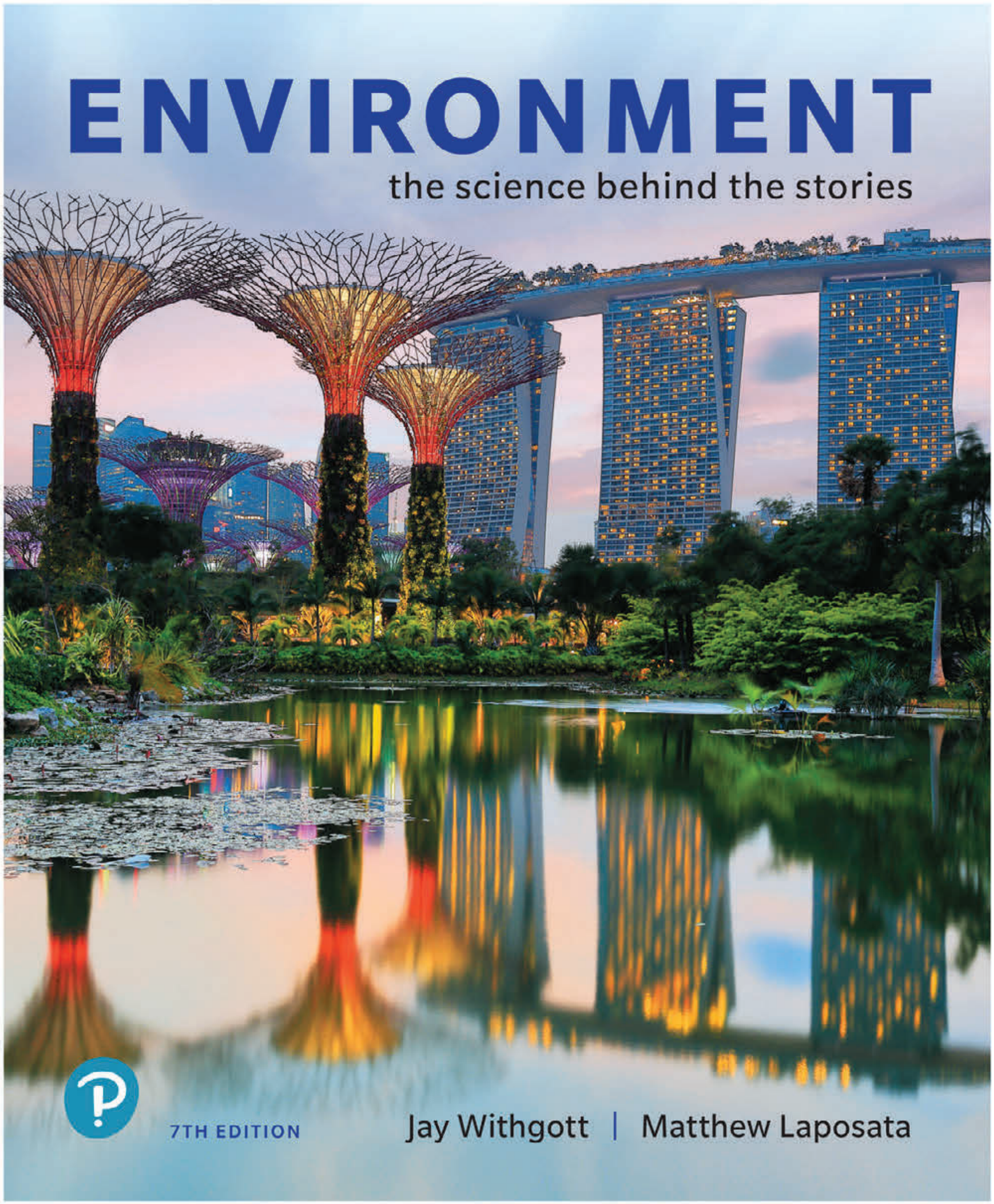

ENVIRONMENT

the science behind the stories

7TH EDITION

Jay Withgott | Matthew Laposata

Brief Contents

environment

THE SCIENCE BEHIND THE STORIES

7TH EDITION

Jay Withgott
Matthew Laposata

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Cover Photo Credit: Seng Chye Teo/Moment Unreleased/Getty Images

Library of Congress Cataloging-in-Publication Data
Names: Withgott, Jay author. | Laposata, Matthew, author.
Title: Environment : the science behind the stories / Jay Withgott, Matthew Laposata.
Description: 7th edition. | New York, NY : Pearson, [2019] | Includes bibliographical references and index. | Summary: "Environment: The Science Behind the Stories 7e is written for an introductory environmental science course for non-science majors. The "central case studies" hook students with stories at the beginning of a chapter and are threaded throughout. Related "Science Behind the Stories" boxes are integrated throughout to guide students through scientific discoveries, the ongoing pursuit of questions, and an understanding of the process of science. Unfolding stories about real people and places make environmental science memorable to non-science majors, and engage them in the content"-- Provided by publisher.
Identifiers: LCCN 2019041501 (print) | LCCN 2019041502 (ebook) | ISBN 9780135269145 (Rental Edition) | ISBN 9780135866108 (Loose-Leaf Print Offer Edition) | ISBN 9780136451471 (AP Edition) | 9780136623533: (Instructor's Review Edition)
Subjects: LCSH: Environmental sciences.
Classification: LCC GE105 .B74 2019 (print) | LCC GE105 (ebook) | DDC 363.7--dc23
LC record available at https://lccn.loc.gov/2019041501
LC ebook record available at https://lccn.loc.gov/2019041502

1 20

ISBN 10: 0-135-26914-8; ISBN 13: 978-0-135-26914-5 (Rental Edition)
ISBN 10: 0-135-84845-8; ISBN 13: 978-0-135-84845-6 (Loose-Leaf Print Offer Edition)
ISBN 10: 0-136-45147-0; ISBN 13: 978-0-136-45147-1 (AP Edition)
ISBN 10: 0-136-62353-0; ISBN 13: 978-0-136-62353-3: (Instructor's Review Edition)

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About the Authors

Jay Withgott has authored *Environment: The Science Behind the Stories* as well as its brief version, *Essential Environment,* since their inception. In dedicating himself to these books, he works to keep abreast of a diverse and rapidly changing field and continually seeks to develop new and better ways to help today's students learn environmental science.

As a researcher, Jay has published scientific papers in ecology, evolution, animal behavior, and conservation biology in journals ranging from *Evolution* to *Proceedings of the National Academy of Sciences*. As an instructor, he has taught university lab courses in ecology and other disciplines. As a science writer, he has authored articles for numerous journals and magazines, including *Science, New Scientist, BioScience, Smithsonian,* and *Natural History*. By combining his scientific training with prior experience as a newspaper reporter and editor, he strives to make science accessible and engaging for general audiences. Jay holds degrees from Yale University, the University of Arkansas, and the University of Arizona.

Jay lives with his wife, biologist Susan Masta, in Portland, Oregon.

Matthew Laposata is a professor of environmental science at Kennesaw State University (KSU). He holds a bachelor's degree in biology education from Indiana University of Pennsylvania, a master's degree in biology from Bowling Green State University, and a doctorate in ecology from The Pennsylvania State University.

Matt is the coordinator of KSU's two-semester general education science sequence titled Science, Society, and the Environment, which enrolls roughly 6000 students per year. He focuses exclusively on introductory environmental science courses and has enjoyed teaching and interacting with thousands of students during his nearly two decades in higher education. He is an active scholar in environmental science education and has received grants from state, federal, and private sources to develop innovative curricular materials. His scholarly work has received numerous awards, including the Georgia Board of Regents' highest award for the Scholarship of Teaching and Learning.

Matt resides in suburban Atlanta with his wife, Lisa, and children, Lauren, Cameron, and Saffron.

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Contents

Environmental Issues and the Search for Solutions

PART 2

Preface

Dear Student,

You are coming of age at a unique and momentous time in history. Within your lifetime, our global society must chart a promising course for a sustainable future. The stakes could not be higher.

Today we live long lives enriched with astonishing technologies, in societies more free, just, and equal than ever before. We enjoy wealth on a scale our ancestors could hardly have dreamed of. However, we have purchased these wonderful things at a steep price. By exploiting Earth's resources and ecosystem services, we are depleting our planet's ecological bank account. We are altering our planet's land, air, water, nutrient cycles, biodiversity, and climate at dizzying speeds. More than ever before, the future of our society rests with how we treat the world around us.

Your future is being shaped by the phenomena you will learn about in your environmental science course. Environmental science gives us a big-picture understanding of the world and our place within it. Environmental science also offers hope and solutions, revealing ways to address the problems we confront. Environmental science is more than just a subject you study in college. It provides you basic literacy in the foremost issues of the 21st century, and it relates to everything around you throughout your lifetime.

We have written this book because today's students will shape tomorrow's world. At this unique moment in history, the decisions and actions of your generation are key to achieving a sustainable future for our civilization. The many environmental challenges we face can seem overwhelming, but you should feel encouraged and motivated. Remember that each dilemma is also an opportunity. For every problem that human carelessness has created, human ingenuity can devise a solution. Now is the time for innovation, creativity, and the fresh perspectives that a new generation can offer. Your own ideas and energy can, and *will,* make a difference.

—Jay Withgott and Matthew Laposata

Dear Instructor,

You perform one of our society's most vital functions by educating today's students—the citizens and leaders of tomorrow—on the processes that shape the world around them, the nature of scientific inquiry, and the pressing environmental challenges we face. We have written this book to assist you in this endeavor because we feel that the crucial role of environmental science in today's world makes it imperative to engage, educate, and inspire a broad audience of students.

In *Environment: The Science Behind the Stories,* we strive to show students how science informs our efforts to bring about a sustainable society. We also aim to encourage critical thinking and to maintain a balanced approach as we flesh out the vibrant social debate that accompanies environmental issues. As we assess the challenges facing our civilization and our planet, we focus on providing realistic, forward-looking solutions, for we truly feel there are many reasons for optimism.

In crafting the seventh edition of this text, we have incorporated the most current information from this dynamic discipline and have tailored our presentation to best promote student learning. We have examined every line of text and every figure with great care to ensure that all content is accurate, clear, and up-to-date. Moreover, we have introduced a number of changes that are new to this edition.

New to This Edition

This seventh edition includes an array of revisions that enhance our content and presentation while strengthening our commitment to teach science in an engaging and accessible manner.

- **SUCCESS story** This new feature highlights discrete stories (one per chapter) of successful efforts to address environmental problems, ranging from local examples (such as prairie restoration in Chicago) to national and global achievements (such as halting ozone depletion by treaty or removing lead from gasoline). Our book has always focused on positive solutions, but the new emphasis these *Success Stories* bring should help encourage and inspire students by demonstrating how sustainable solutions are within reach. Students can explore data behind these solutions with new *Success Story Coaching Activities* in *Mastering Environmental Science*.

- **DATA GRAPHIC** This new and visually striking feature brings life to key questions in environmental science by presenting data in novel yet intuitive ways. The five *DataGraphics* seek to strengthen student skills in analytical thinking by fostering the ability to draw reasonable conclusions when provided with relevant data. Each *DataGraphic* poses a question, assembles an array of datasets, and leads to a unifying conclusion, guiding students through a synthesis of quantitative information in an inviting and appealing manner.
  - **Chapter 8:** Will Nigeria's population overwhelm its water supply?
  - **Chapter 10:** Can we continue to reduce global hunger?
  - **Chapter 11:** Can we save the world's biodiversity?
  - **Chapter 16:** How can we avoid choking the oceans with plastic?
  - **Chapter 18:** How can we stop global warming?
- **CENTRAL case study** Seven *Central Case Studies* are completely new to this edition, while several others have been thoroughly reshaped to add exciting new angles. All other case studies have been updated as needed to reflect recent developments. These updates provide fresh stories and new ways to frame emerging issues in environmental science. Students will learn how Midwesterners are battling an invasion of Asian carp, how Californian farmers are helping pollinators, how Brazilians are struggling to save the Amazon rainforest, how Texans are balancing water use with oil and gas production, and how researchers are documenting the spread of plastic waste across the world's oceans. Readers will also encounter inspiring new stories of Michigan students running sustainable food programs and of young Americans going to court to challenge their government to tackle climate change.
  - **Chapter 4:** Leaping Fish, Backwards River: Asian Carp Threaten the Great Lakes
  - **Chapter 7:** Young Americans Take On Climate Change in the Courts
  - **Chapter 9:** Bees to the Rescue: By Helping Pollinators, Farmers Help Themselves
  - **Chapter 10:** Sustainable Food and Dining at the University of Michigan
  - **Chapter 12:** Saving the World's Greatest Rainforest
  - **Chapter 15:** Reaching the Tipping Point: Fracking and Fresh Water in West Texas
  - **Chapter 16:** A Sea of Plastic in the Middle of the Ocean
- **connect & continue** Each chapter now concludes with a brief section that provides late-breaking updates to the *Central Case Study* and makes connections outward to related themes, events, or locations, to facilitate further discussion. This new *Connect & Continue* section enhances our long-standing and well-received approach of integrating each *Central Case Study* throughout its chapter.
- **THE SCIENCE behind the story** Fourteen *Science Behind the Story* boxes are new to this edition. These new boxes, along with others that have been updated, provide a current and exciting selection of scientific studies to highlight. Students will follow researchers as they discover a global collapse in insect populations, track chemicals hidden in the food we eat, reveal how global warming creates extreme weather, and much more.
  - **Chapter 2:** Are Yeast the Answer to Cleaning Up Nuclear Waste?
  - **Chapter 4:** How Do Asian Carp Affect Aquatic Communities?
  - **Chapter 7:** What Does the Science on Climate Change Tell Us?
  - **Chapter 8:** Measuring Our "Human Footprint": A Roadmap to Sustainability *and* Prosperity?
  - **Chapter 9:** If We Help Pollinators, Will It Boost Crop Production?
  - **Chapter 11:** Are Insects Vanishing?
  - **Chapter 14:** Are Endocrine Disruptors Lurking in Your Fast Food?
  - **Chapter 14:** What Role Do Pesticides Play in the Collapse of Bee Colonies?
  - **Chapter 15:** What's Killing Smallmouth Bass in the Potomac River Watershed?
  - **Chapter 16:** Inventorying the Great Pacific Garbage Patch
  - **Chapter 18:** Why and How Does Global Warming Lead to Extreme Weather Events?
  - **Chapter 21:** How Well Do Wind and Solar Complement One Another in Texas?
  - **Chapter 22:** Can Campus Research Help Reduce Waste?
  - **Chapter 23:** Mapping Mountaintop Mining's "Footprint" in Appalachia
- **New and revised DATA Q, FAQ, and Weighing the Issues items** Incorporating feedback from instructors across North America, we have examined each example of these three features that boost student engagement and have revised them and added new examples as appropriate.
- **Currency and coverage of topical issues** To live up to our book's hard-won reputation for currency, we've incorporated the most recent data possible throughout, and we've enhanced coverage of emerging issues. As climate change and energy concerns play ever-larger roles in today's world, our coverage has kept pace. This edition highlights the tremendous growth and potential of renewable energy, yet also shows how we continue reaching further for fossil fuels using ever more powerful technologies. The text tackles the complex issue of climate change in depth, while connections to this issue proliferate among

topics in every chapter. And in a world newly shaken by dynamic political forces amid concerns relating to globalization, trade, immigration, health care, jobs, racial discrimination, social justice, and wealth inequality, our introduction of ethics, economics, and policy early in the book serves as a framework to help students relate the scientific knowledge they are learning to the complex cultural aspects of the society around them.

- **Enhanced style and design** We have refreshed and improved the look and clarity of our visual presentation throughout the text. A more appealing layout, striking visuals, and an inviting new style all make the book more engaging for students. Over 50% of the photos, graphs, and illustrations in this edition are new or have been revised to reflect current data or for enhanced clarity or pedagogy.

Existing Features

We have also retained the major features that made the first six editions of our book unique and that are proving so successful in classrooms across North America:

- **A focus on science and data analysis** We have maintained and strengthened our commitment to a rigorous presentation of modern scientific research while simultaneously making science clear, accessible, and engaging to students. Explaining and illustrating the *process* of science remains a foundational goal of this endeavor. We also continue to provide an abundance of clearly cited data-rich graphs, with accompanying tools for data analysis. In our text, our figures, and our online features, we aim to challenge students and to assist them with the vital skills of data analysis and interpretation.
- **An emphasis on solutions** For many students, today's deluge of environmental dilemmas can lead them to feel that there is no hope or that they cannot personally make a difference. We have aimed to counter this impression by highlighting innovative solutions being developed around the world—a long-standing approach now enhanced by our new *Success Story* feature. While taking care not to paint too rosy a picture of the challenges that lie ahead, we demonstrate that there is ample reason for optimism, and we encourage action. Our campus sustainability coverage (Chapter 1 and *Central Case Studies* in Chapters 9 and 22) shows students how their peers are applying principles and lessons from environmental science to forge sustainable solutions on their own campuses.
- **Integration of a CENTRAL case study throughout each chapter.** We integrate each chapter's *Central Case Study* into the main text, weaving information and elaboration throughout the chapter. In this way, compelling stories about real people and real places help to teach foundational concepts by giving students a tangible framework with which to incorporate novel ideas. Students can explore the locations featured in each *Central Case Study* with new Case Study Video Tours in *Mastering Environmental Science*.
- **THE SCIENCE behind the story** Because we strive to engage students in the scientific process of testing and discovery, we feature *The Science Behind the Story* boxes in each chapter. By guiding students through key research efforts, this feature shows not merely *what* scientists discovered, but *how* they discovered it.
- **FAQ** The *FAQ* feature highlights questions frequently posed by students, thereby helping to address widely held misconceptions and to fill in common conceptual gaps in knowledge. By also including questions students sometimes hesitate to ask, the *FAQs* show students that they are not alone in having these questions, which helps to foster a spirit of open inquiry in the classroom.
- **WEIGHING the issues** These questions aim to help develop the critical-thinking skills students need to navigate multifaceted issues at the juncture of science, policy, and ethics. They serve as stopping points for students to reflect on what they have read, wrestle with complex dilemmas, and engage in spirited classroom discussion.
- **Diverse end-of-chapter features** *Reviewing Objectives* summarizes each chapter's main points and relates them to the chapter's learning objectives, enabling students to confirm that they have understood the most crucial ideas. *Seeking Solutions* encourages broad creative thinking that supports our emphasis on finding solutions. "Think It Through" questions personalize the quest for creative solutions by placing students in a scenario and empowering them to make decisions. *Calculating Ecological Footprints* enables students to quantify the impacts of their own choices and measure how individual impacts scale up to the societal level.

Mastering™ Environmental Science

With this edition we continue to offer expanded opportunities through *Mastering Environmental Science,* our powerful yet easy-to-use online learning and assessment platform. We have developed new content and activities specifically to support features in the textbook, thus strengthening the connection between these online and print resources. This approach encourages students to practice their science literacy skills in an interactive environment with a diverse set of automatically graded exercises. Students benefit from self-paced activities that feature immediate wrong-answer feedback, while instructors can gauge student performance with informative diagnostics. By enabling assessment of student learning outside the classroom, *Mastering Environmental Science* helps the instructor to maximize the impact of in-classroom time. As a result, both educators and learners benefit from an integrated text-and-online solution.

- DATA GRAPHIC The five new DataGraphics from the text come to life in the eText, allowing students to interact with the data. These interactives are assignable in *Mastering Environmental Science*.

- DATA Q These popular data analysis questions have been moved to *Mastering Environmental Science* in this edition to help students actively engage with graphs and other data-driven figures and allow instructors to assign these questions for practice or homework.
- *GraphIt* activities help students put data analysis and science reasoning skills into practice through a highly interactive and engaging format. Each *GraphIt* prompts students to manipulate a variety of graphs and charts, from bar graphs to line graphs to pie charts, and develop an understanding of how data can be used in decision making about environmental issues. Topics range from agriculture to fresh water to air pollution. These mobile-friendly activities are accompanied by assessment in *Mastering Environmental Science*.
- *Everyday Environmental Science* videos highlight current environmental issues in short (5 minutes or less) video clips and are produced in partnership with BBC News. These videos will pique student interest and can be used in class or assigned as a high-interest out-of-class activity.
- *Dynamic Study Modules* help students study effectively on their own by continuously assessing their activity and performance in real time. Students complete multiple sets of questions for any given topic, to demonstrate concept mastery with confidence. Each *Dynamic Study Module* question set concludes with an explanation of concepts students may not have mastered. They are available as graded assignments prior to class and are accessible on smartphones, tablets, and computers.
- *Process of Science* activities help students navigate the scientific method, guiding them through in-depth explorations of experimental design using *The Science Behind the Story* features from the current and former editions. These activities encourage students to think like a scientist and to practice basic skills in experimental design.
- *Interpreting Graphs and Data: Data Q* activities pair with the in-text *Data Analysis Questions* and coach students to further develop skills related to presenting, interpreting, and thinking critically about environmental science data.
- *"First Impressions" Pre-Quizzes* help instructors determine their students' existing knowledge of environmental issues and core content areas at the outset of the academic term, providing class-specific data that can then be employed for powerful teachable moments throughout the term. Assessment items in the Test Bank connect to each quiz item, so instructors can formally assess student understanding.
- *Video Field Trips* enable students to visit real-life sites that bring environmental issues to life. Students can tour a power plant, a wind farm, a wastewater treatment facility, a site combating invasive species, and more—all without leaving campus.

Environment: The Science Behind the Stories has grown from our collective experiences in teaching, research, and writing. We have been guided in our efforts by input from the hundreds of instructors across North America who have served as reviewers and advisers. The participation of so many learned, thoughtful, and committed experts and educators has improved this volume in countless ways.

We sincerely hope that our efforts are worthy of the immense importance of our subject matter. We invite you to let us know how well we have achieved our goals and where you feel we have fallen short. Please write to us in care of our content analyst, Thomas Hoff (thomas.hoff@pearson.com), at Pearson Education. We value your feedback and are eager to learn how we can serve you better.

—Jay Withgott and Matthew Laposata

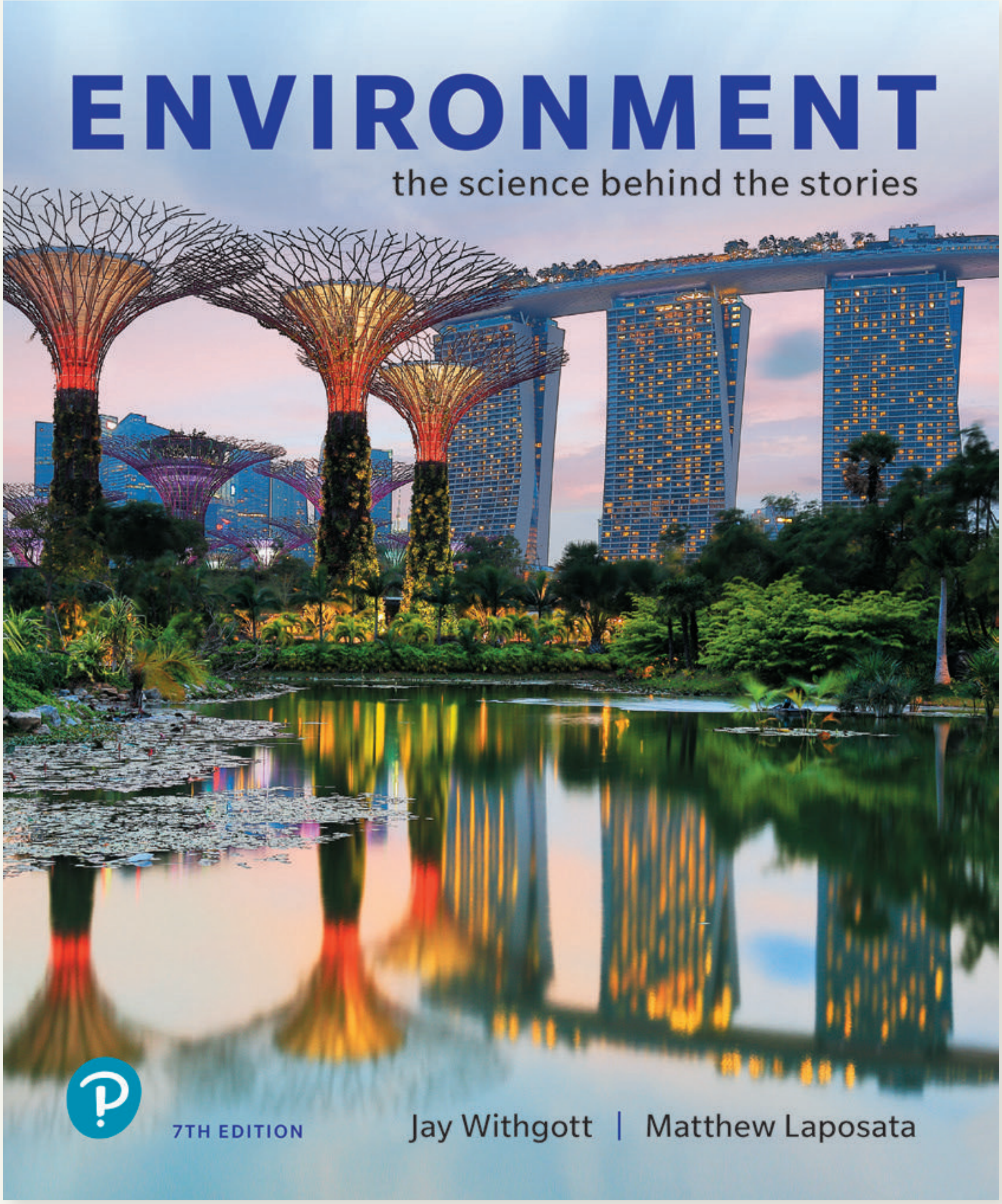
Instructor Supplements

A robust set of instructor resources and multimedia accompany the text and can be accessed through *Mastering Environmental Science.* Organized chapter-by-chapter, everything you need to prepare for your course is offered in one convenient set of files. Resources include the following: Video Field Trips, Everyday Environmental Science Videos, PowerPoint Lecture presentations, Instructor's Guide, Active Lecture "clicker" questions to facilitate class discussions (for use with or without clickers), and an image library that includes all art and tables from the text.

The Test Bank files, offered in both Word and TestGen formats, include hundreds of multiple-choice questions plus unique graphing and scenario-based questions to test students' critical-thinking abilities. The *Mastering Environmental Science* platform is the most effective and widely used online tutorial, homework, and assessment system for the environmental sciences.

Getting Students to See the Data, Connections, and Solutions behind Environmental Issues

Environment: The Science Behind the Stories **is known for its student-friendly narrative style, its integration of real stories and case studies, and its presentation of the latest science and research.**



Engage Students with


CENTRAL
case study

Costa Rica Values Its Ecosystem Services

"Costa Rica's PSA program has been one of the conservation success stories of the last decade.
Stefano Pagiola, The World Bank

In the last 25 years, my home country has tripled its GDP while doubling the size of its forests."
Carlos Manuel Rodriguez, former Minister of Energy and the Environment, Costa Rica

Upon completing this chapter, you will be able to:

+ Describe how culture and worldview influence the choices people make
+ Discuss the nature and historical expansion of environmental ethics in Western culture
+ Compare and contrast major approaches in environmental ethics
+ Explain how our economies exist within the environment and rely on ecosystem services
+ Identify principles of classical and neoclassical economics, and summarize their implications for the environment
+ Describe aspects of environmental economics and ecological economics, including valuation of ecosystem services and full cost accounting
+ Discuss how individuals and businesses can help move our economic system in a sustainable direction
+ Define sustainable development, explain the "triple bottom line," and describe how sustainable development is pursued worldwide

Very few nations have transformed their path of development in just decades—but Costa Rica has. In the 1980s, this small Central American country was losing its forests as fast as any place on Earth. Today, this nation of 5 million people has regained much of its forest cover, boasts a world-class park system, and stands as a global model for sustainable resource management.

Costa Rica took many steps on this impressive road to success. One key step was to begin paying landholders to conserve forest on private land, in a novel government program called *Pago por Servicios Ambientales* (PSA)—Payment for Environmental Services.

Nature provides ecosystem services (pp. 4, 120–121) such as air and water purification, climate regulation, and nutrient cycling. For example, forests in Costa Rica's mountains capture rainfall and provide clean drinking water for farms, towns, and cities below. Ecosystem services are vital for our lives, but historically we have tended to take them for granted, and rarely do we acknowledge their value by paying for them in the marketplace. As a result, these services have diminished as we degrade the natural systems that provide them. For these reasons, many economists believe that it is important to create financial incentives for conserving ecosystem services.

In Costa Rica, which had lost more than three-fourths of its forest, political leaders created financial incentives for conserving ecosystem services through the PSA program—established as part of Forest Law 7575, passed in 1996. Since then, the Costa Rican government has been paying farmers and ranchers to preserve forest on their land, replant cleared areas, allow forest to regenerate naturally, and establish sustainable forestry systems. Payments are designed to approximate potential profits from farming or cattle ranching, and in recent years, these payments have averaged \$78/hectare (ha)/yr (\$32/acre/yr).

The PSA program recognizes four ecosystem services that forests provide:

- *Watershed protection:* Forests cleanse water by filtering pollutants, and they conserve water and reduce soil erosion by slowing runoff.
- *Biodiversity:* Tropical forests such as Costa Rica's are especially rich in life.

◄ **A Costa Rican banana plantation**

▲ **A keel-billed toucan, one of many species relying on Costa Rica's forests**

P. 133

UPDATED! Central Case Studies begin and are woven throughout the chapter, drawing students into learning about the real people, real places, and real data behind environmental issues. These provide a contextual framework to make science memorable and engaging.

NEW! Connect & Continue brings the Central Case Study in each chapter full circle by revisiting it at the end of the chapter and offering specific activities related to the case study. The Case Study Solutions activity encourages students to think about possible ways to address the featured environmental issue. The Local Connections activity allows instructors to relate the case study to their students' local area. And the new Explore the Data links to assignable coaching activities on Mastering Environmental Science.


CENTRAL CASE STUDY
connect & continue

TODAY, the concept of paying for ecosystem services has gone global, as Costa Rica's pioneering PSA program has inspired similar approaches throughout the world. In Mexico, Australia, Tanzania, China, Indonesia, Vietnam, and many other nations, these programs are gaining ground as people begin to better appreciate the contributions of ecological systems to human economies. By 2018, according to one scientific assessment, more than 550 active programs were operating in more than 60 nations, involving between \$36 billion and \$42 billion in transactions annually. These programs are varied but can be broken into three main types: (1) government-financed programs like Costa Rica's and similar ones in China to pay landowners for forest conservation and replanting, (2) user-financed programs whereby users of services pay landholders (e.g., hydroelectric dam operators paying upstream landholders to preserve forest in the watershed), and (3) programs in which regulated entities compensate other parties for conserving ecosystem services for them (e.g., developers paying mitigation fees for wetland restoration or emitters in carbon-trading markets paying carbon offsets for forest conservation).

One example of payments for ecological services in the United States is the federal government's Conservation Reserve Program (p. 236). This program, reauthorized every five years in the Farm Bill, pays farmers to retain natural vegetation on portions of their land to prevent erosion, conserve soil, enhance wildlife habitat, and reduce water pollution. Farmers are thereby compensated for land they do not put into crop production while they (and society as a whole) also benefit from the conservation of ecosystem services. Like Costa Rica's PSA program, the Conservation Reserve Program seeks to defuse a dilemma facing many rural landholders, who often feel short-term economic pressure to clear natural land for agriculture even though they may have an ethical concern for the land's flora and fauna.

In Costa Rica, policymakers have responded to researchers' suggestions and have enhanced the PSA program with the help of funding from new tariffs and fees and by 2021. The country already gets 99% of its electricity from renewable sources, and it hopes that carbon dioxide stored by newly conserved forests will help cancel out carbon dioxide emissions from gasoline-burning vehicles. "We are the heirs of a beautiful tradition of innovation and change," Costa Rican President Carlos Alvarado Quesada told Stanford University scientists who are helping his government study and place values on its natural capital. "That's why we're doing this: not because it's fashionable, but because it's an ethical responsibility." In Costa Rica and many other places around the world today for reasons of ethics, economics, and sustainability, public and private parties are engaged in a wide variety of economic transactions that explicitly recognize the importance of natural resources and ecosystem services.

- **CASE STUDY SOLUTIONS** Suppose you are a Costa Rican farmer who needs to decide whether to clear a stand of forest or apply to receive payments to preserve it through the PSA program. Describe all the types of information you would want to consider before making your decision. Now describe what you think each of the following people would recommend to you if you were to go to them for advice: (a) a preservationist, (b) a conservationist, (c) a neoclassical economist, and (d) an ecological economist.
- **LOCAL CONNECTIONS** Costa Rica isn't the only place where forests are threatened, and it isn't the only place where programs have been established to pay people for conserving ecological services. Name and describe several natural resources and ecosystem services that are important in your region. For each of these resources and services, assess whether it is being sustained or whether it is being degraded. How do you think each resource or service could best be conserved? Would you recommend a program of payments to provide incentives for conservation? Why or why not? What other steps might be

P. 157

Interactive Data & Stories

SUCCESS **story**

Considering Cost When Saving the Bay

The Chesapeake Bay offers a case study that illustrates the importance of understanding systems, chemistry and the need for taking a systems-level approach to restore ecosystems degraded by human activities. Tools such as landscape ecology, GIS, and ecological modeling aid these efforts by providing a broad view of the Chesapeake Bay ecosystem and how it may react to changes in nutrient inputs and restoration efforts. The Chesapeake Bay Foundation's most recent "State of the Bay" report concluded that the bay's health rating in 2018 was the highest it had been since CBF's founding in 1964, with meaningful improvements in pollution reduction, fisheries recovery, and the restoration of natural habitats in and around the bay (see Figure 5.1, p. 106).

One reason for the recent success is that farmers, residents, resource managers, and local, state, and federal government agencies have embraced a variety of approaches to reduce nutrient inputs into the bay. By educating people about the many inexpensive yet effective steps that can be taken in yards, farms, businesses, and local communities to reduce nutrient inputs into the Chesapeake Bay, saving the bay became something for which everyone can do his or her part.

A forested buffer lining a waterway on agricultural land in Maryland.

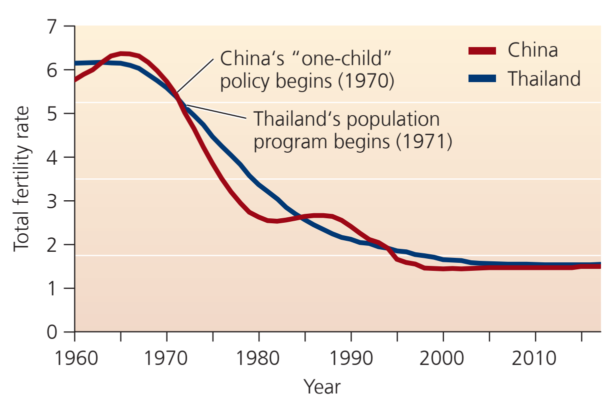
→ **Explore the Data** at Mastering Environmental Science

P. 124

SUCCESS **story**

Family Planning without Coercion: Thailand's Population Program

The government of Thailand, facing many of the same population challenges as its populous neighbor to the north, instituted a comprehensive population program in 1971. At the time, Thailand's population growth rate was 2.3%, and the nation's TFR was 5.4. But unlike the Chinese reproductive program, Thais were given control over their own reproductive choices, provided with family-planning counseling and modern contraceptives, and supported by an engaging public education campaign. Aided by a relatively high level of women's rights in Thai society, Thailand's population program—and the fertility reductions that accompanied the nation's economic development over the past 47 years—reduced its population growth rate to 0.2%, with a TFR of 1.5 children per woman in 2018. The success of this program, and similar initiatives in nations such as Brazil, Cuba, Iran, and Mexico, show that government interventions to reduce birth rates need not be as intrusive as China's to produce similar declines in population growth.



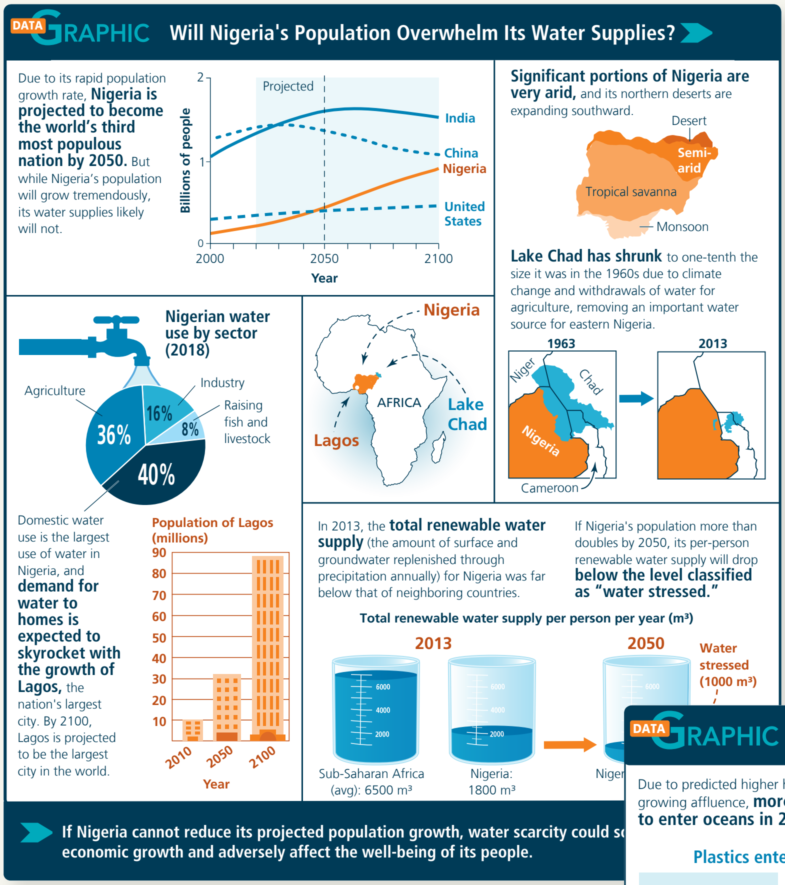
China and Thailand instituted population control programs at roughly the same time and showed similar patterns in fertility declines over the subsequent 45 years, despite utilizing very different approaches. *Data from World Bank, 2017, http://data.worldbank.org.*

→ **Explore the Data** at Mastering Environmental Science

P. 203

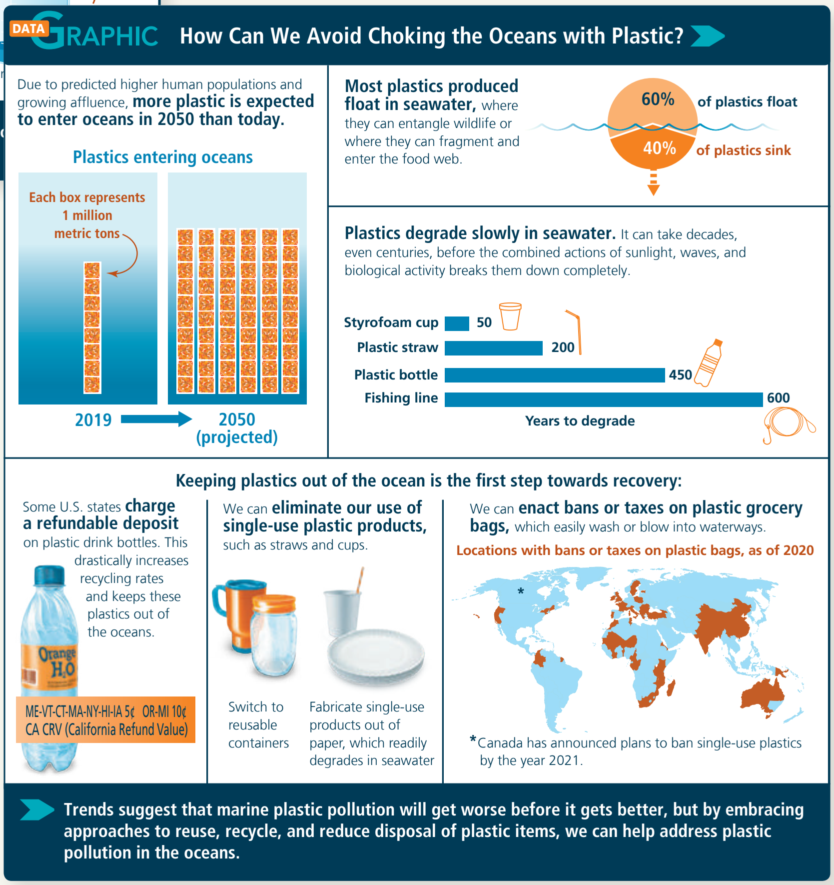
Success Stories, one in every chapter, highlight forward-thinking solutions and successful efforts to address environmental issues. Each Success Story links to new data-analysis activities on Mastering Environmental Science that are available for assignment and grading.

Increase Students’ Scientific Literacy



P. 191

NEW! **DataGraphics** are Infographic-style illustrations that enable students to **see the data** behind complex issues and understand how to tie it all together.

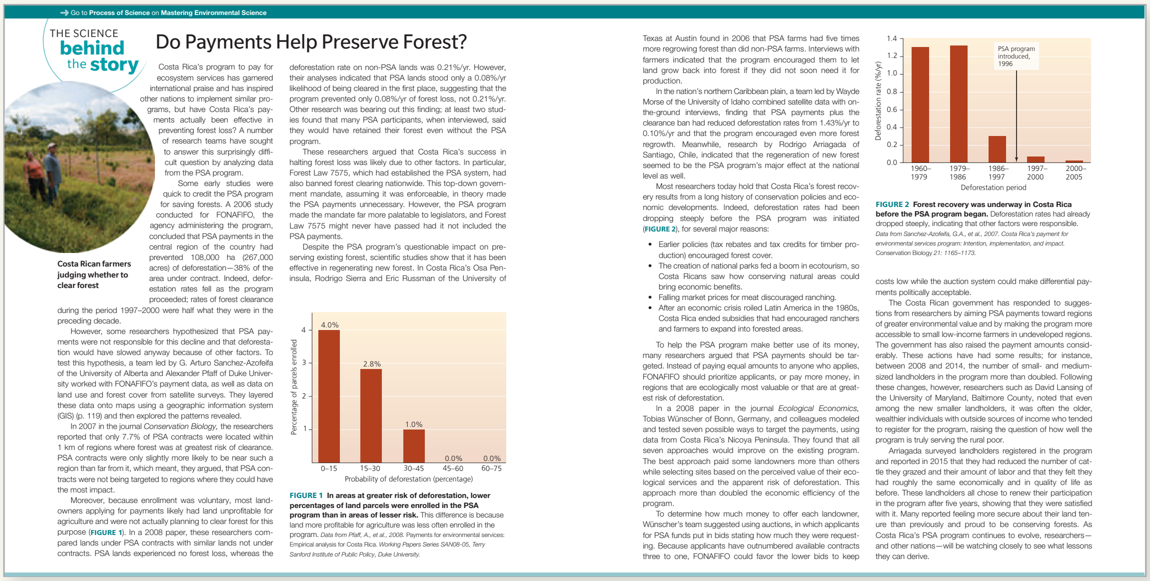


P. 434

DataGraphics include:

- Will Nigeria’s population overwhelm its water supply?
- Can we continue to reduce global hunger?
- Can we save the world’s biodiversity?
- How can we avoid choking the oceans with plastic?
- How can we stop global warming?

The Science behind the Stories



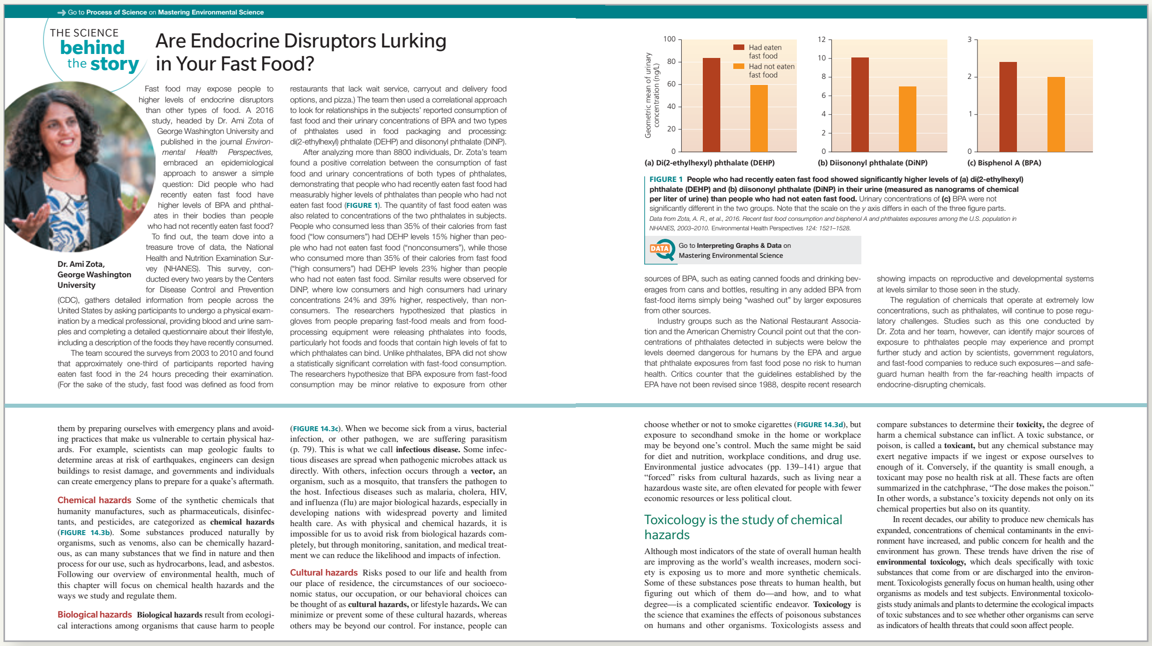
UPDATED! The Science behind the Story essays each offer real, current, and fascinating research that delves into an environmental issue.

P. 144

New Topics Include:

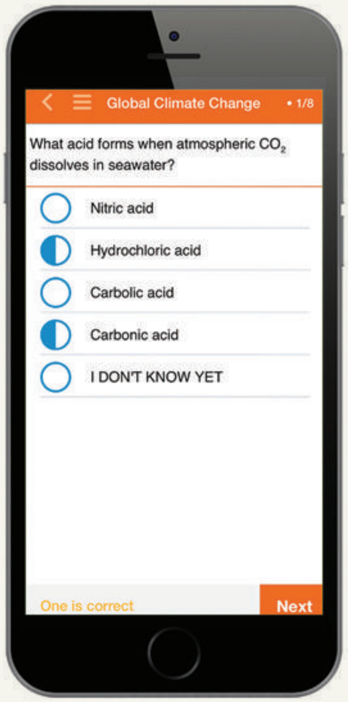
- Are Endocrine Disruptors Lurking in Your Fast Food?
- What Role Do Pesticides Play in the Collapse of Bee Colonies?
- Inventorying the Great Pacific Garbage Patch
- Why and How Does Global Warming Lead to Extreme Weather Events?
- Can Campus Research Help Reduce Waste?

And more!

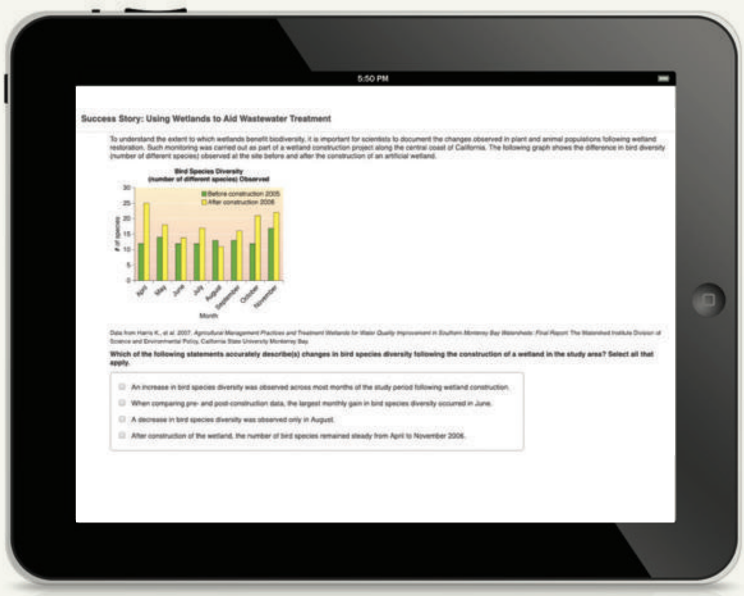


P. 362

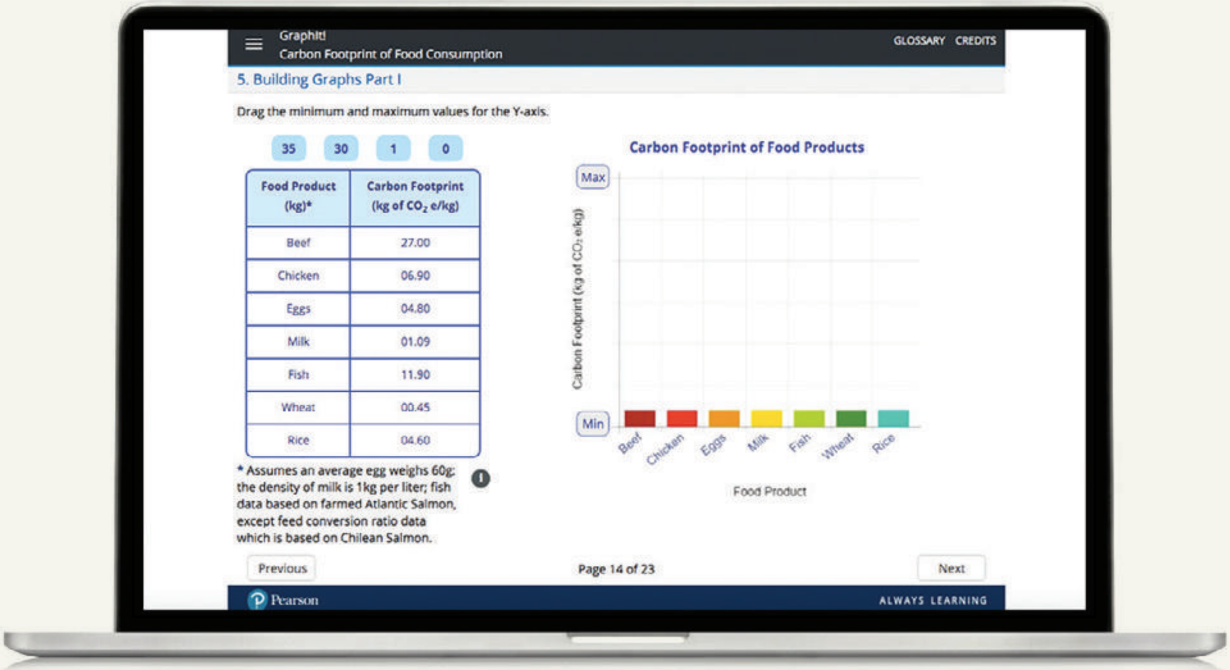
Bring Environmental Science to Life with Mastering



Dynamic Study Modules help students study effectively—and at their own pace. These rely on the latest research in cognitive science, to stimulate learning and improve retention.



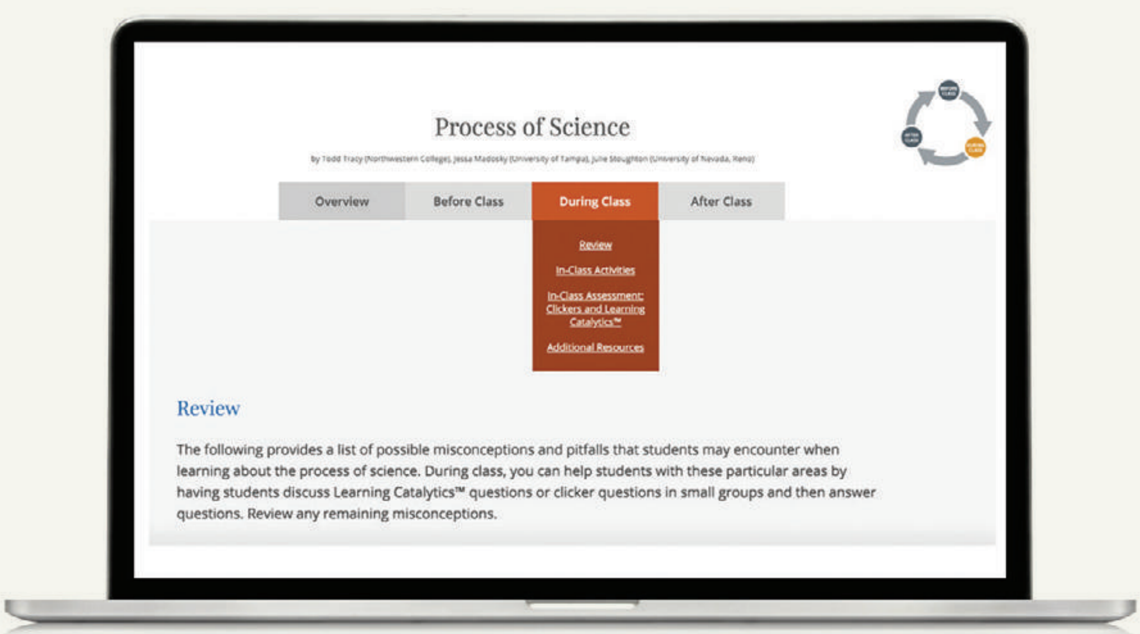
NEW! Data Analysis Activities give students an opportunity to explore data related to the Central Case Studies and Success Stories from the text.



GraphIt! Coaching Activities help students read, interpret, and create graphs that explore real environmental issues using real data.

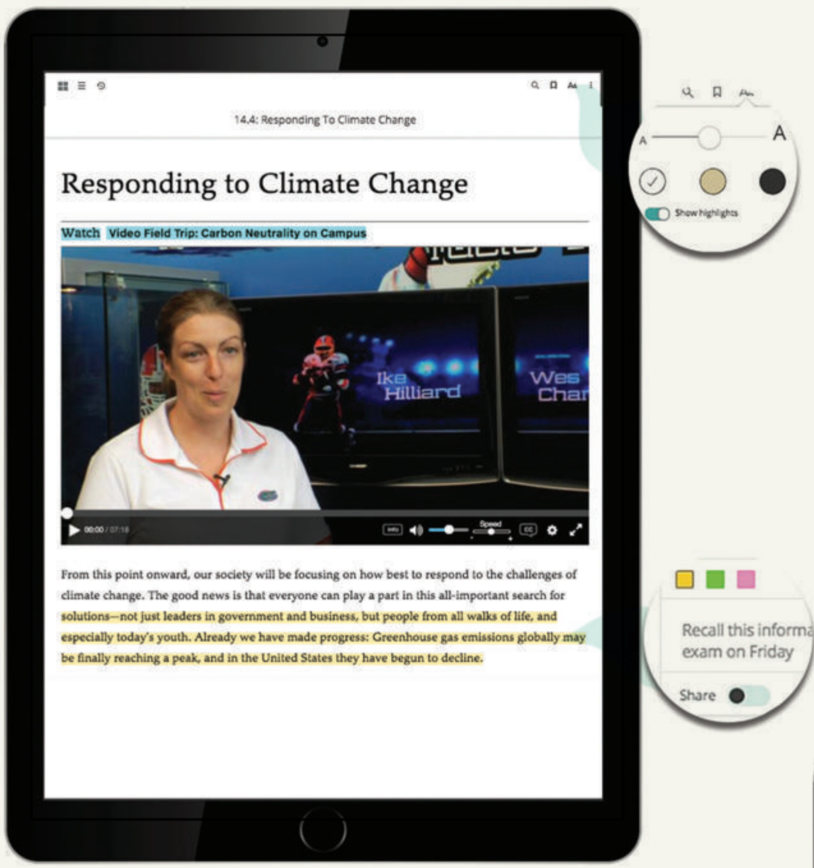
Engage Students with Active Learning

Learning Catalytics enables you to hear from every student in real-time, when it matters most. Choose from a variety of question types that help students recall ideas, apply concepts, and develop critical-thinking skills. Students answer on their own device. Instructors receive analytics in real-time to find out what their students know and don't know and how peer-to-peer learning can be facilitated to help students engage and stay motivated.



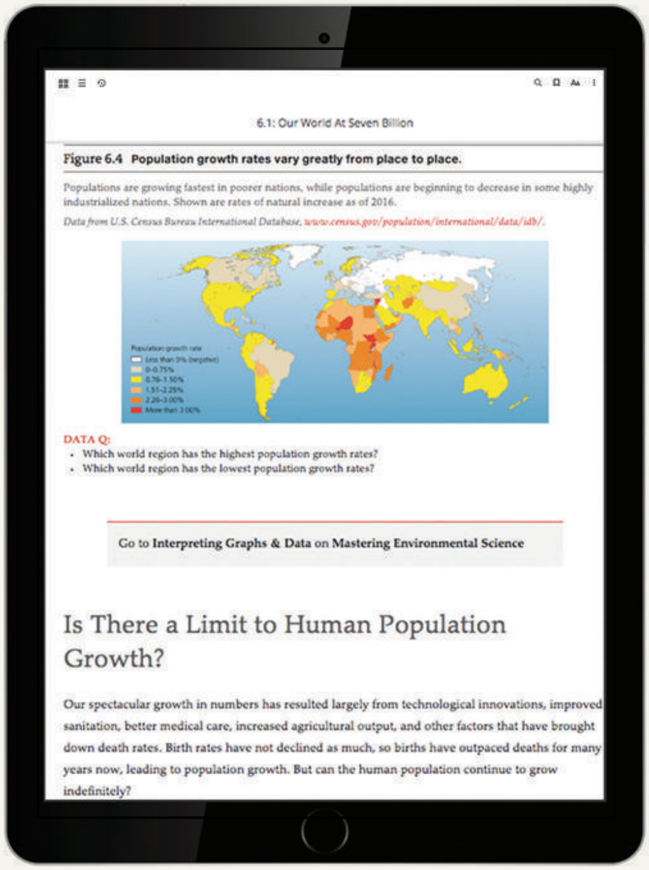
To-Go Teaching Modules help instructors make use of teaching tools before, during, and after class, including new ideas for in-class activities. The modules incorporate the best that the text, Mastering, and Learning Catalytics have to offer. These can be accessed through the Instructor Resources area in Mastering Environmental Science.

A Whole New Reading Experience



Pearson eText is a simple-to-use, mobile-optimized, personalized reading experience available within Mastering Environmental Science. It allows students to easily highlight, take notes, and review key vocabulary all in one place—even when offline. Seamlessly integrated videos and other rich media engage students and give them access to the help they need, when they need it.

Available for download in the app store for approved devices



Acknowledgments

This textbook results from the collective labor and dedication of innumerable people. The two of us are fortunate to be supported by a tremendous publishing team.

Product manager Cady Owens coordinated our team's efforts for this seventh edition of *Environment: The Science Behind the Stories*. We remain deeply thankful to Cady and appreciate her creative thinking, sound judgment, and committed engagement with our work. Senior content analyst Tom Hoff helped to bring the edition across the finish line. We were excited to welcome back developmental editors Susan Teahan and Sonia Divittorio. Susan had helped pioneer the very first edition of this book years ago, and to Susan's keen eye and resourcefulness Sonia added her own remarkable skills, ensuring this edition a wealth of talented input. Director of content development Ginnie Simione Jutson oversaw our development needs, while content producer Margaret Young effectively managed the innumerable steps in the publishing process.

It was a pleasure to collaborate with senior analyst Hilair Chism, who spearheaded the creation of the new *DataGraphics* that enliven this edition, and with photo researcher Kristin Piljay, who helped us acquire the highest-quality images possible. Mark Mykytiuk of Imagineering oversaw a smooth art production process for hundreds of figures. Kathleen Lafferty and Denne Wesolowski performed meticulous copyediting and proofreading across every page of text. Jeff Puda created this edition's engaging interior and cover design. Associate content analyst Chelsea Noack managed the review process and provided timely assistance as needed. And our thanks go to project manager Sharon Cahill of SPi Global for her excellent work interacting with the compositor to ensure a clean layout and a successful production process.

We welcome and look forward to working with global content manager Josh Frost and director of product management Michael Gillespie as we move collectively toward an exciting future. And we will always be indebted to our former executive editor Alison Rodal, who guided us in the last two editions of *Environment,* and to our former editor-in-chief, Beth Wilbur, for her steadfast support of this textbook across its seven editions.

As always, a select number of top instructors from around North America produced the supplementary materials that support the text. Our thanks go to Sarah Schliemann for updating our Instructor's Guide, to David Serrano for his work with the Test Bank, to James Dauray for revising the PowerPoint lectures, and to Jennifer Biederman for updating the Active Lecture clicker questions.

We give thanks to marketing manager Alysun Burns Estes. And we admire and appreciate the work and commitment of the many sales representatives who help communicate our vision, deliver our product, and collaborate with instructors to ensure their satisfaction.

In the lists of reviewers that follow, we acknowledge the many instructors and outside experts who have helped us to maximize the quality and accuracy of our content and presentation through their chapter reviews, feature reviews, class tests, focus group participation, and other services. The thoughtfulness and thoroughness of these reviewers make clear to us that the teaching of environmental science is in excellent hands.

Finally, we each owe personal debts to the people nearest and dearest to us. Jay thanks his parents and his many teachers and mentors over the years for making his own life and education so enriching. He gives loving thanks to his wife, Susan, who has patiently provided caring support throughout this book's writing and revision over the years. Matt thanks his family, friends, and colleagues, and is grateful for his children, who give him three reasons to care passionately about the future. Most importantly, he thanks his wife, Lisa, for being a beacon of love and support in his life for more than 30 years. The talents, input, and advice of Susan and of Lisa have been vital to this project, and without their support our own contributions would not have been possible.

We dedicate this book to today's students, who will shape tomorrow's world.

—Jay Withgott and Matthew Laposata

Reviewers

We wish to express special thanks to the dedicated reviewers who shared their time and expertise to help make this seventh edition the best it could be. Their efforts built on those of the nearly 700 instructors and outside experts who have reviewed material for the previous six editions of this book through chapter reviews, pre-revision reviews, feature consultation, student reviews, class testing, and focus groups. Our sincere gratitude goes out to all of them.

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About the Cover

"Supertrees"—decorative vertical gardens that collect rainwater and generate renewable solar energy—tower over the Gardens by the Bay park in Singapore. A tiny and densely populated island city-state in Southeast Asia, Singapore has become a model of urban sustainability, leading the drive to design clean, healthy cities that conserve resources and enrich the lives of their residents. Rigorous central planning has created a city that boasts affordable housing, efficient mass-transit, and a high quality of life. Natural areas are an integral part of this planning: Gardens adorn roofs and balconies, green spaces crisscross the city, and incentives promote the incorporation of plant life into new construction. Singapore is even innovating the growth of food in vertical indoor farms. As our population grows and more people move to urban areas, creating sustainable cities is one of humanity's great challenges, intertwined with pressing issues of health, food security, biodiversity conservation, and energy use in a world of changing climate. Join us in this seventh edition of *Environment: The Science Behind the Stories*, as we discover success stories and creative solutions while exploring the frontiers of environmental science.

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PART 1

Foundations of Environmental Science

CHAPTER 1

Science and Sustainability

An Introduction to Environmental Science

Upon completing this chapter, you will be able to:

- Describe the field of environmental science
- Explain the importance of natural resources and ecosystem services to our lives
- Discuss population growth, resource consumption, and their consequences
- Explain what is meant by an ecological footprint
- Describe the scientific method and the process of science
- Apply critical thinking to judge the reliability of information sources
- Identify major pressures on the global environment
- Discuss the concept of sustainability, and describe sustainable solutions being pursued on campuses and across the world

Our Island, Earth

Viewed from space, our home planet resembles a small blue marble suspended in a vast inky-black void. Earth may seem enormous to us as we go about our lives on its surface, but the astronaut's view reveals that our planet is finite and limited. With this perspective, it becomes clear that as our population, technological power, and resource consumption all increase, so does our capacity to alter our surroundings and damage the very systems that keep us alive. Learning how to live peacefully, healthfully, and sustainably on our diverse and complex planet is our society's prime challenge today. The field of environmental science is crucial in this endeavor.

Our environment surrounds us

A photograph of Earth from space offers a revealing perspective, but it cannot convey the complexity of our environment. Our **environment** consists of all the living and nonliving things around us. It includes the continents, oceans, clouds, and ice caps you can see in a photo from space, as well as the fields, forests, plants, and animals of the landscapes in which we live. In a more inclusive sense, it also encompasses the towns, cities, farms, buildings, and living spaces that people have created. In its fullest sense, our environment includes the complex webs of social relationships and institutions that shape our daily lives.

People commonly use the term *environment* in the narrowest sense—to mean a non-human or "natural" world apart from human society. This is unfortunate, because it masks the vital fact that all of us exist within the environment and are part of nature. As one of many species on Earth, we share dependence on a healthy, functioning planet. The limitations of language lead us to speak of "people and nature" or "humans and the environment" as though they were separate and did not interact. However, the fundamental insight of environmental science is that we are part of the "natural" world and that our interactions with the rest of it matter a great deal.

Environmental science explores our interactions with the world

Understanding our relationship with the world around us is vital because we depend on our environment for air, water, food, shelter, and everything else essential for living. Throughout human history, we have modified our environment. By doing so, we have enriched our lives, improved our health, lengthened our life spans, and secured greater material wealth, mobility, and leisure time. Yet many of the changes we have made to our surroundings have degraded the natural systems that sustain us. We have brought about air and water pollution, soil erosion, species extinction, and other environmental impacts that compromise our well-being and jeopardize our ability to survive and thrive in the long term.

Environmental science is the scientific study of how the natural world works, how our environment affects us, and how we affect our environment. Understanding these interactions helps us devise solutions to society's many pressing challenges. It can be daunting to reflect on the number and magnitude of dilemmas that confront us, but these problems also bring countless opportunities for creative solutions.

Environmental scientists study the issues most centrally important to our future. Right now, global conditions are changing more quickly than ever. Right now, we are gaining scientific knowledge more rapidly than ever. And right now, there is still time to tackle society's biggest challenges. With such bountiful opportunities, this moment in history is an exciting time to be alive—and to be studying environmental science.

◄ **Our island, Earth**

(a) Inexhaustible renewable natural resources

(b) Exhaustible renewable natural resources

(c) Nonrenewable natural resources

FIGURE 1.1 Natural resources may be renewable or nonrenewable. Perpetually renewable, or inexhaustible, resources such as sunlight and wind energy **(a)** will always be there for us. Renewable resources such as timber, soils, and fresh water **(b)** are replenished on intermediate timescales, if we are careful not to deplete them. Nonrenewable resources such as minerals and fossil fuels **(c)** exist in limited amounts that could one day be gone.

We rely on natural resources

Islands are finite and bounded, and their inhabitants must cope with limitations in the materials they need. On our island—planet Earth—there are limits to many of our **natural resources,** the substances and energy sources from our environment that we rely on to survive (**FIGURE 1.1**).

Natural resources that are replenished over short periods are known as **renewable natural resources.** Some renewable natural resources, such as sunlight, wind, and wave energy, are perpetually renewed and essentially inexhaustible. Others, such as timber, water, animal populations, and fertile soil, renew themselves over months, years, or decades. These types of renewable resources may be used at sustainable rates, but they may become depleted if we consume them faster than they are replenished. **Nonrenewable natural resources,** such as minerals and fossil fuels, are in finite supply and are formed far more slowly than we use them. Once we deplete a nonrenewable resource, it is no longer available.

We rely on ecosystem services

If we think of natural resources as "goods" produced by nature, we soon realize that Earth's natural systems also provide "services" on which we depend. Our planet's ecological systems purify air and water, cycle nutrients, regulate climate, pollinate plants, and recycle our waste. Such essential services are commonly called **ecosystem services** (**FIGURE 1.2**). Ecosystem services arise from the normal functioning of natural systems and are not meant for our benefit, yet we could not survive without them. The ways that ecosystem services support our lives and civilization are countless and profound (pp. 120–121, 149, 280).

Just as we sometimes deplete natural resources, we often degrade ecosystem services when, for example, we destroy habitat or generate pollution. The degradation of ecosystem services can have stark economic consequences. For instance, if a community's drinking water source becomes polluted, it may require a great deal of money to clean up the pollution, restore the water quality, and deal with the health impacts on community members. In recent decades, our depletion of nature's goods and our disruption of nature's services have intensified, driven by rising resource consumption and a human population that grows larger every day.

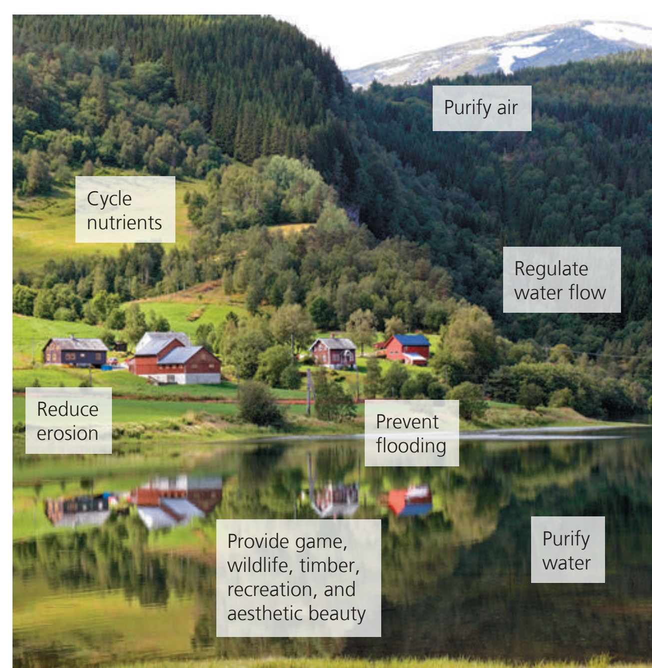


FIGURE 1.2 We rely on the ecosystem services that natural systems provide. For example, forested hillsides help people living below by purifying water and air, cycling nutrients, regulating water flow, preventing flooding, and reducing erosion, as well as by providing game, wildlife, timber, recreation, and aesthetic beauty.

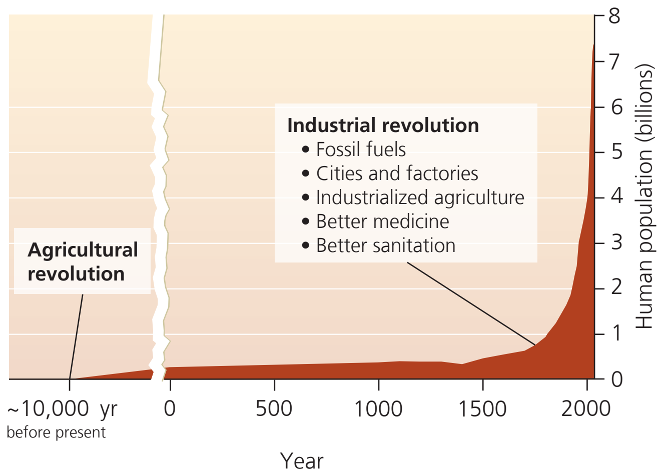


FIGURE 1.3 The global human population increased after the agricultural revolution and then skyrocketed following the industrial revolution. Note that the tear in the graph represents the passage of time and a change in *x*-axis values. *Data compiled from U.S. Census Bureau, U.N. Population Division, and other sources.*

DATA Go to **Interpreting Graphs & Data** on Mastering Environmental Science

Population growth amplifies our impact

For nearly all human history, fewer than a million people populated Earth at any one time. Today, our population is approaching 8 *billion* people. For every one person who existed more than 10,000 years ago, several thousand people exist today! **FIGURE 1.3** shows just how recently and suddenly this monumental change has taken place.

Two phenomena triggered our remarkable increase in population size. The first was our transition from a hunter-gatherer lifestyle to an agricultural way of life. This change began about 10,000 years ago and is known as the **agricultural revolution.** As people began to grow crops, domesticate animals, and live sedentary lives on farms and in villages, they produced more food to meet their nutritional needs and began having more children.

The second phenomenon, known as the **industrial revolution,** began in the mid-1700s. It entailed a shift from rural life, animal-powered agriculture, and handcrafted goods toward an urban-centered society provisioned by the mass production of factory-made goods and powered by **fossil fuels** (nonrenewable energy sources including oil, coal, and natural gas; pp. 529–531). Industrialization brought dramatic advances in technology, sanitation, and medicine. It also enhanced food production through the use of fossil-fuel-powered equipment and synthetic pesticides and fertilizers (pp. 215, 246).

The factors driving population growth have brought us better lives in many ways. Yet as our world fills with people, population growth has begun to threaten our well-being. We must ask how well the planet can accommodate the nearly 10 billion people forecast by 2050. Already our sheer numbers are putting unprecedented stress on natural systems and the availability of resources.

Resource consumption exerts social and environmental pressures

Besides stimulating population growth, industrialization increased the amount of resources each of us consumes. By mining energy sources and manufacturing more goods, we have enhanced our material affluence—but have also consumed more and more of the planet's limited resources.

One way to quantify resource consumption is to use the concept of the ecological footprint, developed in the 1990s by environmental scientists Mathis Wackernagel and William Rees. An **ecological footprint** expresses the cumulative area of biologically productive land and water required to provide the resources a person or population consumes and to dispose of or recycle the waste the person or population produces (**FIGURE 1.4**). It measures the total area of Earth's biologically productive surface that a given person or population "uses" once all direct and indirect impacts are summed up.

For humanity as a whole, Wackernagel and his colleagues at the Global Footprint Network calculate that we are now using 69% more of the planet's renewable resources than are available on a sustainable basis. In other words, we are depleting renewable resources by using them 69% faster than they are being replenished. To look at this in yet another way, it would take 1.69 years for the planet to regenerate the renewable resources that people use in just 1 year. The practice of consuming more resources than are being replenished

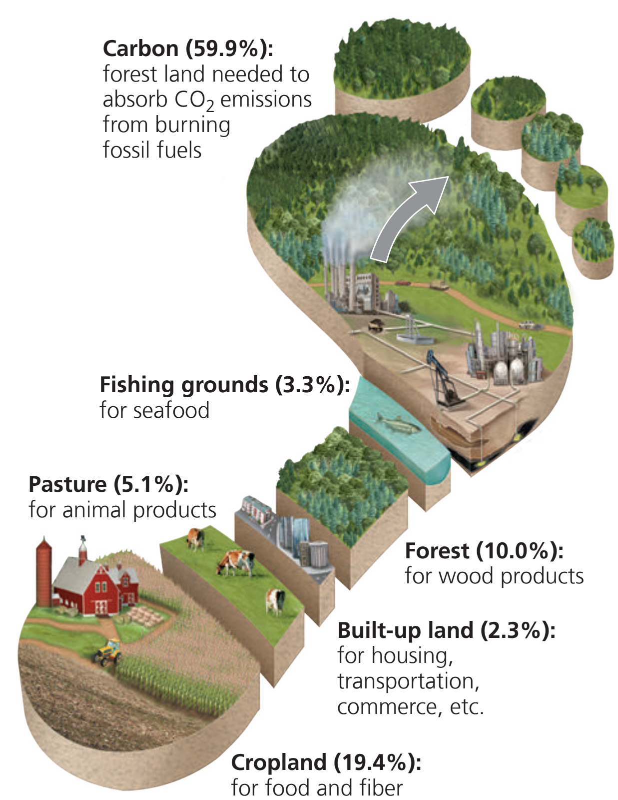


FIGURE 1.4 An ecological footprint shows the total area of biologically productive land and water used by a given person or population. Shown is a breakdown of major components of the average person's footprint. *Data from Global Footprint Network, 2019.*

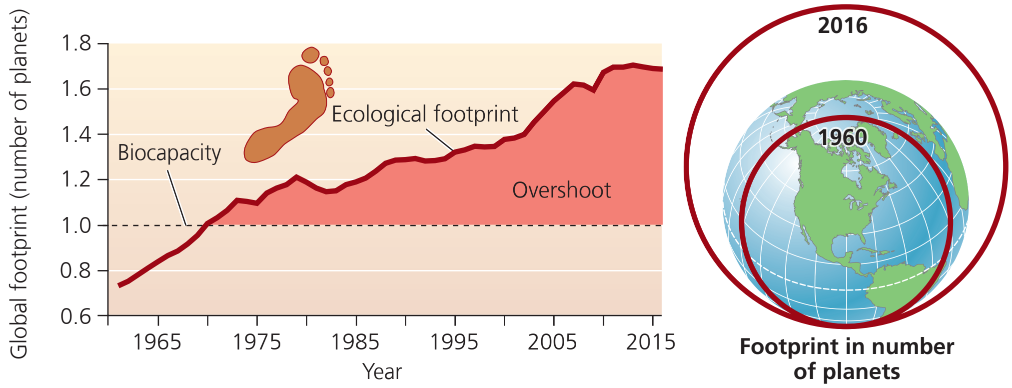


FIGURE 1.5 Analyses by the leading research group into ecological footprints indicate that we have overshot Earth's biocapacity—its capacity to support us—by 69%. We are using renewable natural resources 69% faster than they are being replenished. *Data from Global Footprint Network, 2019.*

DATA Go to **Interpreting Graphs & Data** on Mastering Environmental Science

is termed **overshoot** because we are overshooting, or surpassing, Earth's capacity to sustainably support us (**FIGURE 1.5**).

Scientists debate how best to calculate footprints and measure overshoot. Yet some things are clear; for instance, people from wealthy nations such as the United States have much larger ecological footprints than do people from poorer nations. Using the Global Footprint Network's calculations, if all the world's people consumed resources at the rate of Americans, humanity would need the equivalent of almost five planet Earths!

We can think of our planet's vast store of resources and ecosystem services—Earth's **natural capital**—as a bank account. To keep a bank account full, we need to leave the principal intact and spend just the interest so that we can continue living off the account far into the future. If we begin depleting the principal, we draw down the bank account. To live off nature's interest—the renewable resources that are replenished year after year—is sustainable. To draw down resources faster than they are replaced is to eat into nature's capital, the bank account for our planet and our civilization. Currently we are drawing down Earth's natural capital—and we cannot get away with it for long.

Environmental science can help us learn from mistakes

Historical evidence suggests that civilizations can crumble when pressures from population and consumption overwhelm resource availability. Historians have inferred that environmental degradation contributed to the fall of the Greek and Roman empires, the Angkor civilization of Southeast Asia, and the Maya, Anasazi, and other civilizations of the Americas. In Syria, Iraq, and elsewhere in the Middle East, areas that in ancient times were lush enough to support thriving ancient societies are today barren desert. Easter Island has long been held up as a society that self-destructed after depleting its resources, although new research paints a more complex picture (see **THE SCIENCE BEHIND THE STORY**, pp. 8–9).

In today's globalized society, the stakes are higher than ever because our environmental impacts are global. If we cannot forge sustainable solutions to our problems, the resulting societal collapse will be global. Fortunately, environmental science holds keys to building a better world. Studying environmental science will help you learn to evaluate the whirlwind of changes taking place around us and to think critically and creatively about ways to respond.

Environmental Science

Environmental scientists examine how Earth's natural systems function, how these systems affect people, and how we influence these systems. Many environmental scientists are motivated by a desire to develop solutions to environmental problems. These solutions (such as new technologies, policies, or resource management strategies) are *applications* of environmental science. The study of such applications and their consequences is, in turn, also part of environmental science.

Environmental science is interdisciplinary

Studying our interactions with our environment is a complex endeavor that requires expertise from many academic disciplines, including ecology, earth science, chemistry, biology, geography, economics, political science, demography, and ethics. Environmental science is **interdisciplinary,** bringing techniques, perspectives, and research results from multiple disciplines together into a broad synthesis (**FIGURE 1.6**).

Traditional established disciplines are valuable because their scholars delve deeply into topics, developing expertise in particular areas and uncovering new knowledge. In contrast, interdisciplinary fields are valuable because their practitioners consolidate and synthesize the specialized knowledge from many disciplines and make sense of it in a broad context to better serve the multifaceted interests of society.

Environmental science is especially broad because it encompasses not only the **natural sciences** (disciplines that examine the natural world) but also the **social sciences** (disciplines that address human interactions and institutions). Most environmental science programs focus more on the natural sciences, whereas programs that emphasize the social sciences often use the term **environmental studies.** Whichever approach one takes, these fields bring together many diverse perspectives and sources of knowledge.

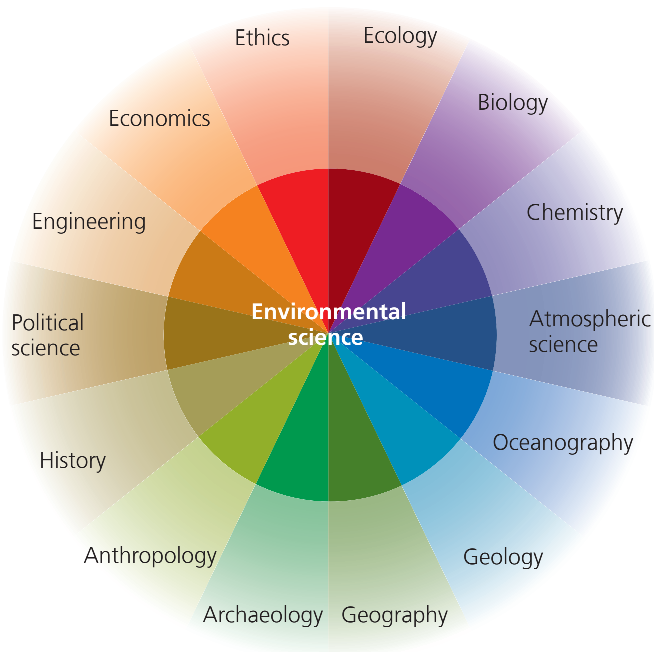


FIGURE 1.6 Environmental science is an interdisciplinary pursuit. It draws from many different established fields of study across the natural sciences and social sciences.

Environmental science is not the same as environmentalism

Although many environmental scientists are interested in solving problems, it would be incorrect to confuse environmental science with environmentalism or environmental activism. They are very different. Environmental science involves the scientific study of the environment and our interactions with it. In contrast, **environmentalism** is a social movement dedicated to protecting the natural world—and, by extension, people—from undesirable changes brought about by human actions.

Of course, like all human beings, scientists are motivated by personal values and interests—and, like any human endeavor, science can never be entirely free of social influence. However, whereas personal values and social concerns may help shape the questions scientists ask, scientists strive to keep their research rigorously objective and free from advocacy. Researchers do their utmost to carry out their work impartially and to interpret their results with wide-open minds, remaining open to whatever conclusions the data demand.

The Nature of Science

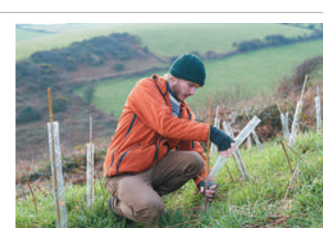
Science is a systematic process for learning about the world and testing our understanding of it. The term *science* is also used to refer to the accumulated body of knowledge that arises from this dynamic process of observing, questioning, testing, and discovery.

Knowledge gained from science can be applied to address society's needs—for instance, to develop technology or to inform policy and management decisions (**TABLE 1.1**). From the food we eat to the clothing we wear to the health care we depend on, virtually everything in our lives has been improved by the application of science. Many scientists are motivated by the potential for developing useful applications. Others are inspired simply by a desire to understand how the world works.

Scientists test ideas by critically examining evidence

Science is all about asking and answering questions. Scientists examine how the world works by making observations, taking measurements, and testing whether their ideas are supported by evidence. The effective scientist thinks critically and does not simply accept conventional wisdom from others. The scientist becomes excited by novel ideas but is skeptical and judges ideas by the strength of evidence that supports them.

TABLE 1.1 Examples of Societal Applications of Science

	Science **enhances our health and well-being**. Treatments for illness, cures for disease, technologies for better health care (here, **ultrasound imaging** for assessing fetal development)—indeed, all aspects of medicine—rely on scientific research.		Scientific study leads to **advances in engineering and technology**. Energy-efficient vehicles such as **electric cars** are made possible by research and development in materials science and energy efficiency.
	By revealing our impacts on the atmosphere and climate, scientific research has led to **policies** to fight climate change and to **technology** for producing clean renewable energy, such as these **offshore wind turbines**.		Science can help us **reduce environmental impacts**. The pursuit of **ecological restoration**—restoring disturbed areas to an earlier, more natural state—is a common land management practice informed by ecological research.

THE SCIENCE **behind** the **story**

What Are the Lessons of Easter Island?

Terry Hunt and Carl Lipo on Easter Island

A mere speck of land in the vast Pacific Ocean, Easter Island is one of the most remote spots on the globe. Yet this far-flung island—called Rapa Nui by its inhabitants—has been the focus of an intense debate among scientists seeking to solve its mysteries and decipher the lessons it offers. The debate shows how, in science, new information can challenge existing ideas—and also how interdisciplinary research helps us tackle complex questions.

Ever since European explorers stumbled upon Rapa Nui on Easter Sunday in 1722, outsiders have been struck by the island's barren landscape. Early European accounts suggested that the 2000 to 3000 people living on the island at the time seemed impoverished, subsisting on a few meager crops and possessing only stone tools. Yet the forlorn island also featured hundreds of gigantic statues of carved rock (**FIGURE 1**). How could people without wheels or ropes, on an island without trees, have moved 90-ton statues 10 m (33 ft) high as far as 10 km (6.2 mi) from the quarry where they were chiseled to the sites where they were erected? Apparently, some calamity must have befallen a once-mighty civilization on the island.

Researchers who set out to solve Rapa Nui's mysteries soon discovered that the island had once been lushly forested. Scientist John Flenley and his colleagues drilled cores deep into lake sediments and examined ancient pollen grains preserved there, seeking to reconstruct, layer by layer, the history of vegetation in the region. Finding a great deal of palm pollen, they inferred that when Polynesian people colonized the island (A.D. 300–900, they estimated), it was covered with palm trees similar to the Chilean wine palm—a tree that can live for centuries.

By studying pollen and the remains of wood from charcoal, archaeologist Catherine Orliac found that at least 21 other plant species—now gone—had also been common. Clearly the island had once supported a diverse forest. Forest plants would have provided fuelwood, building material for houses and canoes, fruit to eat, fiber for clothing, and, researchers guessed, logs and fibrous rope to help move statues.

But pollen analysis also showed that trees began declining after human arrival and were replaced by ferns and grasses. Then between 1400 and 1600, pollen levels plummeted. Charcoal in the soil proved that the forest had been burned, likely in slash-and-burn farming. Researchers concluded that the islanders, desperate for forest resources and cropland, had deforested their own island.

With the forest gone, soil eroded away—data from lake bottoms showed a great deal of accumulated sediment. Erosion would have lowered yields of bananas, sugarcane, and sweet potatoes, perhaps leading to starvation and population decline.

Further evidence indicated that wild animals disappeared. Archaeologist David Steadman analyzed 6500 bones and found that at least 31 bird species had provided food for the islanders. Today, only one native bird species is left. Remains from charcoal fires show that early islanders feasted on fish, sharks, porpoises, turtles, octopus, and shellfish—but in later years they consumed little seafood.

As resources declined, researchers concluded, people fell into clan warfare, revealed by unearthed weapons and skulls with head wounds. Rapa Nui appeared to be a tragic case of ecological suicide: A once-flourishing civilization depleted its resources and destroyed itself. In this interpretation—advanced by Flenley and writer Paul Bahn, and popularized by scientist Jared Diamond in his best-selling 2005 book *Collapse*—Rapa Nui seemed to offer a clear lesson: We on our global island, planet Earth, had better learn to use our limited resources sustainably.

When Terry Hunt and Carl Lipo began research on Rapa Nui in 2001, they expected simply to help fill gaps in a well-understood history. But science is a process of discovery, and sometimes evidence leads researchers far from where they anticipated. For Hunt, an anthropologist at the University of Hawai'i at Manoa, and Lipo, an archaeologist at California State University, Long Beach, their work led them to conclude that the traditional "ecocide" interpretation didn't tell the whole story. First, their radiocarbon dating (dating of items using radioisotopes of carbon; p. 26) indicated that people had not colonized the island until about A.D. 1200, suggesting that deforestation occurred rapidly after their arrival. How could so few people have destroyed so much forest so fast?

Hunt and Lipo's answer: rats. When Polynesians settled new islands, they brought crop plants, as well as chickens and other domestic animals. They also brought rats—intentionally as a food source or unintentionally as stowaways. In either case, rats can multiply quickly, and they soon overran Rapa Nui.

Researchers found rat tooth marks on old nut casings, and Hunt and Lipo suggested that rats ate so many palm nuts and shoots that the trees could not regenerate. With no young trees growing, the palm went extinct once mature trees died.

Diamond and others counter that plenty of palm nuts on Easter Island escaped rat damage, that most plants on other islands survived rats introduced by Polynesians, and that more than 20 additional plant species went extinct on Rapa Nui. Moreover, people brought the rats, so even if rats destroyed the forest, human colonization was still to blame.

Despite the forest loss, Hunt and Lipo argue that islanders were able to persist and thrive. Archaeology shows how islanders adapted to Rapa Nui's poor soil and windy weather by developing rock gardens to protect crop plants and nourish the soil. Hunt and Lipo contended that tools viewed by previous researchers as weapons were actually farm implements, that lethal injuries were rare, and that no evidence of battle or defensive fortresses was uncovered.

Hunt, Lipo, and others also unearthed old roads and inferred how the famous statues were transported. It had been thought that a powerful central authority must have forced armies of laborers to roll them over countless palm logs, but Hunt and Lipo concluded that small numbers of people could have moved them by tilting and rocking them upright—much as we might move a refrigerator. Indeed, the distribution of statues on the island suggested the work of family groups. Islanders had adapted to their resource-poor environment by becoming a peaceful and cooperative society, Hunt and Lipo maintained, with the statues providing a harmless outlet for competition over status and prestige.

Altogether, the evidence led Hunt and Lipo to propose that far from destroying their environment, the islanders had acted as responsible stewards. The collapse of this sustainable civilization, they argue, came with the arrival of Europeans, who unwittingly brought contagious diseases to which the islanders had never been exposed. Indeed, historical journals of sequential European voyages depict a society falling into disarray as if reeling from epidemics.

Peruvian ships then began raiding Rapa Nui and taking islanders away into slavery. Foreigners acquired the land, forced the remaining people into labor, and introduced thousands of sheep, which destroyed the few native plants left on the island. Thus, the new hypothesis holds that the collapse of Rapa Nui's civilization resulted from a barrage of disease, violence, and slave raids following foreign contact. Before that, Hunt and Lipo say, Rapa Nui's people boasted 500 years of a peaceful and resilient society.

Hunt and Lipo's interpretation, put forth in a 2011 book, *The Statues That Walked,* would represent a paradigm shift (p. 14) in how we view Easter Island. Debate between the two camps remains heated, however, and interdisciplinary research continues as scientists look for new ways to test the differing hypotheses. This is an example of how science advances, and in the long term, data from additional studies should lead us closer and closer to the truth.

Like the people of Rapa Nui, we are all stranded together on an island with limited resources. What is the lesson of Easter Island for our global island, Earth? Perhaps there are two: Any island population must learn to live within its means, but with care and ingenuity, there is hope that we can.

FIGURE 1 Were the haunting statues of Easter Island (Rapa Nui) erected by a civilization that collapsed after devastating its environment or by a sustainable civilization that fell because of outside influence?

A great deal of scientific work is **descriptive science,** research in which scientists gather basic information about organisms, materials, systems, or processes that are not yet well known. In this approach, researchers explore new frontiers of knowledge by observing, recording, and measuring phenomena to gain a better understanding of them.

Once enough basic information is known about a subject, scientists can begin posing questions that seek deeper explanations about how and why things are the way they are. At this point scientists may pursue **hypothesis-driven science,** research that proceeds in a more targeted and structured manner, using empirical observations or controlled experiments to test hypotheses within a framework traditionally known as the scientific method.

The scientific method is a traditional approach to research

The **scientific method** is a technique for testing ideas with observations. There is nothing mysterious about the scientific method; it is merely a formalized version of the way any of us would naturally use logic to resolve a question. Because science is an active, creative process, innovative researchers may depart from the traditional scientific method when particular situations demand it. Moreover, scientists in different fields approach their work differently because they deal with dissimilar types of information. Nonetheless, scientists of all persuasions broadly agree on fundamental elements of the process of scientific inquiry. As practiced by individual researchers or research teams, the scientific method (**FIGURE 1.7**) typically follows the steps outlined next.

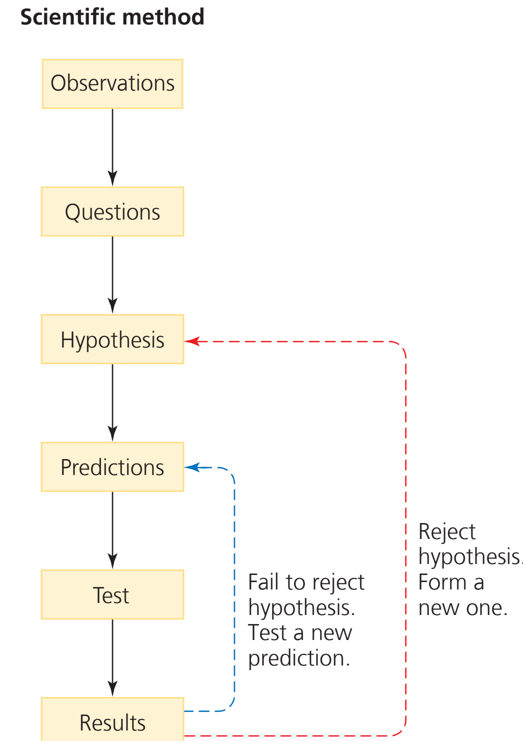


FIGURE 1.7 The scientific method is the traditional experimental approach scientists use to learn how the world works.

Make observations Advances in science generally begin with the observation of some phenomenon that the scientist wishes to explain. Observations set the scientific method in motion by inspiring questions—and observations also play a role throughout the process.

Ask questions Curiosity is in our human nature. Just observe young children exploring a new environment—they want to touch, taste, watch, and listen to everything, and as soon as they can speak, they begin asking questions. Scientists, in this respect, are kids at heart. Why is the ocean salty? Why are storms becoming more severe? What is causing algae to cover local ponds? When pesticides poison fish or frogs, are people also affected? How can we help restore populations of plants or animals? All these are questions environmental scientists ask.

Develop a hypothesis Scientists pursuing hypothesis-driven science address their questions by devising explanations that they can test. A **hypothesis** is a statement that attempts to explain a phenomenon or answer a scientific question. For example, a scientist wondering why algae are growing excessively in local ponds might observe that chemical fertilizers are being applied on farm fields nearby. The scientist might then propose a hypothesis as follows: "Agricultural fertilizers running into ponds cause the amount of algae in the ponds to increase."

Make predictions The scientist next uses the hypothesis to generate **predictions,** specific statements that are logical consequences of the hypothesis and that can be directly and unequivocally tested. In our algae example, a researcher might predict the following: "If agricultural fertilizers are added to a pond, the quantity of algae in the pond will increase."

Test the predictions Scientists test predictions by gathering evidence that could potentially refute the predictions and thus disprove the hypothesis. The strongest form of evidence comes from experiments. An **experiment** is an activity designed to test the validity of a prediction or a hypothesis.

An experiment involves manipulating **variables,** or conditions that can change. For example, a scientist could test the prediction linking algal growth to fertilizer by selecting two identical ponds and adding fertilizer to one of them. In this example, fertilizer input is an **independent variable,** a variable the scientist manipulates, whereas the quantity of algae that results is the **dependent variable,** a variable that depends on the fertilizer input. If the two ponds are identical except for a single independent variable (fertilizer input), any differences that arise between the ponds can be attributed to the independent variable. Such an experiment is known as a **controlled experiment** because the scientist attempts to control for the effects of all variables except for the one that he or she is testing. In our example, the pond left unfertilized serves as a **control,** an unmanipulated point of comparison for the manipulated **treatment** pond.

Whenever possible, it is best to replicate one's experiment—that is, to perform multiple tests of the same comparison.

Our scientist could perform a replicated experiment on, say, 10 pairs of ponds, adding fertilizer to one of each pair.

An experiment in which the researcher actively chooses and manipulates the independent variable is known as a *manipulative experiment*. A manipulative experiment provides strong evidence because it can reveal causal relationships, showing that changes in an independent variable cause changes in a dependent variable. In practice, however, we cannot run manipulative experiments for all questions, especially for processes involving large spatial scales or long timescales. For example, to study global climate change (Chapter 18), we cannot run a manipulative experiment adding carbon dioxide to 10 treatment planets and 10 control planets and then compare the results! Thus, it is common for researchers to run *natural experiments*, which compare how dependent variables are expressed in naturally occurring, but different, contexts. In such experiments, the independent variable varies naturally, and researchers test their hypotheses by searching for **correlation,** or statistical association among variables. For instance, let's suppose our scientist studying algae surveys 50 ponds, 25 of which happen to be fed by fertilizer runoff from nearby farm fields and 25 of which are not. Let's say the scientist finds seven times more algal growth in the fertilized ponds. The scientist may conclude that algal growth is correlated with fertilizer input—that is, that one tends to increase along with the other.

Evidence based on correlation alone is not as strong as the causal evidence that manipulative experiments can provide, but often a natural experiment is the only feasible approach. Because many questions in environmental science are complex and exist on large scales, they must be addressed with correlative data. One benefit of natural experiments is that they preserve the real-world complexity that manipulative experiments often sacrifice. When possible, scientists often try to integrate natural and manipulative experiments to gain the advantages of each.

Analyze and interpret results Scientists record **data,** or information, from their studies (**FIGURE 1.8**). Researchers particularly value quantitative data (information expressed using numbers), because numbers provide precision and are easy to compare. The scientist conducting the fertilization experiment, for instance, might quantify the area of water surface covered by algae in each pond or might measure the dry weight of algae in a certain volume of water taken from each. It is vital, however, to collect data that are representative. Because it is impractical to measure a pond's total algal growth, our researcher might instead sample from multiple areas of each pond. These areas must be selected in a random manner; choosing areas with the most growth or the least growth, or areas most convenient to sample, would not provide a representative sample.

Even with the precision that numerical data provide, experimental results may not be clear-cut. Data from treatments and controls may vary only slightly or replicates may yield different results. Researchers must therefore analyze their data using statistical tests. With these mathematical methods, scientists can determine objectively and precisely the strength and reliability of patterns they find.

FIGURE 1.8 Researchers gather data to test predictions in experiments. Here, a scientist samples algae from a pond.

If experiments disprove a hypothesis, the scientist will revise the hypothesis or may formulate a new hypothesis to replace it. If experiments fail to disprove a hypothesis, such failure lends support to the hypothesis but does not *prove* that the hypothesis is correct. The scientist may choose to generate new predictions to test the hypothesis in different ways and further assess its likelihood of being valid. In this way, the scientific method loops back on itself, giving rise to repeated rounds of hypothesis revision and experimentation (see Figure 1.7).

If repeated tests fail to reject a hypothesis, evidence in favor of it accumulates, and the researcher may eventually conclude that the hypothesis is well supported. Ideally, the scientist would want to test all possible explanations. For instance, our algae researcher might formulate an additional hypothesis, proposing that algae increase in fertilized ponds because chemical fertilizers diminish the numbers of fish or invertebrate animals that eat algae. It is possible, of course, that both hypotheses could be correct and that each may explain some portion of the initial observation that local ponds were experiencing algal blooms.

FAQ

Can science *prove* that an idea is correct?

Technically speaking, science never "proves" an idea to be correct. By following the method and process of experimental scientific research, a scientist may disprove a hypothesis, or the scientist may find support for the hypothesis by testing it and failing to falsify it. But even if a hypothesis attains strong and repeated support from extensive research, it could potentially be shown to be incorrect in the future as a result of newly discovered evidence or of research that is more thorough or better informed. The fact that scientific explanations are always subject to revision, if needed, demonstrates the strength of the scientific process. Unlike opinion or ideology, science is open-ended and tends to be self-corrective and ever-improving, bringing us closer and closer over time to full and accurate understanding.

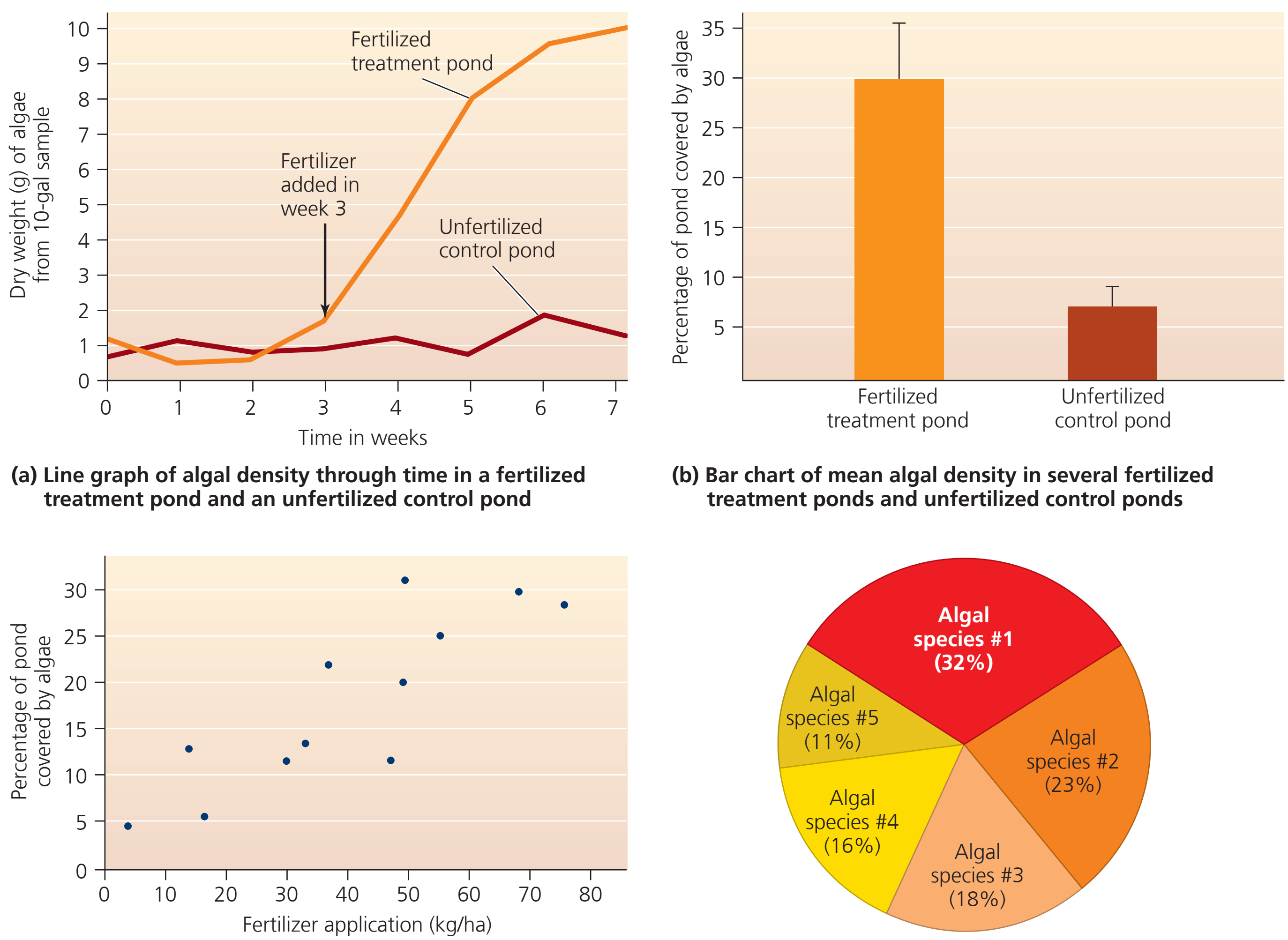
Scientists use graphs to represent data visually

To summarize and present the data they obtain, scientists often use graphs. Graphs help make patterns and trends in the data visually apparent and easy to understand. **FIGURE 1.9** shows a few examples of how different types of graphs can be used to present data. Each of these types of graphs is illustrated clearly and explained further in **APPENDIX A: HOW TO INTERPRET GRAPHS** at the back of this book. The ability to interpret graphs is a skill you will find useful throughout your life. We encourage you to consult Appendix A closely as you begin your environmental science course.

You also will note that many of the graphs in this book are accompanied by **DATA Q** questions that you can find online at **Mastering Environmental Science**. These questions are designed to help you interpret scientific data and build your graph-reading skills. You can check your answers to these questions in **Mastering Environmental Science**.

The scientific process continues beyond the scientific method

Scientific research takes place within the context of a community of peers. To have impact, a researcher's work must be published and made accessible to this community (**FIGURE 1.10**).



(a) Line graph of algal density through time in a fertilized treatment pond and an unfertilized control pond

(b) Bar chart of mean algal density in several fertilized treatment ponds and unfertilized control ponds

(c) Scatter plot of algal density correlated with fertilizer use on surrounding farmland

(d) Pie chart of species of algae in a sample of pond water

FIGURE 1.9 Scientists use graphs to present and visualize their data. For example, in **(a),** a line graph shows how the amount of algae increased when fertilizer was added to a treatment pond in an experiment yet stayed the same in an unfertilized control pond. In **(b),** a bar chart shows how fertilized ponds, on average, have several times more algae than unfertilized ponds. In **(c),** a scatter plot shows how ponds with more fertilizer tend to contain more algae. In **(d),** a pie chart shows the relative abundance of five species of algae in a sample of pond water. See **APPENDIX A** to learn more about how to interpret these types of graphs.

DATA Q Go to **Interpreting Graphs & Data** on Mastering Environmental Science

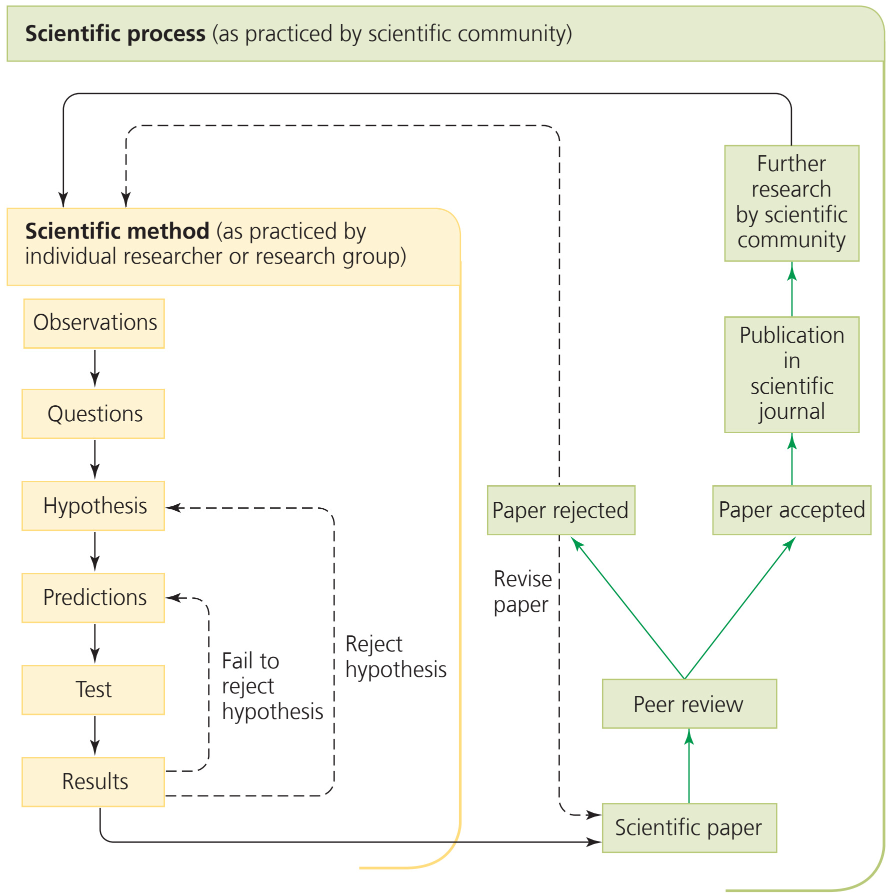


FIGURE 1.10 The scientific method that many research teams follow is part of a larger framework—the overall process of science carried out by the scientific community. This process includes peer review and publication of research, acquisition of funding, and the elaboration of theory through the cumulative work of many researchers.

Peer review Once a researcher's work is complete, he or she writes up the findings in a research paper and submits the manuscript to a journal (a scholarly publication in which scientists share their work). The journal's editor asks several other scientists who specialize in the subject area to volunteer their time to examine the manuscript, provide comments and criticism (generally anonymously), and judge whether the work merits publication in the journal. This procedure, known as **peer review,** is an essential part of the scientific process.

Peer review is a valuable guard against faulty research contaminating the literature (the body of published studies) on which all scientists rely. It is what makes scientific research papers so much more accurate and reliable than many other forms of publication. Of course, scientists are human, so personal biases and politics can sometimes creep into the review process. Fortunately, just as individual scientists strive to remain objective in conducting their research, the scientific community does its best to ensure fair review of all work.

Conference presentations Scientists frequently present their work at professional conferences, where they interact with colleagues and receive feedback on their research. Such interactions can help improve a researcher's work and foster collaboration among researchers, thus enhancing the overall quality and impact of science.

Grants and funding To fund their research, most scientists need to spend a great deal of time and effort requesting money from private foundations or from government agencies such as the National Science Foundation. Grant applications undergo peer review just as scientific papers do, and competition for funding is generally intense.

Scientists' reliance on funding sources can occasionally lead to conflicts of interest. A researcher who obtains data showing his or her funding source in an unfavorable light may become reluctant to publish the results for fear of losing funding. This situation can arise, for instance, when an industry funds research to test its products for health or safety. Most scientists resist these pressures, but when you are assessing a scientific study, it is always a good idea to note where the researchers obtained their funding. Because of the potential conflicts of interest that can sometimes arise from private funding, it is important for our society that scientists have access to adequate levels of funding from impartial public sources such as government science agencies.

Repeatability The careful scientist may test a hypothesis repeatedly in various ways. Following publication, other scientists may attempt to reproduce the results in their own experiments. Scientists are inherently cautious about accepting a novel hypothesis, so the more a result can be reproduced by different research teams, the more confidence scientists will gain that it provides a correct explanation.

Theories If a hypothesis survives repeated testing by numerous research teams and continues to predict experimental

WEIGHING the issues

Follow the Money

Let us say you are a scientist wanting to study the impacts of chemicals released into lakes by pulp-and-paper mills. Obtaining research funding has been difficult. Then a large pulp-and-paper firm contacts you and offers to fund your research examining how the company's chemical effluents affect water bodies. What do you think the benefits and drawbacks of such an offer would be? Would you accept the offer? Why or why not?

outcomes and observations accurately, it may be incorporated into a theory. A **theory** is a widely accepted, well-tested explanation of one or more cause-and-effect relationships that has been extensively validated by a great amount of research. Whereas a hypothesis is a simple explanatory statement that may be disproven by a single experiment, a theory consolidates many related hypotheses that have been supported by a large body of data.

Note that scientific use of the word *theory* differs from popular usage of the word. In everyday language, if we say something is "just a theory," we are suggesting it is a speculative idea without much substance. However, scientists mean exactly the opposite when they use the term. In a scientific context, a theory is a conceptual framework that explains a phenomenon and has undergone extensive and rigorous testing, such that confidence in it is extremely strong. For example, Darwin's theory of evolution by natural selection (pp. 50–51) has been supported and elaborated by many thousands of studies over 160 years of intensive research. Observations and experiments have shown repeatedly and in great detail how plants and animals evolve over generations, attaining characteristics that best promote survival and reproduction. Because of its strong support and explanatory power, evolutionary theory is the central unifying principle of modern biology. Other prominent scientific theories include atomic theory, cell theory, big bang theory, plate tectonics, and general relativity.

Paradigm shifts occur

As the scientific community accumulates data in an area of research, interpretations sometimes may change. Thomas Kuhn's influential 1962 book, *The Structure of Scientific Revolutions,* argued that science goes through periodic upheavals in thought in which one scientific **paradigm,** or dominant view, is abandoned for another. For example, before the 16th century, European scientists believed Earth was at the center of the universe. Their data on the movements of planets fit that concept somewhat well—yet the idea eventually was disproved after Nicolaus Copernicus showed that placing the sun at the center of the solar system explained the data much better.

Another paradigm shift occurred in the 1960s when geologists came to accept plate tectonics (pp. 35–37). By this time, evidence for the movement of continents and the action of tectonic plates had accumulated and become overwhelmingly convincing. Paradigm shifts demonstrate the strength and vitality of science, showing science to be a process that refines and improves itself through time.

Understanding how science works is vital to assessing how scientific interpretations progress through time as information accrues. This is especially relevant in environmental science—a young field that is changing rapidly as we obtain vast amounts of new information, as human impacts on our planet multiply, and as we gather lessons from the consequences of our actions.

How can we judge the reliability of information?

Even if you are not a scientist, every one of us in our everyday lives can benefit from using the type of careful, logical, critical thinking that scientists use. In fact, developing critical thinking skills might well be the single most important thing a student can do to prepare for a lifetime of navigating our society—a society in which far too many uninformed and unscrupulous interests act to confuse, manipulate, and mislead us by distorting information.

In our society today, we are awash in information—and misinformation—from all kinds of sources. To get the day's news, for instance, we can tune into a diversity of television and radio stations, or check countless online websites, or receive social media news feeds, or even open up a good old-fashioned print newspaper. When it comes to news about science, some popularized news coverage is excellent, but some is sorely lacking. And when it comes to coverage of environmental issues, we may receive very different messages from sources with differing political viewpoints.

At a time when some politicians try to discredit any information they do not like as "fake news" and armies of bots and hackers regularly manipulate information online, it can be challenging to know what to trust. However, we know that science—including all the understanding it can bring us—is too valuable to ignore or discard. How, then, can a person find reliable information about scientific research? How can we know which sources to trust and which to be skeptical of?

One key criterion in evaluating the reliability of a source is to determine whether or not the information it offers is solidly based in evidence. It is not always easy to ascertain whether a source is objective, unbiased, and evidence-based, but one can look for a number of clues. **TABLE 1.2** walks you through a checklist of questions to ask yourself whenever you are assessing a source for reliability—for information on science or on anything else.

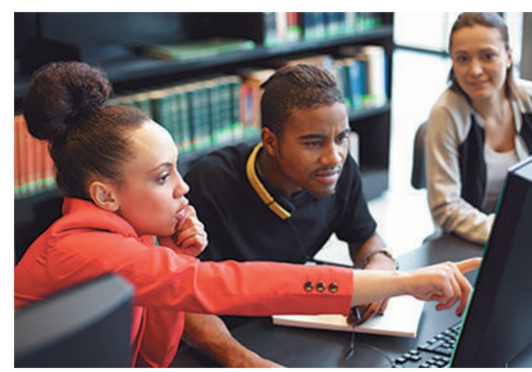
One question to ask when evaluating sources of information about a scientific matter is how many steps removed from the original research a source is. A person can get the most accurate understanding of a scientific question by reading the scientific literature directly. Your college or university library will have scientific journals full of research papers that are current and peer-reviewed. However, reading original research papers in scientific journals requires a level of specialized education that most of us lack. Thankfully, many of the most prestigious journals, such as *Science* and *Nature,* also feature articles written by their staff that explain the results and relevance of their most groundbreaking and socially relevant papers in language we all can understand.

Another way to learn about important scientific advances is to read articles by science writers published in media outlets that have built solid reputations over years or decades. Magazines like *Scientific American, National Geographic,* and *New Scientist* are examples, as are newspapers such as *The New York Times, Los Angeles Times,* and *Wall Street Journal*—all of which are accessible online as well as in print (and are likely available for free in your campus library). Websites like *Science News* and *Science Daily* and podcasts, videos, television programs, and radio broadcasts from proven media outlets like PBS's *NOVA* and NPR's *Science Friday* are excellent as well. Science journalists inform their articles and broadcasts by reading original research papers, interviewing the scientists who conducted the work, and speaking with other scientists for context and criticism. Most science journalists are trained in science and steeped in their areas of expertise but are also skilled at communicating with a broad audience. They often are able to explain research and bring the wonders of science to life in a way that most scientists cannot.

An original scientific research paper in a journal is an example of a **primary source,** a source that presents novel information and stands on its own. Articles or broadcasts produced by others about the contents of a primary source are examples of a **secondary source.** Secondary sources are often easier to read and understand than primary sources, but as one moves further from the primary source, there is more and more risk of inaccurate information being introduced. Material that has "gone viral" through social media is often the most unreliable because information can easily become altered, just as it is in the classic "telephone game" in which a sentence is whispered from person to person around a circle.

These days the internet is awash in accounts from secondary sources that are distant from the actual research or are not wholly reliable. Writers and broadcasters with little knowledge of science may nonetheless need to produce a news piece on deadline about some new advance. Bloggers who love communicating with their readers and are skillful writers may inadvertently pass along information that is inaccurate.

TABLE 1.2 Questions to Ask When Evaluating a Source for Reliability



WHO is presenting the information?
What are the presenter's profession, credentials, and qualifications?
What are the presenter's organizational affiliations?
What person or institution is financially supporting presentation of the information (e.g., university, private company, government agency, non-profit organization)?
Does the website URL reveal anything about the source (e.g., .com, .org, .edu, .gov)?
WHY is the information being presented?
Does the presenter or sponsor make his or her motivations clear?
Is the presenter trying to teach and inform or to persuade and sell?
Are there advertisements related to the content?
Could the presenter have a financial interest or other vested interest in promoting the argument being made?
HOW reliable is the information?
Is the information based on factual evidence?
Does the source cite *its* sources or explain where *its* information is coming from? (Original research? Personal experience? Other sources?)
Can you find, examine, and verify the information elsewhere?
Do the language and tone seem unbiased and free of emotion?
If an opinion is being expressed, are reasons given to back up the opinion?
Are there spelling, grammar, or typographical errors?
Has the information been reviewed or refereed?
Can you detect political, ideological, cultural, religious, institutional, or personal biases?
Is the information current? When was the information created or last updated?
Have you looked at and compared a variety of sources before choosing this one?

Some table items are based on those in Blakeslee, S., 2010. *Evaluating information—Apply the CRAAP test*. Meriam Library, California State Library, Chico.

FAQ

What about Wikipedia?

Wikipedia can be a tremendous source of information as long as one keeps in mind the way it is created. Wikipedia is a crowd-sourced online encyclopedia whose entries are written by volunteers, and the entries are peer-reviewed by other volunteers. Entries on popular topics that many people with expertise have contributed to are often comprehensive and accurate, but entries on obscure topics that have received less critical attention can sometimes contain unreliable information. Examining the number and quality of sources cited at the end of a Wikipedia entry is one good way to assess the strength of the entry. In fact, a Wikipedia page can often be a helpful way to begin researching a topic because it generally provides citations of some of the most relevant primary sources, which you can then check on your own.

Of most concern is that people with financial conflicts of interest or with strong political ideologies may intentionally sow misinformation to advance their own agendas. Examples in recent years relevant to environmental science have involved the denial of climate change, particularly in U.S. media and politics. Many ideologically driven politicians and many individuals with financial ties to fossil fuel industries have spread doubt about the extent, causes, and consequences of climate change, ignoring or distorting the immense amount of scientific evidence that thousands of researchers worldwide have built up over many decades of careful study.

It is up to each of us to be smart, educated consumers of information and to recognize when sources are misinformed or are trying to sell us their own version of reality. Sorting good information from bad is not always easy, but it is one of the most important life skills any of us can develop.

Seeking a Sustainable Future

As environmental scientists study the causes and consequences of environmental change, they are helping to address today's primary challenge for society: determining how to live within our planet's means such that Earth and its resources can sustain us—and all life—for the future. This is the challenge of **sustainability,** a guiding principle of modern environmental science and a concept you will encounter throughout this book.

Sustainability is a condition in which our actions do not cause lasting harm to the environment and are socially and economically beneficial as well so that people's needs today are met without impairing future generations' abilities to meet their own needs. Sustainability means leaving our children and grandchildren a world as rich and full as the world we live in now. It means conserving Earth's resources so that our descendants may enjoy them as we have. It means reducing poverty and making a good life possible for all people. It means developing solutions that work in the long term. Sustainability requires maintaining fully functioning ecological systems, because we cannot sustain human civilization without sustaining the natural systems that nourish it.

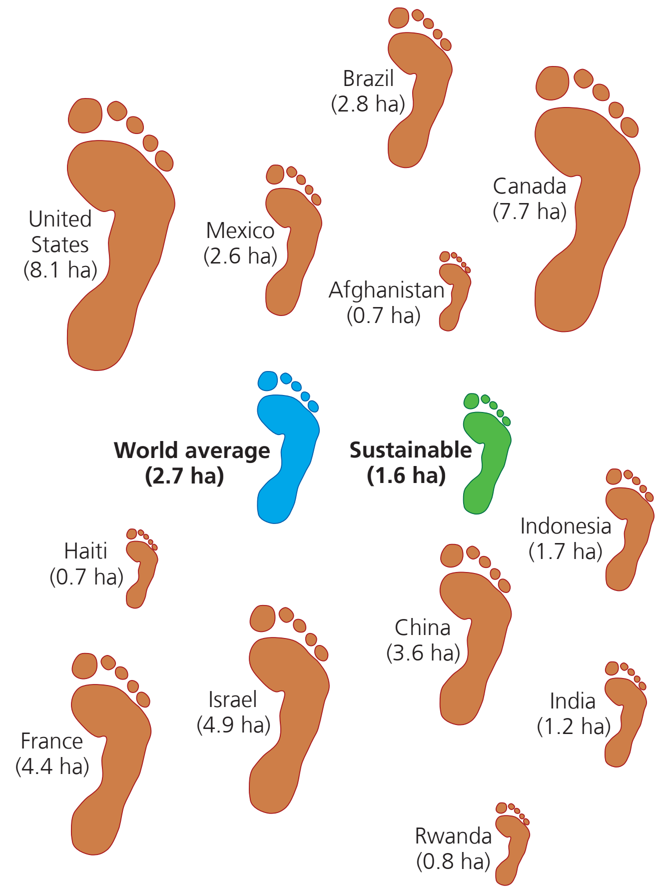


FIGURE 1.11 People of some nations have much larger ecological footprints than people of others. Shown are ecological footprints for average citizens of several nations along with the world's average per capita footprint of 2.7 hectares. To achieve sustainable consumption, we would need to have a global per-person average footprint of 1.6 ha. One hectare (ha) = 2.47 acres. *Data from Global Footprint Network, 2019.*

DATA Go to **Interpreting Graphs & Data** on Mastering Environmental Science

An examination of the ecological footprints of the world's nations (**FIGURE 1.11**) indicates that we are not (yet) on a sustainable trajectory. Yet as we will see throughout this book, there are many reasons to be optimistic. In each chapter, a **SUCCESS STORY** will feature one specific example of a problem-solving effort that has met with success and produced a sustainable solution. In addition, you will encounter a variety of further solutions to environmental challenges, addressed in many ways, throughout the text.

Population and consumption drive environmental impact

Every day we add more than 200,000 people to the planet. This is like adding a city the size of Augusta, Georgia, on Monday; Akron, Ohio, on Tuesday; Richmond, Virginia, on Wednesday; Rochester, New York, on Thursday; Amarillo, Texas, on Friday; and on and on, day after day. The rate of population growth is now slowing, but our absolute numbers continue to increase. This ongoing rise in human population (Chapter 8) amplifies nearly all our impacts.

Our consumption of resources has risen even faster than our population. The modern rise in affluence has been a positive development for humanity, and our conversion of the planet's natural capital has made life better for most of us so far. However, like rising population, rising per capita (per person) consumption magnifies the demands we make on our environment.

The world's people have not benefited equally from society's overall rise in affluence. Today, the 20 wealthiest nations boast more than 55 times the per capita income of the 20 poorest nations—three times the gap that existed just two generations ago. Within the United States, the richest 10% of people now claim half of the total income and more than 70% of the total wealth. The ecological footprint of the average resident of a developed nation such as the United States is considerably larger than that of the average resident of a developing country (see Figure 1.11).

Our growing population and consumption are intensifying the many environmental impacts we examine in this book, including erosion and other impacts from agriculture (Chapters 9 and 10), deforestation (Chapter 12), toxic substances (Chapter 14), freshwater depletion (Chapter 15), fisheries declines (Chapter 16), air and water pollution (Chapters 15–17), waste generation (Chapter 22), mineral extraction and mining impacts (Chapter 23), and, of course, global climate change (Chapter 18). These impacts degrade our health and quality of life, and they alter the ecosystems and landscapes in which we live. They also are driving the loss of Earth's biodiversity (Chapter 11), which is perhaps our greatest problem because extinction is irreversible. Once a species becomes extinct, it is lost forever.

Energy choices will shape our future

Our reliance on fossil fuels amplifies virtually every impact we exert on our environment. Yet fossil fuels have also helped bring us the material affluence we enjoy. By exploiting the richly concentrated energy in coal, oil, and natural gas, we have been able to power the machinery of the industrial revolution, produce chemicals that boost crop yields, run vehicles and transportation networks, and manufacture and distribute countless consumer products.

However, in extracting coal, oil, and natural gas, we are splurging on a one-time bonanza, because these fuels are nonrenewable and in finite supply. As we pour more money, energy, and resources into extracting fossil fuels that are more difficult to access, we threaten greater environmental and social impacts for relatively less fuel. The energy choices we make today will greatly influence the nature of our lives for the foreseeable future.

WEIGHING the issues

Leaving a Large Footprint

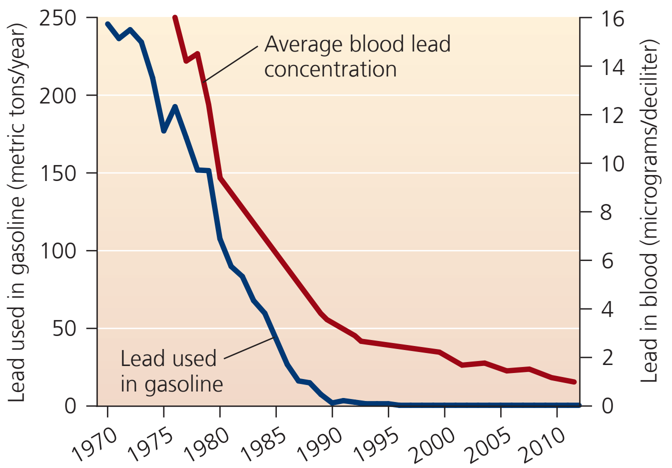
What do you think accounts for the variation in per capita (per person) ecological footprints among societies? Do you believe that people with larger footprints have an ethical obligation to reduce their environmental impact so as to leave more resources available for people with smaller footprints? Why or why not?

SUCCESS story

Removing Lead from Gasoline

Did you ever wonder why unleaded gas is called "unleaded"? It's because we used to add lead to gasoline to make cars run more smoothly—even though scientific research showed that emissions of this toxic heavy metal from vehicle tailpipes caused severe health problems, including brain damage and premature death. Back in 1970, air pollution was severe in many U.S. cities, and motor vehicle exhaust accounted for 78% of U.S. lead emissions. In response, environmental scientists, medical researchers, auto engineers, and policymakers all merged their knowledge and skills into a process that brought about the removal of lead from gasoline. Because some older vehicles required leaded gas, the ban on lead was phased in gradually but by 1996, all gasoline sold in the United States was unleaded, and the nation's largest source of atmospheric lead pollution was eliminated. As a result, levels of lead in people's blood fell dramatically, producing one of America's greatest public health successes.

➜ **Explore the Data** at Mastering Environmental Science



Levels of lead in the blood of U.S. children (ages 1–5) declined as lead use in U.S. gasoline was reduced. *Data from National Health and Nutrition Examination Survey (CDC) and other sources.*

TABLE 1.3 Major Approaches in Campus Sustainability


Wayne State University

Waste reduction

Reusing, recycling, and composting offer abundant opportunities for tangible improvements, and people understand and enjoy these activities. Waste reduction events such as trash audits and recycling competitions can be fun and productive. Compost can be applied to plantings to beautify the campus. Some schools aim to become "zero-waste."


Oberlin College

Green buildings

Constructed from sustainable materials, "green buildings" feature designs and technologies to reduce pollution, use renewable energy, and encourage efficiency in water and energy use. These sustainable buildings are certified according to LEED standards (pp. 348–350).


University of South Florida

Water conservation

Indoors, schools are installing water-saving faucets, toilets, urinals, and showers in dorms and classroom buildings to reduce water waste. Outdoors, students are helping to landscape gardens that harvest rainwater and to build facilities to treat and reuse wastewater.


Xavier University of Louisiana

Energy efficiency

Campuses are installing energy-efficient lighting, motion detectors to shut off lights when rooms are empty, and sensors to record and display a building's energy consumption. Students are mounting campaigns to reduce thermostat settings, distribute efficient bulbs, and publicize energy-saving tips to their peers.


The Catholic University of America

Renewable energy

Many schools are switching from fossil fuels to renewable heating and electricity. Some are installing solar panels, others use biomass in power plants, and a few have built wind turbines on campus. Students have persuaded administrators—and have voted for student fees—to buy "green tags" or carbon offsets to fund renewable energy.


Yale University

Food and dining

More and more schools grow their own food on campus farms and in gardens, supplying students with local, healthy, organic food. In dining halls, trayless dining cuts down on waste (on average, 25% of food taken is wasted otherwise) because people take only what they really want. Food scraps are composted on many campuses.

University of Virginia

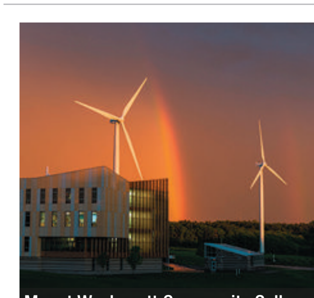
Transportation

Half the greenhouse gas emissions of the average college or university come from commuting to and from campuses in motor vehicles. To combat pollution, traffic congestion, delays, and parking shortages, schools are investing in bus and shuttle systems, hybrid and alternative-fuel fleet vehicles, and programs to promote carpooling, walking, and bicycling.


University of Arizona

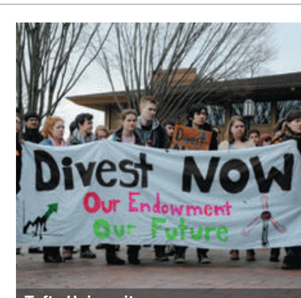
Plants and landscaping

Students are helping to restore native plants and communities, remove invasive species, improve habitat for wildlife, and enhance soil and water quality. Some schools have green roofs, greenhouses, and botanical gardens. Enhancing a campus's natural environment creates healthier, more attractive surroundings, and makes for educational opportunities in ecology and natural resources.


Mount Wachusett Community College

Carbon-neutrality

To combat climate change, many campuses aim to become carbon-neutral, emitting no net greenhouse gases. These schools seek to power themselves with clean renewable energy, although for most, buying carbon offsets is also necessary. Several hundred college and university presidents have signed the Presidents' Climate Leadership Commitments, with carbon-neutrality as a goal.



Tufts University

Fossil fuel divestment

Endowment money in U.S. higher education is estimated at more than $400 billion, and some of it is invested in stocks of coal, oil, and gas corporations. Since 2012, students have lobbied their administrators, boards of trustees, and fund managers to divest from, or sell off, stocks in fossil fuel companies.

Sustainable solutions abound

Humanity's challenge is to develop solutions that enhance our quality of life while protecting and restoring the environment that supports us. Many workable solutions are at hand:

- Renewable energy sources (Chapters 20 and 21) are beginning to replace fossil fuels.
- Energy-efficiency efforts continue to gain ground (Chapter 19).
- Scientists and farmers are pursuing soil conservation, high-efficiency irrigation, pollinator conservation, and organic agriculture (Chapters 9 and 10).
- Laws and new technologies have reduced air and water pollution in wealthier societies (Chapters 15–17).
- Conservation biologists are protecting habitat and endangered species (Chapter 11).
- Better waste management is helping us conserve resources (Chapter 22).
- Governments, businesses, and individuals are taking steps to reduce emissions of the greenhouse gases that drive climate change (Chapter 18).

These efforts are some of the many sustainable solutions we will examine in the course of this book.

Students are promoting solutions

As a college student, you can help design and implement sustainable solutions on your own campus. Proponents of **campus sustainability** seek ways to help colleges and universities reduce their ecological footprints. Today students, faculty, staff, and administrators on thousands of campuses are working together to make the operations of educational institutions more sustainable (**TABLE 1.3**).

Students are running recycling programs, promoting efficient transportation options, restoring native plants, growing organic gardens, and fostering sustainable dining halls. They are finding ways to improve energy efficiency and water conservation and are pressing for green buildings. To address climate change, students are urging their institutions to reduce greenhouse gas emissions, divest from fossil fuel corporations, and use and invest in renewable energy.

Throughout this book you will encounter examples of campus sustainability efforts (e.g., pp. 241 and 619). Should you wish to pursue such efforts on your own campus, information and links in the **Selected Sources and References for Further Reading** at the back of this book point you toward organizations and resources that can help.

Environmental science prepares you for the future

By taking a course in environmental science, you are preparing yourself for a lifetime in a world increasingly dominated by concerns over sustainability. The course for which you are using this book likely did not exist a generation ago. As society's concerns have evolved, colleges and universities have adapted their curricula. Still, at most schools, fewer than half of students take even a single course on the basic functions of Earth's natural systems, and still fewer take courses on the links between human activity and sustainability. As a result, many educators worry that most students graduate lacking **environmental literacy,** a basic understanding of Earth's physical and living systems and how we interact with them. By taking an environmental science course, you will gain a better understanding of how the world works, you will be better qualified for the green-collar job opportunities of today and tomorrow, and you will be better prepared to navigate the many challenges of creating a sustainable future.

connect & continue

Finding effective ways of living peacefully, healthfully, and sustainably on our diverse and complex planet will require a thorough scientific understanding of both natural and social systems. Environmental science helps us understand our intricate relationship with our environment and informs our attempts to solve and prevent environmental problems. Although many of today's trends may cause concern, a multitude of inspiring success stories give us reason for optimism. Addressing environmental problems can move us toward health, longevity, peace, and prosperity. Science in general, and environmental science in particular, can help us develop balanced, workable, sustainable solutions and create a better world now and for the future.

- **SOLUTIONS** If you could help address three environmental problems in the world today, what would they be? Why did you select each of these three issues? Describe at least one potential solution for each of these challenges. List one obstacle that might stand in the way of each solution. Now describe means by which each of those obstacles might be overcome.
- **LOCAL CONNECTIONS** What environmental issues are people discussing on your campus or in the area where you live? Select one of these issues, and describe two sides of a debate that people are having over it. Where do you stand in this debate and why? Describe how you think the two sides could begin to resolve their differences.
- **EXPLORE THE DATA** Do you know what your ecological footprint is? ➜ **Explore Data** on **Mastering Environmental Science.**

REVIEWING **Objectives**

You should now be able to:

+ **Describe the field of environmental science**

  Environmental science is the study of how the natural world works, how our environment affects us, and how we affect our environment. Environmental science uses approaches and insights from many disciplines in the natural sciences and social sciences. (pp. 3, 6–7)

+ **Explain the importance of natural resources and ecosystem services to our lives**

  Renewable resources are unlimited or replenished naturally at a rapid rate. Nonrenewable resources are limited or replenished very slowly. Ecosystem services are benefits we receive from the normal functioning of natural systems. Natural resources and ecosystem services are essential to human life and civilization. (p. 4)

+ **Discuss population growth, resource consumption, and their consequences**

  Today's human population size and per-person resource consumption both are higher than ever. Population growth magnifies our environmental impact by adding to the number of people putting demands on resources. Growing per capita consumption amplifies our environmental impact by increasing the demand each person makes on resources. (pp. 5–6)

+ **Explain what is meant by an ecological footprint**

  An ecological footprint quantifies resource consumption by expressing the total area of biologically productive land and water that is required to provide the resources and waste disposal for a person or population. (pp. 5–6)

+ **Describe the scientific method and the process of science**

  Science is a process of using observations to test ideas. The scientific method consists of making observations, formulating questions, stating a hypothesis, generating predictions, testing predictions, and analyzing results. Scientific research occurs within a larger process of science that includes peer review, journal publication, and interaction with colleagues. (pp. 7, 10–14)

+ **Apply critical thinking to judge the reliability of information sources**

  Critical thinking is a key life skill. By applying strategies to evaluate the reliability of sources and by assessing primary and secondary sources of information, we all can develop ways to judge the trustworthiness of sources in an information-rich media world. (pp. 14–16)

+ **Identify major pressures on the global environment**

  Rising population and intensifying consumption magnify human impacts on the environment, which include resource depletion, air and water pollution, climate change, habitat destruction, and biodiversity loss. (pp. 16–17)

+ **Discuss the concept of sustainability, and describe sustainable solutions being pursued on campuses and across the world**

  Sustainability describes living within our planet's means such that Earth's resources can sustain us—and all life—for the future. Actively developing sustainable solutions (e.g., replacing fossil fuels with renewable energy) can improve our quality of life while protecting and restoring our environment. Many college students are promoting sustainable solutions on campus, such as recycling, energy efficiency, water conservation, and transportation alternatives. (pp. 16–19)

SEEKING **Solutions**

1. Resources such as soils, timber, fresh water, and biodiversity are renewable if we use them in moderation but can become nonrenewable if we overexploit them (see FIGURE 1.1). For each of these four resources (soils, timber, fresh water, and biodiversity), describe one way we sometimes overexploit the resource and name one thing we could do to conserve the resource. For each, what might constitute sustainable use? (Feel free to look ahead and peruse coverage of these issues throughout this book.)
2. What do you think is the lesson of Easter Island? What more would you like to learn or understand about this island, its history, or its people? What similarities do you perceive between Easter Island and our own modern society? What differences do you see between the predicament of Easter Islanders in 1722 and our situation in the present day?
3. What environmental problem do you feel most acutely yourself? Do you think there are people in the world who do not view your issue as a problem? Who might they be, and why might they take a different view?
4. If the human population were to stabilize tomorrow and never reach 8 billion people, would all our environmental problems be solved? Why or why not? What conditions might get better, and what challenges might remain?
5. Find out what sustainability efforts are being made on your campus. What results have these efforts produced

so far? What further efforts would you like to see pursued on your campus? Do you foresee any obstacles to these efforts? How could these obstacles be overcome? How could you become involved?

6. **THINK IT THROUGH** You have become head of a major funding agency that grants money to scientists pursuing research in environmental science. You must give your staff several priorities to determine what types of scientific research to fund. What environmental problems would you most like to see addressed with research? Describe the research you think would need to be completed to develop workable solutions. What else, beyond scientific research, might be needed to develop sustainable solutions?

CALCULATING **Ecological Footprints**

Mathis Wackernagel and his colleagues at the Global Footprint Network continue to refine the method of calculating ecological footprints—the amount of biologically productive land and water required to produce the energy and natural resources we consume and to absorb the wastes we generate. According to their most recent data, there are 1.63 hectares (4.0 acres) available for each person in the world, yet we use on average 2.75 ha (6.8 acres) per person, creating a global ecological deficit, or overshoot (p. 6), of 69%.

Compare the ecological footprints of each nation listed in the table. Calculate their proportional relationships to the world population's average ecological footprint and to the area available globally to meet our ecological demands.

NATION	ECOLOGICAL FOOTPRINT (HECTARES PER PERSON)	PROPORTION RELATIVE TO WORLD AVERAGE FOOTPRINT	PROPORTION RELATIVE TO WORLD AREA AVAILABLE
Bangladesh	0.84	0.31 (0.84 ÷ 2.75)	0.48 (0.79 ÷ 1.63)
Tanzania	1.22		
Colombia	2.05		
Thailand	2.49		
Mexico	2.60		
Sweden	6.46		
United States	8.10		
World average	2.75	1.00 (2.75 ÷ 2.75)	1.69 (2.75 ÷ 1.63)
Your personal footprint			

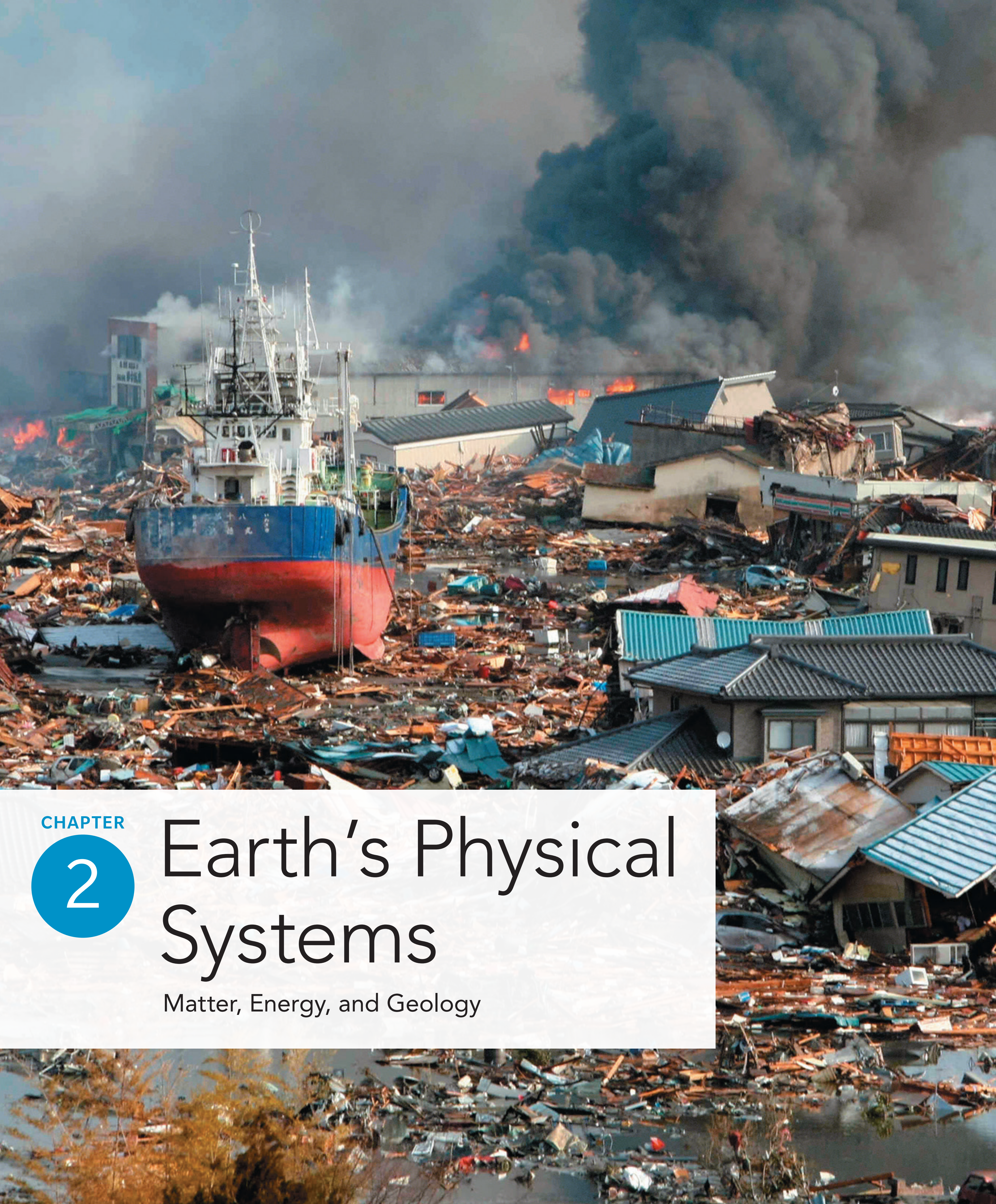
Data from Global Footprint Network, 2019.

1. Why do you think the ecological footprint for people in Bangladesh is so small?
2. Why do you think the ecological footprint for people in the United States is so large?
3. Based on the data in the table, how do you think average per capita income is related to ecological footprints? Name some ways in which you believe a wealthy society can decrease its ecological footprint.
4. Go to an online footprint calculator such as the one at http://www.footprintnetwork.org/en/index.php/GFN/page/personal_footprint and answer the questions to determine your own personal ecological footprint. Enter the value you obtain in the table, and calculate the other values as you did for each nation. How does your footprint compare to that of the average person in the United States? How does it compare to that of people from other nations? Name three actions you could take to reduce your footprint.

Mastering Environmental Science

Students Go to **Mastering Environmental Science** for assignments, an interactive e-text, and the Study Area with practice tests, videos, and activities.

Instructors Go to **Mastering Environmental Science** for automatically graded activities, videos, and reading questions that you can assign to your students, plus Instructor Resources.



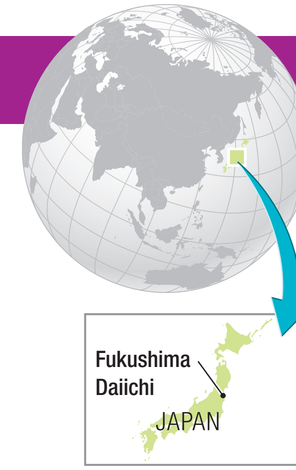
CHAPTER 2

Earth's Physical Systems

Matter, Energy, and Geology

CENTRAL
case study

What Is the Legacy of the Fukushima Daiichi Nuclear Tragedy?



> **This used to be one of the best places for a business. I'm amazed at how little is left.**
>
> Takahiro Chiba, surveying the devastated downtown area of Ishinomaki, Japan, where his family's sushi restaurant was located

> **Fukushima should not just contain lessons for Japan, but for all 31 countries with nuclear power.**
>
> Tatsujiro Suzuki, Vice-Chairman, Japan Atomic Energy Commission

At 2:46 p.m. on March 11, 2011, the land along the northeastern coast of the Japanese island of Honshu began to shake violently—and continued to shake for six minutes. These tremors were caused when a large section of the seafloor along a fault line 125 km (77 mi) offshore suddenly lurched, releasing huge amounts of energy through the earth's crust and generating an earthquake of magnitude 9.0 on the Richter scale (a scale used to measure the strength of earthquakes). The Tohoku earthquake, as it was later named, violently shook the ground in northeastern Japan. In Tokyo, 370 km (230 mi) from the quake's epicenter, commuter trains ground to a stop and skyscrapers swayed to and fro, but major damage to the city was avoided due to earthquake-resistant building codes for structures (see **SUCCESS STORY**, p. 26) and the immediate detection of the offshore earthquake. But even when the earth stopped shaking, the residents of northeastern Japan knew that further danger might still await them—from a tsunami.

A **tsunami** ("harbor wave" in English) is a powerful surge of seawater generated when an offshore earthquake displaces large volumes of rocks and sediment on the ocean bottom, suddenly pushing the overlying ocean water upward. This upward movement of water creates waves that speed outward from the earthquake site in all directions. These waves are hardly noticeable at sea, but can rear up to staggering heights when they enter the shallow waters near shore and can sweep inland with great force. The Japanese had built seawalls to protect against tsunamis, but the Tohoku quake caused the island of Honshu to sink perceptively, thereby lowering the height of the seawalls by up to 2 m (6.5 ft) in some locations. Waves reaching up to 15 m (49 ft) in height then overwhelmed these defenses (**FIGURE 2.1**, p. 24). The raging water swept up to 9.6 km (6 mi) inland; scoured buildings from their foundations; and inundated towns, villages, and productive agricultural land. As the water's energy faded, the water receded, carrying structural debris, vehicles, livestock, and human bodies out to sea.

When the tsunami overtopped the 5.7-m (19-ft) seawall protecting the Fukushima Daiichi nuclear power plant, it flooded the diesel-powered emergency generators responsible for circulating water to cool the plant's nuclear reactors. With the local electrical grid knocked

Upon completing this chapter, you will be able to:

- Explain the fundamentals of matter and chemistry and apply them to real-world situations
- Differentiate among forms of energy, and explain the first and second laws of thermodynamics
- Distinguish photosynthesis, cellular respiration, and chemosynthesis, and summarize their importance to living things
- Explain how plate tectonics and the rock cycle shape the landscape around us
- Identify major types of geologic hazards, and describe ways to minimize their impacts

◀ **Destruction in northeastern Japan from tsunami generated by the Tohoku earthquake**

▲ **One of the 300,000 people displaced by the Tohoku earthquake**

FIGURE 2.1 Tsunami waves overtop a seawall following the Tohoku earthquake in 2011. The tsunami caused a greater loss of life and property than the earthquake that generated it and led to a meltdown at the Fukushima Daiichi nuclear power plant.

out by the earthquake and the backup generators off-line, the nuclear fuel in the cores of the three active reactors at the plant began to overheat. The cooling water that normally kept the nuclear fuel submerged within the reactor cores boiled off, exposing the nuclear material to the air and further elevating temperatures inside the cores. As the overheated nuclear fuel melted its containment vessel (an event called a nuclear meltdown), chemical reactions within the reactors generated hydrogen gas. This hydrogen gas then set off explosions in each of the three active reactor buildings, and in an adjacent inactive reactor that was connected to an active reactor through ductwork, releasing radioactive material into the air (**FIGURE 2.2**). To prevent a full-blown catastrophe that could render large portions of their nation uninhabitable, Japanese authorities flooded the reactor cores with seawater pumped in from the ocean.

The 1–2–3 punch of the earthquake–tsunami–nuclear accident left 18,000 people dead and caused hundreds of billions of dollars in material damage. Around 340,000 people were displaced from their homes, and shortly after the accident the evacuation of a 20-km (12-mi) area around the Fukushima Daiichi plant was ordered due to unsafe levels of radioactive fallout in the soil. After the accident, public opposition to nuclear power in Japan ran high, and the government ordered the immediate shutdown and reinspection of its 54 nuclear reactors, which were, at the time, supplying 30% of Japan's electricity. The once productive fishing industry of the region was shut down over fears of people consuming seafood contaminated with high levels of radioactivity. The world watched and waited to see how the events in Japan would play out over the coming years and took a critical look at the

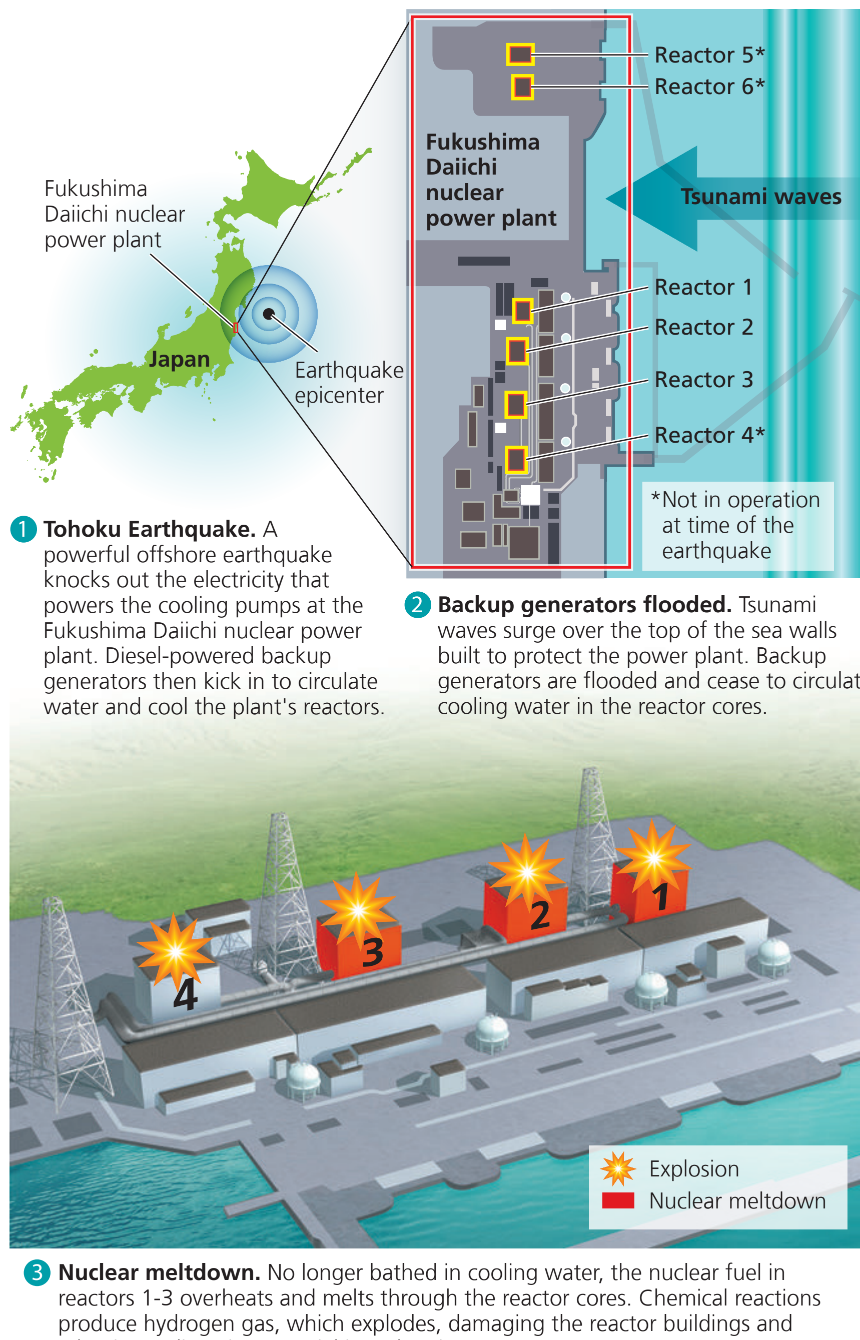


FIGURE 2.2 Timeline of events in the nuclear accident at the Fukushima Daiichi power plant.

future of nuclear power around the world. Whereas nuclear power does have an inherent danger for large-scale accidents and we have yet to find a safe, sustainable way to store the radioactive wastes it produces, it does have benefits over other methods of generating electricity in that it does not release significant amounts of air pollutants or greenhouse gases into the atmosphere when producing energy.

The destruction at Fukushima following the Tohoku earthquake was the product of natural forces—an earthquake and subsequent tsunami—coupled with an accident involving one of humanity's most advanced technologies: nuclear power. These events highlight why knowledge of matter, energy, and geologic forces is vital to understanding environmental impacts in our complex, modern world.

Matter, Chemistry, and the Environment

The tragic events in northeastern Japan in 2011 were the result of large-scale forces generated by the powerful geologic processes that shape the surface of our planet. Environmental scientists regularly study these types of processes to understand how our planet works. Because all large-scale processes are made up of small-scale components, however, environmental science—the broadest of scientific fields—must also study small-scale phenomena. At the smallest scale, an understanding of matter itself helps us to fully appreciate the processes of our world.

All material in the universe that has mass and occupies space—solid, liquid, and gas alike—is called **matter.** The study of types of matter and their interactions is called **chemistry.** Once you examine any environmental issue, from acid rain to toxic chemicals to climate change, you will likely discover chemistry playing a central role.

Matter is conserved

To appreciate the chemistry involved in environmental science, we must begin with the fundamentals. Matter may be transformed from one type of substance into others, but it cannot be created or destroyed, a principle referred to as the **law of conservation of matter.** In environmental science, this principle helps us understand that the amount of matter stays constant as it is recycled in ecosystems and nutrient cycles (p. 121). It also makes it clear that we cannot simply wish away "undesirable" matter, such as nuclear waste and toxic pollutants. Because harmful substances can't be destroyed, we must take steps to minimize their impacts on the environment.

Elements and atoms are chemical building blocks

The nuclear reactors at Fukushima Daiichi used the element **uranium** to power its reactors. An **element** is a fundamental type of matter, a chemical substance with a given set of properties that cannot be broken down into substances with other properties. Chemists currently recognize 118 elements. Most occur in nature, but more than 20 elements have been created solely in the lab. Elements especially abundant on our planet include **oxygen, hydrogen, silicon, nitrogen,** and **carbon** (**TABLE 2.1**). Elements that organisms need for survival, such as carbon, nitrogen, calcium, and phosphorus, are called **nutrients.** Each element is assigned an abbreviation, or chemical symbol (for instance, "H" for hydrogen and "O" for oxygen). The periodic table of the elements organizes the elements according to their chemical properties and behavior (see **APPENDIX C**).

An **atom** is the smallest unit that maintains the chemical properties of the element. Atoms of each element contain a specific number of **protons,** positively charged particles in the atom's nucleus (its dense center), and the number of

TABLE 2.1 Earth's Most Abundant Chemical Elements, by Mass

EARTH'S CRUST		OCEANS		AIR		ORGANISMS	
Oxygen (O)	49.5%	Oxygen (O)	88.3%	Nitrogen (N)	78.1%	Oxygen (O)	65.0%
Silicon (Si)	25.7%	Hydrogen (H)	11.0%	Oxygen (O)	21.0%	Carbon (C)	18.5%
Aluminum (Al)	7.4%	Chlorine (Cl)	1.9%	Argon (Ar)	0.9%	Hydrogen (H)	9.5%
Iron (Fe)	4.7%	Sodium (Na)	1.1%	Other	<0.1%	Nitrogen (N)	3.3%
Calcium (Ca)	3.6%	Magnesium (Mg)	0.1%			Calcium (Ca)	1.5%
Sodium (Na)	2.8%	Sulfur (S)	0.1%			Phosphorus (P)	1.0%
Potassium (K)	2.6%	Calcium (Ca)	<0.1%			Potassium (K)	0.4%
Magnesium (Mg)	2.1%	Potassium (K)	<0.1%			Sulfur (S)	0.3%
Other	1.6%	Bromine (Br)	<0.1%			Other	0.5%

SUCCESS **story**

Saving Lives with Building Codes

The Tohoku earthquake was not the first major earthquake to strike Japan. The city of Kobe experienced substantial damage from a quake in 1995 that claimed more than 5500 lives. And in 1923, an earthquake devastated the cities of Tokyo and Yokohama, resulting in more than 142,000 deaths. Losses of life and property from the Tohoku quake were far less extensive than the losses from these earlier events, thanks to new stringent building codes ensuring that the design and construction of structures are such that they resist crumbling and toppling over during earthquakes.

To minimize damage from earthquakes, engineers have developed ways to protect buildings from collapsing while shaking. They do this by strengthening structural components while also designing points at which a structure can move and sway harmlessly with ground motion. Just as a flexible tree trunk bends in a storm while a brittle one breaks, buildings with built-in flexibility are more likely to withstand an earthquake's violent shaking. Such designs continue to figure in the building codes used in California, Japan, and other quake-prone regions.

Such quake-resistant designs are more expensive to build than conventional designs, so many buildings in poorer nations do not have such protections. Consequently, earthquakes in these regions typically result in greater losses of life and property due to the greater numbers of buildings that collapse. For example, Haiti suffered a 7.0 magnitude earthquake in 2010 that devastated huge portions of the capital city of Port-au-Prince and claimed over 220,000 lives. Although the Tohoku earthquake released more than 950 times the energy than the earthquake that struck Haiti, mortality and property damage from the Tohoku quake (not including the damage and loss of life caused by the subsequent tsunami) were minimized because of Japan's earthquake-conscious building codes.

Collapsed buildings in Port-au-Prince, Haiti, following a 7.0 magnitude earthquake in 2010

➜ **Explore the Data** at Mastering Environmental Science

protons is called the element's atomic number. (Elemental carbon, for instance, has six protons in its nucleus; thus, its atomic number is 6.) Most atoms also contain **neutrons,** particles in the nucleus that lack an electrical charge. An element's mass number denotes the combined number of protons and neutrons in the atom. An atom's nucleus is surrounded by negatively charged particles known as **electrons,** which are equal in number to the protons in the nucleus of an atom, balancing the positive charge of the protons (**FIGURE 2.3**).

Isotopes Although all atoms of a given element contain the same number of protons, they do not necessarily also contain the same number of neutrons. Atoms of the same element with differing numbers of neutrons are **isotopes** (**FIGURE 2.4a**). Isotopes are denoted by their elemental symbol preceded by the mass number, the combined number of protons and neutrons in the nucleus of the atom. For example, ^{14}C (carbon-14) is an isotope of carbon with eight neutrons (and six protons) in the nucleus rather than the six neutrons (and six protons) of ^{12}C (carbon-12), the most abundant carbon isotope.

Some isotopes, called **radioisotopes,** are **radioactive** because their chemical identity changes as they shed subatomic particles and emit high-energy radiation. The radiation released by radioisotopes harms organisms because it focuses a great deal of energy in a very small area, which

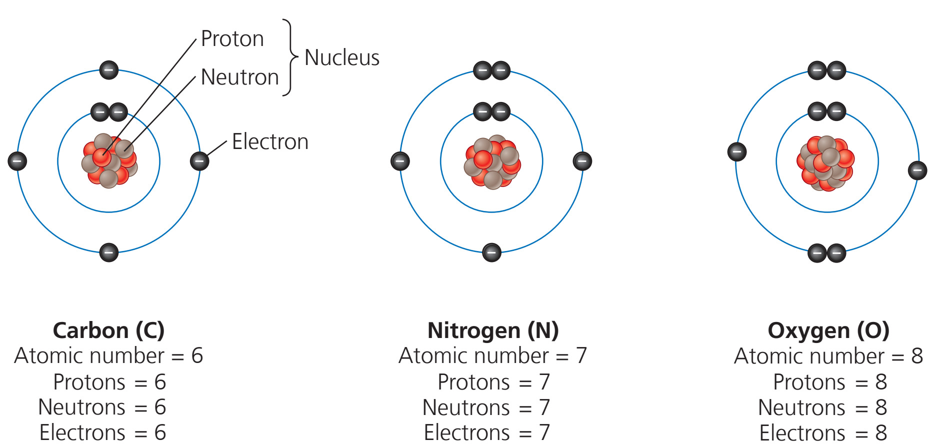


FIGURE 2.3 In an atom, protons and neutrons stay in the nucleus and electrons move about the nucleus. Each chemical element has its own particular number of protons. For example, carbon possesses six protons, nitrogen seven, and oxygen eight. These schematic diagrams are meant to clearly show and compare numbers of electrons for these three elements. In reality, however, electrons do *not* orbit the nucleus in rings as shown; they move through space in more complex ways.

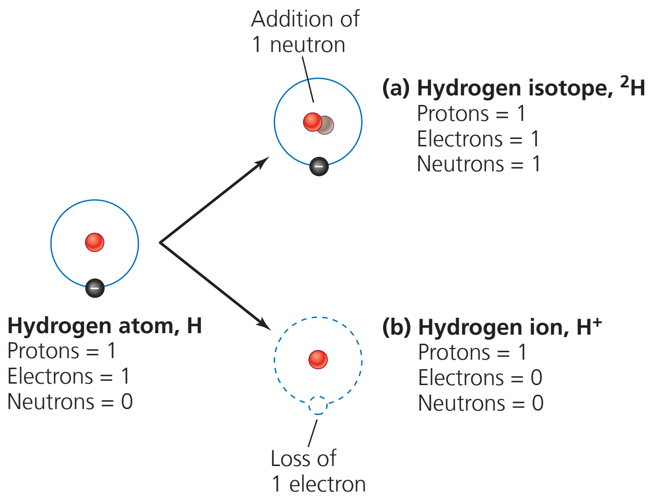


FIGURE 2.4 Hydrogen has a mass number of 1 because a typical atom of this element contains one proton and no neutrons. Deuterium (hydrogen-2, or ^{2}H), an isotope of hydrogen **(a),** contains a neutron, as well as a proton and thus has greater mass than a typical hydrogen atom; its mass number is 2. The hydrogen ion, H^+ **(b),** occurs when an electron is lost; it therefore has a positive charge.

can be damaging to living cells. Intense radiation exposure can kill cells outright or cause changes to the cell's DNA that can increase the probability of the organism developing cancerous tumors.

The greatest danger from radioisotopes occurs when they enter the bodies of organisms through the lungs, skin, or digestive system. It is therefore important after nuclear accidents, like that at Fukushima, to regularly test food and water supplies for radioisotopes and to determine the eventual fate of radioactive particles released into the environment.

A radioisotope decays as it emits radiation, becoming lighter and lighter with the loss of subatomic particles, until it becomes a stable isotope (isotopes that are not radioactive). Each radioisotope decays at a rate determined by its **half-life,** the amount of time it takes for one-half of its atoms to decay. Different radioisotopes have very different half-lives, ranging from fractions of a second to billions of years. The radioisotope uranium-235 (^{235}U), used in commercial nuclear power plants like Fukushima Daiichi, decays into a series of daughter isotopes (atoms formed as radioisotopes that lose protons and neutrons during the process of radioactive decay), eventually forming lead-207 (^{207}Pb). Uranium-235 has a half-life of about 700 million years. Radioisotopes released into the environment from the Fukushima nuclear power plant accident included iodine-131 (half-life of 8 days), cesium-134 (half-life of 2 years), strontium-90 (half-life of 29 years), and cesium-137 (half-life of 30 years). Given these lengthy half-lives, finding ways to safely contain radioisotopes at nuclear waste storage sites and in areas, like Fukushima, that have experienced nuclear accidents is an area of active research (see **THE SCIENCE BEHIND THE STORY**, pp. 30–31).

Ions Atoms may also gain or lose electrons, thereby becoming **ions,** electrically charged atoms or combinations of atoms (**FIGURE 2.4b**). Ions are denoted by their elemental symbol followed by their ionic charge. For instance, a common ion used by mussels and clams to form shells is Ca^{2+}, a calcium atom that has lost two electrons and thus has a charge of positive 2. The damaging radiation emitted by radioisotopes is called **ionizing radiation** (see Figure 2.11, p. 33) because it generates ions when it strikes molecules. These ions affect the stability and functionality of biological important molecules such as enzymes (p. 28) and DNA (p. 28), and this can harm cells, cause them to die, or mutate their genetic code.

Atoms bond to form molecules and compounds

Atoms bond together and form **molecules,** combinations of two or more atoms. Common molecules containing only a single element include those of hydrogen (H_2) and oxygen (O_2), each of which exists as a gas at room temperature. A molecule composed of atoms of two or more elements is called a **compound.** One compound is **water;** it is composed of two hydrogen atoms bonded to one oxygen atom, and it is denoted by the chemical formula H_2O. Another compound is **carbon dioxide,** consisting of one carbon atom bonded to two oxygen atoms; its chemical formula is CO_2.

Atoms bond together because of an attraction for one another's electrons. Because the strength of this attraction varies among elements, atoms may be held together in different ways. When electrons are shared between atoms, a **covalent bond** forms. For example, two atoms of hydrogen will share electrons equally as they bind together to form

FAQ

When something is irradiated, does it become radioactive?

Thanks to comic books and movies, many people believe that when an organism is exposed to ionizing radiation from nuclear waste or a solar flare from the sun, the organism becomes a *source* of ionizing radiation—that is, it becomes "radioactive." In reality, this does not happen.

An irradiated organism suffers damage from radiation, but it does not absorb the ionizing radiation, store it, and then re-emit it to the environment. The radiation simply enters the organism's cells, causes damage, and passes through the organism. So even after experiencing substantial impacts from radiation poisoning, the organism is no more radioactive than it was before exposure. This occurs because the organism was only exposed to radiation (a form of energy) and was not contaminated with radioisotopes (a form of matter) that emit harmful radiation. It is for this reason that it is safe to expose raw meat to ionizing radiation in order to kill harmful microbes that may be lurking within it, such as *Salmonella* or disease-causing strains of *Escherichia coli (E. coli)*. The process, which is done to prevent foodborne illness in people with compromised immune systems and to prevent astronauts from becoming ill while in space, sterilizes the meat of microbes but does not cause the meat to become radioactive.