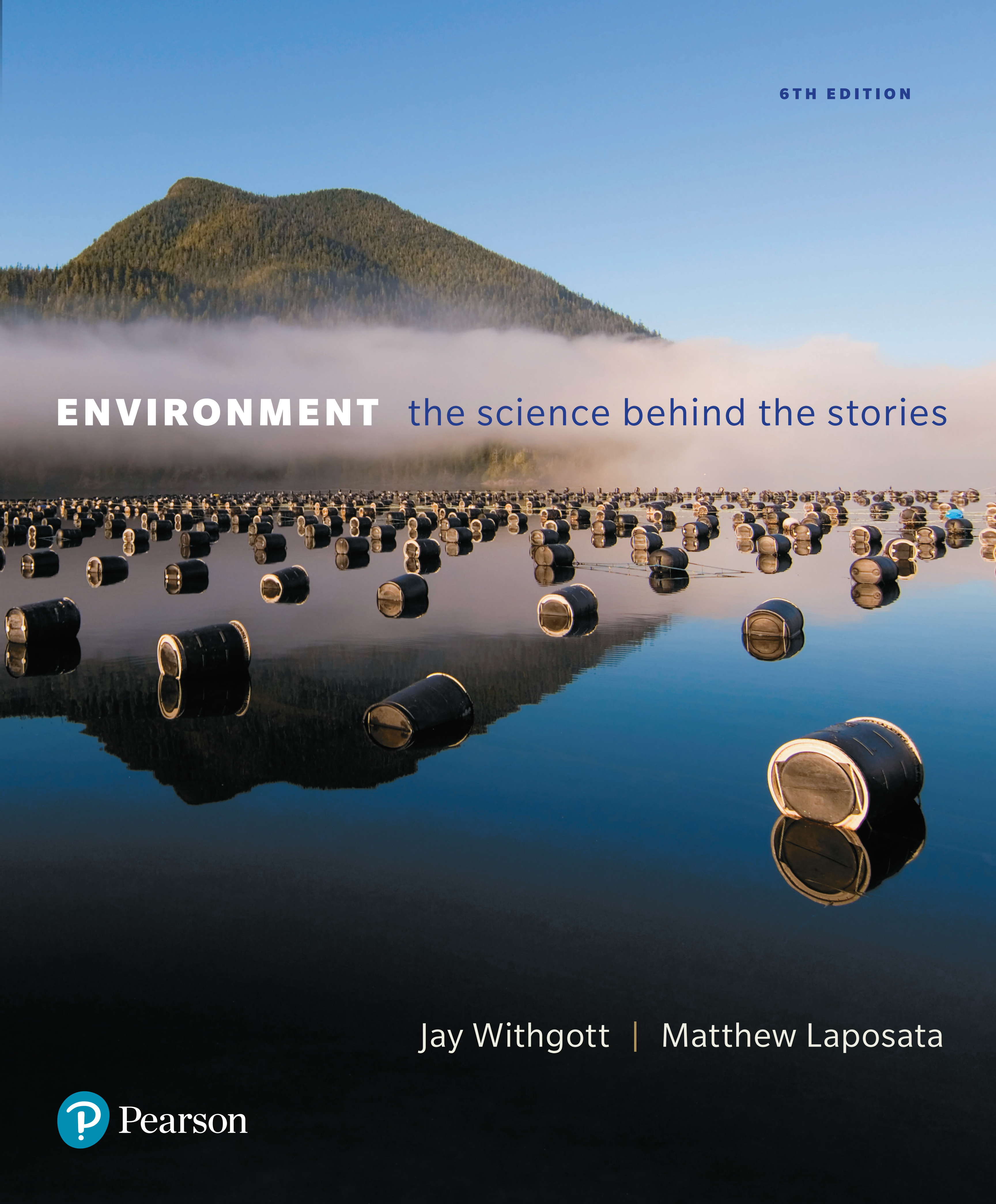

6TH EDITION

ENVIRONMENT the science behind the stories

Jay Withgott | Matthew Laposata

Pearson

environment

THE SCIENCE BEHIND THE STORIES

6TH EDITION

Jay Withgott

Matthew Laposata

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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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Brief Contents

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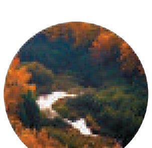
PART 1 Foundations of Environmental Science



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 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 create. Environmental science is not simply a subject you learn in college. Rather, it provides you a solid understanding of some of the most important issues of the 21st century, and it relates to everything around you over your entire lifetime.

We have written this book because today's students will shape tomorrow's world. At this unique moment in history, students of your generation are key to achieving a sustainable future for our civilization. The many environmental challenges that face us 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 facing us in our new century. 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 create 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 sixth 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 make sure 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 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.

- central **CASE STUDY** Five *Central Case Studies* are completely new to this edition, complementing the 10 new case studies added in the fifth edition. 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 compare organic farming with agriculture that uses genetically modified organisms, learn of the approaches California is taking to tackle chronic water shortages, examine how Miami is coping with sea level rise, and visit college campuses to see how students are promoting recycling and sustainable dining.
    - **Chapter 9:** Farm to Table (And Back Again) at Kennesaw State University
    - **Chapter 10:** Can Organic Farming and GMOs Coexist?

- **Chapter 15:** Conserving Every Drop in California
- **Chapter 18:** Rising Seas Threaten South Florida
- **Chapter 22:** A Mania for Recycling on Campus

- **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.

- **THE SCIENCE behind the story** Six *Science Behind the Story* boxes are new to this edition, expanding our library of recently added examples of this feature. 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 determine whether fracking is inducing earthquakes in Oklahoma; conduct a wide-ranging analysis of genetically modified crops; use DNA fingerprinting to combat poaching; ascertain if endocrine-disrupting chemicals are present in bottled water; predict the future of drought in the American West; and use toxic by-products of mining to reduce water use in hydraulic fracturing.
  - **Chapter 2:** Are the Earthquakes Rattling Oklahoma Caused by Human Activity?
  - **Chapter 10:** What Are the Impacts of GM Crops?
  - **Chapter 11:** Can Forensic DNA Analysis Help Save Elephants?
  - **Chapter 15:** Are We Destined for a Future of "Megadroughts" in the United States?
  - **Chapter 15:** Is Your Bottled Water as Safe as You Think It Is?
  - **Chapter 23:** Can Acid Mine Drainage Reduce Fracking's Environmental Impact?

- **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.
- **End-of-chapter elements** Several new approaches are introduced in our redesigned end-of-chapter material. Our *Reviewing Objectives* section is now more streamlined and focused on the learning objectives, and also incorporates visual icons as mileposts to help students connect to the material's location in the chapter. New "Case Study Connection" questions encourage students to craft solutions to issues raised in the chapter's *Central Case Study*.
- **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 of these topics has kept pace. This edition highlights how renewable energy is growing, yet also how we continue reaching further for fossil fuels with deep offshore drilling, hydraulic fracturing for oil and shale gas, and extraction of oil sands. The text tackles the complex issue of climate change directly, while connections to this issue proliferate among topics throughout our book.

  This edition also evolves and improves its coverage of a diversity of topics including the valuation of ecosystem services, invasive species and their ecological impacts, hormone-disrupting substances, fresh water shortages, advanced biofuels, plastic pollution in the oceans, sustainable agriculture, campus sustainability, green-collar jobs, and technologies that help reduce environmental impacts. We continue to use sustainability as an organizing theme throughout the book.
- **Enhanced style and design** We have significantly updated and improved the look and clarity of our visual presentation throughout the text. A more open layout, striking visuals, and an inviting new style all make the book more engaging for students. Over 40% 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 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 believe that there is no hope or that they cannot personally make a difference in tackling these challenges. We have aimed to counter this impression by highlighting innovative solutions being developed around the world. While being careful 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 (Chapters 1 and 24, 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.

- **Central Case Studies integrated throughout the text** 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.
- **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.
- These data analysis questions help students to actively engage with graphs and other data-driven figures. This feature accompanies several figures in each chapter, challenging students 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 new *Interpreting Graphs and Data: DataQs* in MasteringEnvironmentalScience.
- **FAQ** The *FAQ* feature highlights questions frequently posed by students in introductory environmental science courses, 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** In addition to our new and revised end-of-chapter features detailed above, several hallmark features help students review and apply the concepts in each chapter. *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. *Testing Your Comprehension* provides concise study questions on key topics, while *Seeking Solutions* encourages broader creative thinking that supports our emphasis on finding solutions. "Think It Through" questions in this section 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.

MasteringEnvironmental Science®

With this edition we continue to offer expanded opportunities through *MasteringEnvironmentalScience*, 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, *MasteringEnvironmentalScience* 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.

NEW TO THIS EDITION *MasteringEnvironmentalScience* for this edition of *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 through a highly interactive and engaging format. Each of the 10 *GraphIts* 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 *MasteringEnvironmentalScience*.
- *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.
- *NEW 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.

EXISTING FEATURES *MasteringEnvironmentalScience* retains its popular existing features:

- *Process of Science* activities help students navigate the scientific method, guiding them through in-depth 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 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 editor, Alison Rodal (**alison.rodal@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 accompanies the text and can be accessed through the Pearson Instructor Resource Center or *MasteringEnvironmentalScience.* 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.

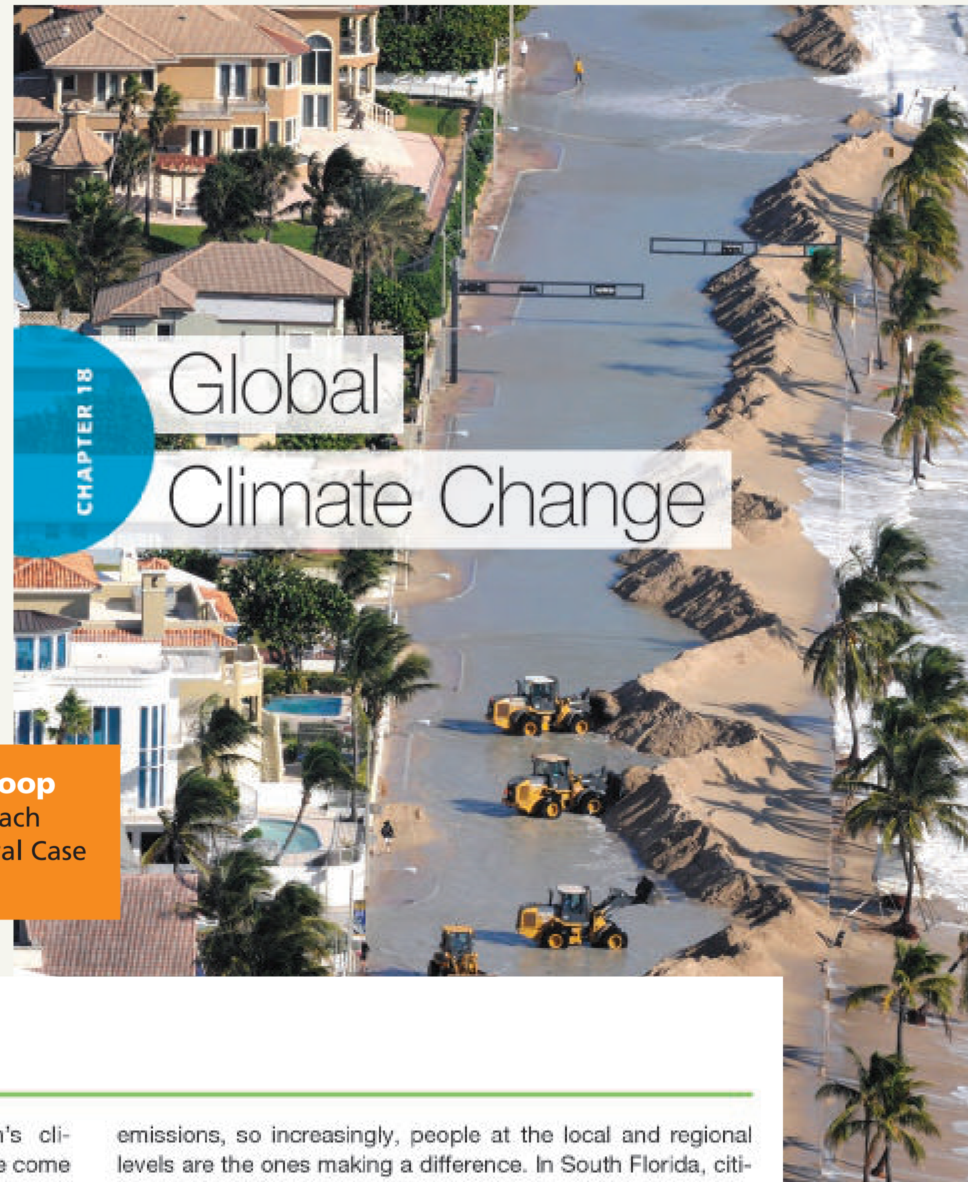
The Test Bank files, offered in both MS Word and TestGen, include hundreds of multiple-choice questions plus unique graphing and scenario-based questions to test students' critical-thinking abilities.

***MasteringEnvironmentalScience*® for *Environment: The Science Behind the Stories* (0-134-51016-X)**

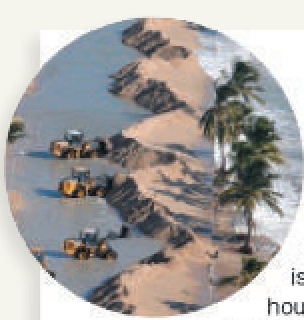
The *MasteringEnvironmentalScience* platform is the most effective and widely used online tutorial, homework, and assessment system for the environmental sciences.

Help students connect
current environmental issues ...

Now in its Sixth Edition, ***Environment: The Science Behind the Stories,*** draws students into the science behind the issues with **updated central case studies** integrated into each chapter, a focus on building **science literacy skills,** and **captivating media** that brings concepts to life.



NEW! Closing the Loop sections at the end of each chapter bring the Central Case Studies full circle.



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 increasingly severe and varied impacts. Sea level rise and other consequences of global climate change are affecting locations worldwide from Miami to the Maldives, from Alaska to Bangladesh, and from New York to the Netherlands. As scientists and policymakers come to better understand anthropogenic climate change 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 the 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.

... to the science

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.**
> University of Miami geologist Dr. Harold Wanless

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

It happens now in Miami at least six times a year. Salty water bubbles up from drains, seeps up from the ground, fills the streets, and spills across lawns and sidewalks. Under the dazzling 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 rises from a seven-mile barrier island just offshore from Miami. The carefree affluent image of Miami Beach, with its sun and fun, is increasingly jeopardized by the grimy reality of these unwelcome saltwater intrusions. By 2030, 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 mysterious floods that seem to come out of nowhere are a recent phenomenon, so Miami-area residents are just now coming to realize 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. These processes are accelerating today, and scientists predict that sea level will rise another 25–98 cm (10–39 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 shores 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, disruption to daily life, and property damage as beaches erode, neighborhoods flood, aquifers are fouled, 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

A motorist stranded in Miami floodwaters

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 around the world
- Suggest and assess ways we may respond to climate change

Bulldozing beach sand off a Fort Lauderdale boulevard after a storm surge

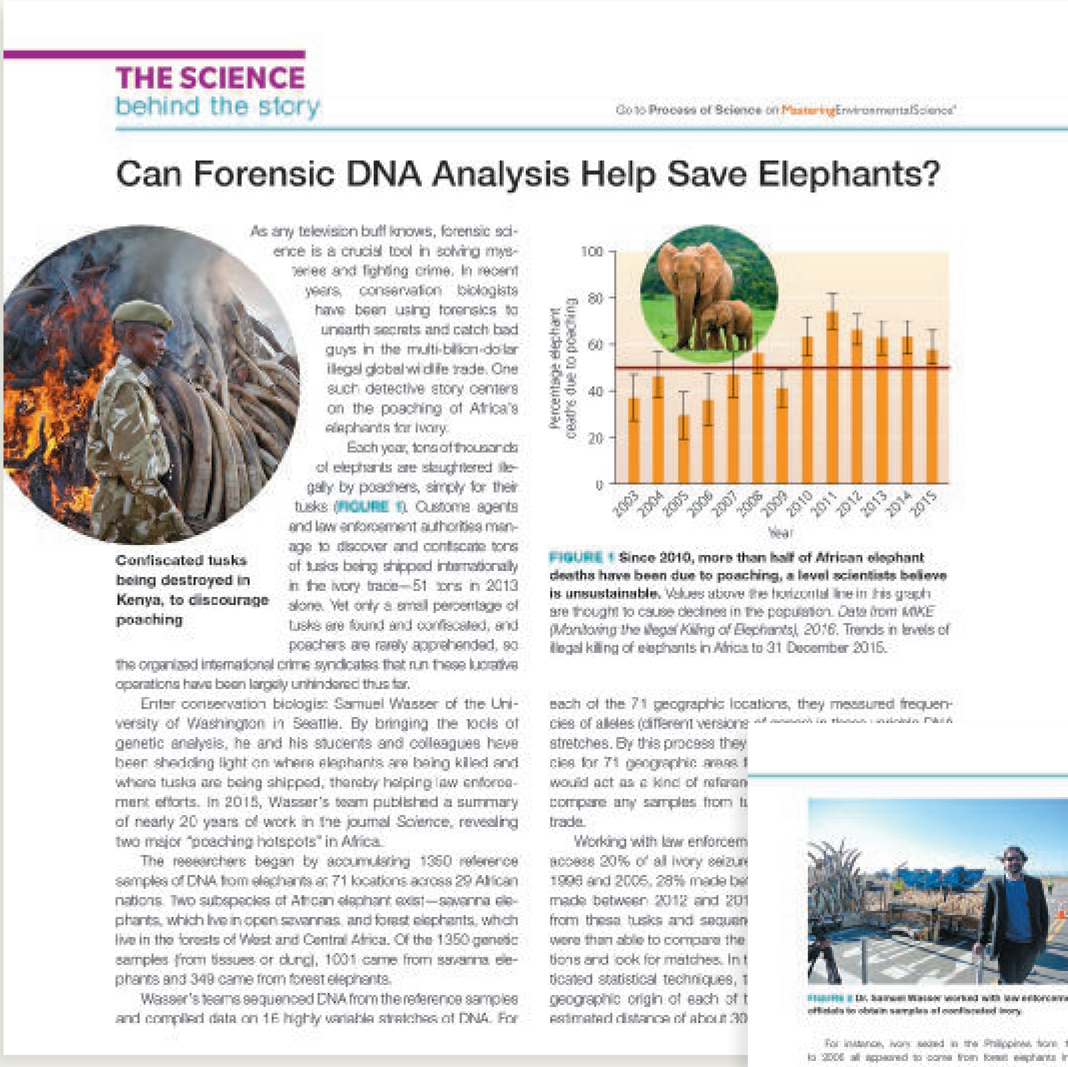
NEW and UPD ATED! Central Case Studies begin and are woven throughout each chapter, drawing students in and provide a contextual framework to make science memorable and engaging.

NEW! Case Study Connection questions in the end of chapter material prompt students to think critically.

4. **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 just 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 change 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.

Bring **real conversations** into the classroom ...

NEW and UPDATED! Science Behind the Story features highlight the process of science and profile the current scientific research behind today's most pressing environmental issues.



THE SCIENCE behind the story

Go to Process of Science on MasteringEnvironmentalScience®

Can Forensic DNA Analysis Help Save Elephants?

Confiscated tusks being destroyed in Kenya, to discourage poaching

As any television buff knows, forensic science is a crucial tool in solving mysteries and fighting crime. In recent years, conservation biologists have been using forensics to unearth secrets and catch bad guys in the multi-billion-dollar illegal global wildlife trade. One such detective story centers on the poaching of Africa's elephants for ivory.

Each year, tens of thousands of elephants are slaughtered illegally by poachers, simply for their tusks (FIGURE 1). Customs agents and law enforcement authorities manage to discover and confiscate tons of tusks being shipped internationally in the ivory trade—51 tons in 2013 alone. Yet only a small percentage of tusks are found and confiscated, and poachers are rarely apprehended, so the organized international crime syndicates that run these lucrative operations have been largely unhindered thus far.

Enter conservation biologist Samuel Wasser of the University of Washington in Seattle. By bringing the tools of genetic analysis, he and his students and colleagues have been shedding light on where elephants are being killed and where tusks are being shipped, thereby helping law enforcement efforts. In 2015, Wasser's team published a summary of nearly 20 years of work in the journal Science, revealing two major "poaching hotspots" in Africa.

The researchers began by accumulating 1350 reference samples of DNA from elephants at 71 locations across 29 African nations. Two subspecies of African elephant exist—savanna elephants, which live in open savannas, and forest elephants, which live in the forests of West and Central Africa. Of the 1350 genetic samples (from tissues or dung), 1001 came from savanna elephants and 349 came from forest elephants.

Wasser's teams sequenced DNA from the reference samples and compiled data on 16 highly variable stretches of DNA. For

FIGURE 1 Since 2010, more than half of African elephant deaths have been due to poaching, a level scientists believe is unsustainable. Values above the horizontal line in this graph are thought to cause declines in the population. *Data from MIKE (Monitoring the Illegal Killing of Elephants), 2016.* Trends in levels of illegal killing of elephants in Africa to 31 December 2015.

each of the 71 geographic locations, they measured frequencies of alleles (different versions ...
stretches. By this process they ...
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would act as a kind of referen...
compare any samples from ...
trade.

Working with law enforcem...
access 20% of all ivory seizu...
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tions and look for matches. In t...
ticated statistical techniques, t...
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estimated distance of about 30...

NEW Science Behind the Stories include:

- **Ch 2** Are the Earthquakes Rattling Oklahoma Caused by Human Activity?
- **Ch 10** What Are the Impacts of GM Crops?
- **Ch 11** Can Forensic DNA Analysis Help Save Elephants?
- **Ch 15** Are We Destined for a Future of "Megadroughts" in the United States?
- **Ch 23** Can Acid Mine Drainage Reduce Fracking's Environmental Impact?

... and encourage students to **think scientifically**

FAQ

How big is a billion?

Human beings have trouble conceptualizing huge numbers. As a result, we often fail to recognize the true magnitude of a number such as 7 billion. Although we know that a billion is bigger than a million, we tend to view both numbers as impossibly large and therefore similar in size. For example, guess (without calculating) how long it would take a banker to count out $1 million if she did it at a rate of a dollar a second for 8 hours a day, 7 days a week. Now guess how long it would take to count $1 billion at the same rate. The difference between your estimate and the answer may surprise you. Counting $1 million would take a mere 35 days, whereas counting $1 billion would take 95 years! Living 1 million seconds takes only 12 days, while living for 1 billion seconds requires more than 31 years. You couldn't live for 7 billion seconds—that would take 221 years. Examples like these can help us appreciate the *b* in *billion*.

FAQs probe common misconceptions students often hold about environmental issues.

First Impression questions, assignable in Mastering, gather data on your students' misconceptions and relate to chapter FAQs.

Weighing the Issues activities encourage students to grapple with environmental problem solving, and apply what they have learned as they go through each chapter.

More species have been identified and classified in this group than in any other.

- Mammals
- Plants
- Fishes
- Insects
- Bacteria

The global human population recently surpassed 7 billion people, and its annual growth is approximately _____ at the present.

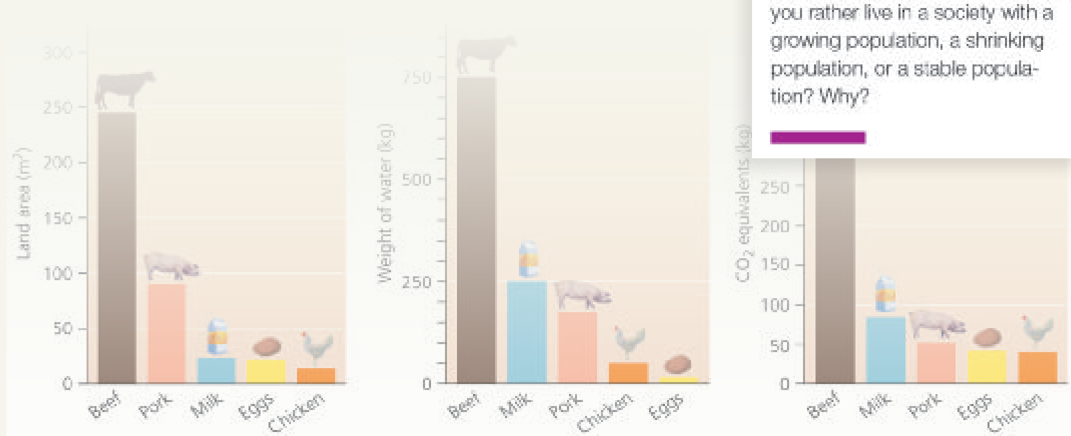
- 1%
- 4%
- 7%
- 10%
- 12%

Submit   My Answers   Give Up

weighing the ISSUES

What Are the Consequences of Low Fertility?

In the United States, Canada, and almost every European nation, the total fertility rate is now at or below the replacement fertility rate (although some of these nations are still growing because of immigration). What economic or social consequences do you think might result from below-replacement fertility rates? Would you rather live in a society with a growing population, a shrinking population, or a stable population? Why?



(a) Land required to produce 1 kg of protein

(b) Water required to produce 1 kg of protein

(c) Greenhouse gas emissions released in producing 1 kg of protein

FIGURE 10.9 Producing different types of animal products requires different amounts of (a) land and (b) water—and releases different amounts of (c) greenhouse gas emissions. Raising cattle for beef exerts the greatest impacts in all three ways. *Data (a, b) from Smil, V., 2001. Feeding the world: A challenge for the twenty-first century. Cambridge, MA: MIT Press; and (c) from FAO, 2015. Global Livestock Environmental Assessment Model (GLEAM).*

DATA Q Answer the following in terms of protein, pound for pound.

- How many times more land does it take to produce beef than chicken?
- How many times more water does beef require, compared with chicken?
- How many times more greenhouse gas emissions does beef release, relative to chicken?

Go to **Interpreting Graphs & Data** on MasteringEnvironmentalScience®.

UPDATED! DataQs are data analysis questions paired with select figures in each chapter and are designed to help students develop their scientific literacy skills.

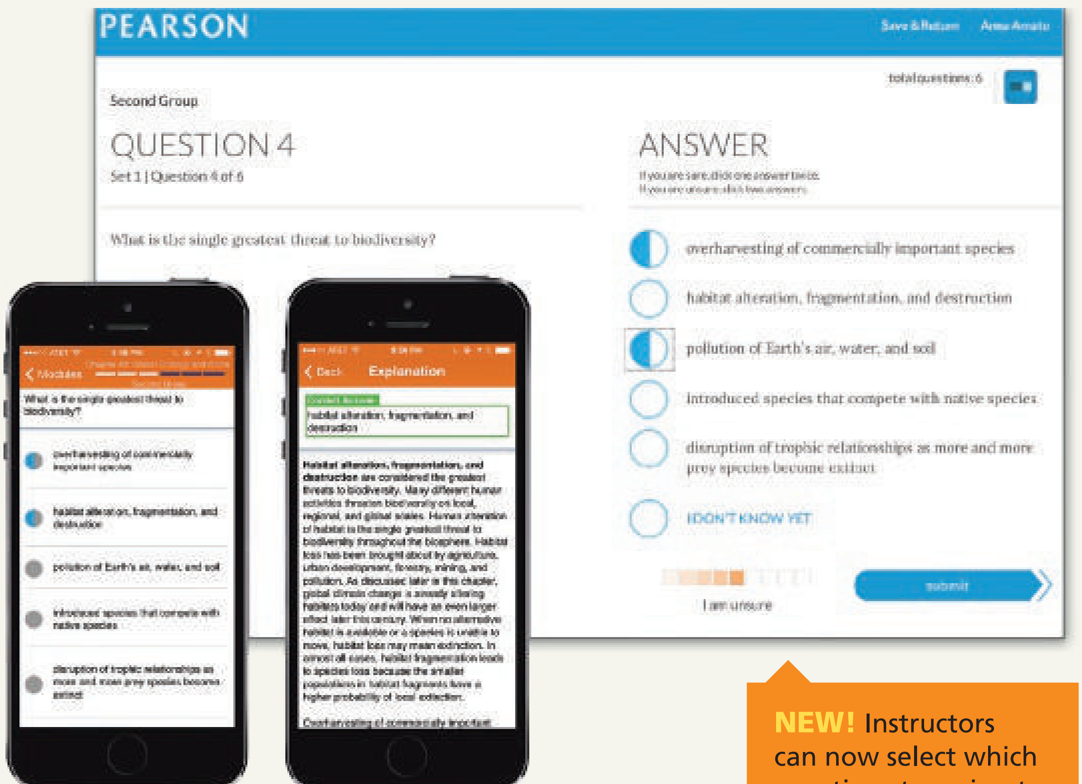
Continuous Learning
Before, During, and After Class

BEFORE CLASS

Give students a preview of what's to come with activities that introduce them to key concepts.

Dynamic Study Modules enable students to study more effectively on their own.

With the **Dynamic Study Modules mobile app,** students can quickly access the concepts they need to be more successful in the course.

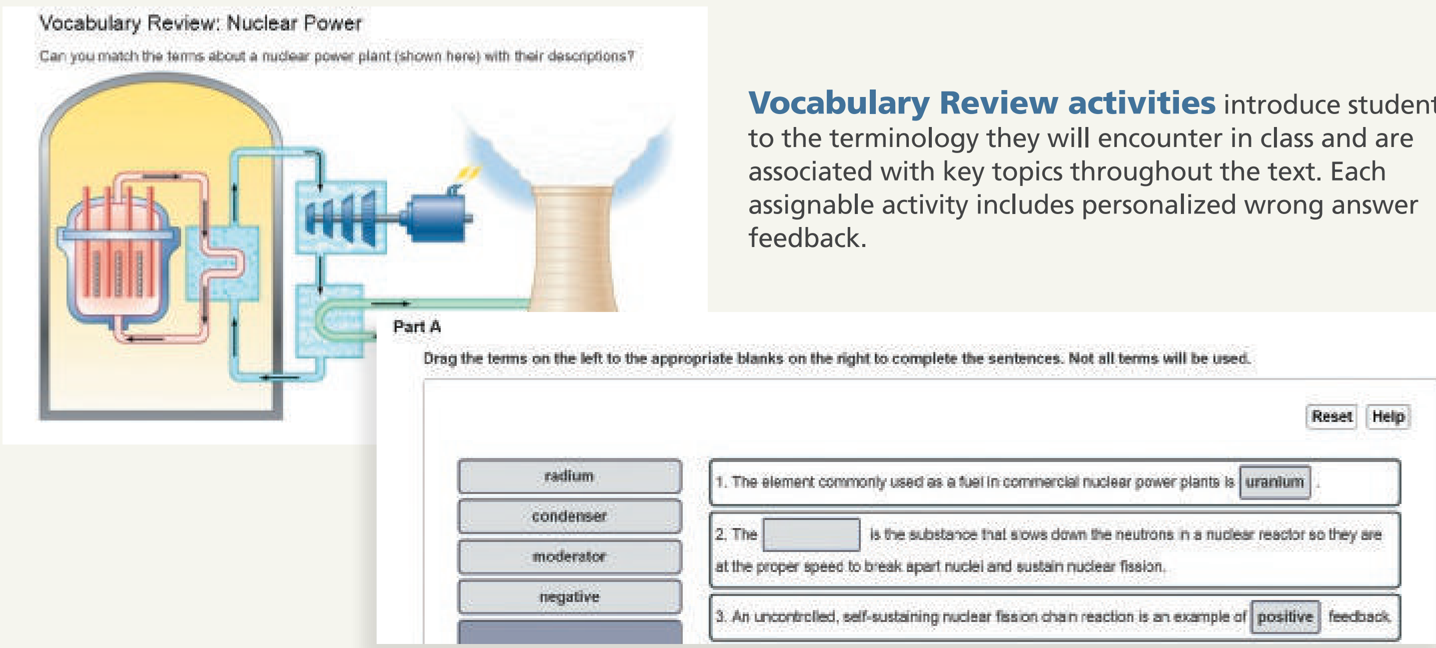


NEW! Instructors can now select which questions to assign to students.

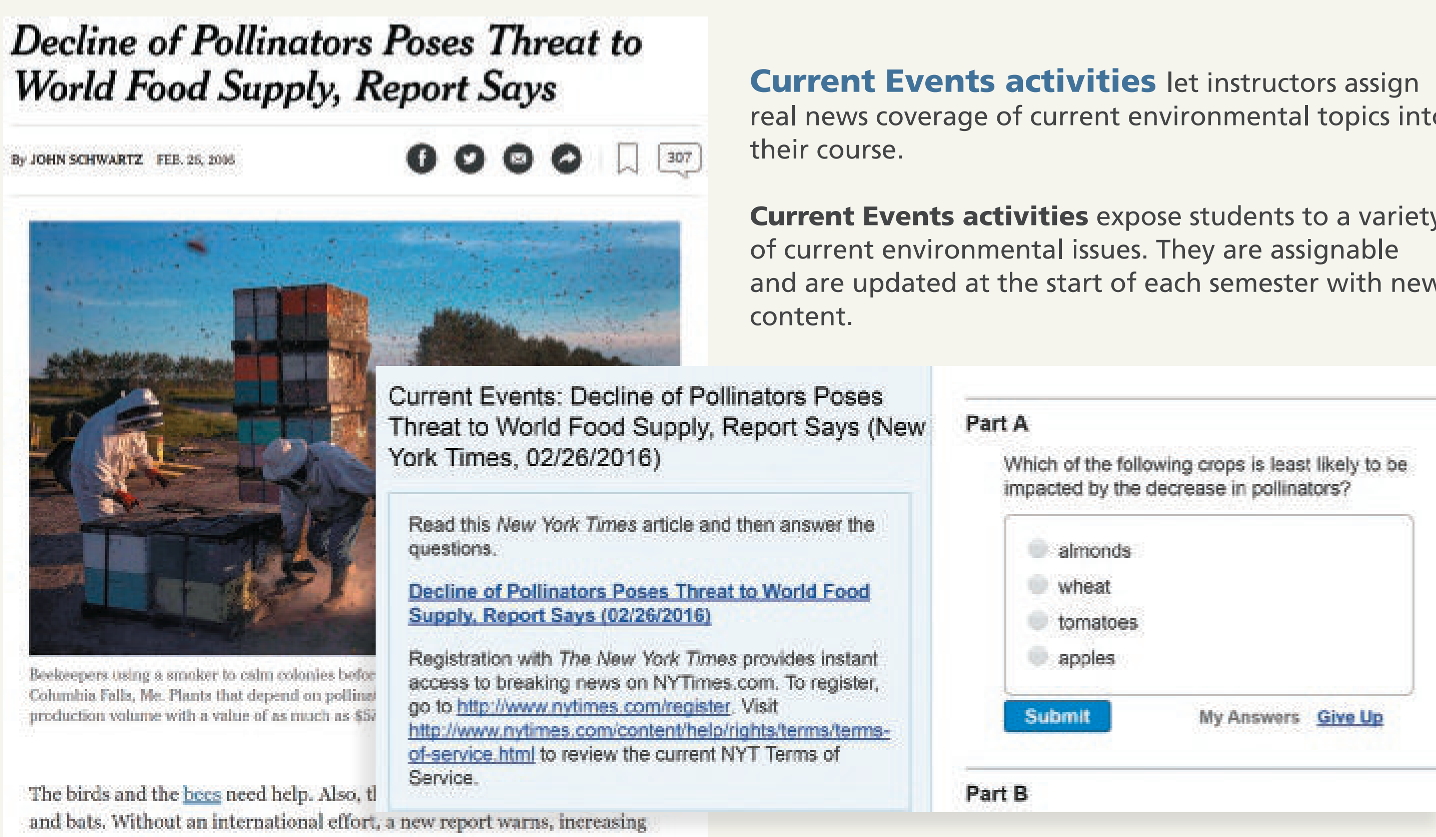
NEW! Case Study Tour Videos use Google Earth and vibrant images to introduce students to each Central Case Study in the text. These dynamic videos bring each story to life and are assignable in Mastering.

with MasteringEnvironmentalScience

MasteringEnvironmentalScience®



Vocabulary Review activities introduce students to the terminology they will encounter in class and are associated with key topics throughout the text. Each assignable activity includes personalized wrong answer feedback.



Current Events activities let instructors assign real news coverage of current environmental topics into their course.

Current Events activities expose students to a variety of current environmental issues. They are assignable and are updated at the start of each semester with new content.

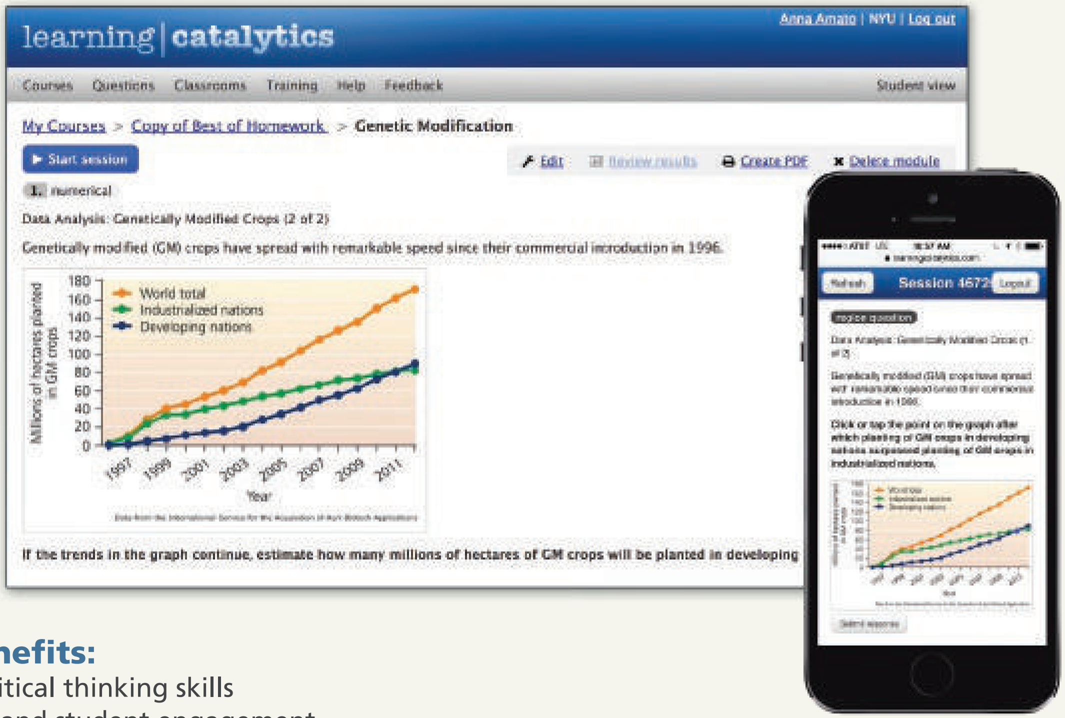
Continuous Learning
Before, During, and After Class

DURING CLASS

Engage students with active learning and video field trips.

Learning Catalytics

is a “bring your own device” engagement, assessment, and classroom intelligence system. Students use their own device (laptop, smartphone, or tablet) to respond to open-ended questions and then discuss answers in groups based on their responses.



Learning Catalytics benefits:

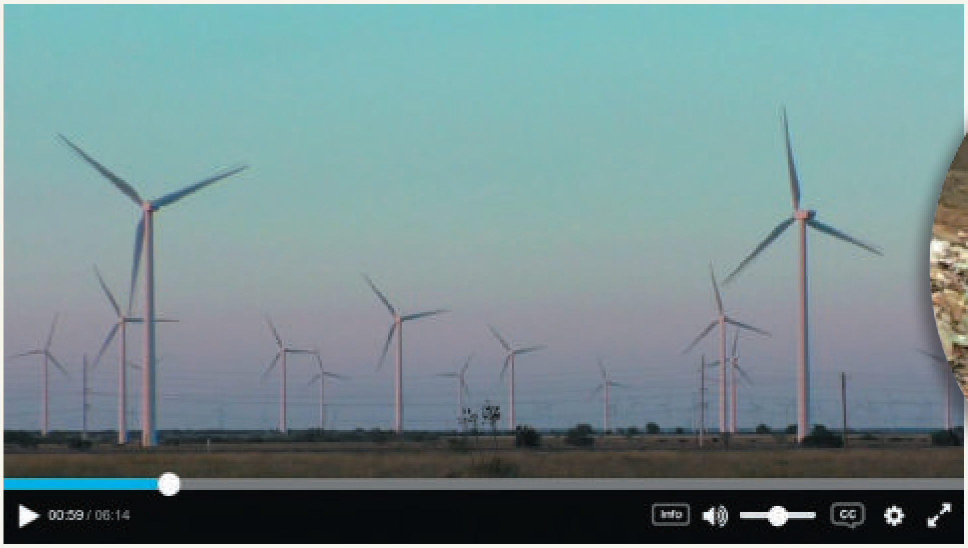
- Developing higher-level critical thinking skills
- Promoting active learning and student engagement
- A team-based approach to learning
- Peer instruction methods
- Understand student misconceptions and adjust teaching in real time

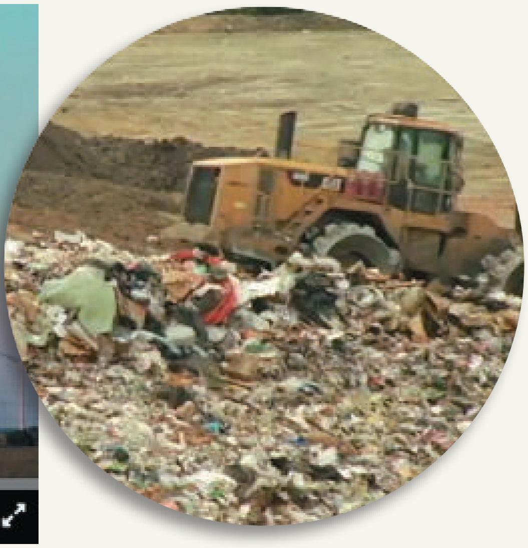
> *“My students are so busy and engaged answering Learning Catalytics questions during lecture that they don’t have time for Facebook.”*
>
> Declan De Paor, *Old Dominion University*

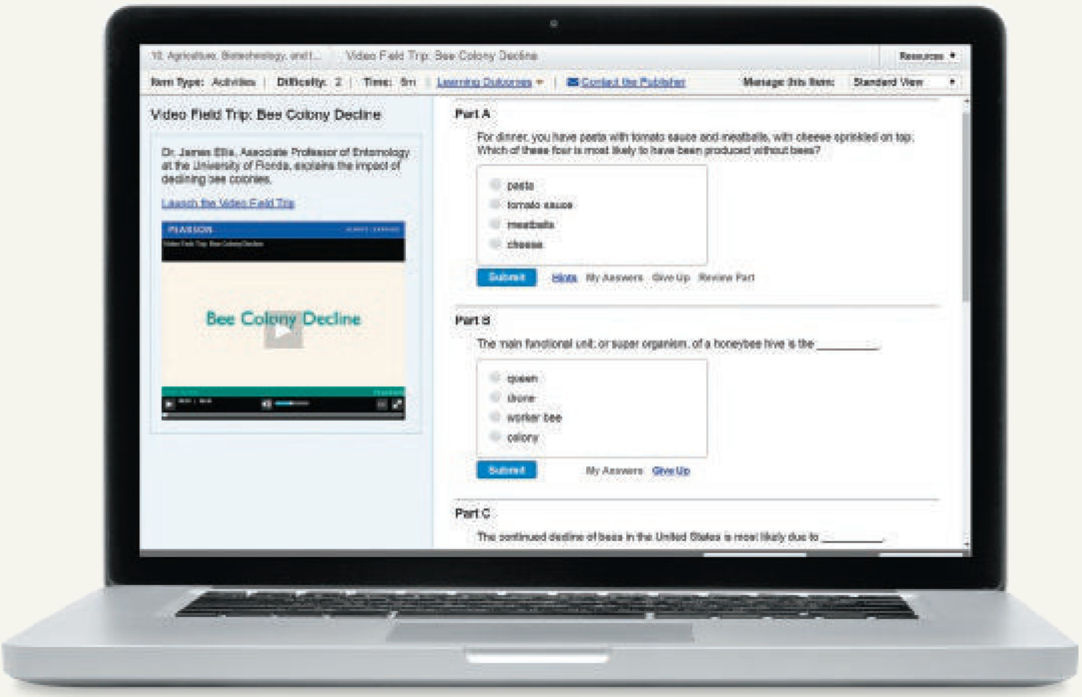
with MasteringEnvironmentalScience

MasteringEnvironmentalScience®

Video Field Trips developed exclusively for Pearson Environmental Science provide fascinating behind-the-scenes tours of real environmental concerns and the strategies and solutions employed to address them. These popular, short videos engage students as they learn about bee colony collapse, take a tour of a water desalination plant, a wind farm, and more.





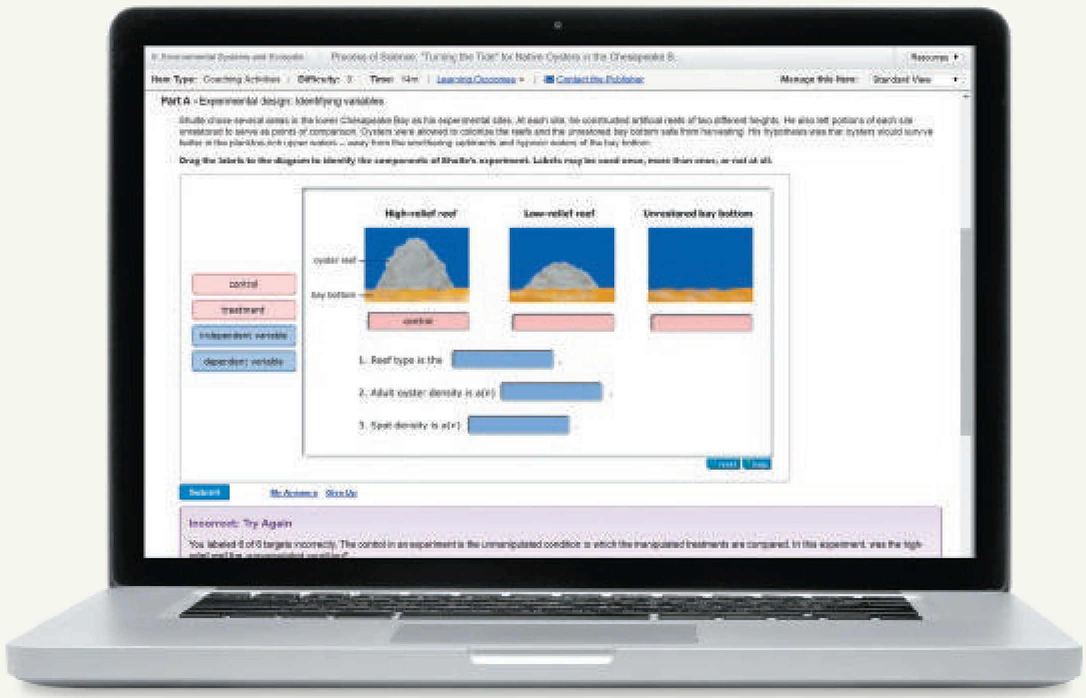


Continuous Learning
Before, During, and After Class

AFTER CLASS

Help students put scientific thinking into practice.

Process of Science coaching activities help students practice the process of science demonstrated in the *Science Behind the Stories* and encourage students to put scientific inquiry skills into action.



Process of Science coaching activities include:

- “Turning the Tide” for Native Oysters in the Chesapeake Bay
- Determining Zebra Mussels’ Impacts on Fish Communities
- Did Soap Operas Reduce Fertility in Brazil?
- Using Forensics to Uncover Illegal Whaling
- And more!

NEW! GraphIt activities are interactive. mobile-friendly and assignable. Each GraphIt will encourage students to graph, interpret and analyze data on topics ranging from agriculture to water availability.

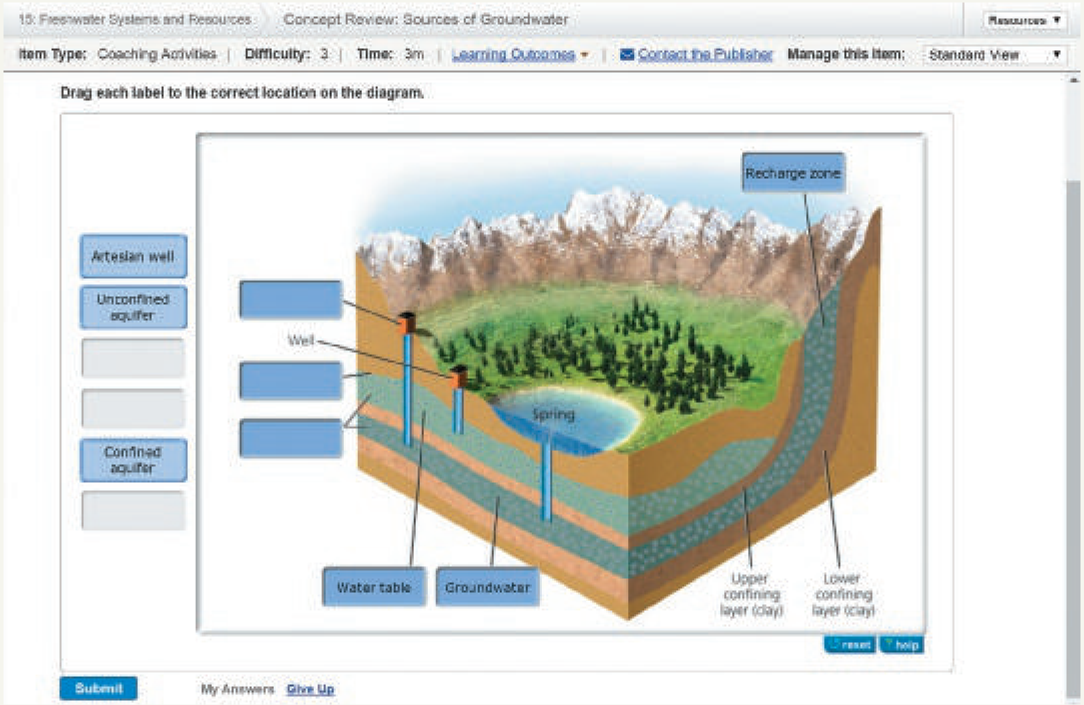
GraphIt topics include:

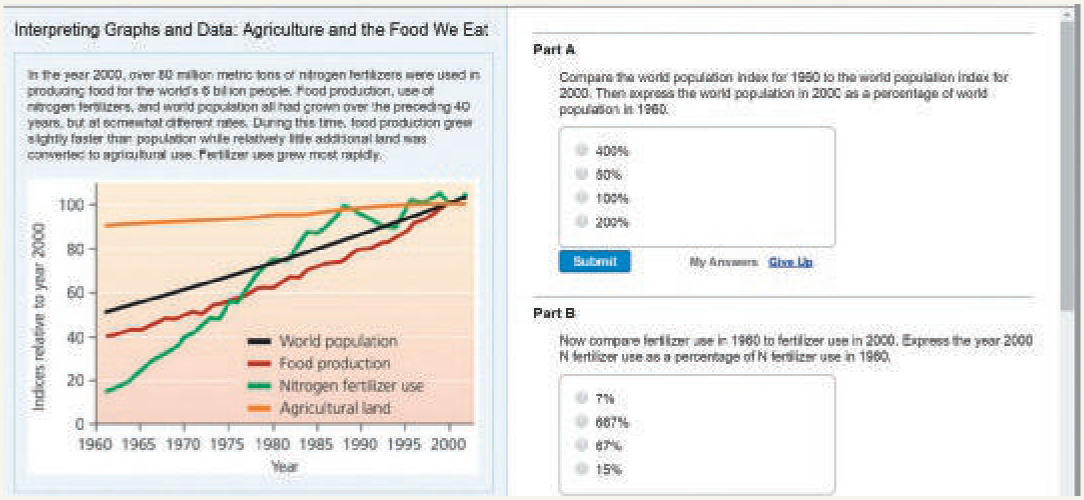
- Agriculture
- Freshwater Availability
- Nutrient Cycling
- Carrying Capacity
- Renewable Energy
- And more!

with MasteringEnvironmentalScience

MasteringEnvironmentalScience®

Concept Review coaching activities created by coauthor Matt Laposata guide students through understanding tough topics.





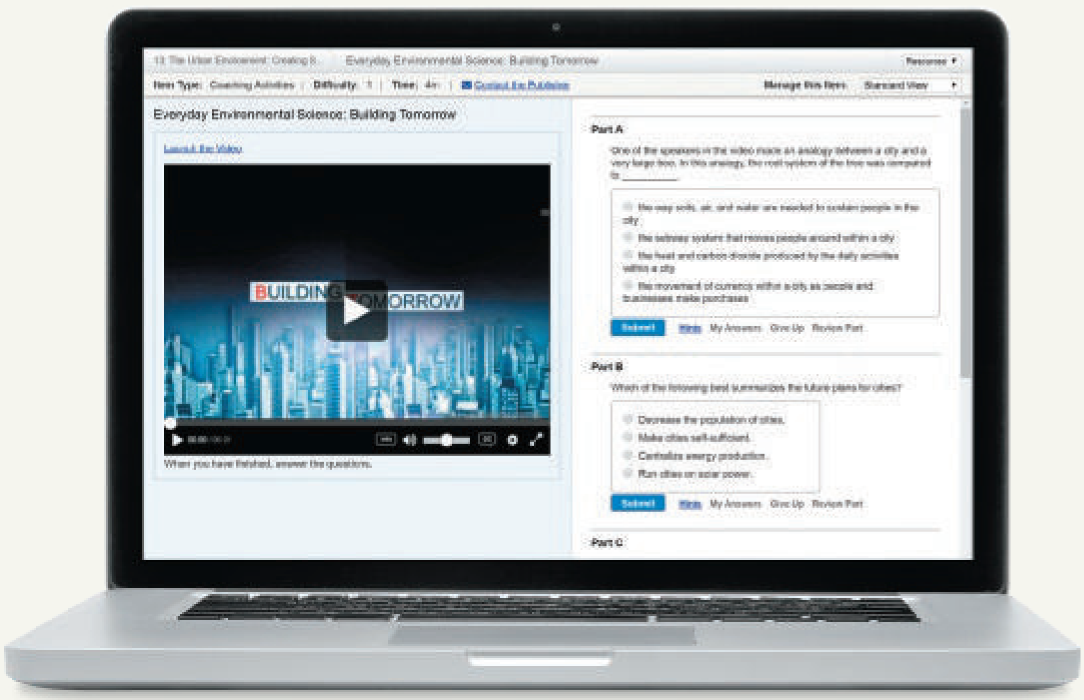
NEW and EXPANDED! Interpreting Graphs and Data activities help students practice quantitative literacy and scientific reasoning skills. Each activity includes personalized feedback for wrong answers.

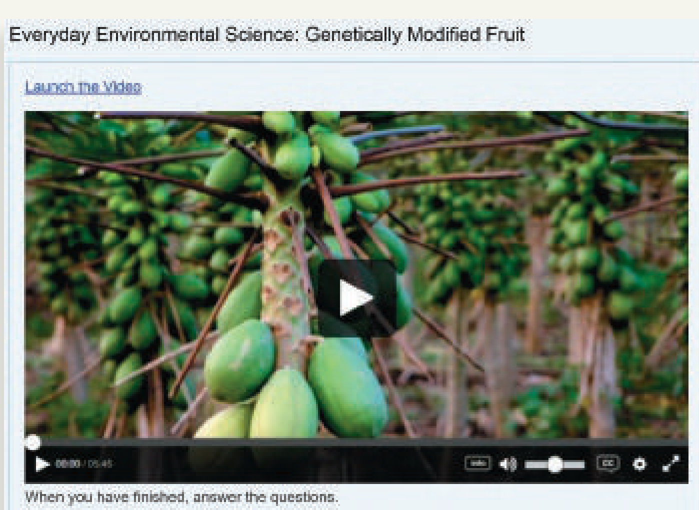
MasteringEnvironmentalScience®

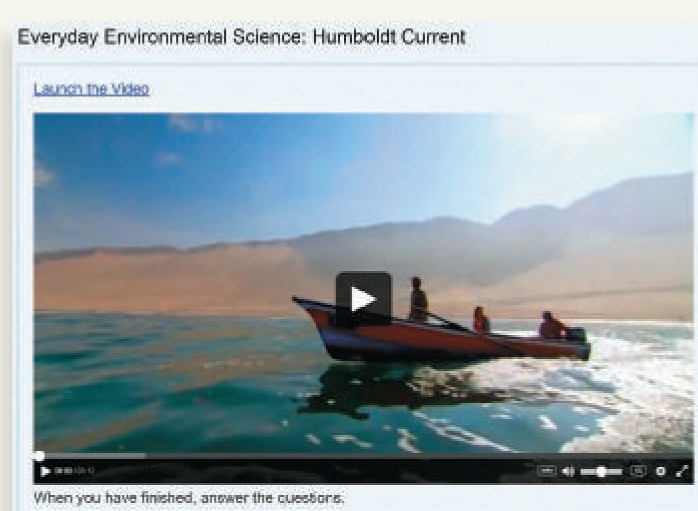
MasteringEnvironmentalScience delivers engaging, dynamic learning opportunities—focusing on course objectives and responsive to each student's progress—that are proven to help students absorb course material and understand challenging environmental processes and concepts.

NEW! Everyday Environmental Science video activities connect course topics with current stories in the news.

Produced by the BBC, these high-quality videos highlight current environmental issues and can be assigned for pre- and post-lecture homework, or can be shown in class to engage students in the topic at hand.







Access the complete textbook online or offline with eText 2.0

NEW! The **Sixth Edition** is available in Pearson's fully-accessible eText 2.0 platform, live for Fall 2017 classes.

NEW! The eText 2.0 mobile app offers offline access and can be downloaded for most iOS and Android phones and tablets from the iTunes or Google Play stores.

Powerful interactive and customization functions include night mode, seamlessly integrated video and other rich media, instructor and student note-taking, highlighting, bookmarking, search, and links to glossary terms.

Accessible (screen-reader ready).

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.

Development editors Sonia DiVittorio and Debbie Hardin provided structure for our work and beauty and coherence for our chapter layouts. Their careful edits, along with those of Jennifer Angel, ensured clarity and accuracy in content. Project managers Brett Coker and Margaret Young choreographed the delicate scheduling dance required for timely project completion. As program manager, Anna Amato managed the complex logistics inherent to an endeavor of this size. Media producer Chloe Veylit managed the many moving parts of the *MasteringEnvironmentalScience* course for this new edition, including production of our new *GraphIt* activities—with help from instructional designer Sarah Young Dualan and executive media producer Laura Tommasi. Executive editor Alison Rodal facilitated the interactions of the editorial team and effectively collaborated with marketing managers Christa Pesek Pelaez and Mary Salzman, as well as the many sales representatives across the country, to communicate our vision, deliver our text to instructors, and work with instructors to ensure their satisfaction.

Editorial assistant Alison Cagle provided timely and effective assistance, while executive editorial manager Ginnie Simione Jutson oversaw our development needs. Bonnie Boehme provided meticulous copy editing of our text, and photo researcher Kristin Piljay helped secure quality photos. Wynne Au Yeung and Alicia Elliot of Imagineering did an exceptionally good job overseeing production of the art program, and Lisa Buckley designed our engaging new textbook style. Senior production manager Norine Strang worked with our compositor to help guide our book through production. We wish to thank our editor-in-chief Beth Wilbur for her continued support of this book through its six editions and for helping to invest the resources that our books enjoy.

As always, a select number of top instructors from around North America produced the supplementary materials that support the text. Our thanks go to Danielle DuCharme for updating our Instructor's Guide, to Todd Tracy 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 also wish to thank Shamili Sandiford for her creativity and effort in developing the *GraphIt* activities, and Stephan Fitzpatrick, Karyn Alme, and Donna Bivans for their work on *MasteringEnvironmental Science*.

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.

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 endured this book's writing and revision over the years with patience and understanding, and who has provided caring support throughout. 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 enriching his existence with love, joy, and wisdom—and for providing him a lifetime of experiences that would have been impossible without her. 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 sixth edition the best it could be. Their efforts built on those of the roughly 600 instructors and outside experts who have reviewed material for the previous five editions of this book through chapter reviews, pre-revision reviews, feature consultation, student reviews, class testing, and focus groups. Our sincere gratitude goes out to all of them.

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environment

THE SCIENCE BEHIND THE STORIES

6TH EDITION

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PART 1

Foundations of Environmental Science

The view from Preikestolen (Pulpit Rock) in Norway

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.

Upon completing this chapter, you will be able to:

- Describe the field of environmental science
- Compare renewable and nonrenewable resources, and 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
- Identify and illustrate major pressures on the global environment
- Discuss the concept of sustainability, and cite sustainable solutions being pursued on campuses and in the wider world

Our environment surrounds us

A photograph of Earth 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 of Earth 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 first, most narrow 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 utterly on our environment for air, water, food, shelter, and everything else essential for life. 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 particular moment in history is an exciting time to be alive—and to be studying environmental science.

(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 that 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 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. 116–117, 148–149).

Just as we may deplete natural resources, we may degrade ecosystem services when, for example, we destroy habitat or generate pollution. In recent 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 *billion* people. **FIGURE 1.3** shows just how recently and suddenly this monumental change has taken place. For every one person who used to exist more than 10,000 years ago, several thousand people exist today!

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.

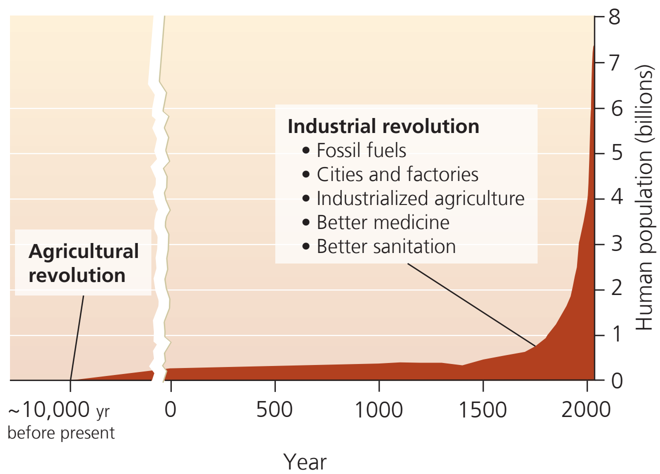


FIGURE 1.3 The global human population increased after the agricultural revolution and then skyrocketed as a result of the industrial revolution. Note that the tear in the graph represents the passage of time and a change in *x*-axis values. *Data compiled from U.S. Census Bureau, U.N. Population Division,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

DATA Q For every person alive in the year 1800, about how many people 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 MasteringEnvironmentalScience®.

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 including oil, coal, and natural gas; pp. 521–523). 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. 212, 238).

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 7 billion of us—or the 9 billion 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 the material affluence of many of the world's people. In the process, however, we have 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

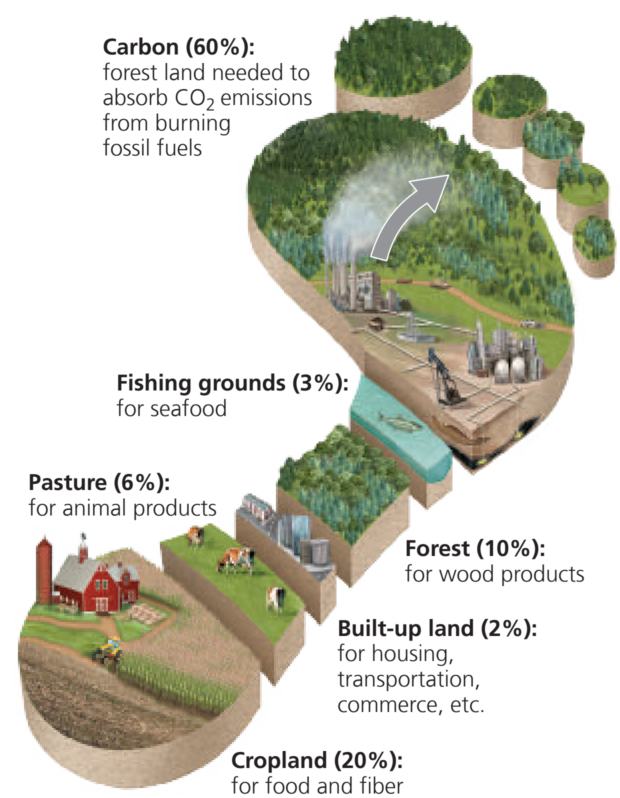


FIGURE 1.4 An ecological footprint shows the total area of biologically productive land and water used by a given person or population. Shown is a breakdown of major components of the average person's footprint. *Data from Global Footprint Network, 2016.*

biologically productive surface that a given person or population "uses" once all direct and indirect impacts are summed together.

For humanity as a whole, Wackernagel and his colleagues at the Global Footprint Network calculate that our species is now using 64% more of the planet's renewable resources than are available on a sustainable basis. That is, we are depleting renewable resources by using them 64% faster than they are being replenished. To look at this another way, it would take 1.64 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**).

Some scientists have criticized the methods by which the Global Footprint Network calculates footprints, and many question how well its methods measure overshoot. Indeed, any attempt to boil down complicated issues to a single number is fraught with peril, 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, humanity would need the equivalent of four planet Earths!

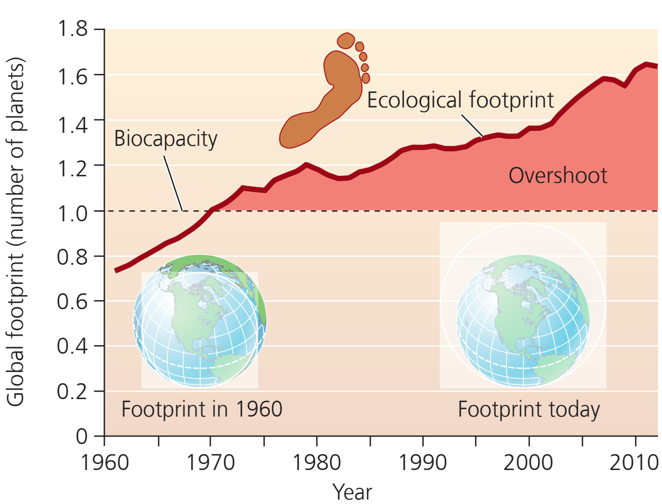


FIGURE 1.5 Analyses by one research group indicate that we have overshot Earth's biocapacity—its capacity to support us—by 64%. We are using renewable natural resources 64% faster than they are being replenished. *Data from Global Footprint Network, 2016.*

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

Go to **Interpreting Graphs & Data** on MasteringEnvironmentalScience®.

Conserving Earth's 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 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 this 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 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 aim to comprehend how Earth's natural systems function, how these systems affect people, and how we influence those systems. Many environmental scientists are motivated by a desire to develop solutions to environmental problems. These solutions (such as new technologies, policy decisions, or resource management strategies) are *applications* of environmental science. The study of such applications and their consequences is 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, 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.

An interdisciplinary approach to addressing environmental problems can produce effective solutions for society. For example, we used to add lead to gasoline to make cars run more smoothly, even though research showed that lead emissions from tailpipes caused health problems, including brain damage and premature death. In 1970 air pollution was severe in many American cities, and motor vehicles accounted for 78% of U.S. lead emissions. In response, environmental scientists, engineers, medical researchers, and policymakers all merged their knowledge and skills into a process that eventually brought about a ban on leaded gasoline. By 1996 all gasoline sold in the United States was unleaded, and the nation's largest source of atmospheric lead pollution had been completely eliminated.

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.

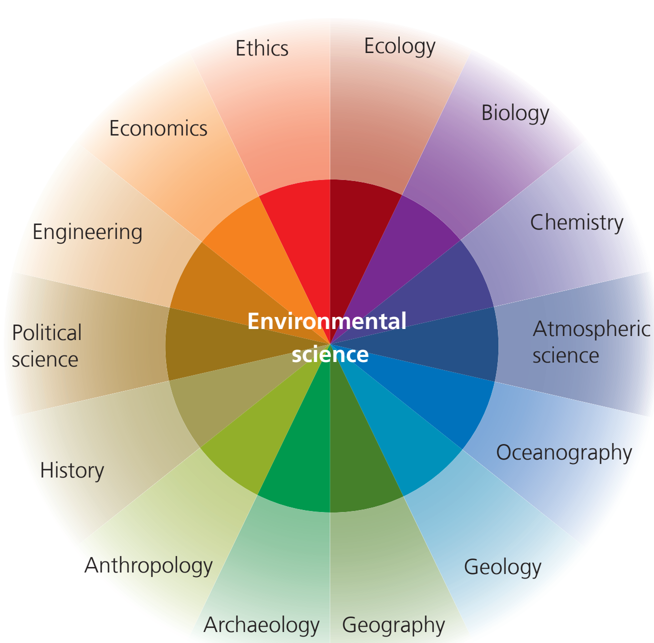


FIGURE 1.6 Environmental science is an interdisciplinary pursuit. It draws from many different established fields of study across the natural sciences and social sciences.

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.

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

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 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 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 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. 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 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. 24) 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 that previous researchers viewed 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 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.

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

(a) Prescribed burning

(b) An electric car

FIGURE 1.7 Scientific knowledge is applied in engineering and technology and in policy and management decisions. Prescribed burning **(a)** is a forest management practice informed by ecological research. Energy-efficient electric automobiles **(b)** are technological advances made possible by materials and energy research.

or to inform policy and management decisions (**FIGURE 1.7**). 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 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.

The scientific method is a traditional approach to research

The **scientific method** is a technique for testing ideas with observations. There is nothing mysterious or intimidating about the scientific method; it is merely a formalized version of the way any of us might naturally use logic to resolve a question. Because science is an active, creative process, innovative researchers may depart from the traditional scientific method when particular situations demand it. Moreover, scientists in different fields approach their work differently because they deal with dissimilar types of information. Nonetheless, scientists of all persuasions broadly agree on fundamental elements of the process of scientific inquiry. As practiced by individual researchers or research teams, the scientific method (**FIGURE 1.8**) typically follows the steps outlined below.

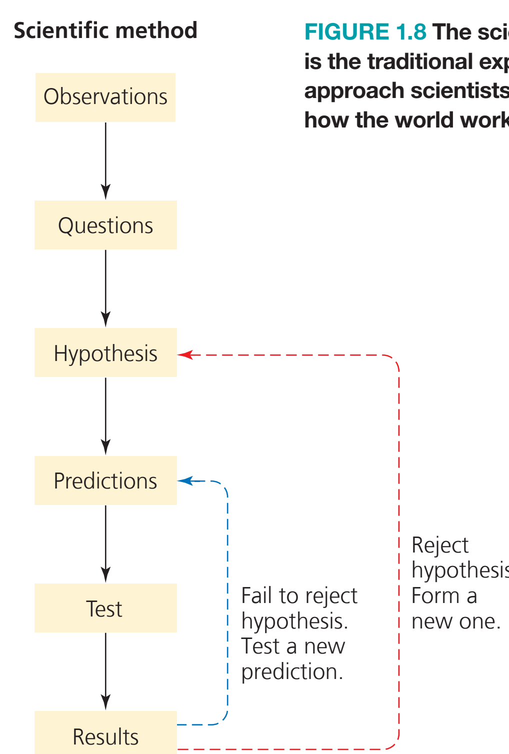


FIGURE 1.8 The scientific method is the traditional experimental approach scientists use to learn how the world works.

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

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

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 attempts to control 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.

FIGURE 1.9 Researchers gather data to test predictions in experiments. Here, a scientist samples algae from a pond.

Analyze and interpret results Scientists record **data,** or information, from their studies (**FIGURE 1.9**). Researchers particularly value quantitative data (information expressed using numbers), because numbers provide precision and are easy to compare. The scientist conducting the fertilization experiment, for instance, might quantify the area of water surface covered by algae in each pond or might measure the dry weight of algae in a certain volume of water taken from each. It is vital, however, to collect data that are representative. Because it is impractical to measure a pond's total algal growth, our researcher might instead sample from multiple areas of each pond. These areas must be selected in a random manner; choosing areas with the most growth or the least growth, or areas most convenient to sample, would not provide a representative sample.

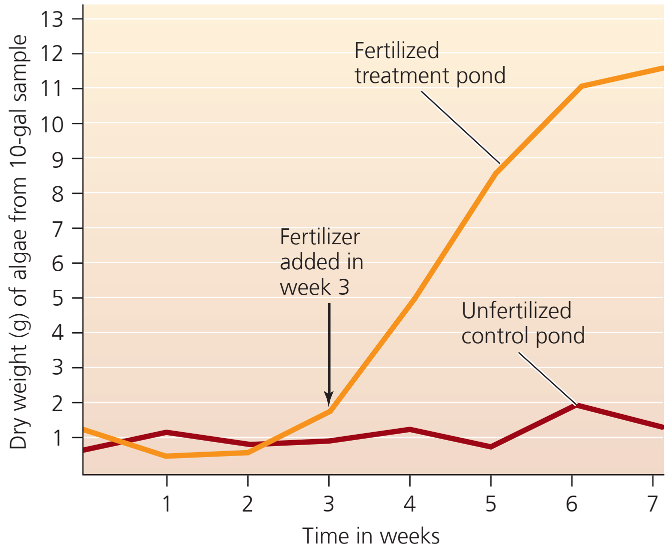
To summarize and present the data they obtain, scientists often use graphs. Graphs help to make patterns and trends in the data visually apparent and easy to understand. **FIGURE 1.10** (on page 12) shows just a few examples of how different types of graphs can be used to present data. Each of these types of graphs is explained further in **APPENDIX B: HOW TO INTERPRET GRAPHS** at the back of this book. The ability to interpret graphs is a skill you will find useful throughout your life. We encourage you to consult Appendix B closely as you begin your environmental science course.

You also will note that many of the graphs in this book are accompanied by "DATA Q" questions to help you build your graph-reading skills. You can check your answers to these questions by referring to **APPENDIX A: ANSWERS TO DATA ANALYSIS QUESTIONS** at the back of this book.

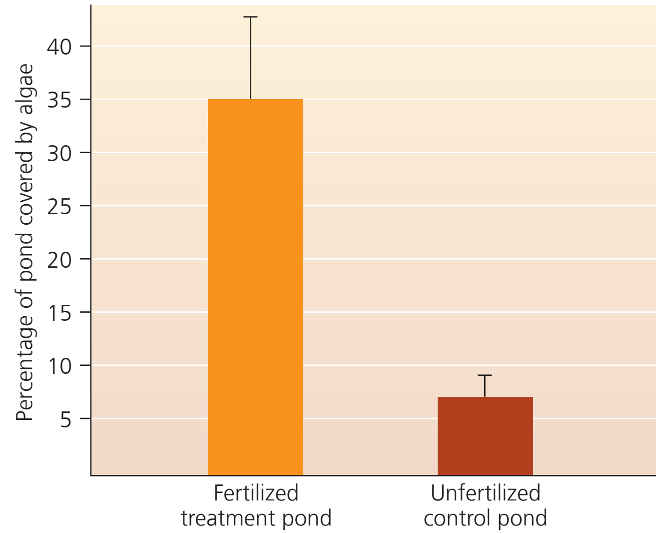
Even with the precision that numerical data provide, experimental results may not be clear-cut. Data from treatments and controls may vary only slightly, or replicates may yield different results. Researchers must therefore analyze their data using statistical tests. With these mathematical methods, 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 1.8).

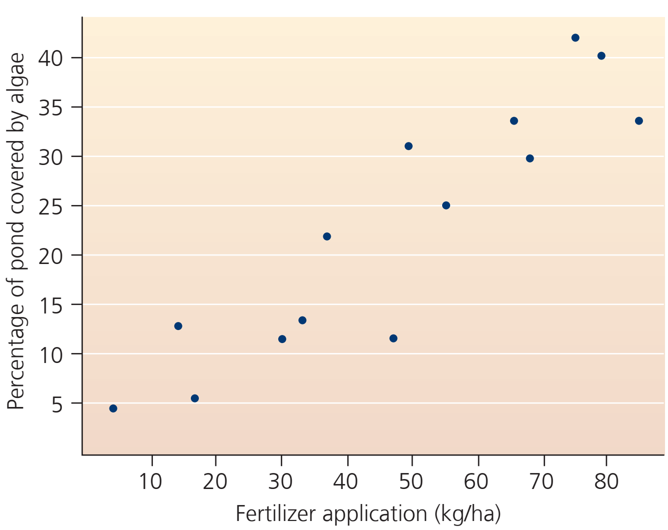
If repeated tests fail to reject a hypothesis, evidence in favor of it accumulates, and the researcher may eventually



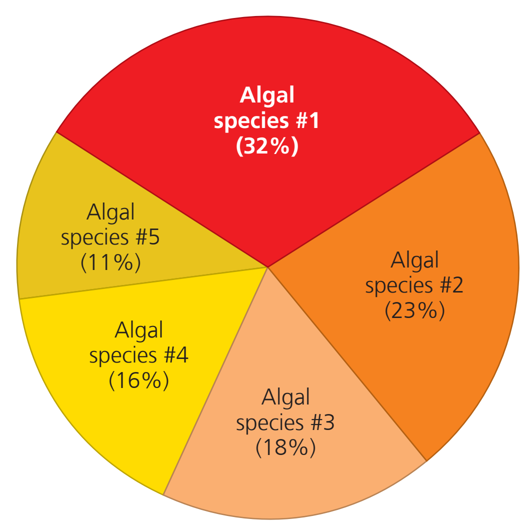
(a) Line graph of algal density through time in a fertilized treatment pond and an unfertilized control pond



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



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



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

FIGURE 1.10 Scientists use graphs to present and visualize their data. For example, in **(a)**, a line graph shows how the amount of algae increased when fertilizer was added to a treatment pond in an experiment yet stayed the same in an unfertilized control pond. In **(b)**, a bar chart shows how fertilized ponds, on average, have several times more algae than unfertilized ponds. In **(c)**, a scatter plot shows how ponds with more fertilizer tend to contain more algae. In **(d)**, a pie chart shows the relative abundance of five species of algae in a sample of pond water. See **APPENDIX B** to learn more about how to interpret these types of graphs.

DATA Q

- In part **(a)**, is time in weeks shown on the *x* axis or the *y* axis?
- In part **(b)**, what is the dependent variable?
- In part **(c)**, do the data show a positive correlation or a negative correlation?
- In part **(d)**, which species is most numerous? Which is least numerous?
- What are the thin black lines atop the colored bars in part **(b)** called? Explain what these lines indicate.

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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 18), we cannot run a manipulative experiment adding carbon dioxide to 10 treatment planets and 10 control planets and then compare the results! Thus, it is common for researchers to run *natural experiments*, which compare how dependent variables are expressed in naturally occurring, but different, contexts. In such experiments, the independent variable varies naturally, and researchers test their hypotheses by searching for **correlation,** or statistical association among variables.

For instance, let's suppose our scientist studying algae surveys 50 ponds, 25 of which happen to be fed by fertilizer runoff from nearby farm fields and 25 of which are not. Let's say 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 on large scales, they must be addressed with correlative data. As such, environmental scientists cannot always provide black-and-white 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.

The scientific process continues beyond the scientific method

Scientific research takes place within the context of a community of peers. To have impact, a researcher's work must be published and made accessible to this community (**FIGURE 1.11**).

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

Peer review is a valuable guard against faulty research contaminating the literature (the body of published studies) on which all scientists rely. However, because scientists are human, personal biases and politics can sometimes creep into the review process. Fortunately, just as individual scientists strive to remain objective in conducting their research, the scientific community does its best to ensure fair review of all work.

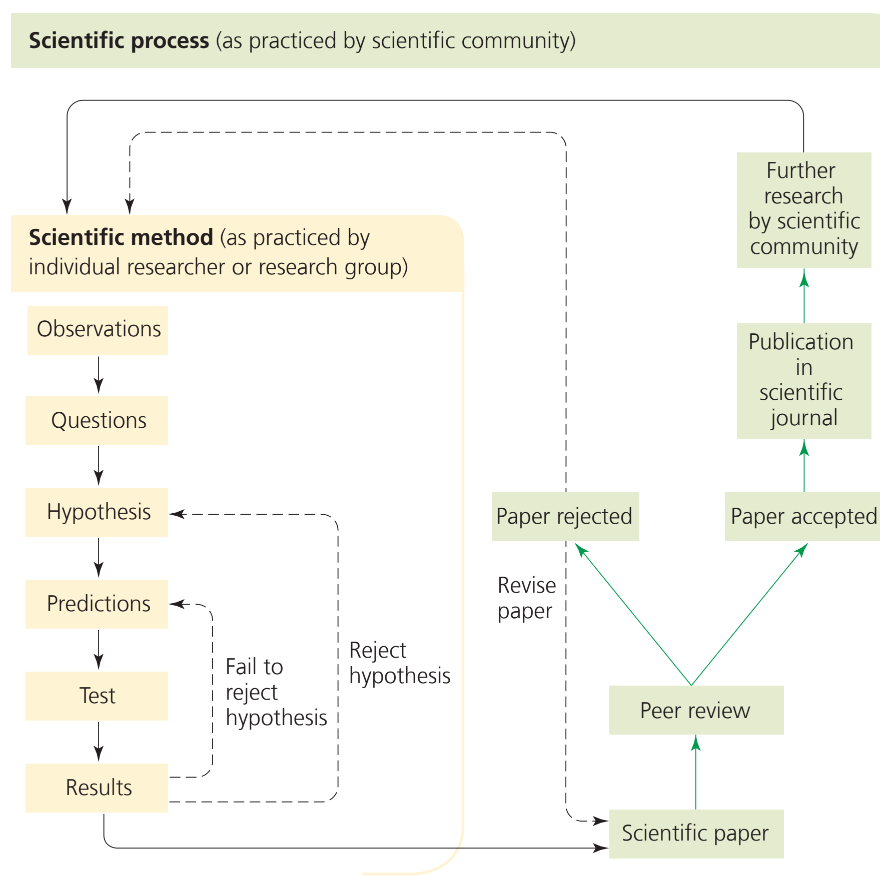

FIGURE 1.11 The scientific method that research teams follow is part of a larger framework—the overall process of science carried out by the scientific community. This process includes peer review and publication of research, acquisition of funding, and the elaboration of theory through the cumulative work of many researchers.

Note that scientists are not paid money for peer review; their services are entirely voluntary. Moreover, researchers generally have to pay the journals that publish their papers.

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

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

Scientists' reliance on funding sources can occasionally lead to conflicts of interest. A researcher who obtains data showing his or her funding source in an unfavorable light may be reluctant to publish the results for fear of losing funding—or, worse yet, could be tempted to doctor the results. This situation can arise, for instance, when an industry funds research to test its products for health or safety. Most scientists resist these pressures, but whenever you are assessing a scientific study, it is always a good idea to note where the researchers obtained their funding.

weighing the ISSUES

Follow the Money

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

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

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

Note that scientific use of the word *theory* differs from popular usage of the word. In everyday language when we say something is "just a theory," we are suggesting it is a speculative idea without much substance. However, scientists mean just the opposite when they use the term. In a scientific context, a theory is a conceptual framework that explains a phenomenon and has undergone extensive and rigorous testing, such that confidence in it is extremely strong.

For example, Darwin's theory of evolution by natural selection (pp. 48–49) has been supported and elaborated by many thousands of studies over 160 years of intensive research. Observations and experiments have shown repeatedly and in great detail how plants and animals change over generations, or evolve, expressing characteristics that best promote survival and reproduction. Because of its strong support and explanatory power, evolutionary theory is the central unifying principle of modern biology. Other prominent scientific theories include atomic theory, cell theory, big bang theory, plate tectonics, and general relativity.

Science goes through paradigm shifts

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

Another paradigm shift occurred in the 1960s, when geologists accepted plate tectonics (p. 32). By this time, evidence for the movement of continents and the action of tectonic plates had accumulated and become overwhelmingly convincing. Paradigm shifts demonstrate the strength and vitality of science, showing science to be a process that refines and improves itself through time.

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

Sustainability and Our Future

Throughout this book you will encounter environmental scientists asking questions, testing hypotheses, conducting experiments, analyzing data, and drawing conclusions about the causes and consequences of environmental change. Environmental scientists, who study the condition of our environment and the nature of our impacts, are addressing the most centrally important issues of our time.

Achieving sustainable solutions is vital

Society's primary challenge today is finding how to live within our planet's means, such that Earth and its resources can sustain us—and all life—for the future. This is the challenge of **sustainability,** a guiding principle of modern environmental science and a concept you will encounter throughout this book. Sustainability means leaving our children and grandchildren a world as rich and full as the world we live in now. It means conserving Earth's resources so that our descendants may enjoy them as we have. It means developing solutions that work in the long term. Sustainability requires maintaining fully functioning ecological systems, because we cannot sustain human civilization without sustaining the natural systems that nourish it.

Population and consumption drive environmental impact

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

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

The world's citizens have not benefited equally from society's overall rise in affluence. Today the 20 wealthiest nations boast more than 55 times the per capita income of the 20 poorest nations—three times the gap that existed just two generations ago. Within the United States, the richest 10% of citizens now claim half of the total income and more than 70% of the total wealth. The ecological footprint of the average citizen of a developed nation such as the United States is considerably larger than that of the average resident of a developing country (**FIGURE 1.12**).

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

The most comprehensive scientific assessment of the condition of the world's ecological systems and their capacity to continue supporting our civilization was completed in 2005, when more than 2000 leading environmental scientists from nearly 100 nations completed the Millennium Ecosystem

FIGURE 1.12 People of some nations have much larger ecological footprints than people of others. Shown are ecological footprints for average citizens of several nations, along with the world's average per capita footprint of 2.7 hectares. One hectare (ha) = 2.47 acres. *Data from WWF, 2014.* Living planet report 2014. *Gland, Switzerland: WWF International.*

DATA Q Which nation shown here has the largest footprint? How many times larger is it than that of the nation shown here with the smallest footprint?

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Ecological Footprints

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

TABLE 1.1 Main Findings of the Millennium Ecosystem Assessment

- Over the past 50 years, people have altered ecosystems more rapidly and extensively than ever, largely to meet growing demands for food, fresh water, timber, fiber, and fuel. This has caused a substantial and largely irreversible loss in the diversity of life on Earth.
- Changes to ecosystems have contributed to substantial net gains in human well-being and economic development. However, these gains have been achieved at growing costs, including the degradation of ecosystems and the services they provide and, for some people, the worsening of poverty.
- This degradation could grow significantly worse during the first half of this century.
- We can reverse the degradation of ecosystems while meeting increasing demands for their services, but doing so will require that we significantly modify many policies, institutions, and practices.

Adapted from Millennium Ecosystem Assessment, 2005. *Ecosystems and human well-being: biodiversity synthesis.* Washington, D.C.: World Resources Institute.

Assessment (**TABLE 1.1**). The Millennium Ecosystem Assessment makes clear that our degradation of environmental systems is causing harm—but that with care and diligence we can still reverse many of these trends and restore health to the natural systems that support us.

Energy choices will shape our future

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

However, in extracting coal, oil, and natural gas, we are splurging on a one-time bonanza, because these fuels are nonrenewable and in finite supply. Attempts to reach further for new fossil fuel sources all seem to threaten more impacts for relatively less fuel. The energy choices we make now will greatly influence the quality of our lives for the rest of the 21st century and beyond.

Sustainable solutions abound

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

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

These are a few of the many efforts we will examine while exploring sustainable solutions in the course of this book.

Students are promoting solutions on campus

As a college student, you can help to design and implement sustainable solutions on your own campus. Proponents of **campus sustainability** seek ways to help colleges and universities reduce their ecological footprints. Although we tend to think of colleges and universities as enlightened and progressive institutions that benefit society, they also are centers of lavish resource consumption. Classrooms, offices, research labs, residence halls, dining halls, sports arenas, and vehicle fleets all consume resources and generate waste. Together the 4500 campuses in the United States spend $400 billion each year on products and services and generate about 2% of U.S. carbon emissions. Reducing the ecological footprint of a campus can be challenging, but students, faculty, staff, and administrators on thousands of campuses are working together to make the operations of educational institutions more sustainable (**FIGURE 1.13**).

Students are running recycling programs, planting trees and restoring native plants, growing organic gardens, and fostering sustainable dining halls. They are finding ways to improve energy efficiency and water conservation and are pressing for new buildings to meet certification guidelines for sustainable construction. To help address climate change, students are urging their institutions to reduce greenhouse gas emissions, divest from fossil fuel corporations, and use and invest in renewable energy.

In response, nearly 700 university presidents have signed onto the American College and University Presidents' Climate Commitment—a public pledge to inventory emissions, set target dates and milestones for becoming carbon-neutral, take immediate steps to lower emissions, and integrate sustainability into the curriculum.

In our final chapter and throughout this book you will encounter examples of campus sustainability efforts (for example, pp. 209, 605, and 649). Should you wish to pursue such efforts on your own campus, information and links available in the **SELECTED SOURCES AND REFERENCES** at the back of this book point you toward organizations and resources that can help.

(a) Urging divestment from fossil fuels (b) Recycling at Davidson College (c) Promoting energy efficiency at Amherst College

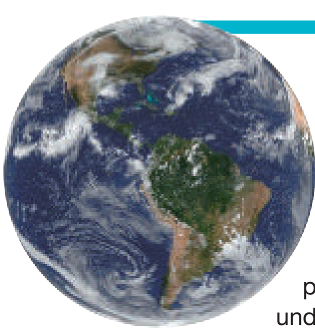
FIGURE 1.13 **Students are helping to make their campuses more sustainable in all kinds of ways.**

Environmental science prepares you for the future

By taking a course in environmental science, you are preparing yourself for a lifetime in a world increasingly dominated by concerns over sustainability.

The course for which you are using this book right now likely did not exist a generation ago. But as society's concerns have evolved, colleges and universities have adapted their academic curricula. As our society comes to appreciate the challenges of creating a sustainable future, colleges and universities are helping students learn how to confront these challenges.

Yet at most schools, fewer than half of students take even a single course on the basic functions of Earth's natural systems, and still fewer take courses on the links between human activity and sustainability. As a result, many educators worry that most students graduate lacking **environmental literacy,** a basic understanding of Earth's physical and living systems and how we interact with them. By taking an environmental science course, you join a privileged minority, benefiting from a valuable education that most of your peers are missing. Your course will equip you with a better understanding of how the world works. You will be better qualified for the green-collar job opportunities of today and tomorrow. And you will be better prepared to navigate the many challenges of creating a sustainable future.



closing THE LOOP

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

REVIEWING Objectives

You should now be able to:

Describe the field of environmental science

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

Compare renewable and nonrenewable resources, and explain the importance of natural resources and ecosystem services to our lives

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

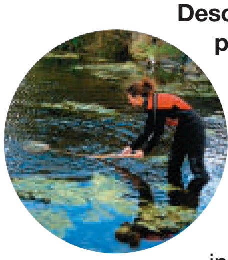
Discuss population growth, resource consumption, and their consequences

Today's human population size and per-person level of resource consumption both are higher than ever. Population growth magnifies our environmental impact by adding to the number of people putting demands on resources. Growing per capita consumption amplifies our environmental impact by increasing the demand each person makes on resources. (pp. 4–6)

Explain what is meant by an ecological footprint

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

Describe the scientific method and the process of science



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

Identify and illustrate major pressures on the global environment

Rising population and intensifying consumption magnify human impacts on the environment, which include resource depletion, air and water pollution, climate change, habitat destruction, and biodiversity loss. (pp. 14–16)

Discuss the concept of sustainability, and cite sustainable solutions being pursued on campuses and in the wider world

Sustainability is a term that describes living within our planet's means, such that Earth's resources can sustain us—and all life—for the future. Today we are actively developing sustainable solutions (such as replacing fossil fuels with renewable energy) that promote our quality of life while protecting and restoring our environment. Many college students are taking action to promote sustainable solutions on their campuses, including recycling, energy efficiency, water conservation, transportation alternatives, and. (pp. 14–17)

TESTING Your Comprehension

1. What do renewable resources and nonrenewable resources have in common? How are they different? Identify two renewable and two nonrenewable resources.
2. How and why did the agricultural revolution affect human population size? How and why did the industrial revolution affect human population size? Explain what benefits and what environmental impacts have resulted from these two revolutions.
3. What is an *ecological footprint*? Describe how *natural capital* is similar to a bank account.
4. What is *environmental science*? Name several disciplines that environmental science draws upon.
5. Compare and contrast the two meanings of *science*. Name three applications of science.
6. Describe the scientific method. What is its typical sequence of steps?
7. Explain the difference between correlation and causation, and state how these concepts relate to manipulative and natural experiments.
8. What occurs before a researcher's results are published in a scientific journal? Why is this process important?
9. Give examples of three major environmental problems, along with their causes. How are these problems interrelated? Now name one potential solution for each.
10. Describe in your own words what you think is meant by the term *sustainability*. List three ways that students, faculty, and administrators are seeking to make their campuses more sustainable.

SEEKING Solutions

1. Resources such as soils, timber, fresh water, and biodiversity are renewable if we use them in moderation but can become nonrenewable if we overexploit them (see Figure 1.1). For each of these four resources, describe one way we sometimes overexploit the resource and name one thing we could do to conserve the resource. For each, what might constitute sustainable use? (Feel free to look ahead and peruse coverage of these issues throughout this book.)
2. What do you think is the lesson of Easter Island? What more would you like to learn or understand about this island, its history, or its people? What similarities do you perceive between Easter Island and our own modern society? What differences do you see between their predicament and ours?
3. What environmental problem do *you* feel most acutely yourself? Do you think there are people in the world who do not view your issue as a problem? Who might they be, and why might they take a different view?

4. If the human population were to stabilize tomorrow and never reach 8 billion people, would that solve all our environmental problems? Why or why not? What conditions might get better, and what challenges might remain?
5. Find out what sustainability efforts are being made on your campus. What results have these efforts produced so far? What further efforts would you like to see pursued on your campus? Do you foresee any obstacles to these efforts? How could these obstacles be overcome? How could you become involved?
6. **THINK IT THROUGH** You have become head of a major funding agency that grants money to scientists pursuing research in environmental science. You must give your staff several priorities to determine what types of scientific research to fund. What environmental problems would you most like to see addressed with research? Describe the research you think would need to be completed to develop workable solutions. What else, beyond scientific research, might be needed to develop sustainable solutions?

CALCULATING Ecological Footprints

Mathis Wackernagel and his colleagues at the Global Footprint Network continue to refine the method of calculating ecological footprints—the amount of biologically productive land and water required to produce the energy and natural resources we consume and to absorb the wastes we generate. According to their most recent data, there are 1.8 hectares (4.4 acres) available for each person in the world, yet we use on average 2.7 ha (6.7 acres) per person, creating a global ecological deficit, or overshoot (p. 6), of 50%.

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

NATION	ECOLOGICAL FOOTPRINT (HECTARES PER PERSON)	PROPORTION RELATIVE TO WORLD AVERAGE FOOTPRINT	PROPORTION RELATIVE TO WORLD AREA AVAILABLE
Bangladesh	0.7	0.3 (0.7 ÷ 2.7)	0.4 (0.7 ÷ 1.8)
Tanzania	1.2		
Colombia	1.8		
Thailand	2.4		
Mexico	3.3		
Sweden	5.7		
United States	7.2		
World average	2.7	1.0 (2.7 ÷ 2.7)	1.5 (2.7 ÷ 1.8)
Your personal footprint			

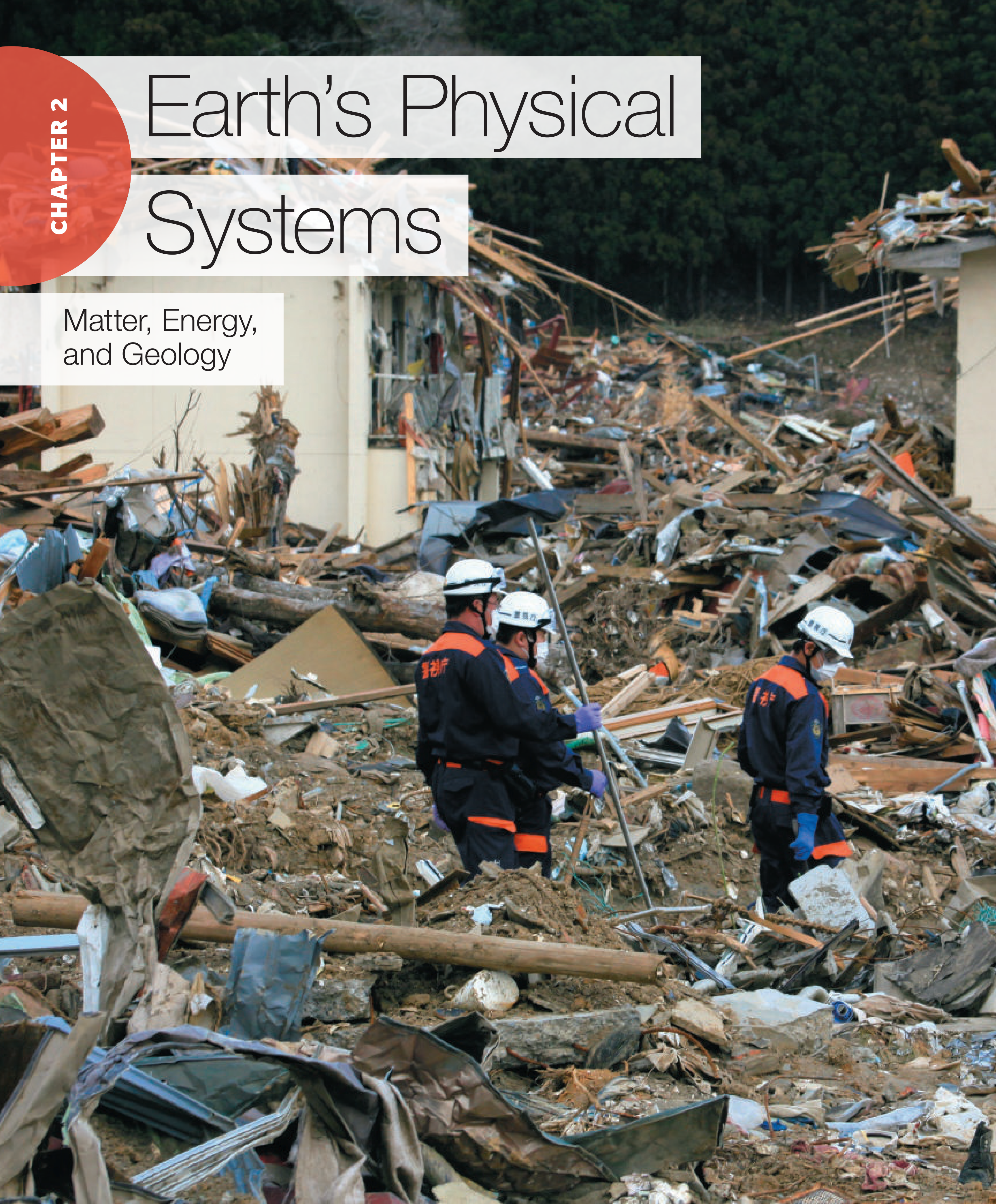
Data from Global Footprint Network, in: WWF, 2014. *Living planet report 2014*. Gland, Switzerland: WWF International.

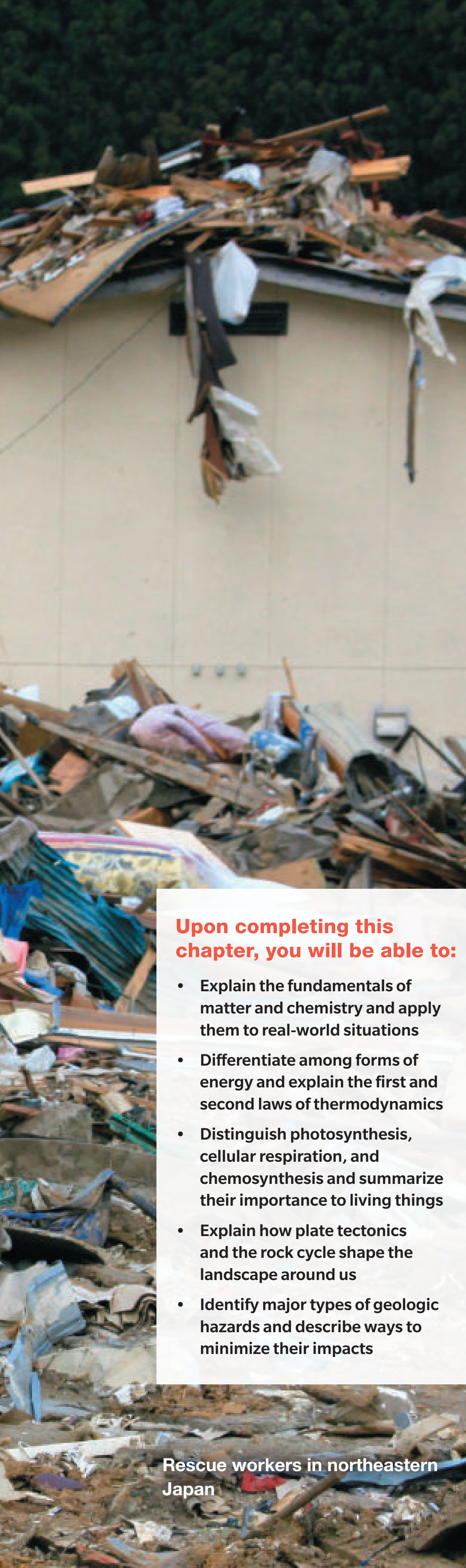
1. Why do you think the ecological footprint for people in Bangladesh is so small?
2. Why do you think the ecological footprint is so large for people in the United States?
3. Based on the data in the table, how do you think average per capita income is related to ecological footprints? Name some ways in which you believe a wealthy society can decrease its ecological footprint.
4. Go to an online footprint calculator such as the one at http://www.footprintnetwork.org/en/index.php/GFN/page/personal_footprint and take the test to determine your own personal ecological footprint. Enter the value you obtain in the table and calculate the other values as you did for each nation. How does your footprint compare to that of the average person in the United States? How does it compare to that of people from other nations? Name three actions you could take to reduce your footprint. (*Note*: Save this number—you will calculate your footprint again in Chapter 24 at the end of your course!)

CHAPTER 2

Earth's Physical Systems

Matter, Energy, and Geology



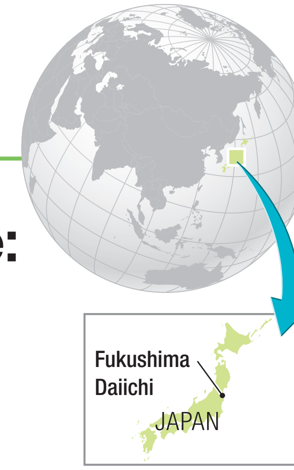


Upon completing this chapter, you will be able to:

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

Rescue workers in northeastern Japan

central
CASE STUDY



The Tohoku Earthquake:

Has It Shaken the World's Trust in Nuclear Power?

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

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

At 2:46 p.m. on March 11, 2011, the land along the northeastern coast of the Japanese island of Honshu began to shake violently—and continued to shake for six minutes. These tremors were caused when a large section of the seafloor along a fault line 125 km (77 mi) offshore suddenly lurched, releasing huge amounts of energy through the crust and generating an earthquake of magnitude 9.0 on the Richter scale (a scale used to measure the strength of earthquakes).

The Tohoku earthquake, as it was later named, was not the first major earthquake to strike Japan. The city of Kobe experienced substantial damage from a quake in 1995 that claimed more than 5500 lives. And in 1923, an earthquake devastated the cities of Tokyo and Yokohama, resulting in more than 142,000 deaths. Losses of life and property from the Tohoku quake were far less extensive than the losses from these earlier events, thanks to new stringent building codes that enable buildings to resist crumbling and toppling over during earthquakes. But even when the earth stopped shaking, the residents of northeastern Japan knew that further danger might still await them—from a tsunami.

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

When the tsunami overtopped the 5.7-m (19-ft) seawall protecting the Fukushima Daiichi nuclear power plant, it

One of the 300,000 people displaced by the Tohuku quake

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

flooded the diesel-powered emergency generators responsible for circulating water to cool the plant's nuclear reactors. With the local electrical grid knocked out by the earthquake and the backup generators off-line, the nuclear fuel in the cores of the three active reactors at the plant began to overheat. The water that normally kept the nuclear fuel submerged within the reactor cores boiled off, exposing the nuclear material to the air and further elevating temperatures inside the cores. As the overheated nuclear fuel melted (an event called a nuclear meltdown), chemical reactions within the reactors generated hydrogen gas, which set off explosions in each of the three reactor buildings, releasing radioactive material into the air. To prevent a full-blown catastrophe that could render large portions of their nation uninhabitable, Japanese authorities flooded the reactor cores with seawater pumped in from the ocean.

The 1–2–3 punch of the earthquake–tsunami–nuclear accident left 18,000 people dead and caused hundreds of billions of dollars in material damage. Around 340,000 people were displaced from their homes, and a 20-km (12-mi) area around the Fukushima Daiichi plant has been permanently evacuated due to unsafe levels of radioactive fallout in the soil. Some of the greatest concerns center on contaminated food and water, so crops and seafood from the region will require testing for radiation for many years to come (see **THE SCIENCE BEHIND THE STORY**, pp. 24–25).

After the accident, public opposition to nuclear power in Japan ran high, and the government ordered the immediate shutdown and reinspection of its 48 nuclear reactors. At the time of the earthquake, these reactors supplied 30% of the nation's electricity.

Remediation efforts at the Fukushima Daiichi nuclear power plant are expected to take decades and cost around $17 billion, and fears of radiation poisoning in the region will linger for generations. Given its global implications for the future of energy production, the events of March 11, 2011, will be keenly recalled in all corners of our world.

Matter, Chemistry, and the Environment

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

All material in the universe that has mass and occupies space—solid, liquid, and gas alike—is called **matter.** In our quick tour of matter in the pages that follow, we examine types of matter and some of the important ways they interact—phenomena that together we term **chemistry.** Once you examine any environmental issue, from acid rain to toxic chemicals to climate change, you will likely discover chemistry playing a central role.

Matter is conserved

To appreciate the chemistry involved in environmental science, we must begin with the fundamentals. Matter may be transformed from one type of substance into others, but it cannot be created or destroyed. This principle is referred to as the **law of conservation of matter.** In environmental science, this principle helps us understand that the amount of matter stays constant as it is recycled in ecosystems and nutrient cycles (p. 117). The law of conservation of matter also makes it clear that we cannot simply wish away "undesirable" matter, such as nuclear waste and toxic pollutants. Because harmful substances can't be destroyed, we must take steps to minimize their impacts on the environment.

Atoms and elements are chemical building blocks

The nuclear reactors at Fukushima Daiichi used the element **uranium** to power its reactors. An **element** is a fundamental type of matter, a chemical substance with a given set of properties that cannot be broken down into substances with other properties. Chemists currently recognize 92 elements occurring in nature, as well as more than 20 others that they have created in the lab. Elements especially abundant on our planet include **oxygen, hydrogen, silicon, nitrogen,** and **carbon** (**TABLE 2.1**). Each element is assigned an abbreviation, or chemical symbol (for instance, H for hydrogen and O for oxygen). The periodic table of the elements (see **APPENDIX D**) organizes the elements according to their chemical properties and behavior.