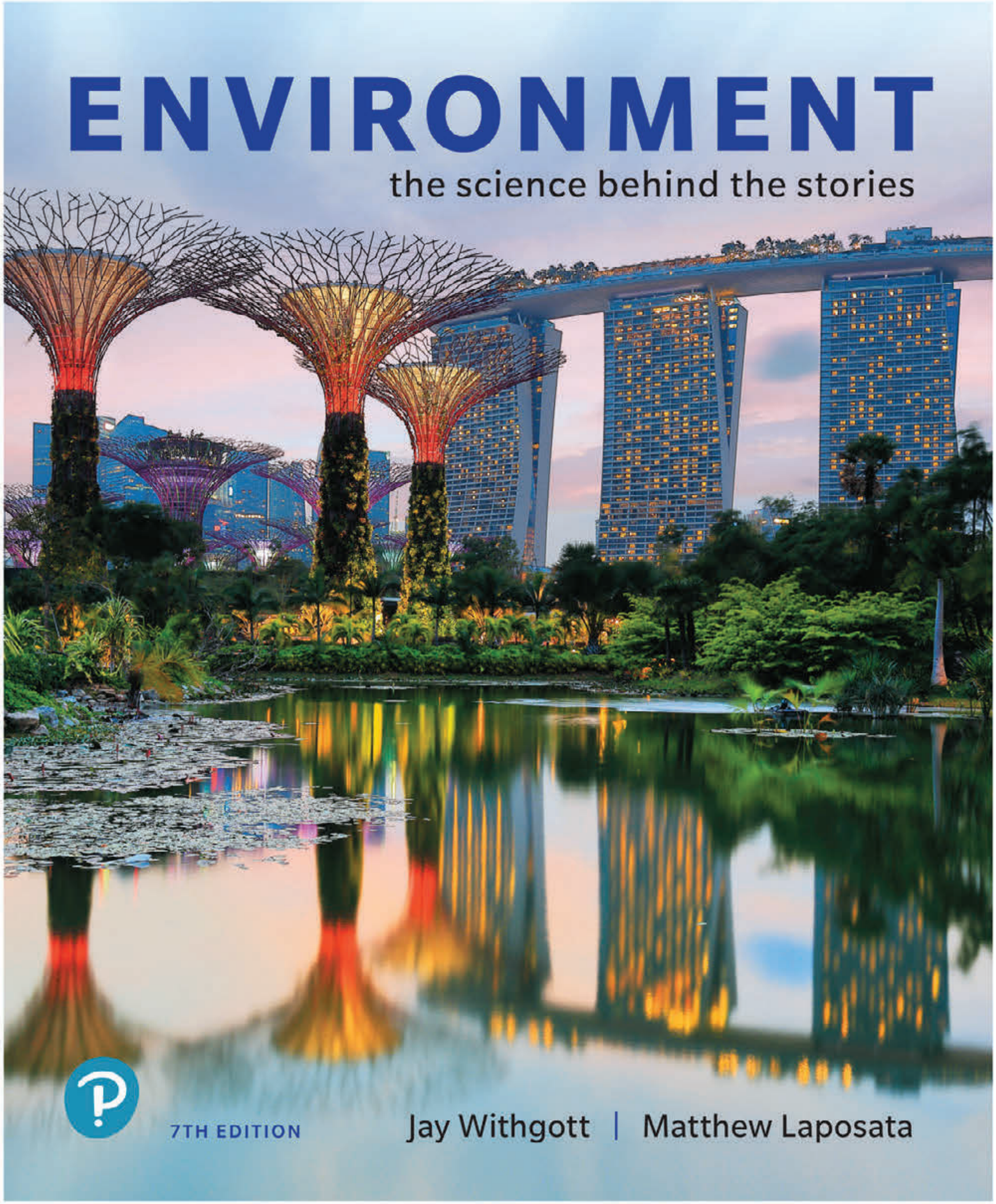

ENVIRONMENT
the science behind the stories

7TH EDITION

Jay Withgott | Matthew Laposata

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THE SCIENCE BEHIND THE STORIES

7TH EDITION

Jay Withgott

Matthew Laposata

Pearson 330 Hudson Street, NY NY 10013

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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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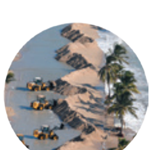

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Preface

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?
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  - **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*.

- 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

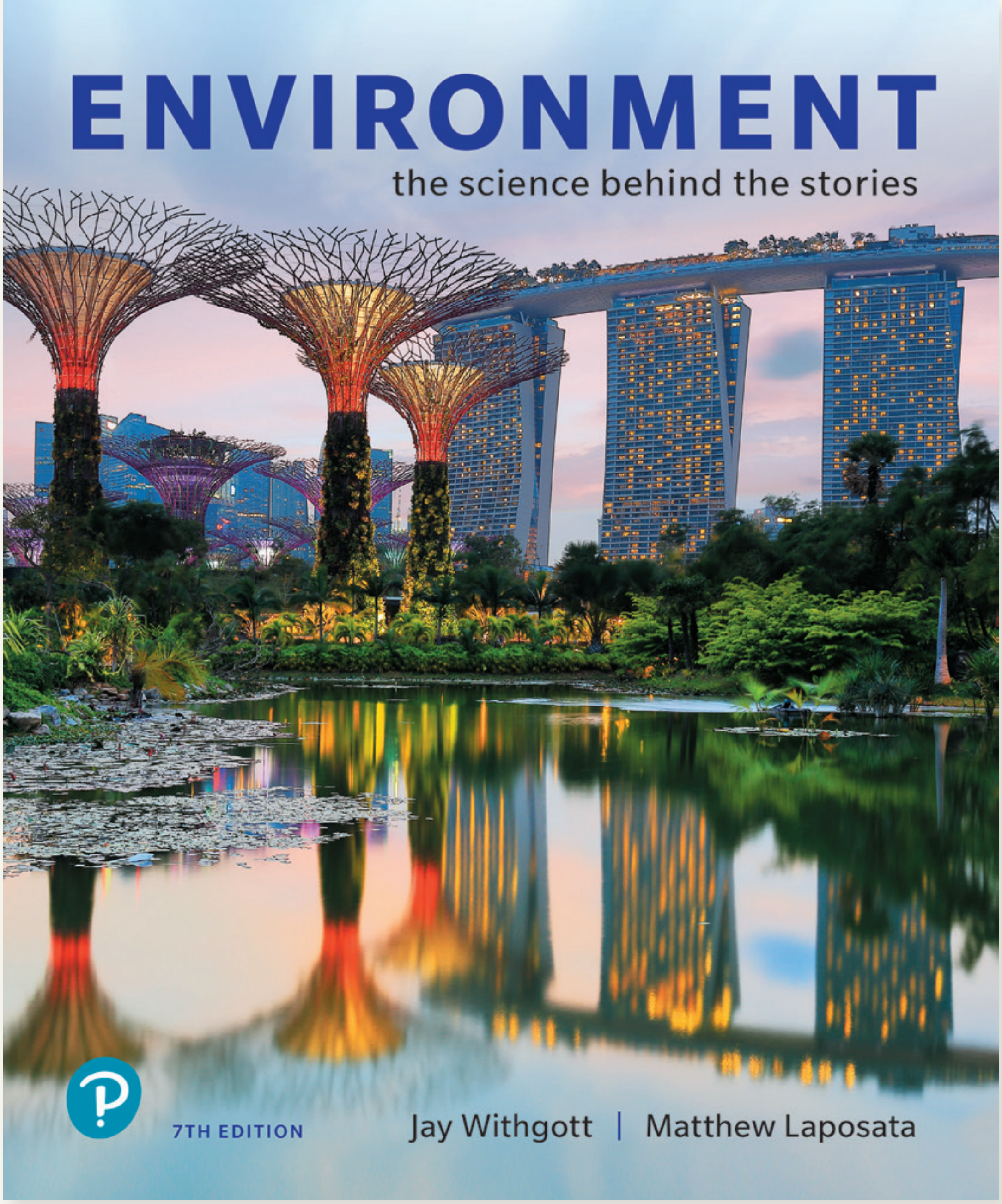
Instructor Supplements

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 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

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

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

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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

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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

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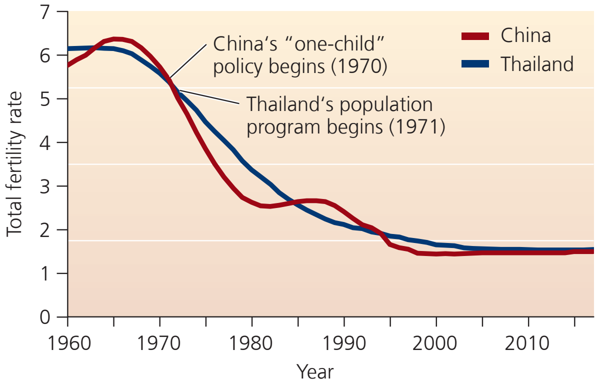
SUCCESS **story**

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

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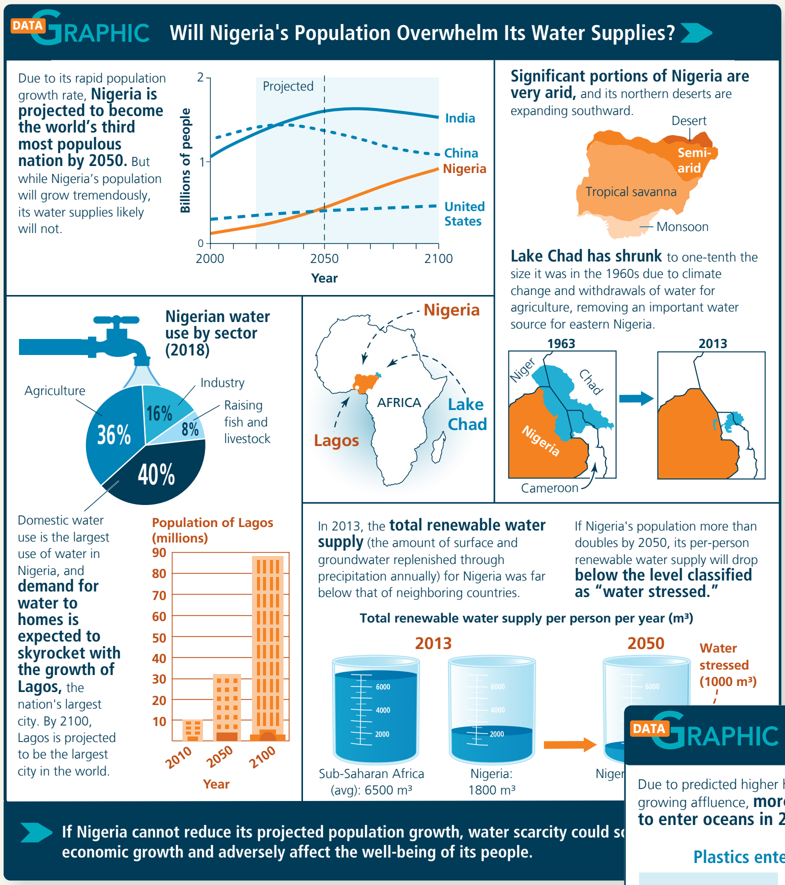
Success Stories, one in every chapter, highlight forward-thinking solutions and successful efforts to address environmental issues. Each Success Story links to new data-analysis activities on Mastering Environmental Science that are available for assignment and grading.

Increase Students' Scientific Literacy



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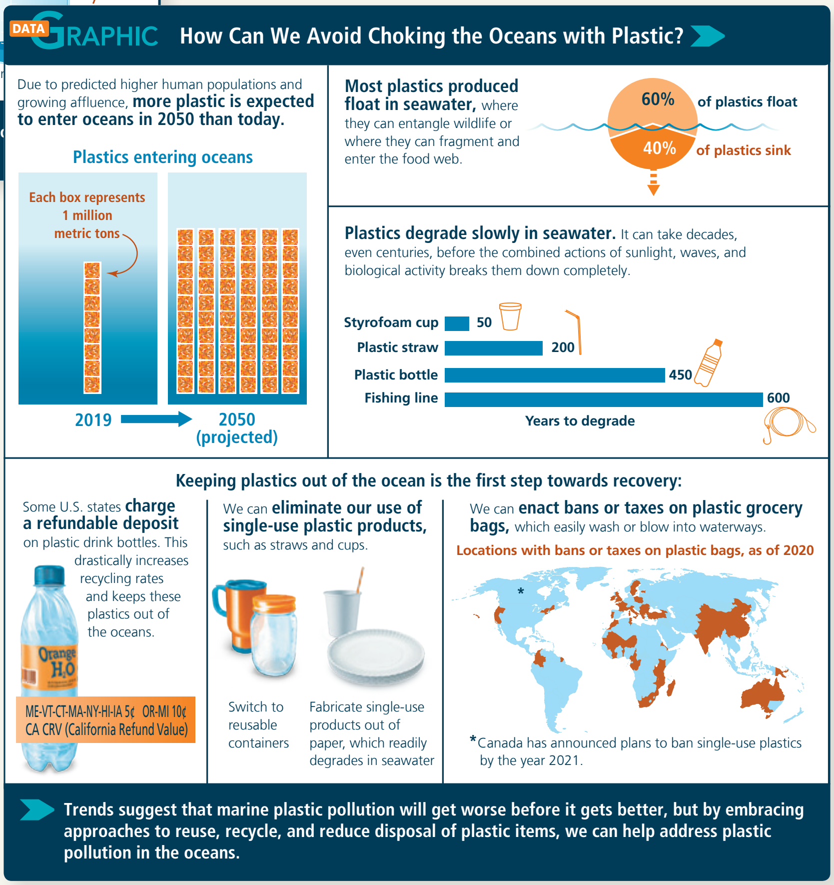
NEW! DataGraphics are Infographic-style illustrations that enable students to **see the data** behind complex issues and understand how to tie it all together.

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?



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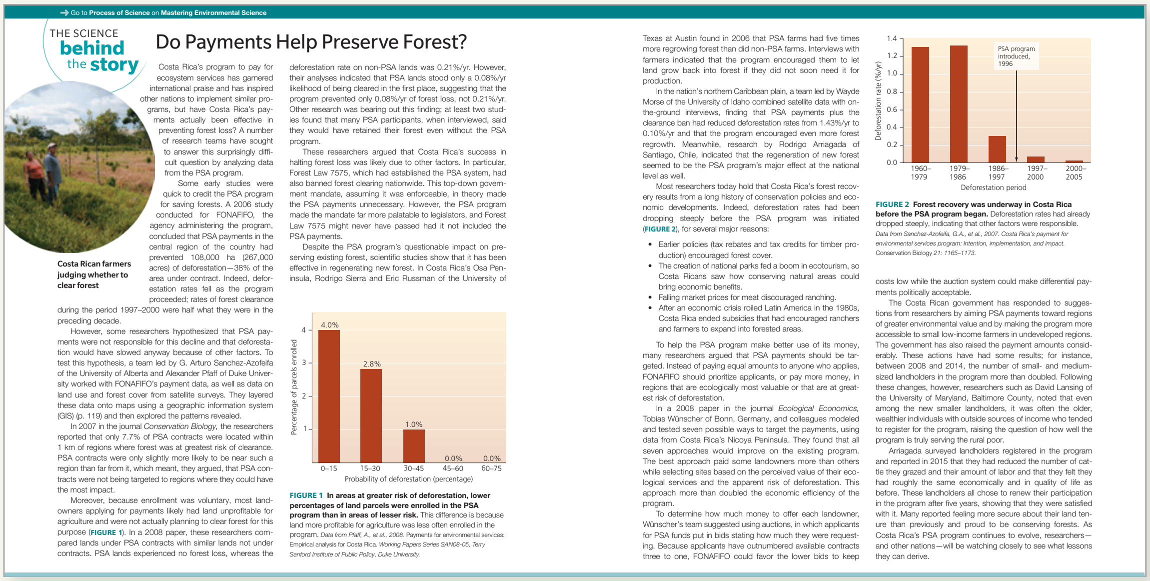
The Science behind the Stories



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

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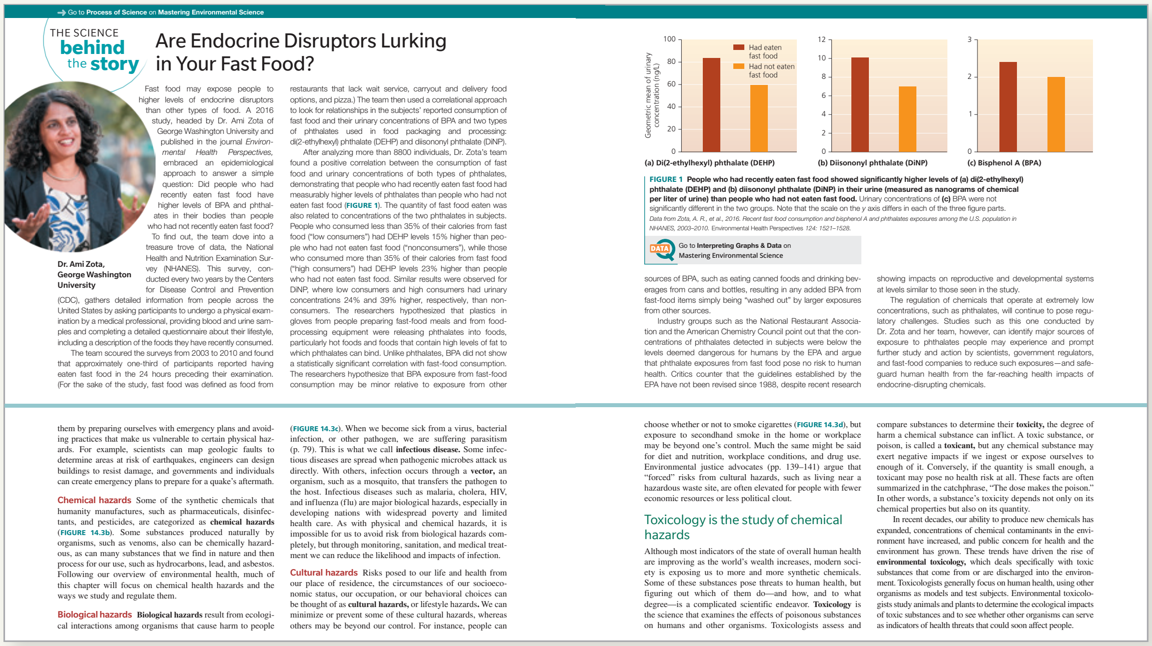
New Topics Include:

- 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!



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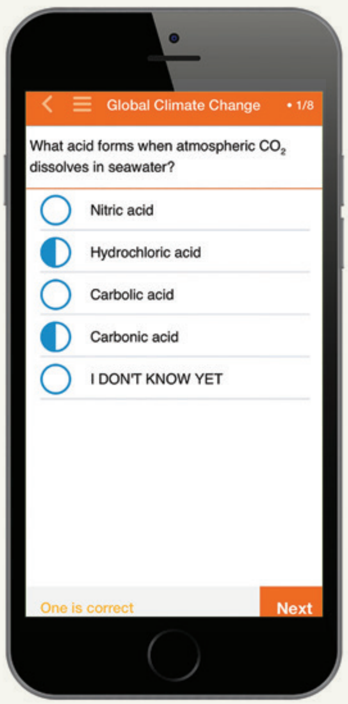
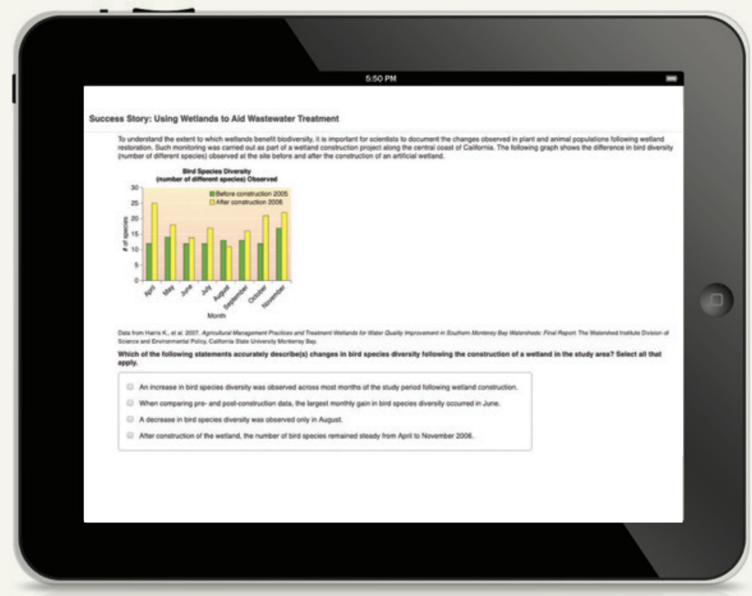
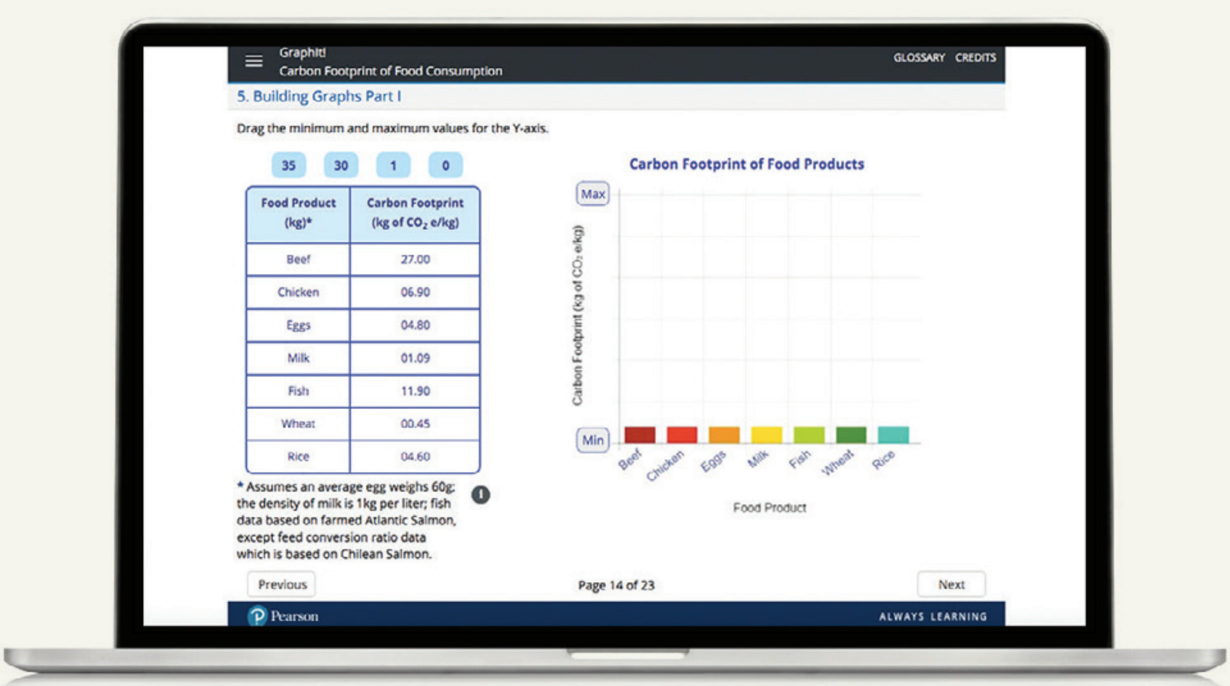
Bring Environmental Science to Life with Mastering



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.

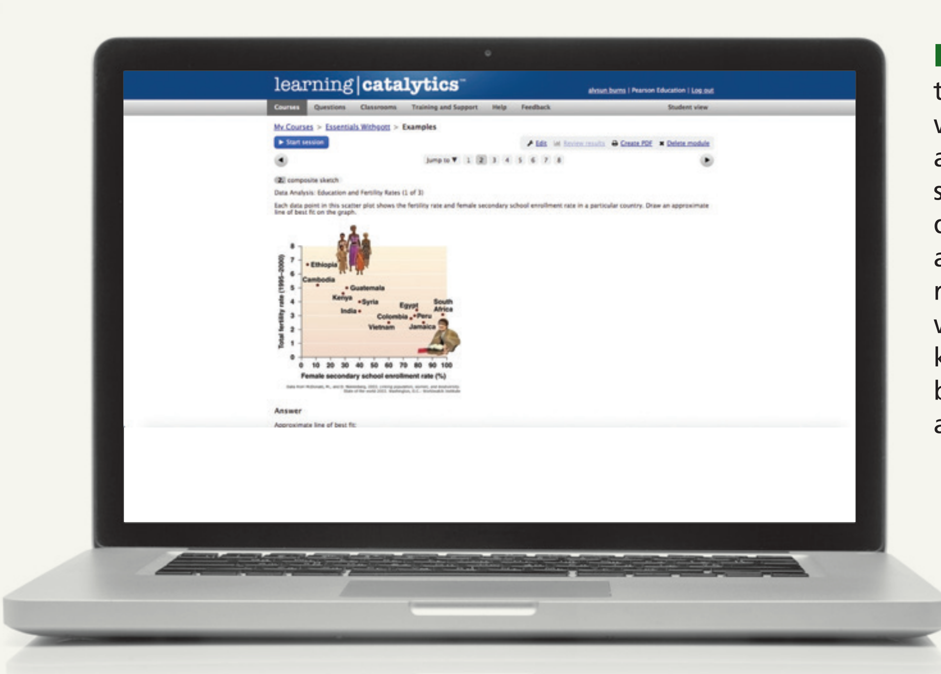


NEW! Data Analysis Activities give students an opportunity to explore data related to the Central Case Studies and Success Stories from the text.

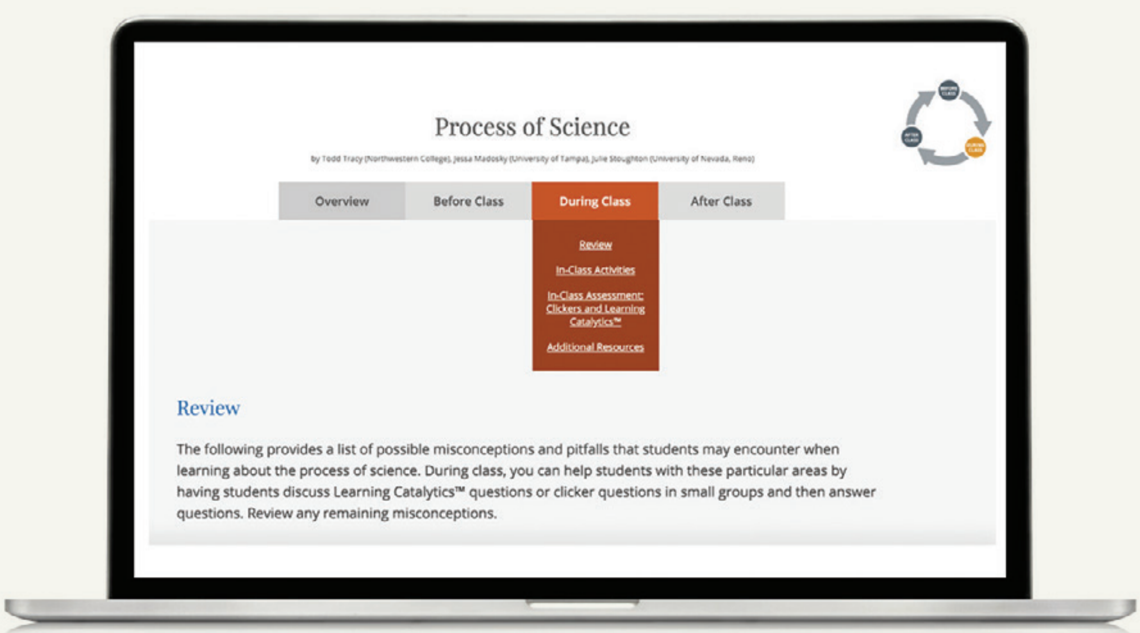


GraphIt! Coaching Activities help students read, interpret, and create graphs that explore real environmental issues using real data.

Engage Students with Active Learning

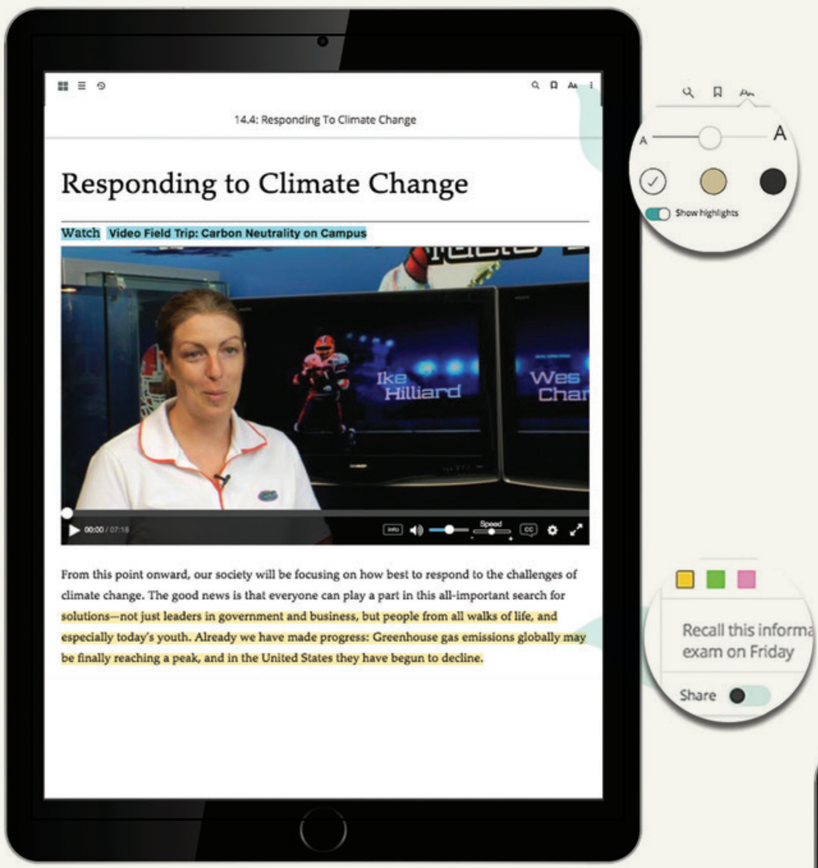


Learning Catalytics enables you to hear from every student in real-time, when it matters most. Choose from a variety of question types that help students recall ideas, apply concepts, and develop critical-thinking skills. Students answer on their own device. Instructors receive analytics in real-time 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.

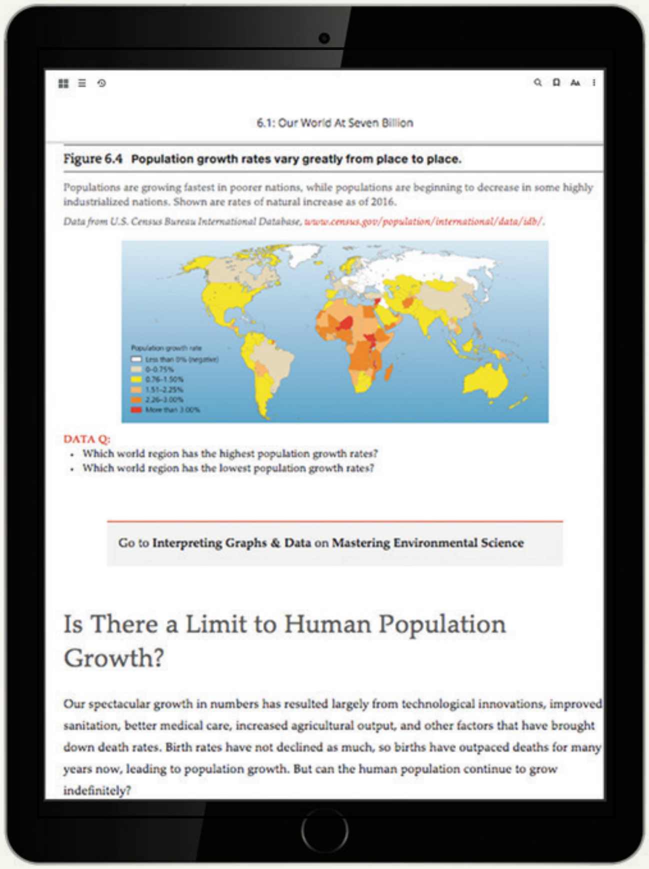


To-Go Teaching Modules help instructors make use of teaching tools before, during, and after class, including new ideas for in-class activities. The modules incorporate the best that the text, Mastering, and Learning Catalytics have to offer. These can be accessed through the Instructor Resources area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

Reviewers for the Seventh Edition

Shamili Ajgaonkar, *College of DuPage*
Scott Benjamin, *Bunker Hill Community College*
Jennifer Biederman, *Winona State University*
Emma Bojinova, *University of Connecticut*
Scott Brames, *Clemson University*
John Brzorad, *Lenoir Rhyne University*
Alyson Center, *Normandale Community College*
James Dauray, *College of Lake County*
Elizabeth Davis-Berg, *Columbia College*
Shannon Davis-Foust, *University of Wisconsin Oshkosh*
Jean DeSaix, *University of North Carolina Chapel Hill*
David Fitzpatrick, *Georgia State University*
Christian George, *High Point University*
David Gillette, *University of North Carolina Asheville*
Heinrich Goetz, *Collin College Preston Ridge*
Richard Grippo, *Arkansas State University Main*
Carl Grobe, *Westfield State University*
Leslie Hendon, *University of Alabama Birmingham*
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Andrew Lapinski, *Reading Area Community College*
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Grace Lasker, *University of Washington Bothell*
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Heidi Marcum, *Baylor University*
Terri Matiella, *University of Texas, San Antonio*
Hussein Mohamed, *Dalton State College*
Gregory O'Mullan, *Queen's College*
Thomas Pliske, *Florida International University*
Daniel Ratcliff, *Rose State College*
Eric Sanden, *University of Wisconsin River Falls*
Debra Socci, *Seminole State College*
Julie Stoughton, *University of Nevada Reno*
Phil Yeager, *Fairmont State University*

Reviewers for Previous Editions

Matthew Abbott, *Des Moines Area Community College;* David Aborne, *University of Tennessee–Chattanooga;* Charles Acosta, *Northern Kentucky University;* Shamim Ahsan, *Metropolitan State College of Denver;* Isoken T. Aighewi, *University of Maryland–Eastern Shore;* Jeffrey Albert, *Watson Institute of International Studies;* John V. Aliff, *Georgia Perimeter College;* Mary E. Allen, *Hartwick College;* Karyn Alme, *Kennesaw State University;* Deniz Z. Altin, *Georgia Perimeter College;* Dula Amarasiriwardena, *Hampshire College;* Gary I. Anderson, *Santa Rosa Junior College;* Mark W. Anderson, *The University of Maine;* Corey Andries, *Albuquerque Technical Vocational Institute;* David M. Armstrong, *University of Colorado–Boulder;* David L. Arnold, *Ball State University;* Joseph Arruda, *Pittsburg State University;* Eric Atkinson, *Northwest College;* Thomas W. H. Backman, *Linfield College;* Timothy J. 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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.

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 nonhuman 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.

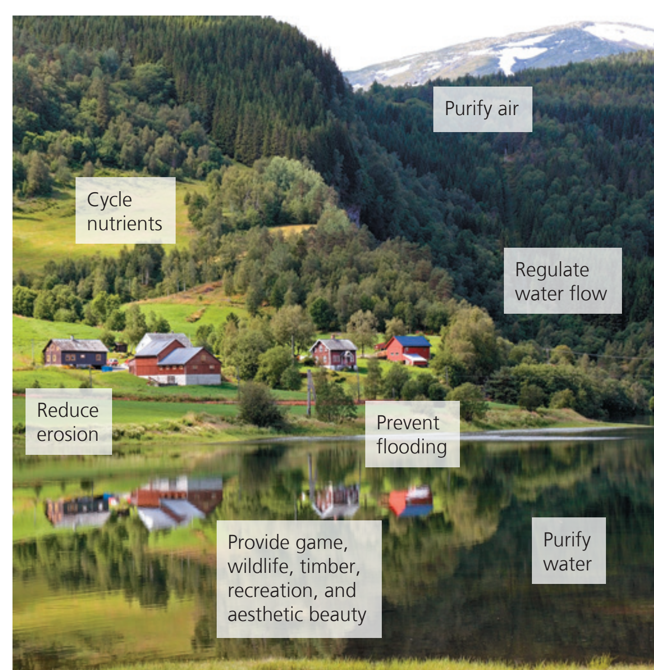

FIGURE 1.2 We rely on the ecosystem services that natural systems provide. For example, forested hillsides help people living below by purifying water and air, cycling nutrients, regulating water flow, preventing flooding, and reducing erosion, as well as by providing game, wildlife, timber, recreation,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

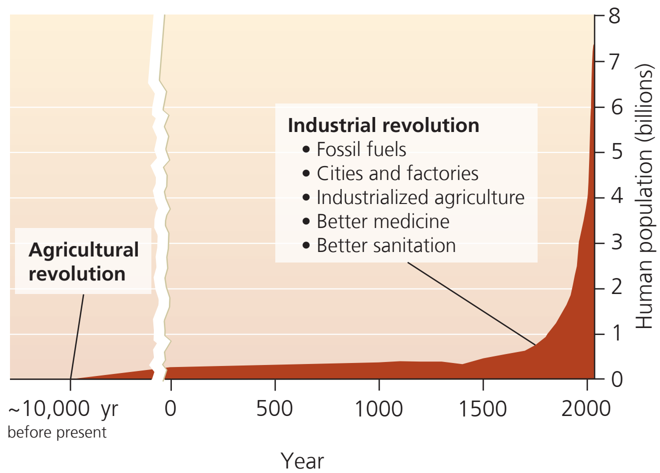

FIGURE 1.3 The global human population increased after the agricultural revolution and then skyrocketed following the industrial revolution. Note that the tear in the graph represents the passage of time and a change in *x*-axis values. *Data compiled from U.S. Census Bureau, U.N. Population Division,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

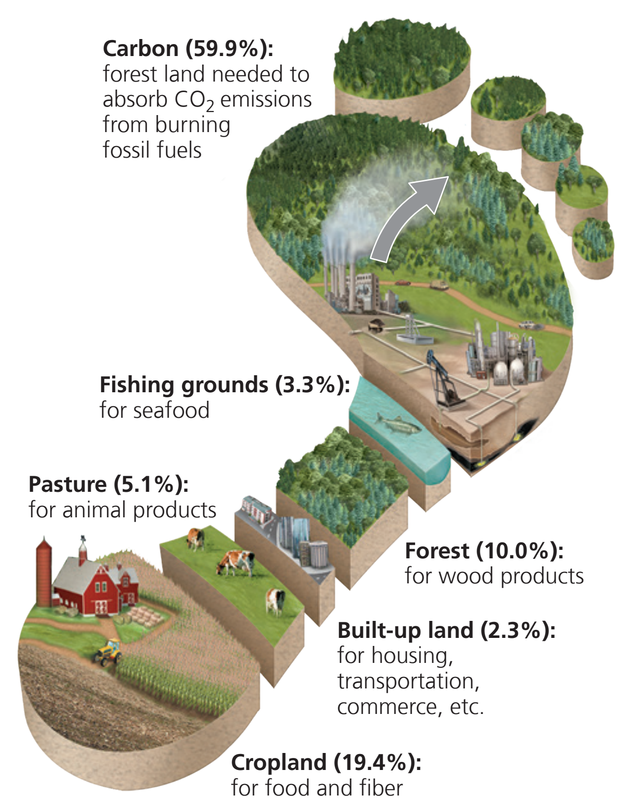

FIGURE 1.4 An ecological footprint shows the total area of biologically productive land and water used by a given person or population. Shown is a breakdown of major components of the average person's footprint. *Data from Global Footprint Network, 2019.*

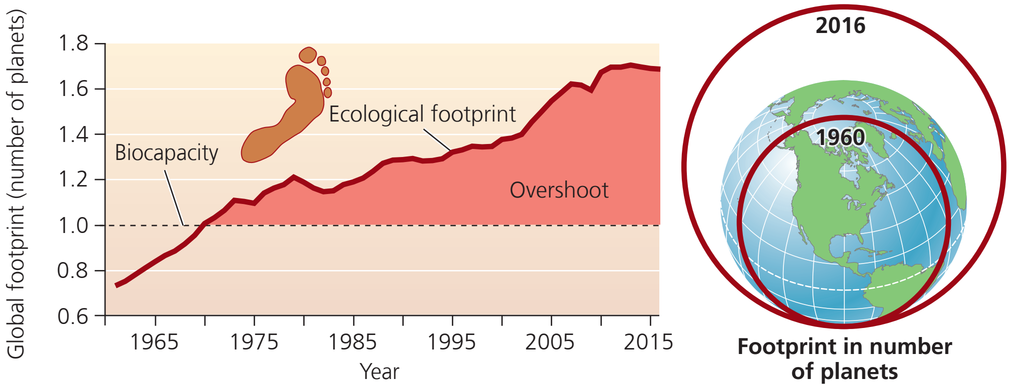

FIGURE 1.5 Analyses by the leading research group into ecological footprints indicate that we have overshot Earth's biocapacity—its capacity to support us—by 69%. We are using renewable natural resources 69% faster than they are being replenished. *Data from Global Footprint Network, 2019.*

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.

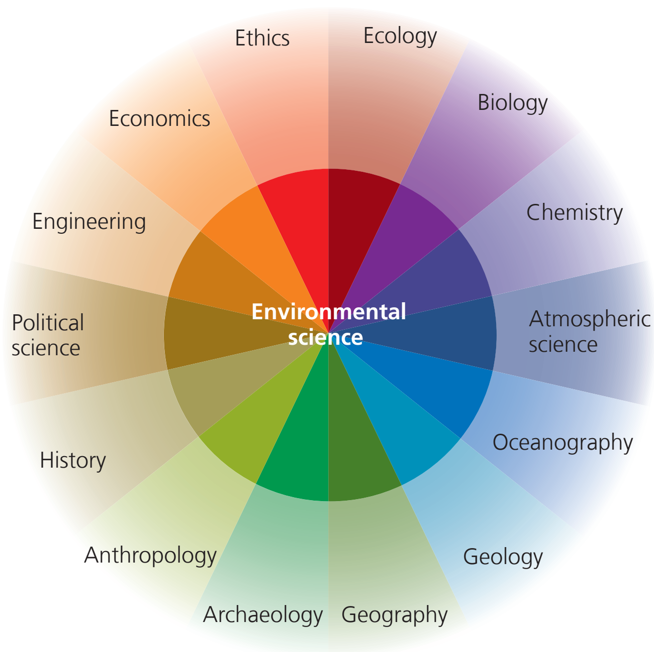

FIGURE 1.6 Environmental science is an interdisciplinary pursuit. It draws from many different established fields of study across the natural sciences and social sciences.

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?**