanity's large and expanding ecological footprints and the resulting widespread natural capital degradation are disturbing warning signs (**Concept 1.3A**).

Some analysts call for us to reduce severe environmental degradation by slowing population growth with the goal of leveling it off at around 8 billion by 2050 instead of 9.9 billion. Some ways to do this include reducing poverty through economic development, promoting family planning, and elevating the status of women, as discussed in Chapter 6.

CONSIDER THIS ...

CONNECTIONS Exponential Growth and Doubling Time: The Rule of 70

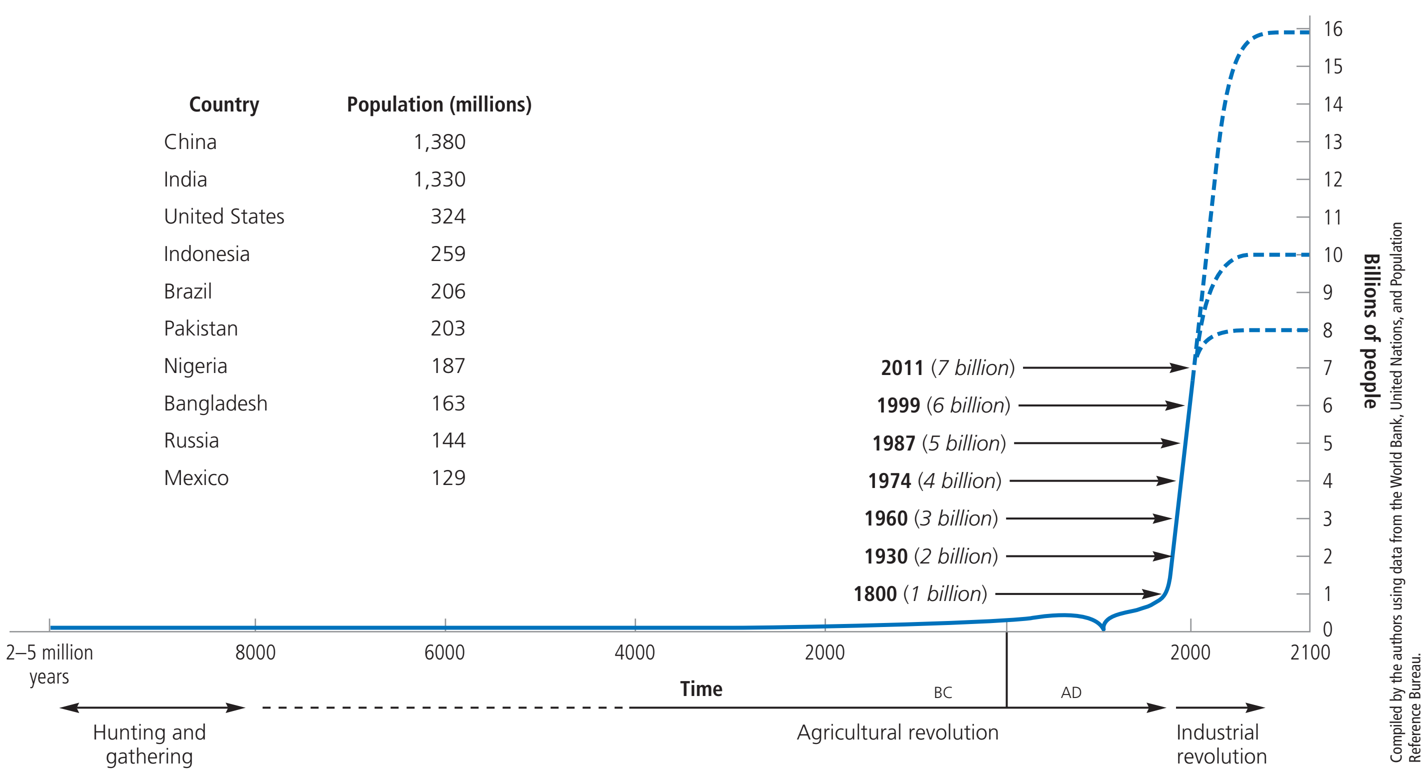
The approximate doubling time of the human population can be calculated by using the rule of 70. (You can apply this rule to any quantity that is growing exponentially.)

doubling time (years) = 70 / annual growth rate (%).

The world's population is growing at about 1.21% per year. At this rate, about how long will it take the human population to double?

Affluence and Unsustainable Resource Use

The lifestyles of many of the world's expanding population of consumers are built on growing affluence, or resource consumption per person, as more people earn higher incomes. As total resource consumption and average resource consumption per person increase, so



Country	Population (millions)
China	1,380
India	1,330
United States	324
Indonesia	259
Brazil	206
Pakistan	203
Nigeria	187
Bangladesh	163
Russia	144
Mexico	129

FIGURE 1.12 *Exponential growth:* The J-shaped curve represents past exponential world population growth, with projections to 2100 showing possible population stabilization as the J-shaped curve of growth changes to an S-shaped curve. The top 10 countries (left) represent nearly 60% of the world's total population. ***Data analysis:*** By what percentage did the world's population increase between 1960 and 2016? (This figure is not to scale.)

do environmental degradation, resource waste, and pollution, unless individuals can live more sustainably (**Concept 1.3A**).

The effects of affluence can be dramatic. The WWF and the Global Footprint Network estimate that the United States, with only 4.4% of the world's population, is responsible for about 23% of the global ecological footprint. The average American consumes about 30 times the amount of resources that the average Indian consumes and 100 times the amount consumed by the average person in the world's poorest countries. The WWF has projected that we would need the equivalent of five planet Earths to sustain the world's population indefinitely if everyone used renewable resources at the same rate as the average American did in 2014.

5 Number of Earths needed to sustain the world's population indefinitely at average per-person U.S. resource consumption rate

On the other hand, affluence can allow for widespread and better education, which can lead people to become more concerned about environmental quality. Affluence also makes more money available for developing technologies to reduce pollution, environmental degradation, and resource waste. It also provides other ways for humans to increase their beneficial environmental impacts.

Poverty Has Harmful Environmental and Health Effects

Poverty is a condition in which people lack enough money to fulfill their basic needs for food, water, shelter, health care, and education. According to the World Bank, about one of every three people, or 2.5 billion people, struggled to live on the equivalent of less than $3.10 a day in 2014. In addition, nearly 900 million people—almost three times the U.S. population—live in *extreme poverty* on the equivalent of less than $1.90 a day, according to the World Bank. This is less than what many people spend for a bottle of water or a cup of coffee. Could you do this? On the other hand, the percentage of the world's population living in extreme poverty decreased from 52% in 1981 to 14% in 2014.

Poverty causes a number of harmful environmental and health effects (**Concept 1.3A**). The daily lives of the world's poorest people center on getting enough food, water, and fuel for cooking and heating to survive. These individuals are too desperate for short-term survival to worry about long-term environmental quality or sustainability. Thus, collectively, they may degrade forests, topsoil, and grasslands, and deplete fisheries and wildlife populations to stay alive.

Poverty does not always lead to environmental degradation. Some of the poor increase their beneficial environmental impact by planting and nurturing trees and conserving the soil that they depend on as a part of their short-term and long-term survival strategy.

CONSIDER THIS . . .

CONNECTIONS Poverty and Population Growth

To many poor people, having more children is a matter of survival. Their children help them gather firewood, haul water, and tend crops and livestock, and some have to work at jobs. The children also help take care of their aging parents, most of whom do not have social security, health care, and retirement funds. This daily struggle for survival is largely why populations in some of the poorest countries continue to grow at high rates.

Environmental degradation can have severe health effects on the poor. One problem is life-threatening *malnutrition*, a lack of protein and other nutrients needed for good health (Figure 1.13). Another effect is illness caused by limited access to adequate sanitation facilities and clean drinking water. More than one-third of world's people have no bathroom facilities and are forced to use backyards, alleys, ditches, and streams. As a result, one of every nine of the world's people gets water for drinking, washing, and cooking from sources polluted by human and animal feces. Another problem for many poor people is indoor air pollution, mostly from the smoke from open fires or poorly vented stoves (Figure 1.14) used for heating and cooking. This form of indoor air pollution kills about 4.3 million people a year in less-developed countries, according to the World Health Organization (WHO).

In 2010, the WHO estimated that these factors, mostly related to poverty, were killing about 7 million children under age 5 each year—an average of 19,000 young children per day. This is equivalent to *95 fully loaded 200-passenger airliners crashing every day with no survivors*. The news media rarely cover this ongoing human tragedy.

CONSIDER THIS . . .

THINKING ABOUT The Poor, the Affluent, and Environmental Harm

Some see the rapid population growth in less-developed countries as the primary cause of our environmental problems. Others say that the high rate of resource use per person in more-developed countries is a more important factor. Which factor do you think is more important? Why?

Prices of Goods and Services Rarely Include Their Harmful Environmental and Health Costs

Another basic cause of environmental problems has to do with how the marketplace prices goods and services (**Concept 1.3A**). Companies using resources to provide

Rowan Gillson/Design Pics/Superstock

FIGURE 1.13 One of every three children younger than age 5 in less-developed countries, such as this starving child in Bangladesh, suffers from severe malnutrition caused by a lack of calories and protein.

Ted Spiegel/National Geographic Creative

FIGURE 1.14 Indoor air pollution from open fires and poorly vented stoves is a major health threat to many poor people in less-developed countries.

goods for consumers generally are not required to pay for most of the harmful environmental and health costs of supplying such goods. For example, timber companies pay the cost of clear-cutting forests but do not pay for the resulting environmental degradation and loss of wildlife habitat.

The primary goal of a company is to maximize profits for its owners or stockholders, so it is not inclined to add these costs to its prices voluntarily. Because the prices of goods and services do not include most of their harmful environmental and health costs, consumers and decision makers have no effective way to evaluate these harmful effects.

Another problem can arise when governments give companies *subsidies* such as tax breaks and payments to assist them with using resources to run their businesses. This helps to create jobs and stimulate economies, but environmentally harmful subsidies encourage the depletion and degradation of natural capital.

According to environmental economists, people could live more sustainably and increase their beneficial environmental impact if the harmful environmental and health costs of the goods and services were included in market prices of the goods they buy and if we place a monetary value on the natural capital that supports all economies. Such full-cost pricing is a powerful economic tool and is one of the six **principles of sustainability**.

Economists propose two ways to implement full-cost pricing over the next two decades. One is to shift from environmentally harmful government subsidies to environmentally beneficial subsidies that sustain or restore natural capital. Examples of environmentally beneficial subsidies are those that reward sustainable forest management, replanting degraded lands, sustainable agriculture, and increased use of wind and solar power to produce electricity. A second way to implement full-cost pricing is to increase taxes on pollution and wastes and reduce taxes on income and wealth. We discuss such *subsidy shifts* and *tax shifts* in Chapter 17.

People Are Increasingly Isolated from Nature

Today, more than half of the world's people and three out of four people in more-developed countries live in urban areas, and this shift from rural to urban living is continuing at a rapid pace. Urban environments and the increasing use of cell phones, computers, and other electronic devices are isolating people, especially children, from the natural world.

Some argue that this has led to a phenomenon called *nature deficit disorder*. People with this disorder may suffer from stress, anxiety, depression, and other problems. Research indicates that experiencing nature (see chapter-opening photo) can reduce stress, improve mental abilities, activate one's imagination and creativity, and lead to better health. The research also shows that when people are isolated from nature, they are less likely to act in ways that will lessen their harmful environmental impacts (**Concept 1.3A**), because they are not aware of their impacts.

Differing Environmental Worldviews

Another reason why environmental problems persist is that people differ over the nature and seriousness of the world's environmental problems, as well as how to solve them (**Concept 1.3B**). These differences arise mostly because of differing environmental worldviews. Your **environmental worldview** is your set of assumptions and values about how the natural world works and how you think you should interact with the environment.

Your environmental worldview is determined partly by your **environmental ethics**—what you believe about what is right and what is wrong in your behavior toward the environment. Here are some important *ethical questions* relating to the environment:

- Why should we care about the environment?
- Are humans the most important species on the planet or are they just another one of the earth's millions of life forms?
- Do people have an obligation to see that their activities do not cause the extinction of other species? If so, should people try to protect all species or only some? How does society decide which ones to protect?
- Does the current human generation have an ethical obligation to pass the natural world on to future generations in a condition as good as or better than what they inherited?
- Should every person be entitled to equal protection from environmental hazards regardless of race, gender, age, national origin, income, social class, or any other factor?
- Should individuals and society as a whole seek to live more sustainably, and, if so, how?

CONSIDER THIS . . .

THINKING ABOUT Our Responsibilities

How would you answer each of the questions above? Compare your answers with those of your classmates. Record your answers and, at the end of this course, return to these questions to see if your answers have changed.

People with different environmental worldviews can take the same data, be logically consistent with it, and arrive at quite different answers to such questions. This happens because individuals start with different assumptions and moral, ethical, or religious beliefs. Environmental worldviews are discussed in detail in Chapter 17, but here is a brief introduction.

There are three major categories of environmental worldviews: human-centered, life-centered, and earth-centered. A **human-centered environmental worldview** sees the natural world primarily as a support system for human life. Two variations in this worldview are the *planetary management worldview* and the *stewardship worldview.* Both worldviews hold that humans are separate from and in charge of nature and that society should manage the earth for the benefit of humans. They also contend that if we degrade or deplete a natural resource or ecosystem service, we can use our technological ingenuity to find a substitute. The stewardship worldview adds that people have a responsibility to be caring and responsible managers, or *stewards*, of the planet for current and future human generations.

According to the **life-centered environmental worldview**, all species have value in fulfilling their ecological roles, regardless of their potential or actual use to society. Eventually, all species become extinct. However, most people with a life-centered worldview believe that we ought to avoid hastening the extinction of species through human activities because each species is a unique part of the biosphere that sustains all life.

According to the **earth-centered environmental worldview**, people are part of and dependent on nature, and the earth's natural capital exists for all species, not just for humans. According to this view, our economic success and the long-term survival of our cultures, our species, and many other species depend on learning how life on the earth has sustained itself for billions of years (Figure 1.2) and integrating such lessons from nature (**Core Case Study** and Science Focus 1.1) into the ways people think and act.

The Rise of Environmental Conservation and Protection in the United States

When European colonists arrived in North America in the early 1600s, Native American tribes had been living sustainably on the continent for thousands of years. The colonists viewed North America as a land with inexhaustible resources and a wilderness to be conquered and managed for human use. As settlers spread across the continent, they cleared forests to build settlements, plowed up grasslands to plant crops, and mined for gold, lead, and other minerals.

In 1864, George Perkins Marsh, a scientist and member of Congress from Vermont, questioned the idea that America's resources were inexhaustible. He used scientific

SCIENCEFOCUS 1.1

Some Biomimicry Principles

According to Janine Benyus (Individuals Matter 1.1), "The study of biomimicry reveals that life creates conditions conducive to life." She calls for us to evaluate each of the goods and services we produce and use by asking: Is it something nature would do? Does it help sustain life? Will it last?

Benyus recognizes three levels of biomimicry. The first involves mimicking the characteristics of species, such as bumps on a whale's fins or the wing and feather designs of birds, which are believed to have enhanced the long-term survival of such species. The second and deeper level involves mimicking the processes that species use to make shells, feathers, and other parts that benefit their long-term survival without using or producing toxins and without using the high-temperature or high-pressure processes we use in manufacturing. The third and deepest level involves mimicking the long-term survival strategies and beneficial environmental effects of natural ecosystems such as forests and coral reefs.

Since 1997, scientists, engineers, and others working in the field of biomimicry have identified several principles that have sustained life on the earth for billions of years. They have found that life

- runs on sunlight;
- does not waste energy;
- adapts to changing environmental conditions;
- depends on biodiversity for population control and adaptation;
- creates no waste because the matter outputs of one organism are resources for other organisms;
- does not pollute its own environment; and
- does not produce chemicals that cannot be recycled by the earth's chemical cycles.

By learning from nature and using such principles, innovative scientists, engineers, and business people are leading a *biomimicry revolution* by creating life-friendly goods and services and profitable businesses that could enrich and sustain humanity and its economies far into the future.

CRITICAL THINKING

Which, if any, of these principles of biomimicry do you follow in your life? How might your lifestyle change if you followed all of these principles? Would you resist or embrace doing this, and why?

studies and case studies to show how the rise and fall of past civilizations were linked to the use and misuse of their soils, water supplies, and other resources. Marsh was one of the founders of the conservation movement in the United States.

Early in the 20th century, this movement split into two factions that differed over how to use U.S. public lands owned jointly by all American citizens. The *preservationist view*, led by naturalist John Muir (Figure 1.15), wanted wilderness areas on some public lands to be left untouched so they would be preserved indefinitely. The *conservationist view*, promoted by President Theodore "Teddy" Roosevelt (Figure 1.16) and Gifford Pinchot, the first chief of the U.S. Forest Service, held that all public lands should be managed wisely and scientifically, primarily to provide resources for people.

Aldo Leopold (Figure 1.17)—wildlife manager, professor, writer, and conservationist—was trained in the conservationist view but shifted toward the preservationist view. He became a pioneer in forestry, soil conservation, wildlife ecology, and wilderness preservation. In 1935, he helped found the U.S. Wilderness Society. Through his writings, especially his 1949 book *A Sand County Almanac,* he laid the groundwork for the field of environmental ethics. He argued that the role of the human species should be to protect nature, not conquer it.

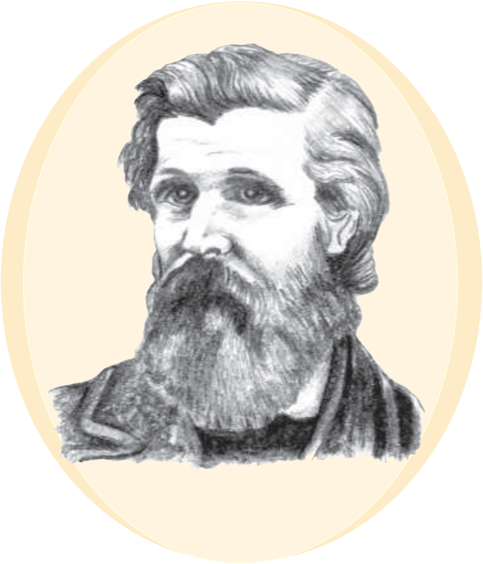


FIGURE 1.15 As leader of the preservationist movement, John Muir (1838–1914) called for setting aside some of the country's public lands as protected wilderness, an idea that was not enacted into law until 1964. Muir was also largely responsible for establishing Yosemite National Park in 1890, and in 1892, he founded the Sierra Club, which is to this day a political force working on behalf of the environment.

FIGURE 1.16 Effective protection of forests and wildlife on federal lands did not begin until Theodore "Teddy" Roosevelt (1858–1919) became president. His term of office, 1901–1909, has been called the country's *Golden Age of Conservation*. He established 36 national wildlife reserves and more than tripled the size of the national forest reserves.

U.S. Fish and Wildlife Service

FIGURE 1.18 Rachel Carson (1907–1964) alerted us to the harmful effects of the widespread use of pesticides. Many environmental historians mark Carson's wake-up call as the beginning of the modern environmental movement in the United States.

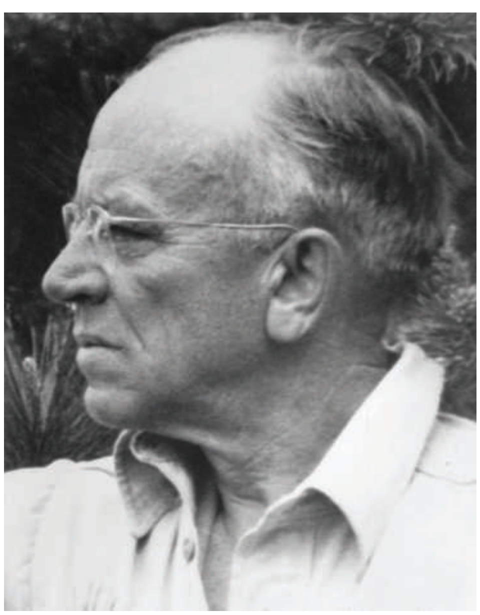


Photo courtesy of the Aldo Leopold Foundation, www.aldoleopold.org

FIGURE 1.17 Aldo Leopold (1887–1948) became a leading conservationist and his book, *A Sand County Almanac*, is considered an environmental classic that helped to inspire the modern conservation and environmental movements.

Later in the 20th century, the concept of resource conservation was broadened to include preservation of the *quality* of the planet's air, water, soil, and wildlife. A prominent pioneer in that effort was biologist Rachel Carson (Figure 1.18), whose book *Silent Spring* was published in 1962. Carson's book documented the pollution of air, water, and wildlife from the widespread use of pesticides such as DDT. This influential book heightened public awareness of pollution problems and led to the regulation of several dangerous pesticides.

Between 1940 and 1970, the United States underwent rapid economic growth and industrialization. The by-products of industrialization were increased air and water pollution and large quantities of solid and hazardous wastes. Air pollution was so bad in many cities that drivers had to use their car headlights during the daytime. Thousands died each year from the harmful effects of air pollution. A stretch of the Cuyahoga River, running through Cleveland, Ohio, was so polluted with oil and other flammable pollutants that it caught fire several times. A devastating oil spill off the California coast occurred in 1969. Well-known wildlife species such as the American bald eagle, the grizzly bear, the whooping crane, and the peregrine falcon became endangered.

Growing publicity over these problems led the American public to demand government action. When the first Earth Day was held on April 20, 1970, some 20 million people in more than 2,000 U.S. communities and college and university campuses attended rallies to demand improvements in environmental quality. Earth Day and the resulting bottom-up political pressure it created led the U.S. government to establish the Environmental Protection Agency (EPA) in 1970 and to pass most of the U.S. environmental laws now in place during the 1970s, which became known as the *decade of the environment.*

Since 1970, many grassroots environmental organizations have sprung up to help deal with environmental threats. Interest in environmental issues has grown on many college and university campuses, resulting in the expansion of environmental science and environmental studies courses and programs. In addition, awareness of critical, complex, and largely invisible environmental issues has increased. These issues include threats to biodiversity, depletion of underground water supplies (aquifers), ocean warming, ocean acidification, atmospheric warming, and climate change.

In the 1980s, there was a backlash against environmental laws and regulations led by some corporate leaders, landowners, and state and local government officials who resented having to implement environmental laws and regulations with little or no federal funding. They contended that environmental laws were hindering economic growth and threatening private property rights and jobs. Since 1980, they have pushed to weaken or eliminate many environmental laws passed during the 1970s and to eliminate the EPA. Since the 1980s, environmental leaders and their supporters have had to spend much of their time and resources fighting to keep key environmental laws from being weakened or repealed.

1.4 WHAT IS AN ENVIRONMENTALLY SUSTAINABLE SOCIETY?

CONCEPT 1.4 Living sustainably means living on the earth's natural income without depleting or degrading the natural capital that supplies it.

Protecting Natural Capital and Living on Its Income

An **environmentally sustainable society** protects natural capital and lives on its income. Such a society would meet the current and future basic resource needs of its people without compromising the ability of future generations to meet their basic resource needs. This is in keeping with the ethical **principle of sustainability**.

Imagine that you win $1 million in a lottery. Suppose you invest this money (your capital) and earn 10% interest per year. If you live on just the interest income made by your capital, you will have a sustainable annual income of $100,000. You can spend $100,000 each year indefinitely and not deplete your capital. However, if you consistently spend more than your income, you will deplete your capital. Even if you spend just $10,000 more per year while still allowing the interest to accumulate, your money will be gone within 18 years.

This lesson is an old one: *Protect your capital and live on the income it provides.* Deplete or waste your capital and you will move from a sustainable to an unsustainable lifestyle.

The same lesson applies to using the earth's natural capital (Figure 1.3). This natural capital is a global trust fund of natural resources and ecosystem services that are available to people now and in the future and to all of the earth's other species. *Living sustainably* means living on **natural income**, which is the renewable resources such as plants, animals, soil, clean air, and clean water, provided by the earth's natural capital. By preserving and replenishing the earth's natural capital that supplies this natural income, people can reduce their ecological footprints and expand their beneficial environmental impact (**Concept 1.4**).

One of our goals in writing this book has been to provide a realistic vision of how we can live more sustainably. We base this vision not on immobilizing fear, gloom, and doom, but on providing education about how the earth sustains life and human economies and on energizing and realistic hope.

BIG IDEAS

- We can ensure a more sustainable future by relying more on energy from the sun and other renewable energy sources, protecting biodiversity through the preservation of natural capital, and avoiding the disruption of the earth's vital chemical cycles.
- A major goal for achieving a more sustainable future is full-cost pricing—the inclusion of harmful environmental and health costs in the market prices of goods and services.
- We will benefit ourselves and future generations if we commit ourselves to finding win–win solutions to environmental problems and to leaving the planet's life-support system in a condition as good as or better than what we inherited.

Tying It All Together

Learning from the Earth and Sustainability

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We opened this chapter with a **Core Case Study** about learning from nature by understanding how the earth—the only truly sustainable system—has sustained an incredible diversity of life for 3.8 billion years despite drastic and long-lasting changes in the planet's environmental conditions. Part of the answer involves learning how to apply the six **principles of sustainability** (see Figures 1.2 and 1.7 and inside the back cover of this book) to the design and management of our economic and social systems, and to our individual lifestyles.

We can use such strategies to slow the rapidly expanding losses of biodiversity, to sharply reduce our production of wastes and pollution, to switch to more sustainable sources of energy, and to promote more sustainable forms of agriculture and uses of land and water. We can also use these principles to sharply reduce poverty and slow human population growth.

You are a member of the 21st century's *transition generation* that will play a major role in deciding whether humanity creates a more sustainable future or continues on an unsustainable path toward further environmental degradation and disruption. It is an incredibly exciting and challenging time to be alive as we struggle to develop a more sustainable relationship with the earth that keeps us alive and supports our economies.

Chapter Review

Core Case Study

1. What is **sustainability**? What is **biomimicry**? Explain why learning from the earth is a key to learning how to live more sustainably.

Section 1.1

2. What are the three key concepts for this section? Define **environment**. Distinguish among **environmental science, ecology**, and **environmentalism (environmental activism)**. Define species. What is an **ecosystem**? Define **solar energy, biodiversity, nutrients,** and **chemical cycling (nutrient cycling)**; and explain why they are important to life on the earth.

3. Define **natural capital**. Define **natural resources** and distinguish among **inexhaustible, renewable**, and **nonrenewable (exhaustible) resources**. What is a **sustainable yield**? Define **ecosystem services** and give two examples. Give three examples of how we are degrading natural capital. Explain how finding solutions to environmental problems involves making trade-offs. Explain why individuals matter in dealing with the environmental problems we face. What are three economic, political, and ethical **principles of sustainability**? What is **full-cost pricing** and why is it important? Describe the role of Janine Benyus in promoting the important and growing field of biomimicry.

4. Define and distinguish between **more-developed countries** and **less-developed countries**; and give one example each of a high-income, middle-income, and low-income country.

Section 1.2

5. What are the two key concepts for this section? How have humans improved the quality of life for many people? How are humans living unsustainably? Define and give three examples of **environmental degradation (natural capital degradation)**. About

what percentage of the earth's natural or ecosystem services have been degraded by human activities? What is the tragedy of the commons? What are two ways to deal with this effect?

6. What is an **ecological footprint**? What is a **per capita ecological footprint**? What is **biocapacity**, or **biological capacity**, and what is an ecological deficit? Use the ecological footprint concept to explain how we are living unsustainably. What is the IPAT model for estimating our environmental impact? Explain how three major cultural changes taking place over the last 10,000 years have increased our overall environmental impact. What would a **sustainability revolution** involve?

Section 1.3

7. What are the two key concepts for this section? Identify five basic causes of the environmental problems that we face. What is **exponential growth**? What is the rule of 70? What is the current size of the human population? About how many people are added each year? How big is the world's population projected to be in 2050? Summarize the potentially harmful and beneficial environmental effects of affluence.

8. What is **poverty** and what are three of its harmful environmental and health effects? About what percentage of the world's people struggle to live on the equivalent of $1.90 a day? About what percentage have to live on $3.10 a day? How are poverty and population growth connected? List three major health problems faced by many of the poor.

9. Explain how excluding the harmful environmental and health costs of production from the prices of goods and services affects the environmental and health problems we face. What is the connection between government subsidies, resource use, and environmental degradation? What are two ways to include the harmful environmental and health costs of the goods and services in their market prices? Explain how a lack of knowledge about nature and the importance of natural capital, along with our increasing isolation from nature, can intensify the environmental problems we face. What is an **environmental worldview**? What is **environmental ethics**? What are five important ethical questions relating to the environment? Distinguish among the **human-centered**, **life-centered**, and **earth-centered environmental worldviews**. What are three levels of biomimicry? List seven key biomimicry principles. Summarize the rise of environmental conservation and protection in the United States.

Section 1.4

10. What is the key concept for this section? What is an **environmentally sustainable society**? What is **natural income** and how is it related to sustainability? What are this chapter's three big ideas?

Note: Key terms are in bold type. Knowing the meanings of these terms will help you in the course you are taking.

Critical Thinking

1. Why is biomimicry so important? Find an example of something in nature that you think could be mimicked for some beneficial purpose. Explain that purpose and how biomimicry could apply.

2. What do you think are the three most environmentally unsustainable components of your lifestyle? List two ways in which you could apply each of the six **principles of sustainability** (Figures 1.2 and 1.7 and inside back cover of book) to making your lifestyle more environmentally sustainable.

3. For each of the following actions, state one or more of the three **scientific principles of sustainability** that are involved: **(a)** recycling aluminum cans; **(b)** using a rake instead of a leaf blower; **(c)** walking or bicycling to class instead of driving; **(d)** taking your own reusable bags to a store to carry your purchases home; and **(e)** volunteering to help restore a prairie or other degraded ecosystem.

4. Explain why you agree or disagree with the following propositions:
  a. Stabilizing population is not desirable because, without more consumers, economic growth would stop.
  b. The world will never run out of resources because we can use technology to find substitutes and to help us reduce resource waste.
  c. We can shrink our ecological footprints while creating beneficial environmental impacts.

5. Should nations with large ecological footprints reduce their footprints to decrease their harmful environmental impact and leave more resources for nations with smaller footprints and for future generations? Explain.

6. When you read that at least 19,000 children of ages 5 and younger die each day (13 per minute) from preventable malnutrition and infectious disease, what is your response? How would you deal with this problem?

7. Explain why you agree or disagree with each of the following statements: **(a)** humans are superior to other forms of life; **(b)** humans are in charge of the earth; **(c)** the value of other forms of life depends only on whether they are useful to humans; **(d)** all forms of life have a right to exist; **(e)** all economic growth is good; **(f)** nature has an almost unlimited storehouse of resources for human use; **(g)** technology can solve our environmental problems; **(h)** I don't have any obligation to future generations; and **(i)** I don't have any obligation to other forms of life.

8. What are the basic beliefs of your environmental worldview? Record your answer. At the end of this course, return to your answer to see if your environmental worldview has changed. Are the beliefs included in your environmental worldview consistent with the answers you gave for Question 7? Are your actions that affect the environment consistent with your environmental worldview? Explain.

Doing Environmental Science

Estimate your own ecological footprint by using one of the many estimator tools available on the Internet. Is your ecological footprint larger or smaller than you thought it would be, according to this estimate? Why do you think this is so? List three ways in which you could reduce your ecological footprint. Try one of them for a week, and write a report on this change. List three ways you could increase your beneficial environmental impact.

Global Environment Watch Exercise

Go to your MindTap course to access the GREENR database. Use the information on pages 9 and 10 in this chapter to choose one more-developed country and one less-developed country to compare their ecological footprints. Use the "World Map" link at the top of the page to access information about the countries you have chosen to research. Once on the country page, view the "Quick Facts" panel at the right. Click on the ecological footprint number to view a graph of both the ecological footprint and biocapacity of each country. Using those graphs, determine whether these countries are living sustainably or not. What would be some reasons for these trends?

Ecological Footprint Analysis

If the *ecological footprint per person* of a country or the world is larger than its *biological capacity per person* to replenish its renewable resources and absorb the resulting waste products and pollution, the country or the world is said to have an *ecological deficit.* If the reverse is true, the country or the world has an *ecological credit* or *reserve.* See Figure 1.11 for a map of the world's ecological debtor and creditor countries. Use the data to the right to calculate the ecological deficit or credit for the countries listed. (As an example, this value has been calculated and filled in for the world.)

1. Which three countries have the largest ecological deficits? For each of these countries, why do you think it has a deficit?

2. Rank the countries with ecological credits in order from highest to lowest credit. For each country, why do you think it has an ecological credit?

3. Rank all of the countries in order from the largest to the smallest per capita ecological footprint.