

# ESSENTIAL. environment

THE SCIENCE BEHIND THE STORIES 6th Edition

Jay Withgott  
Matthew Laposata



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# About the Authors

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**Jay Withgott** has authored *Essential Environment* as well as its parent volume, *Environment: The Science behind the Stories*, 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 over 5000 students per year. He focuses exclusively on introductory environmental science courses and has enjoyed teaching and interacting with thousands of nonscience majors during his career. He is an active scholar in environmental science education and has received grants from state, federal, and private sources to develop and evaluate 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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# Preface

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## 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 ecological 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 *Essential Environment: The Science behind the Stories*, we strive to show students how science informs our efforts to bring about a sustainable society. We 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.

As environmental science has grown, so has the length of textbooks that cover it. With this volume, we aim to meet the needs of instructors who favor a more succinct and affordable book. We have distilled the most essential content from our full-length book, *Environment: The Science behind the Stories*, now in its sixth edition. We have streamlined our material, updated our coverage, and carefully crafted our writing to make *Essential Environment* every bit as readable, informative, and engaging as its parent volume.

## New to This Edition

This sixth 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 brand-new feature highlights one discrete story per chapter of successful efforts to address environmental problems, ranging from local examples (such as prairie restoration in Chicago) to national and global successes (such as halting ozone depletion by treaty, or removing lead from gasoline). Our book has always focused on positive solutions, but the new emphasis the *Success Story* feature brings should help encourage students by showing them that sustainable solutions are within reach. Students can explore the data behind these solutions with new *Success Story Coaching Activities* in *Mastering Environmental Science*.
- **central CASE STUDY** Three *Central Case Studies* are completely new to this edition, complementing the seven new *Central Case Studies* added in the fifth edition. All other *Central 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. In our new *Central Case Studies*, students will learn of the changes that Asian carp and other invasive species are having on North American waterways, wrestle with the challenges of conserving the



Amazon rainforest, and examine how Miami-area residents are coping with sea level rise.


- **Chapter 4:** Leaping Fish, Backwards River: Asian Carp Threaten the Great Lakes
- **Chapter 9:** Saving the World's Greatest Rainforest
- **Chapter 14:** Rising Seas Threaten South Florida
- **closing THE LOOP** Also new to this edition, each chapter now concludes with a brief section that “closes the loop” by revisiting the *Central Case Study* while reviewing key principles from the chapter. This new *Closing the Loop* section enhances our long-standing and well-received approach of integrating each *Central Case Study* throughout its chapter. A further step in this direction is the new **CASE STUDY CONNECTION** question feature. These questions, in the *Seeking Solutions* section at the end of each chapter, place students in a scenario and empower them to craft solutions to issues raised in the *Central Case Study*.
- **THE SCIENCE behind the story** Nine of our 18 *Science behind the Story* features are new to this edition, giving you a current and exciting selection of scientific studies to highlight. Students will follow along as researchers discover how Hawaiian birds evolved, trace ecological recovery at Mt. St. Helens, sleuth out the mystery of honeybee declines, use DNA fingerprinting to combat poaching, reveal synthetic chemicals in fast food, determine whether fracking is causing earthquakes, predict the future of drought in the American West, ask whether renewable energy alone can power civilization, and seek to enhance recycling efforts on campus.
  - **Chapter 3:** How Do Species Form in Hawaii's “Natural Laboratory” of Evolution?
  - **Chapter 4:** How Do Communities Recover after Disturbance?
  - **Chapter 7:** What Role Do Pesticides Play in the Collapse of Bee Colonies?
  - **Chapter 8:** Can Forensic DNA Analysis Help Save Elephants?
  - **Chapter 10:** Are Endocrine Disruptors Lurking in Your Fast Food?
  - **Chapter 11:** Are the Earthquakes Rattling Oklahoma Caused by Human Activity?
  - **Chapter 12:** Are We Destined for a Future of “Megadroughts” in the United States?
  - **Chapter 16:** Can We Power the World with Renewable Energy?
  - **Chapter 17:** Can Campus Research Help Reduce Waste?
- **New and revised DATA Q, FAQ, and Weighing the Issues features** 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 have incorporated the most recent data possible and have enhanced coverage of emerging issues. As climate change and energy concerns play ever-larger roles in today's world, our coverage has evolved to keep pace. This edition highlights the tremendous growth and potential of renewable energy, yet also makes clear 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, national security, and wealth inequality, our introduction of ethics, economics, and policy early in the book serves as a framework to help students relate the scientific findings they learn about to the complex cultural aspects of the society around them.
- **Enhanced style and design** We have significantly refreshed and improved the look and clarity of our presentation throughout the text. A more appealing layout, striking visuals, additional depth in the *Central Case Studies*, and an inviting new style all make the book more engaging for students. More than 40% of the photographs, graphs, and illustrations in this edition are new or have been revised to reflect current data or to enhance clarity or pedagogy.

## Existing Features

We have also retained the major features that made the first five 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 little hope or that they cannot personally make a difference. We have consistently aimed to counter this impression by highlighting innovative solutions being developed on campuses and 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 and engagement.

- **central CASE STUDY integrated throughout the 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* in each chapter. By guiding students through key research efforts, this feature shows not merely *what* scientists discovered, but *how* they discovered it.
-  These data analysis questions help students to actively engage with graphs and other data-driven figures, and challenge them to practice quantitative skills of interpretation and analysis. To encourage students to test their understanding as they progress through the material, answers are provided in Appendix A. Students can practice data analysis skills further with *Interpreting Graphs and Data: DataQs* in *Mastering Environmental Science*.
- **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, thereby fostering 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** *Testing Your Comprehension* provides concise study questions on main topics, while *Seeking Solutions* encourages broader creative thinking aimed at finding solutions. “Think It Through” questions place students in a scenario and empower them to make decisions to resolve problems. *Calculating Ecological Footprints* enables students to quantify the impacts of their 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 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 classroom time. As a result, both educators and learners benefit from an integrated text and online solution.

**New to this edition** *Mastering Environmental Science* for this edition of *Essential Environment: The Science behind the Stories* offers new resources that are designed to grab student interest and help them develop quantitative reasoning skills.

- NEW *GraphIt!* activities help students put data analysis and science reasoning skills into practice in a highly interactive and engaging format. Each of the 10 *GraphIt!* activities prompts students to manipulate a variety of graphs and charts to 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*.
- NEW *Case Study Video Tours* use Google Earth to take students on a virtual tour of the locations featured in each *Central Case Study*.
- NEW *Success Story Coaching Activities* pair with the new in-text *Success Story* features and give students the opportunity to explore the data behind each solution.
- NEW *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.

**Existing features** *Mastering Environmental Science* also retains its popular existing features:

- *Process of Science* activities help students navigate the scientific method, guiding them through explorations of experimental design using *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 Q* questions, coaching 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 core content areas in environmental science 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.

*Essential Environment* has grown from our experiences in teaching, research, and writing. We have been guided in our efforts by input from hundreds of instructors across North America who have served as reviewers and advisors. 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 editor, Cady Owens ([cady.owens@pearson.com](mailto:cady.owens@pearson.com)), at Pearson Education. We value your feedback and are eager to know how we can serve you better.

—Jay Withgott and Matthew Laposata

## Instructor Supplements

A robust set of instructor resources and multimedia accompanies 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 Video Field Trips, Everyday Environmental Science Videos, PowerPoint Lecture presentations, Instructor's Guide, Active Lecture 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 MS Word and Test-Gen 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 sciences.

NEW to this edition, Ready-to-Go Teaching Modules on key environmental issues provide instructors with assignments to use before and after class, as well as in-class activities that use clickers or Learning Catalytics for assessment.

# Acknowledgments

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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.

Sponsoring editor Cady Owens coordinated our team's efforts for this sixth edition of *Essential Environment*. She has been a pleasure to work with, and we are grateful for her guidance, deft touch, and sound judgment. We were also thrilled to welcome back Courseware Sr. analyst Mary Ann Murray, whose past work for our books has stood the test of time. Mary Ann again brought an intense work ethic and a mix of creativity, big-picture smarts, and focus on detail that we truly appreciate. Content producer Margaret Young once more ably steered us through the complex logistical tangles of the textbook process. Executive editor Alison Rodal oversaw the project and lent her steady hand, and we thank director Beth Wilbur for her support of this book through its six editions and for helping to invest the resources that our books continue to enjoy.

Editorial assistant Ali Candlin managed the review process and provided timely assistance, while Courseware director Ginnie Simone-Jutson oversaw our development needs. Bonnie Boehme provided meticulous copy editing, and photo researcher Kristin Piljay helped to acquire quality photos. Eric Schrader managed permissions for our figures. Alicia Elliot of Imagineering Art did a wonderful job executing our art program, and Lisa Buckley designed our engaging new text and cover style. We offer a big thank-you to Norine Strang for her extensive work with our compositor to help guide our book through production.

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Finally, we each owe 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 important, he thanks his wife, Lisa, for being a wonderful constant within a whirlwind of change and for lending him her keen insight and unwavering support. 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

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We wish to express special thanks to the dedicated reviewers who shared their time and expertise to help make this sixth 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 five editions of this book and the six editions of this book's parent volume, where they are acknowledged in full. Here we thank those who contributed in particular to this sixth edition of *Essential Environment*—in most cases with multiple in-depth chapter reviews despite busy teaching schedules. Our sincere gratitude goes out to all of them. If the thoughtfulness and thoroughness of these reviewers are any indication, we feel confident that the teaching of environmental science is in excellent hands!

Donna Bivans, *Pitt Community College*  
Martha Bollinger, *Winthrop University*  
Lynn Corliss, *South Puget Sound Community College*  
James Daniels, *Huntingdon College*  
Eden Effert-Fanta, *Eastern Illinois University*  
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Daniel Wagner, *Eastern Florida State College*

# Engage students in science through current environmental issues

**Essential Environment: The Science Behind the Stories, 6th Edition**, by Jay Withgott and Matt Laposata, is the #1 book in the introductory environmental science market, known for its student-friendly narrative style, its integration of real stories and case studies, and its presentation of the latest science and research.



**CHAPTER 14** Global Climate Change

**central CASE STUDY**

### Rising Seas Threaten South Florida

“Miami, as we know it today, is doomed. It’s not a question of if. It’s a question of when.”  
—Dr. David Hurrell, University of Miami geologist

**Miami Beach is not going to sit back and go underwater.**  
—Phil Levine, mayor of Miami Beach

It ripples rise in Miami at least six times a year. Salty water bubbles up from the ground, fills the streets, and spills across lawns and sidewalks. Under the blazing sun of a South Florida sky, floodwaters stall car traffic, creep into doorways, force businesses to close, and keep people from crossing the street. Employees struggle to get to work while tourists stand around, baffled.

The flooding is most severe in Miami Beach, the celebrated strip of glamorous hotels, clubs, shops, and restaurants that lies from a 7-mile barrier island just offshore from Miami. The carefree affluent image of Miami Beach, with its sun and fun, is increasingly jeopardized by the gritty reality of these unwelcome saltwater intrusions. By 2050, flooding is predicted to strike Miami and Miami Beach about 45 times per year—becoming no longer a curious inconvenience, but an existential threat.

These iridescent floods that seem to come out of nowhere are a recent phenomenon, so Miami-area residents are just now realizing that their coastal metropolis is slowly being swallowed by the ocean. The cause? Rising sea levels driven by global climate change.

The world’s oceans rose 20 cm (8 in.) in the 20th century as warming temperatures expanded the volume of seawater and caused glaciers and ice sheets to melt, discharging water into the oceans. Those processes are accelerating today, and scientists predict that sea level will rise another 20–60 cm (10–24 in.) or more in this century as climate change intensifies.

As sea levels rise, coastal cities across the globe—from Venice to Amsterdam to New York to San Francisco—are facing challenges. In the United States, scientists find that the Atlantic Seaboard and the Gulf Coast are especially vulnerable. The hurricane-prone states of Florida, Louisiana, Texas, and the Carolinas are at risk, as are coastal cities such as Houston and New Orleans. From Cape Cod to Corpus Christi, millions of Americans who live in shoreline communities are beginning to suffer significant expense, disruptive to daily life, and property damage as beaches erode, neighborhoods flood, squalls are fueled, and storms strike with more force.

Perhaps nowhere in America is more vulnerable to sea level rise than Miami and its surrounding communities in South Florida. Six million people live in this region, and three-quarters of them inhabit low-lying coastal areas that also hold most of the region’s wealth and property. Experts calculate that Miami alone has more than \$400 billion in assets at risk from sea level rise—more than any other city in the

**Upon completing this chapter, you will be able to:**

- Describe Earth’s climate system and explain the factors that influence global climate
- Identify greenhouse gases, and characterize human influences on the atmosphere and on climate
- Summarize how researchers study climate
- Outline current and expected future trends and impacts of climate change in the United States and across the world
- Suggest ambitious ways we might respond to climate change

Multitasking beach sand off a Fort Lauderdale boulevard after a storm surge.

Flooding in Miami after Hurricane Irma in 2017. 

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**Integrated Central Case Studies** begin and are woven throughout each chapter, highlighting the real people, real places, and real data behind environmental issues. Revised throughout and updated with current stories, the Central Case Studies draw students in, providing a contextual framework to make science memorable and engaging.

## New Topics Include:

- **Chapter 4:** Leaping Fish, Backwards River: Asian Carp Threaten the Great Lakes
- **Chapter 9:** Saving the World’s Greatest Rainforest
- **Chapter 14:** Rising Seas Threaten South Florida

# Help students see the big picture by making connections

**NEW! Closing the Loop** feature brings each chapter's opening Central Case Study full circle by revisiting the Central Case Study at the end of each chapter. This new feature encourages students to think critically about the issues laid out in the chapter, summarizing the relationship between the chapter concepts and the Central Case Study itself.



## closing THE LOOP

Many factors influence Earth's climate, and human activities have come to play a major role. Climate change is well underway, and additional greenhouse gas emissions will intensify global warming and cause progressively severe and diverse impacts. Sea level rise and other consequences of global climate change are affecting locations worldwide—from Miami to the Maldives, Alaska to Bangladesh, and New York to the Netherlands. As scientists and political leaders come to better understand anthropogenic climate disruption and its consequences, more and more of them are urging immediate action.

Policymakers at the international and national levels have struggled to take meaningful steps to slow greenhouse gas

emissions, so increasingly, people at local and regional levels are the ones making a difference. In South Florida, citizens and local leaders are investing time, thought, money, and creativity into finding solutions to rising sea levels. They are seeking to mitigate climate change by reducing greenhouse gas emissions and to adapt to climate change by building pumping systems, raising streets and foundations, and tailoring financial and insurance incentives to guide development toward upland areas. Like people anywhere who love their homes, residents of South Florida are girding themselves for a long battle to protect their land, communities, and quality of life while our global society inches its way toward emissions reductions. For all of us across the globe, taking steps to mitigate and adapt to climate change represents the foremost challenge for our future.

**NEW! Central Case Study Connection** questions at the end of each chapter allow instructors to assign questions specific to the Central Case Study, prompting students to think about both the problems and potential solutions to the issues explored in the Central Case Study.

**CASE STUDY CONNECTION** You are the city manager for a coastal U.S. city that scientists predict will be hit hard by sea level rise, with risks and impacts trailing those in Miami by just a few years. You have recently returned from a professional conference in Florida, where you toured Miami Beach and learned of the efforts being made there to adapt to climate change. What steps would you take to help your own city prepare for rising sea level? How would you explain the risks and impacts of climate disruption to your fellow city leaders to gain their support? Of the measures being taken in Florida communities, which would you choose to study closely, which would you want to begin right away, and which would be highest priority in the long run? Explain your choices.



**NEW! Case Study Video Tours** use Google Earth™ and striking images delivered in highly engaging videos to bring each chapter's opening Case Study to life. The video tours are embedded in the Pearson eText, encouraging students to immerse themselves in each Case Study's theme, and are assignable in Mastering Environmental Science.

# Encourage students with a focus on sustainable solutions

## SUCCESS STORY

### Using Wetlands to Aid Wastewater Treatment

Long before people built the first wastewater treatment plants, natural wetlands filtered and purified water. Recognizing this, engineers have begun manipulating wetlands—and have even constructed new wetlands—to employ as tools to cleanse wastewater. In this approach, wastewater that has gone through primary or secondary treatment at a conventional facility is pumped into the wetland, where microbes living amid the algae and aquatic plants decompose the remaining pollutants. Water cleansed in the wetland can then be released into waterways or allowed to percolate underground.

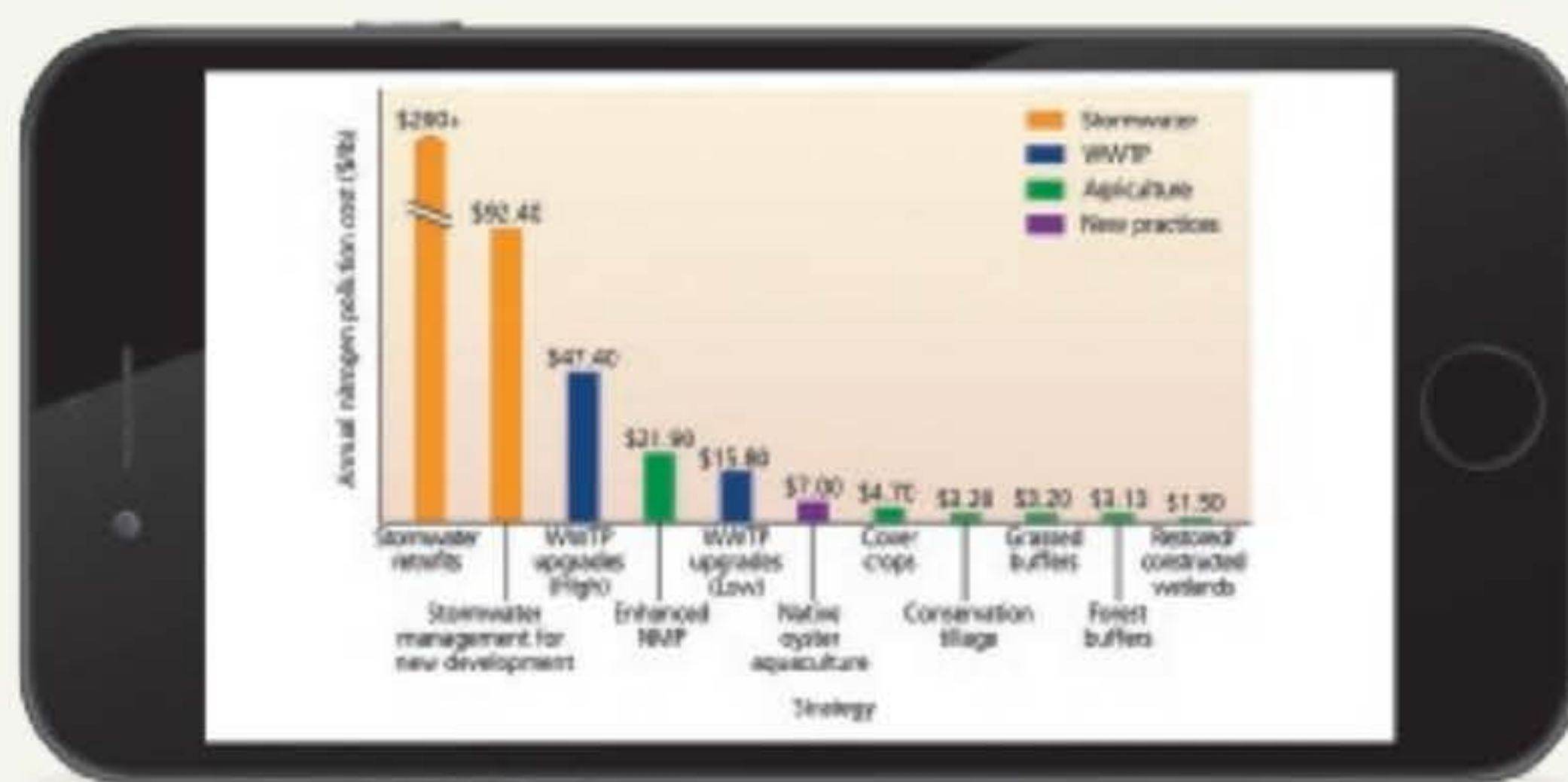


The Arcata Marsh and Wildlife Sanctuary

One of the first constructed wetlands was established in Arcata, a town on northern California's scenic Redwood Coast. This 35-hectare (86-acre) engineered wetland system was built in the 1980s after residents objected to a \$50 million plan to build a large treatment plant that would have pumped treated wastewater into the ocean. The wetland, which cost just \$7 million to build, not only treats wastewater but also serves as a haven for wildlife and human recreation. In fact, the Arcata Marsh and Wildlife Sanctuary has brought the town's waterfront back to life, with more than 200,000 people visiting each year. Additionally, wildlife has flourished in the area, with 100 species of plants, 300 species of birds, 6 species of fish, and a diversity of mammals and invertebrates populating the wetlands. The practice of treating wastewater with artificial wetlands is growing fast; today more than 500 artificially constructed or restored wetlands in the United States are performing this valuable service.

EXPLORE THE DATA at [Mastering Environmental Science](#)

**NEW! Success Story** feature, included in every chapter, highlights successful efforts to address local, national, and global environmental issues. These Success Stories encourage students by showing them that sustainable solutions are within reach.

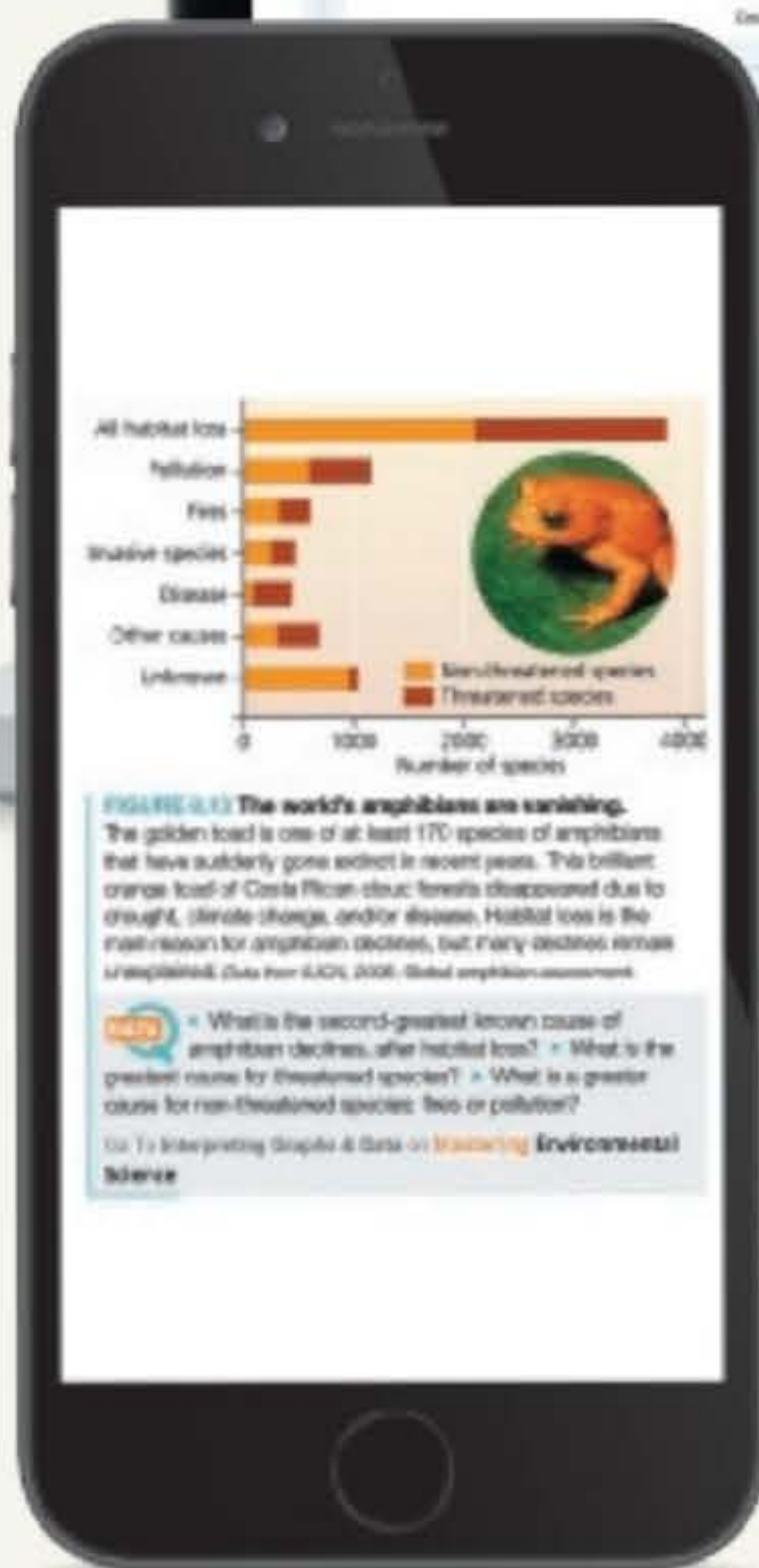
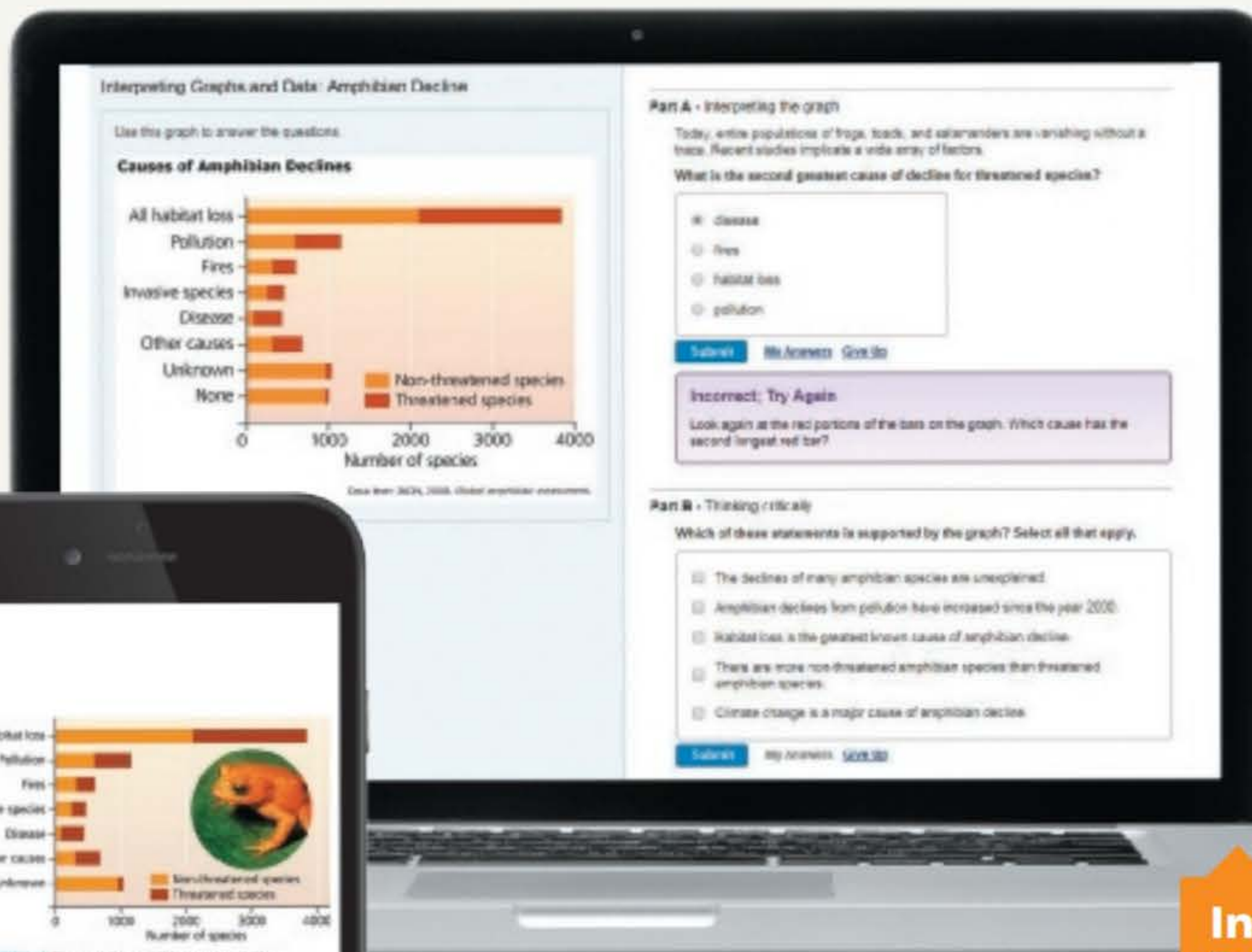


**NEW! Success Story Coaching Activities** pair with the new in-text Success Story feature, giving students the opportunity to explore the data behind each sustainable solution.



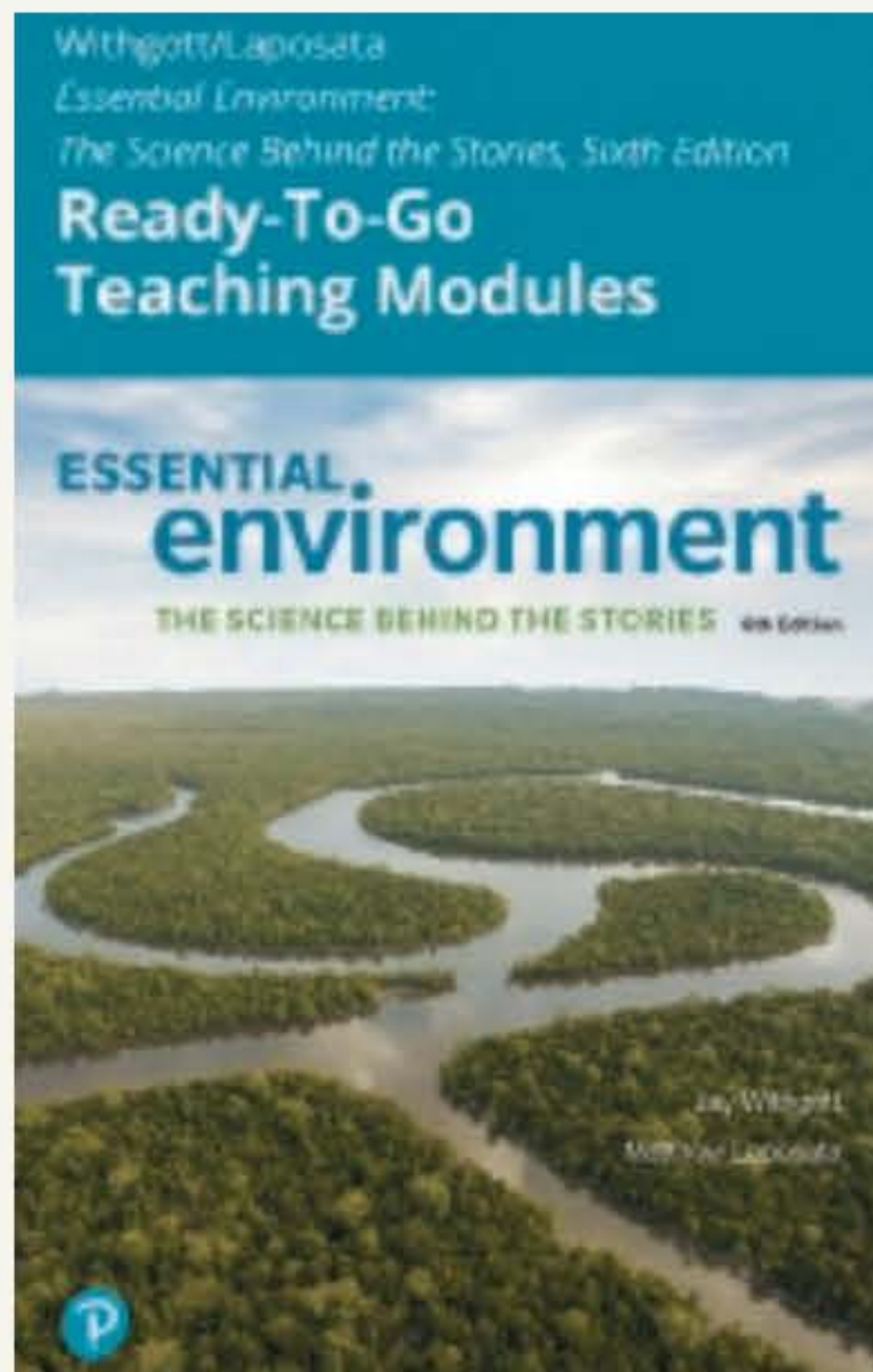
# Assign activities that use real data to help students develop problem-solving skills

**NEW! 10 GraphIt! Coaching Activities** help students develop the skills they need to read, interpret, and plot graphs. Each activity uses real data focusing on a current environmental issue—such as the carbon footprint of food, fresh water availability, and ocean acidification—in an entirely new mobile experience.



**Interpreting Graphs and Data** activities help students develop basic data analysis skills and practice applying those skills by interpreting real data related to environmental issues. Each activity is paired with one of the Data Q questions that appear with a number of figures throughout the text.

# Use Ready-to-Go Teaching Modules to get the most out of your course



**Ready-To-Go Teaching Modules** provide instructors with easy-to-use teaching tools for the toughest topics in Environmental Science.

Assign ready-made activities and assignments for before, during, and after class.

Incorporate active learning with class-tested resources from environmental science instructors.

Take full advantage of Mastering™ Environmental Science and Learning Catalytics™, the powerful "bring your own device" student assessment system.



## Ready-to-Go Teaching Modules

on key topics provide instructors with assignments for before and after class, as well as ideas for in-class activities. These modules incorporate the best that the text, Mastering Environmental Science, and Learning Catalytics have to offer, and are accessible through the Instructor Resources area of Mastering Environmental Science.



Instructors can easily incorporate **active learning** into their courses using suggested activity ideas and questions.

**Learning Catalytics™** helps instructors to customize lectures, generate class discussions, and promote peer-to-peer learning with real-time analytics using students' smartphones, tablets, or laptops. Learning Catalytics allows instructors to:

- Engage students in more interactive tasks, helping them to develop critical thinking skills.
- Monitor student responses to determine where they are struggling.
- Use real-time data to adjust a teaching strategy.
- **Misconception Questions** can be used during class to spark discussion and reveal common misconceptions about environmental issues. Test Bank questions connect to Learning Catalytics, allowing instructors to reinforce concepts and test student understanding.



# Give students access to their textbook, anytime, anywhere

**NEW! Pearson eText** integrates an electronic version of the text with rich media assets, such as Case Study Video Tours, in a customizable format that students can use on smartphones, tablets, and computers.

The Pearson eText mobile app offers offline access and can be downloaded for most iOS and Android phones/tablets from the Apple App Store or Google Play, providing:

- Seamlessly integrated videos and other rich media assets
- ADA accessibility (screen-reader ready)
- Configurable reading settings, including resizable type and night reading mode
- Instructor and student note-taking, highlighting, bookmarking, and search capabilities



**ESSENTIAL**  
**environment**

**THE SCIENCE BEHIND THE STORIES** 6th Edition

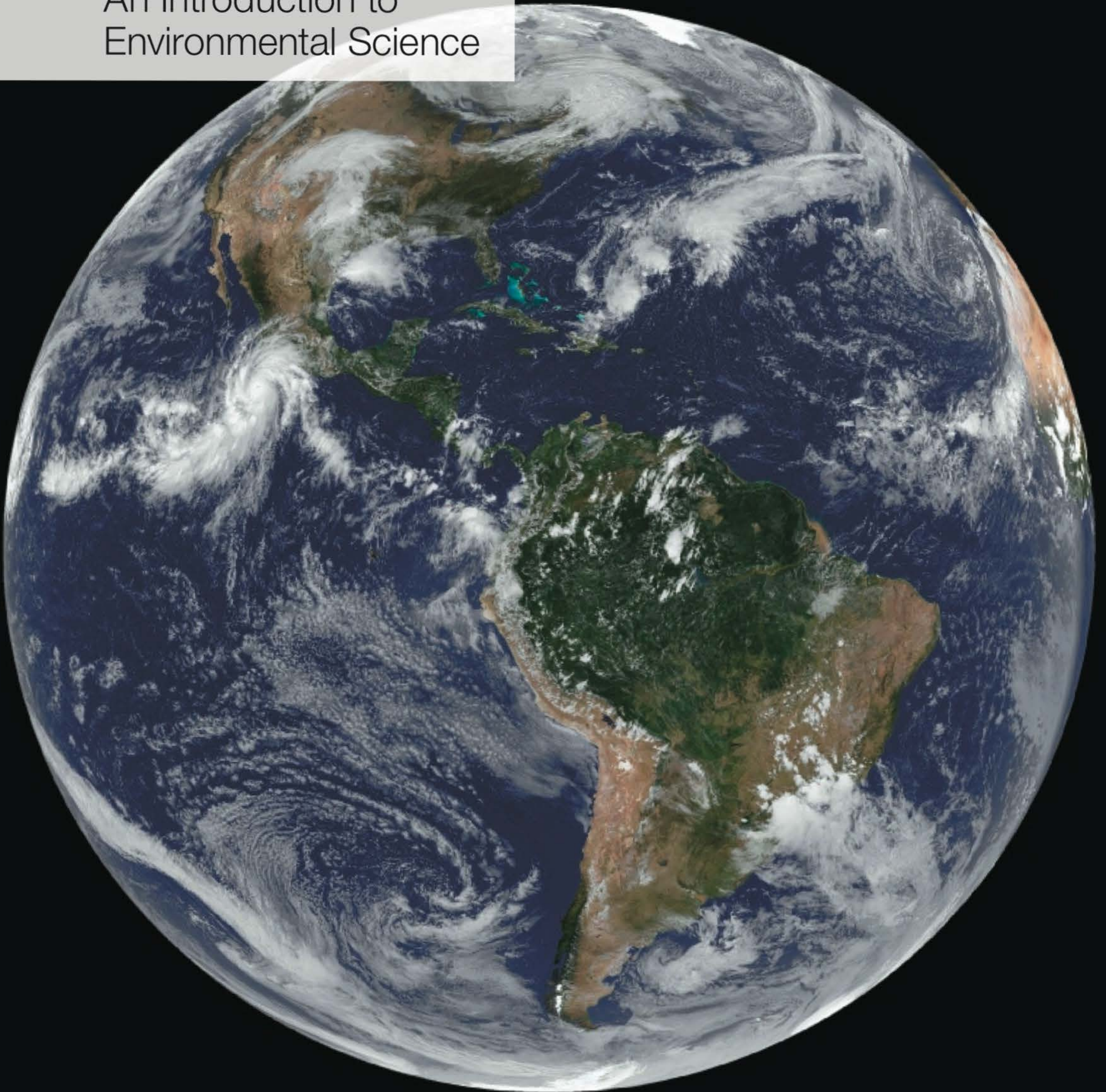
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CHAPTER 1

# Science

# and Sustainability

An Introduction to  
Environmental Science



## 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 animals, plants, forests, and farms of the landscapes in which we live. In a more inclusive sense, it also encompasses the structures, urban centers, and living spaces that people have created. In its broadest 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 people 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 make it all too easy 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. Air and water pollution, soil erosion, species extinction, and other impacts 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 sheer 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 world and its 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.

#### 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
- Appreciate the role of ethics in environmental science, and compare and contrast major approaches in environmental ethics
- Identify major pressures on the global environment
- Discuss the concept of sustainability, and describe sustainable solutions being pursued on campuses and in the wider world



(a) **Inexhaustible renewable natural resources**

- Solar energy
- Wind energy
- Wave energy
- Geothermal energy

(b) **Exhaustible renewable natural resources**

- Fresh water
- Forest products
- Biodiversity
- Soils

(c) **Nonrenewable natural resources**

- Crude oil
- Natural gas
- Coal
- Minerals

**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 we take from our environment and 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, then we soon realize that Earth’s natural systems also provide “services” on which we depend. Our planet’s ecological processes 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. 39, 101–102, 172).

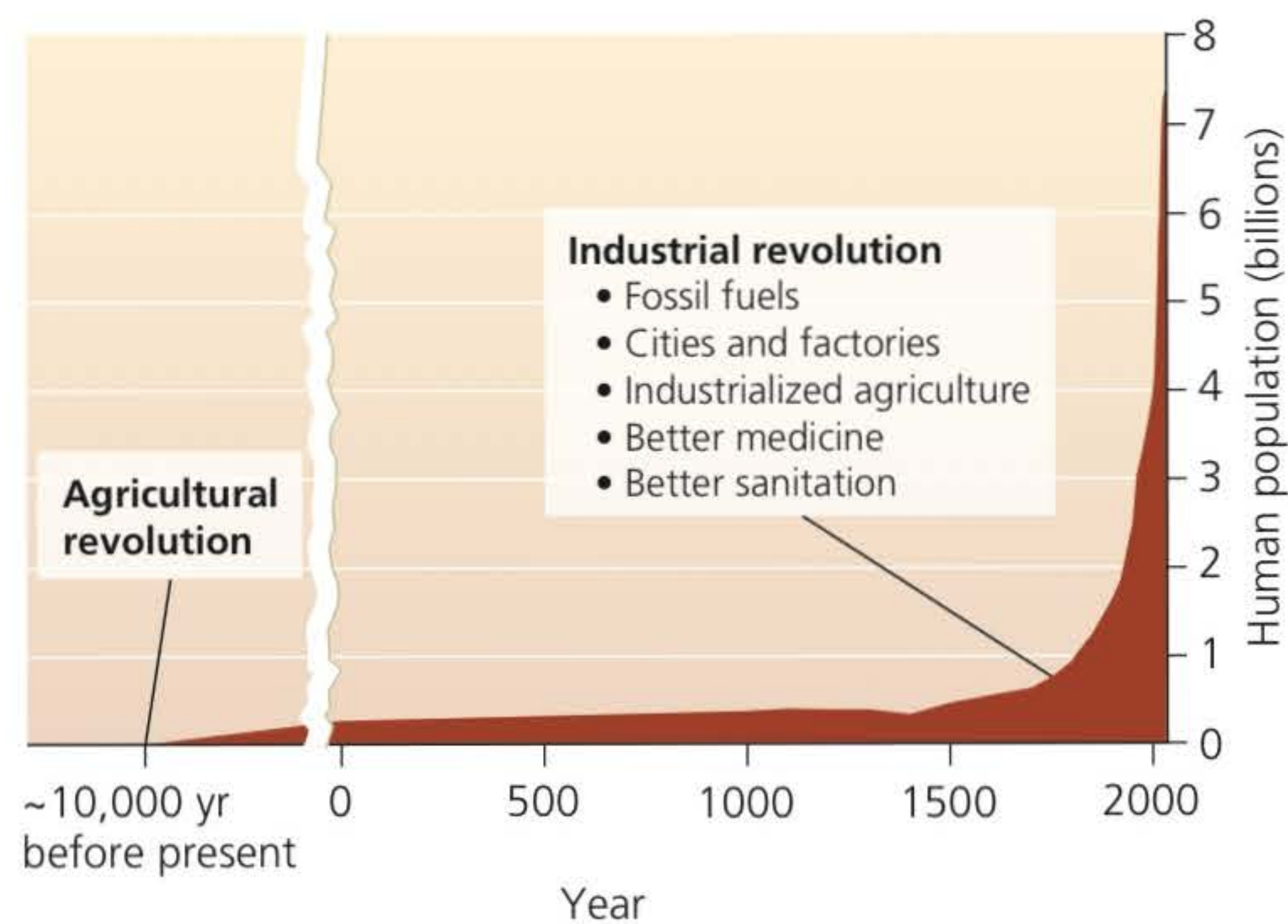
Just as we may deplete natural resources, we may degrade ecosystem services when, for example, we destroy habitat or generate pollution. For years, our depletion of nature’s goods and our disruption of nature’s services have intensified, driven by rising resource consumption and a human population that grows larger every day.

## Population growth amplifies our impact

For nearly all of human history, fewer than a million people populated Earth at any one time. Today our population has grown beyond *7.5 billion* people. For every one person who used to exist 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.



**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 from U.S. Census Bureau, U.N. Population Division, and other sources.*

**DATA Q** For every person alive in the year 1800, about how many are alive today?

**NOTE:** Each **DATA Q** in this book asks you to examine the figure carefully so that you understand what it is showing. Once you take the time to understand what it shows, the rest is a breeze!

Because this is the first **DATA Q** of our book, let's walk through it together. You would first note that in the graph, time is shown on the x-axis and population size on the y-axis. You would find the year 1800 (three-fifths of the way between 1500 and 2000 on the x-axis) and trace straight upward to determine the approximate value of the data in that year. You'd then do the same for today's date at the far right end of the graph. To calculate roughly how many people are alive today for every one person alive in 1800, you would simply divide today's number by the number for 1800.

For each **DATA Q**, you can check your answers in **APPENDIX A** in the back of the book.

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

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.

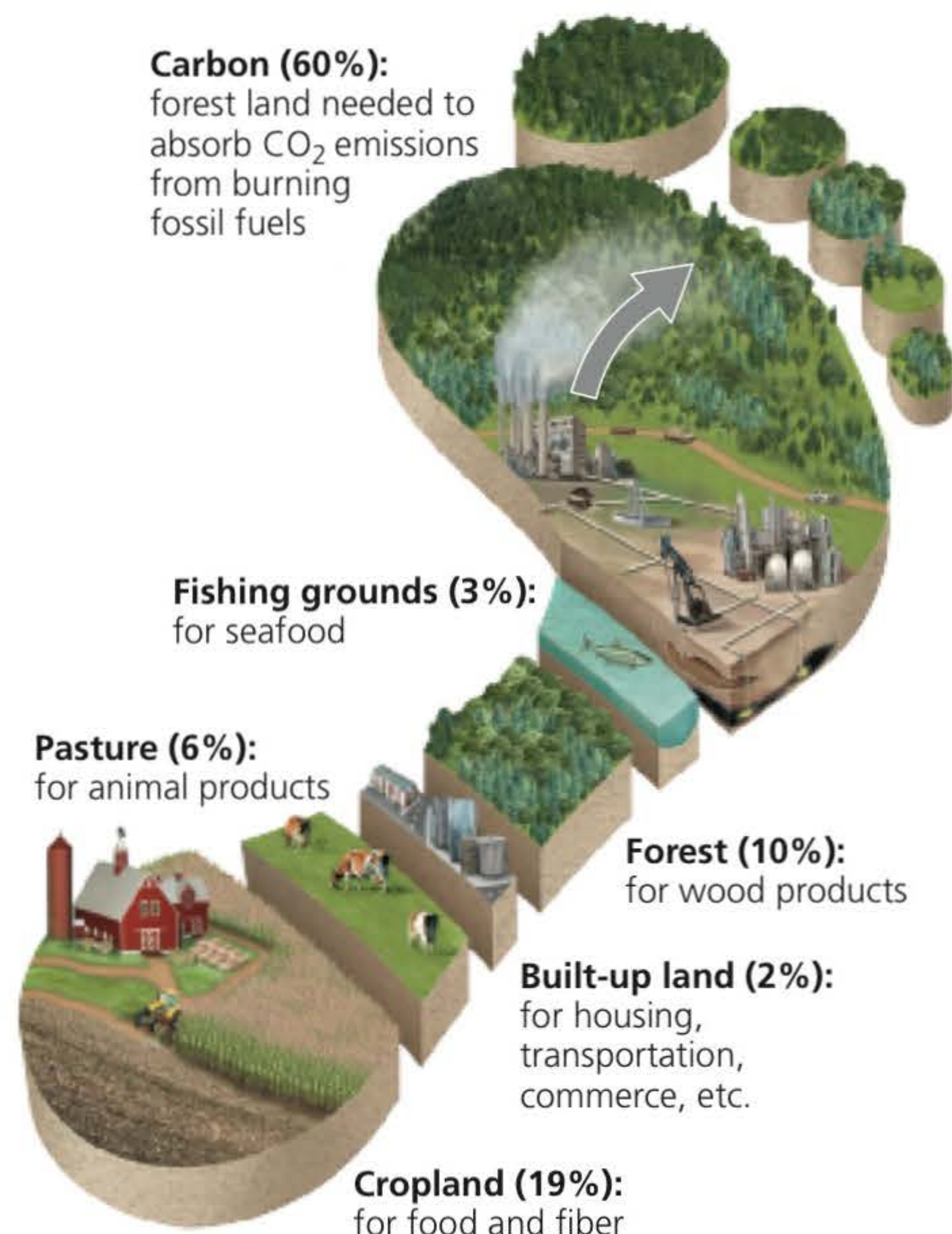
The second phenomenon, known as the **industrial revolution**, began in the mid-1700s. It entailed a shift from rural life, animal-powered agriculture, and handcrafted goods toward an urban society provisioned by the mass production of factory-made goods and powered by **fossil fuels** (nonrenewable energy sources such as coal, oil, and natural gas; pp. 343, 346). 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. 142–143).

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.



**FIGURE 1.4** An ecological footprint shows the total area of biologically productive land and water used by a given person or population. Shown here is a breakdown of major components of the average person's footprint. *Data from Global Footprint Network, 2017.*

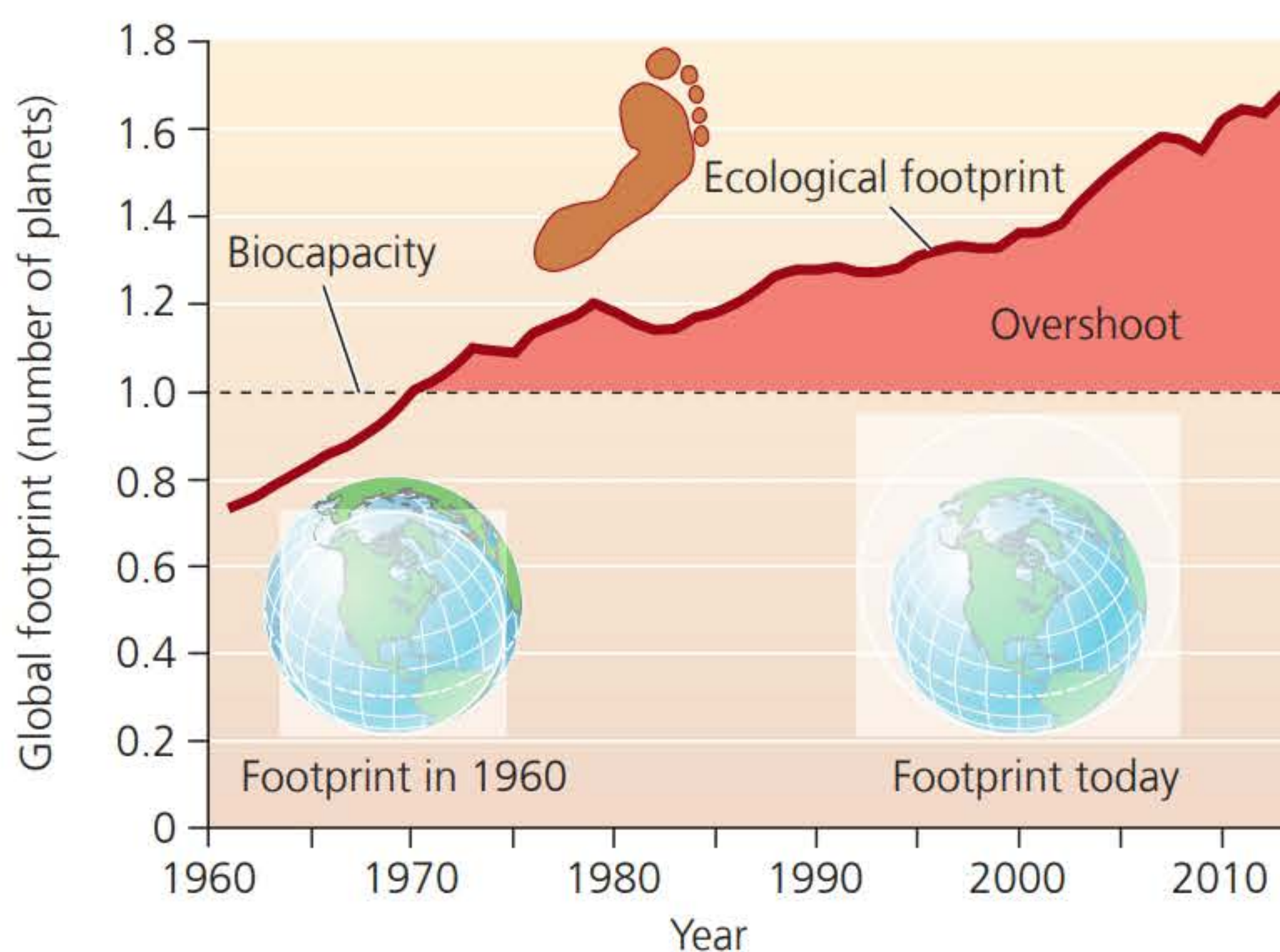


For humanity as a whole, Wackernagel and his colleagues at the Global Footprint Network calculate that we are now using 68% more of the planet's resources than are available on a sustainable basis. That is, we are depleting renewable resources by using them 68% faster than they are being replenished. To look at this another way, it would take 1.68 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 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. Indeed, any attempt to boil down complicated issues to a single number is perilous, even if the general concept is sound and useful. 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, we would need the equivalent of almost five planet Earths!

## Conserving natural capital is like maintaining a bank account

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 only the interest, so that we can



**FIGURE 1.5** Analyses by one research group indicate that we have overshoot Earth's biocapacity—its capacity to support us—by 68%. We are using renewable natural resources 68% faster than they are being replenished. Data from Global Footprint Network, 2017.

**DATA** How much larger is the global ecological footprint today than it was half a century ago?

Go to [Interpreting Graphs & Data](#) on [Mastering Environmental Science](#)

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 this for long.

## Environmental science can help us learn from the past

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 today are barren desert had earlier been lush enough to support the origin of agriculture and thriving ancient societies. 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).

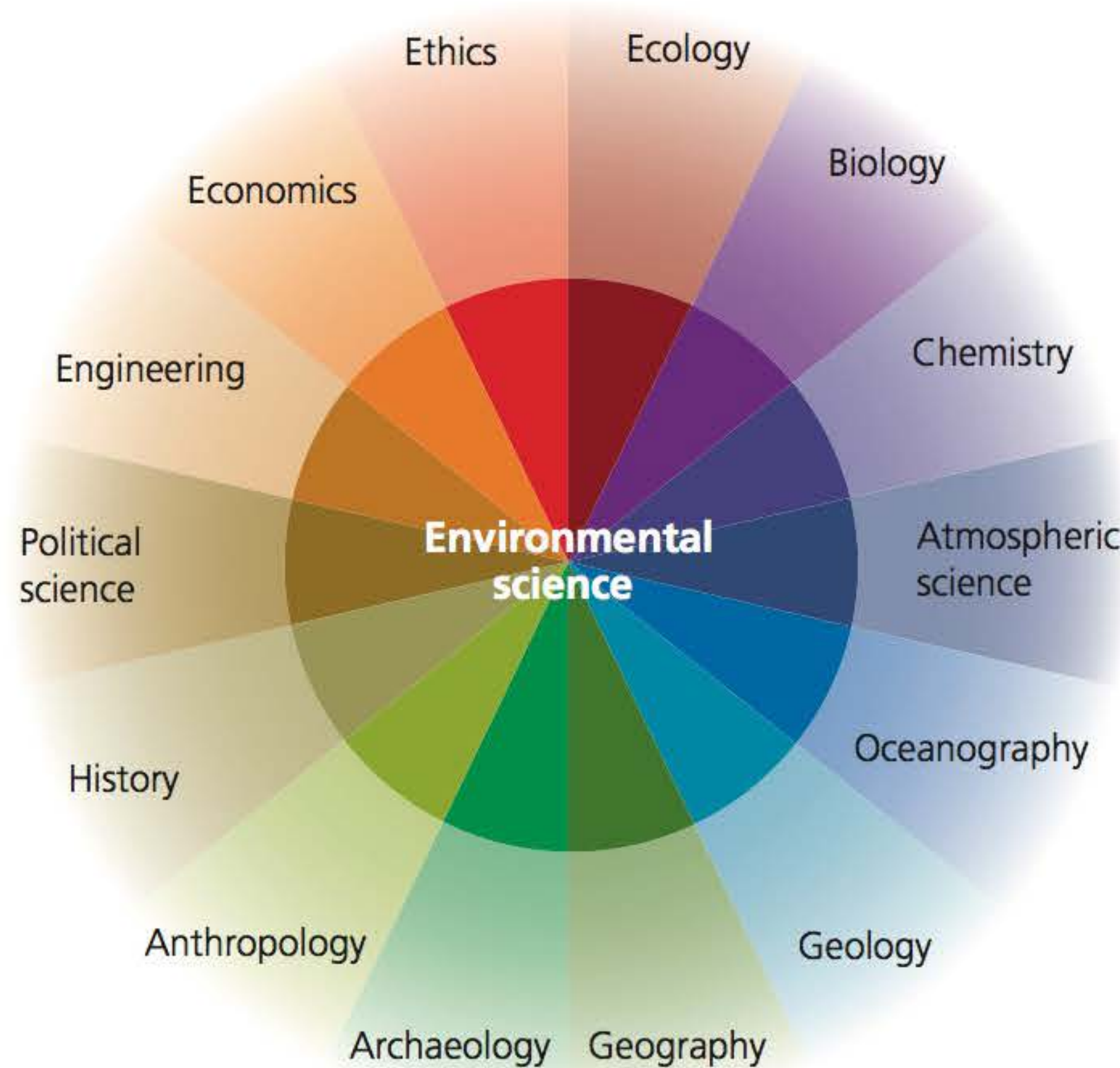
In today's globalized society, the stakes are higher than ever because our environmental impacts are global. If we cannot forge sustainable solutions to our problems, then the resulting societal collapse will be global. Fortunately, environmental science holds keys to building a better world. By studying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

## The Nature of 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,



**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.

biology, geography, economics, political science, demography, ethics, and others. 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.

## 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.

## 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. From the food we eat to the clothing we wear to the health care we rely 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 motivated 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.

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 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 experiments to test hypotheses within a framework traditionally known as the scientific method.

## FAQ

### Aren't environmental scientists also environmentalists?

Not necessarily. Although environmental scientists search for solutions to environmental problems, they strive to keep their research rigorously objective and free from advocacy. 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 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 is a hallmark of the effective scientist.

## 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—is the focus of an intense debate among scientists seeking to solve its mysteries. The debate shows how, in science, new information can challenge existing ideas—and also how interdisciplinary research helps us to tackle complex questions.

Ever since European explorers stumbled upon Rapa Nui on Easter Sunday, 1722, outsiders have been struck by the island's barren landscape. Early European accounts suggested that the 2000–3000 people living on

the island 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. How could people without wheels or ropes, on an island without trees, have moved 90-ton statues as far as 10 km (6.2 mi) from the quarry where they were chiseled to the coastal 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.

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 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 the forest had been burned, likely for 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 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—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. 31) 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 and 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; lethal injuries were rare; and no evidence of battle or defensive fortresses was uncovered.

Hunt, Lipo, and others also unearthed old roads and inferred that the statues could have been moved by tilting and rocking them upright, much as we might move a refrigerator. Islanders had adapted to their resource-poor environment by becoming a peaceful and cooperative society, they maintained, with the statues providing a harmless outlet for competition among family clans 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 progressively 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 research continues as scientists look for new ways to test the differing hypotheses. In 2015, a six-person research team set out to estimate when human land use began to decline for each of three sites on the island. They did this by measuring how long ago pieces of obsidian rock at each site were unearthed from the soil and exposed to the air (obsidian absorbs water molecules very slowly, chemically changing over many years). The researchers found that land use had declined prior to European contact at a dry site and at a site with naturally poor soil, but that land use had continued at a moist site with fertile soil for farming. They proposed that the true picture was complex: Perhaps islanders had indeed degraded their environment in areas where conditions were sensitive, but had sustained themselves in areas where conditions were more forgiving.

Like the people of Rapa Nui, we are all stranded together on an island with limited resources. What, then, 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.



**Were the haunting statues of Rapa Nui erected by a civilization that collapsed after devastating its environment or by a sustainable civilization that fell because of outside influence?**

## 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 might 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 below.

**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 and 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 and animals? All of these are questions environmental scientists ask.

**Develop a hypothesis** Scientists 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 investigating 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 can be directly and unequivocally tested. In our algae example, a researcher might predict: “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. It involves manipulating **variables**, or conditions that can change.

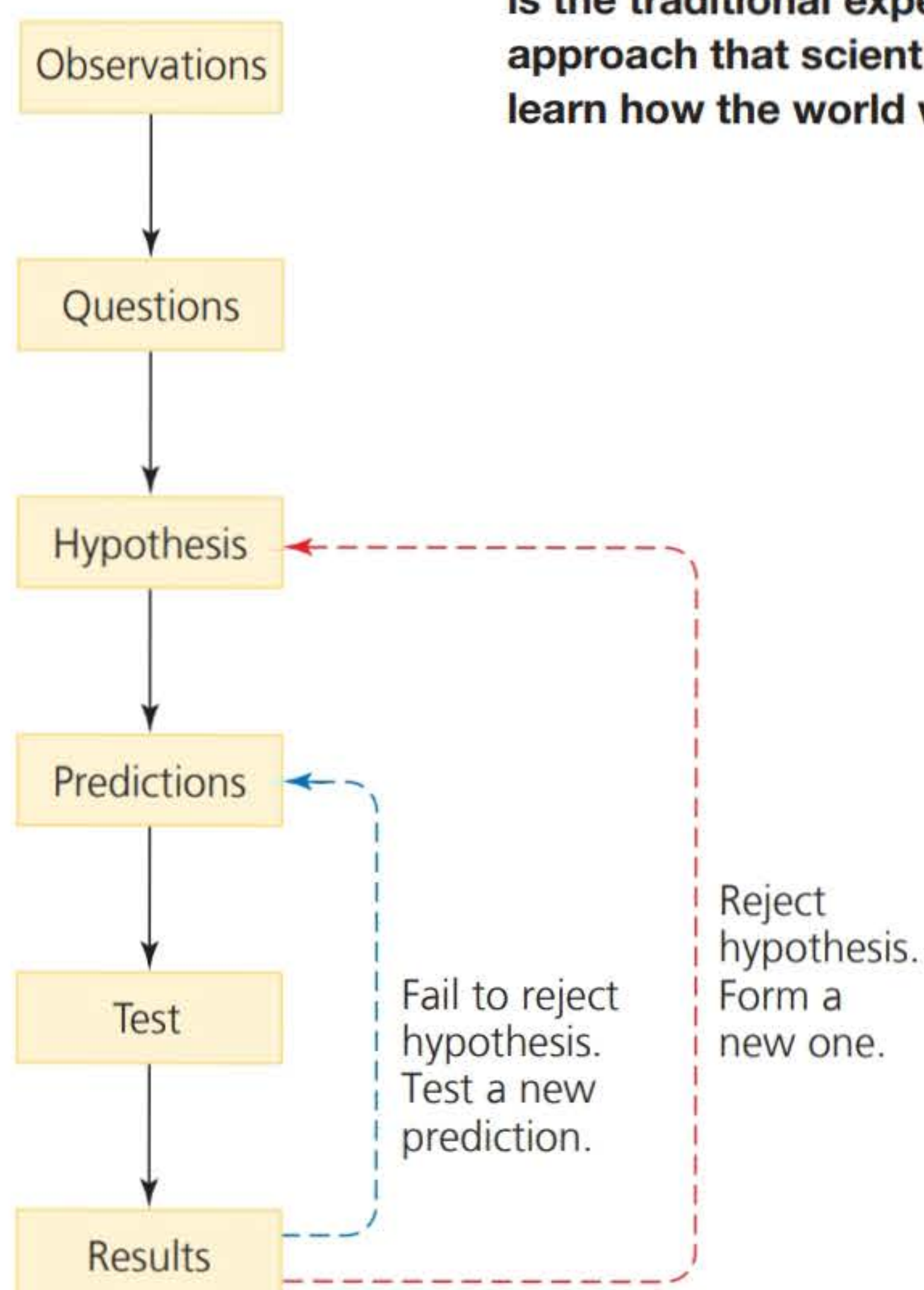
For example, a scientist could test the prediction linking algal growth to fertilizer by selecting two identical ponds and adding fertilizer to one of them. In this example, fertilizer input is an **independent variable**, a variable the scientist manipulates, whereas the quantity of algae that results 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), then any differences that arise between the ponds can be attributed to changes in the independent variable. Such an experiment is known as a **controlled experiment** because the scientist controls for the effects of all variables except the one 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 stage 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.

**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

Scientific method

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



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.

If experiments disprove a hypothesis, the scientist will reject it and may formulate a new hypothesis to replace it. If experiments fail to disprove a hypothesis, this lends support to the hypothesis but does not *prove* it is correct. The scientist may choose to generate new predictions to test the hypothesis in different ways and further assess its likelihood of being true. 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 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.

## We test hypotheses in different ways

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 14), 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



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

say he or she 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.

This type of evidence is not as strong as the causal demonstration 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 at large scales, they must be addressed with correlative data. As such, environmental scientists cannot always provide clear-cut answers to questions from policymakers and the public. Nonetheless, good correlative studies can make for very strong science, and they preserve the real-world complexity that manipulative experiments often sacrifice. Whenever possible, scientists try to integrate natural experiments and manipulative experiments to gain the advantages of each.

## Scientists use graphs to represent data visually

To summarize and present the data they obtain, scientists often use graphs. Graphs help to 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 is illustrated clearly and explained further in **APPENDIX B** 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 B closely as you begin your environmental science course.

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