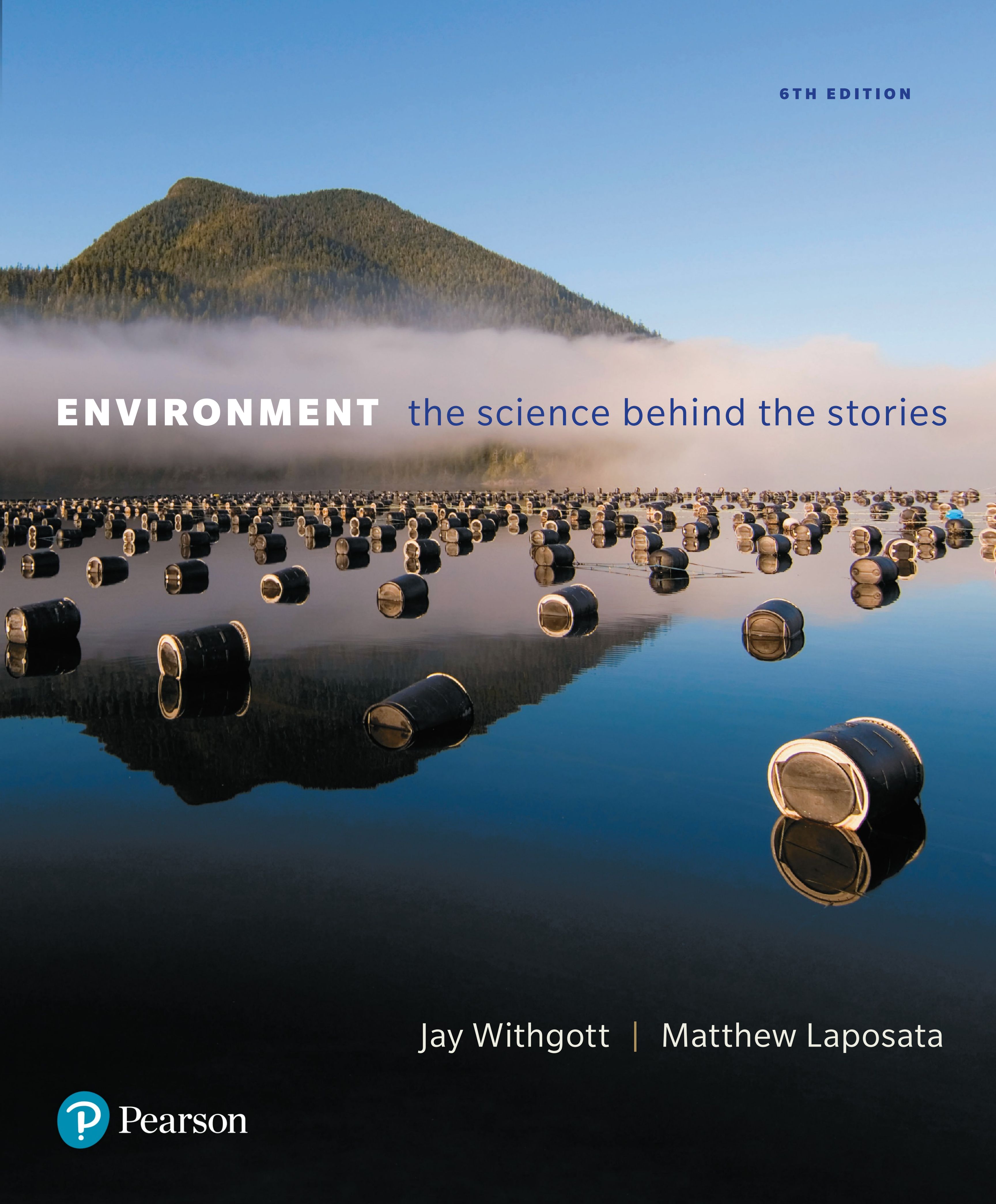

6TH EDITION

# ENVIRONMENT the science behind the stories

Jay Withgott | Matthew Laposata

Pearson

# environment

## THE SCIENCE BEHIND THE STORIES

6TH EDITION

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# About the Authors

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

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

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

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

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

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

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# Brief Contents

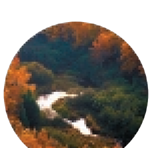
# Contents

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.
- DATA Q 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.

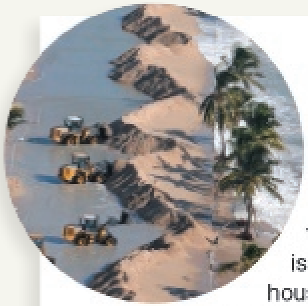
***MasteringEnvironmentalScience®* for *Environment: The Science Behind the Stories* (0-134-51016-X)**

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 26–98 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



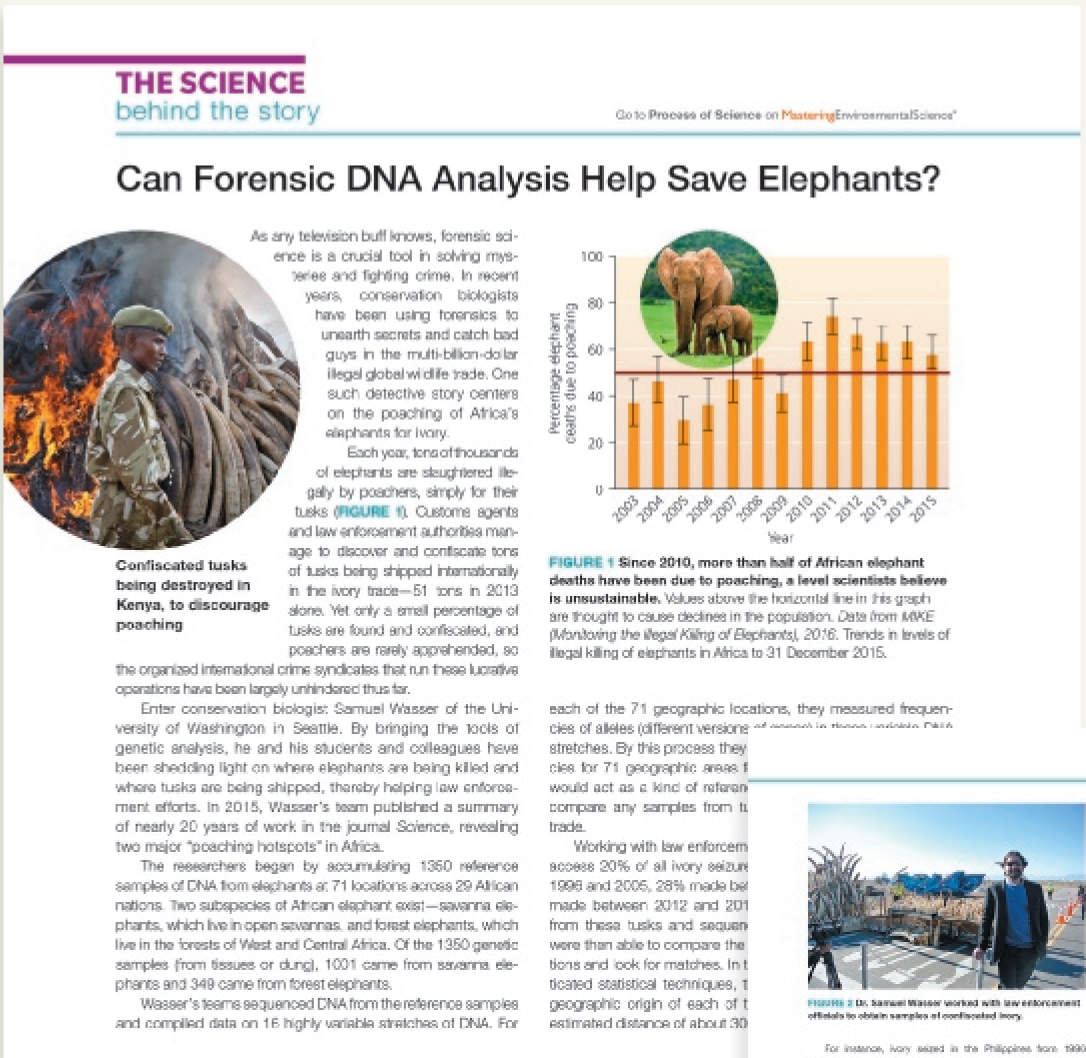
**NEW and UPD ATED!**
**Central Case Studies** begin and are woven throughout each chapter, drawing students in and provide a contextual framework to make science memorable and engaging.

**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 ... cies for 71 geographic areas ... would act as a kind of referen... compare any samples from t... trade.

Working with law enforcem... access 20% of all ivory seizur... 1996 and 2005, 28% made be... made between 2012 and 201... from these tusks and sequen... were then able to compare the... tions and look for matches. In t... ticated statistical techniques, t... geographic origin of each of t... estimated distance of about 30...

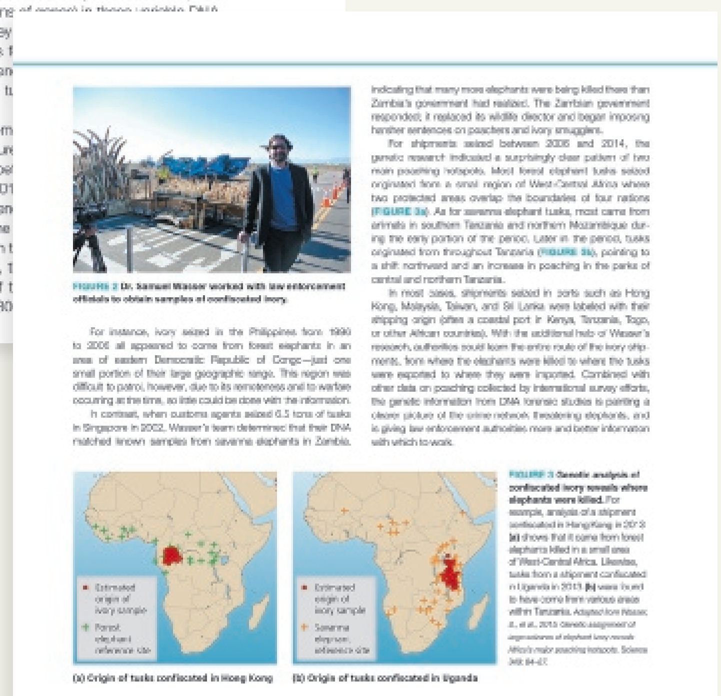


FIGURE 2 **Dr. Samuel Wasser worked with law enforcement officials to obtain samples of confiscated ivory.**

For instance, ivory seized in the Philippines from 1996 to 2006 all appeared to come from forest elephants in an area of eastern Democratic Republic of Congo—just one small portion of their large geographic range. This region was difficult to patrol, however, due to its remoteness and to warfare occurring at the time, so little could be done with the information.

In contrast, when customs agents seized 6.5 tons of tusks in Singapore in 2002, Wasser's team determined that their DNA matched known samples from savanna elephants in Zambia, indicating that many more elephants were being killed there than Zambia's government had realized. The Zambian government responded; it replaced its wildlife director and began imposing harsher sentences on poachers and ivory smugglers.

For shipments seized between 2006 and 2014, the genetic research indicated a surprisingly clear pattern of two main poaching hotspots. Most forest elephant tusks seized originated from a small region of West-Central Africa where two protected areas overlap the boundaries of four nations (FIGURE 3a). As for savanna elephant tusks, most came from animals in southern Tanzania and northern Mozambique during the early portion of the period. Later in the period, tusks originated from throughout Tanzania (FIGURE 3b), pointing to a shift northward and an increase in poaching in the parks of central and northern Tanzania.

In most cases, shipments seized in ports such as Hong Kong, Malaysia, Taiwan, and Sri Lanka were labeled with their shipping origin (often a coastal port in Kenya, Tanzania, Togo, or other African countries). With the additional help of Wasser's research, authorities could learn the entire route of the ivory shipments, from where the elephants were killed to where the tusks were exported to where they were imported. Combined with other data on poaching collected by international survey efforts, the genetic information from DNA forensic studies is painting a clearer picture of the crime network threatening elephants, and is giving law enforcement authorities more and better information with which to work.



(a) Origin of tusks confiscated in Hong Kong

(b) Origin of tusks confiscated in Uganda

FIGURE 3 **Genetic analysis of confiscated ivory reveals where elephants were killed.** For example, analysis of a shipment confiscated in Hong Kong in 2013 (a) shows that it came from forest elephants killed in a small area of West-Central Africa. Likewise, tusks from a shipment confiscated in Uganda in 2013 (b) were found to have come from various areas within Tanzania. Adapted from Wasser, S., et al., 2015. Genetic assignment of large seizures of elephant ivory reveals Africa's major poaching hotspots. *Science* 349: 84–87.

**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.

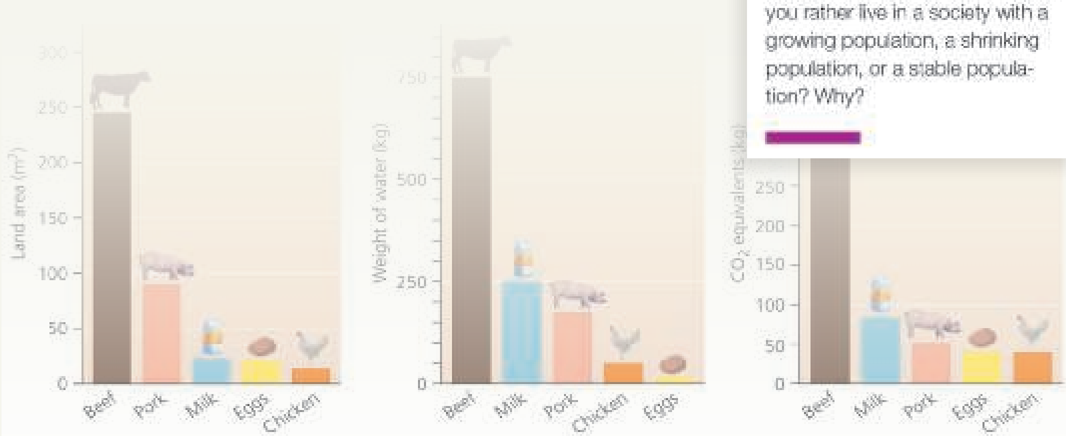
- 1%
- 4%
- 7%
- 10%
- 12%

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.

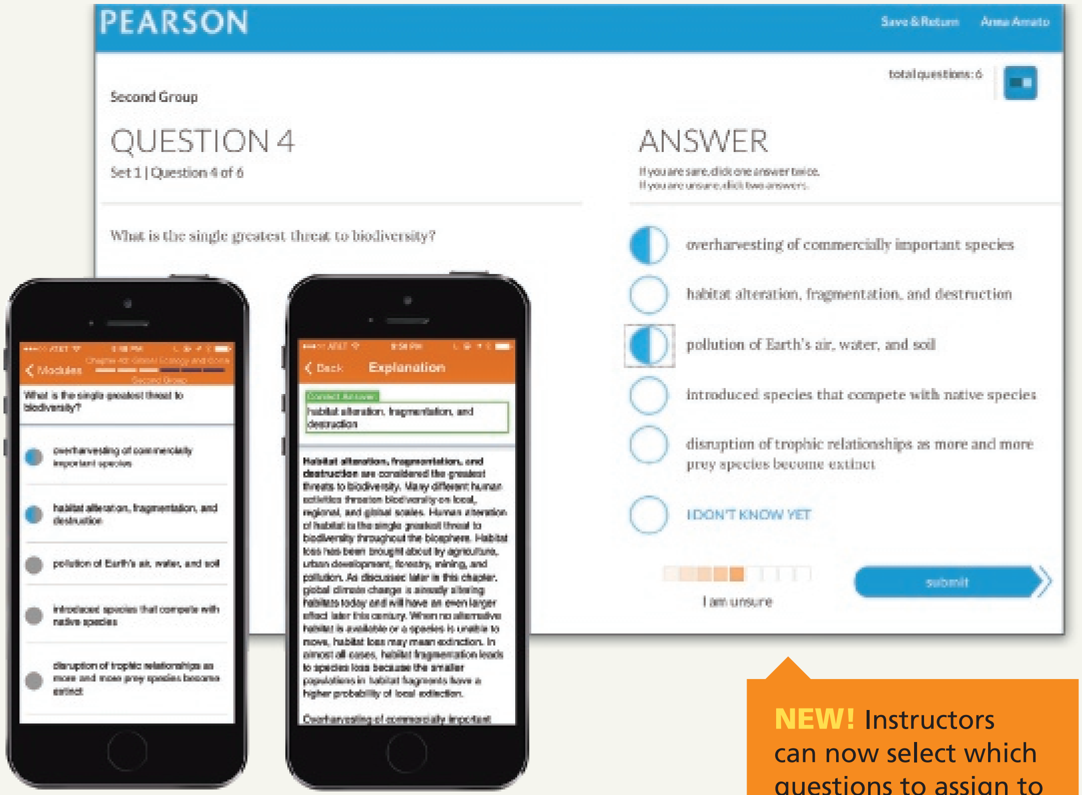
# Continuous Learning
# Before, During, and After Class

## 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.

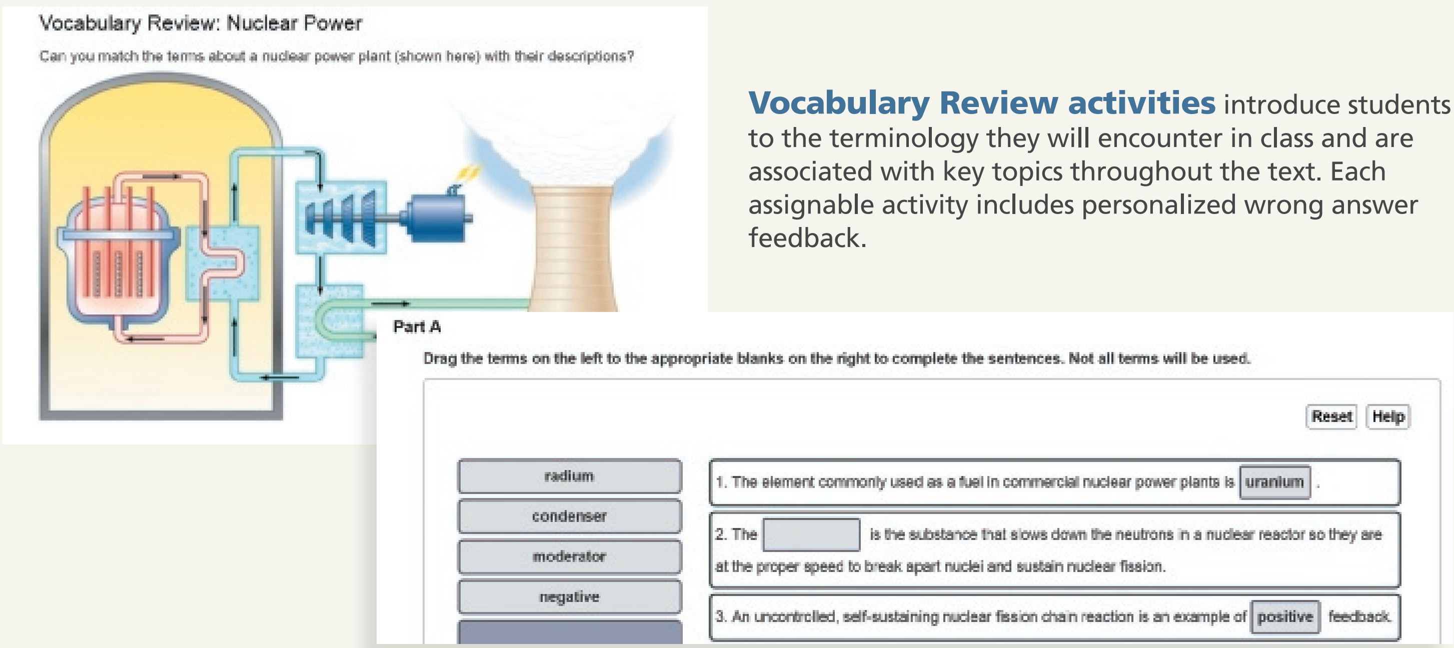



**NEW!** Instructors can now select which questions to assign to students.

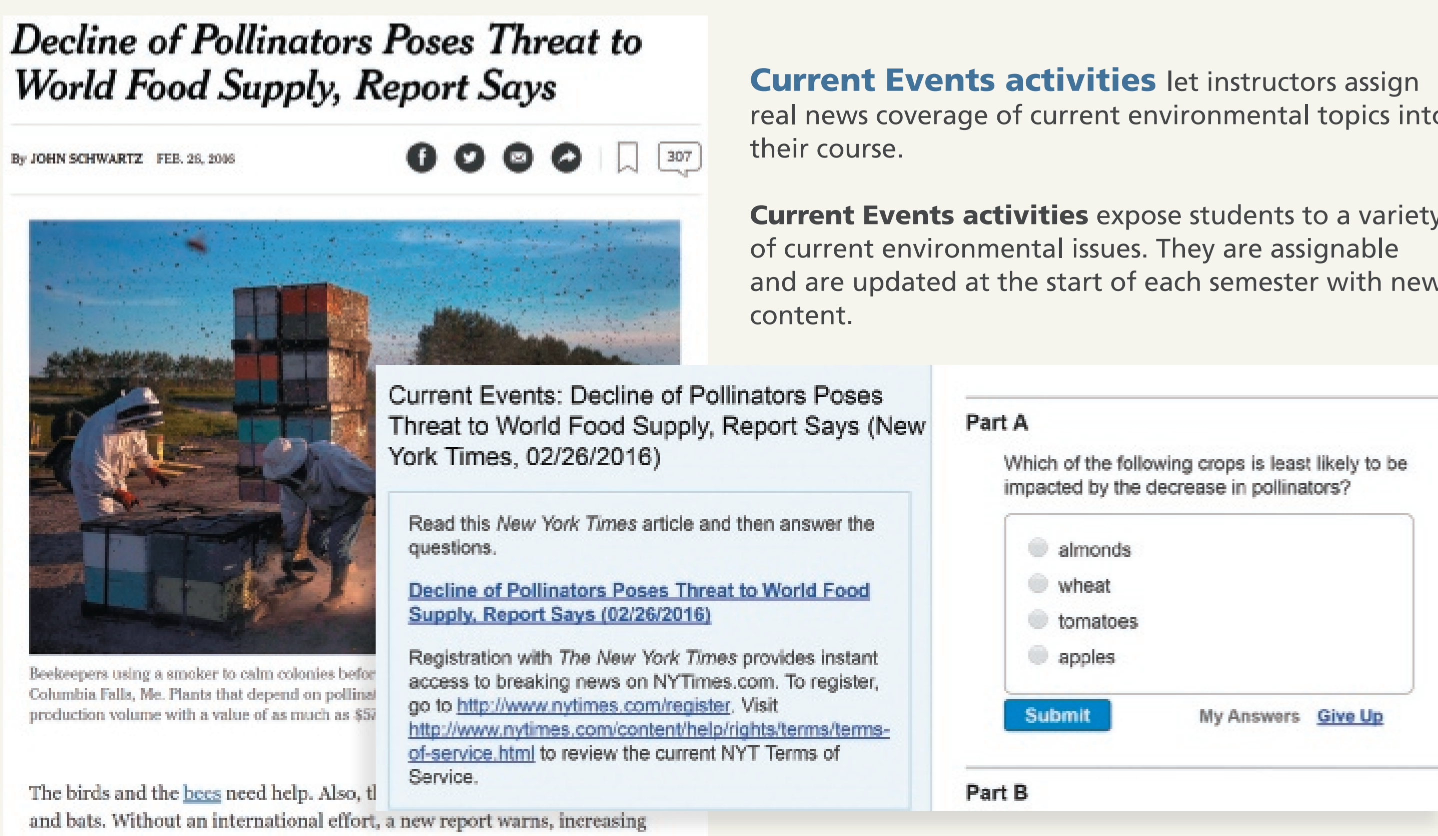

**NEW! Case Study Tour Videos** use Google Earth and vibrant images to introduce students to each Central Case Study in the text. These dynamic videos bring each story to life and are assignable in Mastering.

# 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.



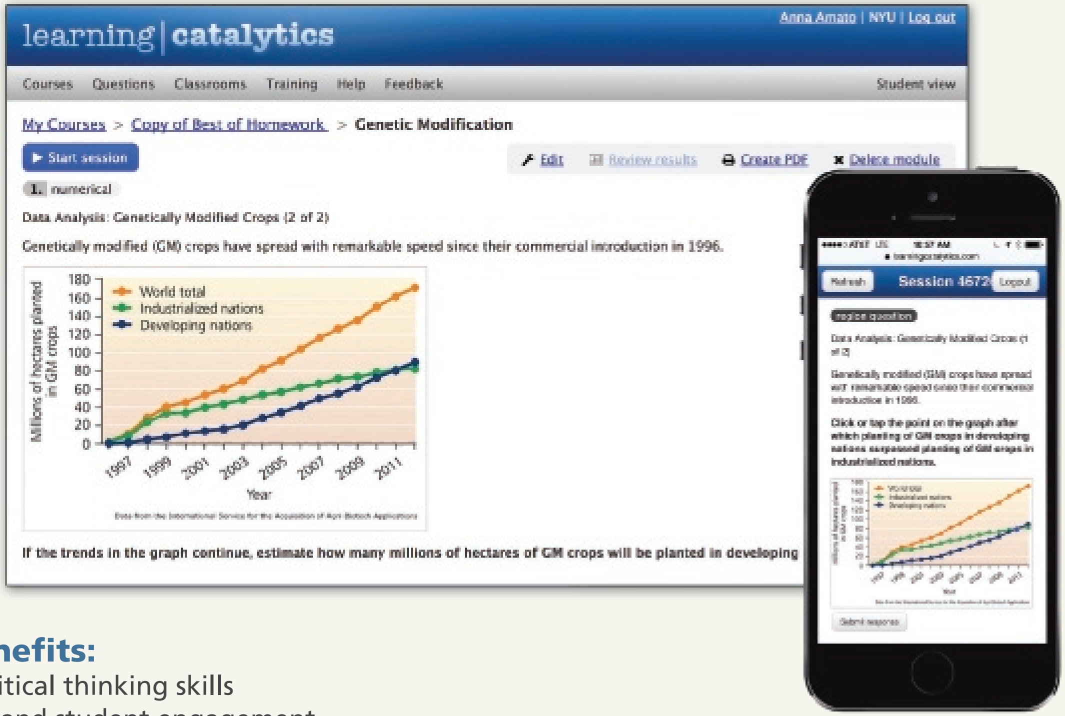

**Current Events activities** let instructors assign real news coverage of current environmental topics into their course.

**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:

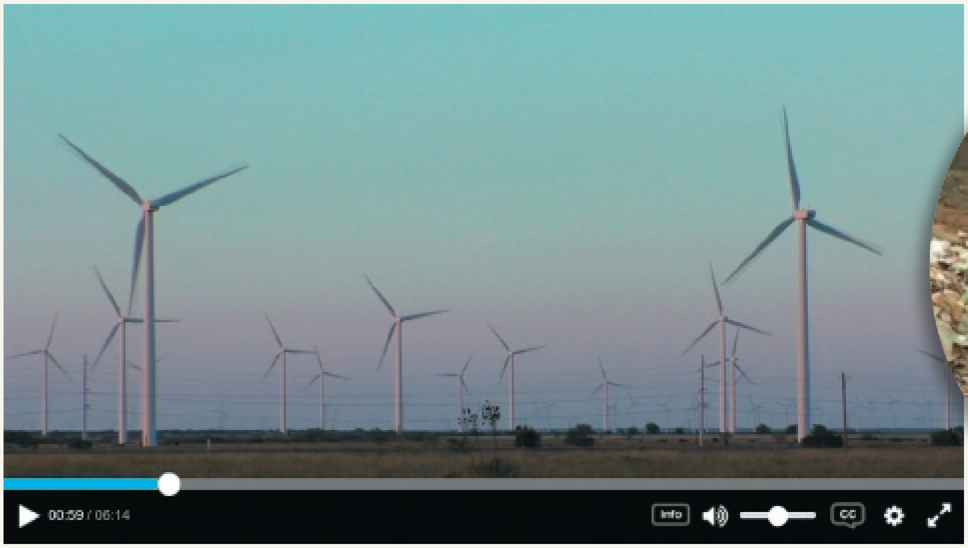
- Developing higher-level critical thinking skills
- Promoting active learning and student engagement
- A team-based approach to learning
- Peer instruction methods
- Understand student misconceptions and adjust teaching in real time

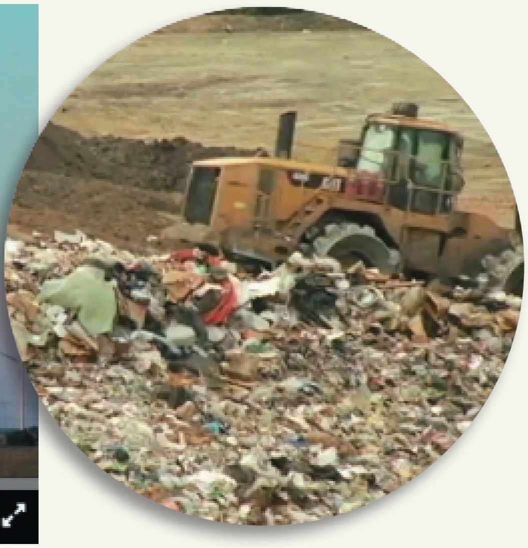
> *"My students are so busy and engaged answering Learning Catalytics questions during lecture that they don't have time for Facebook."*
>
> Declan De Paor, *Old Dominion University*

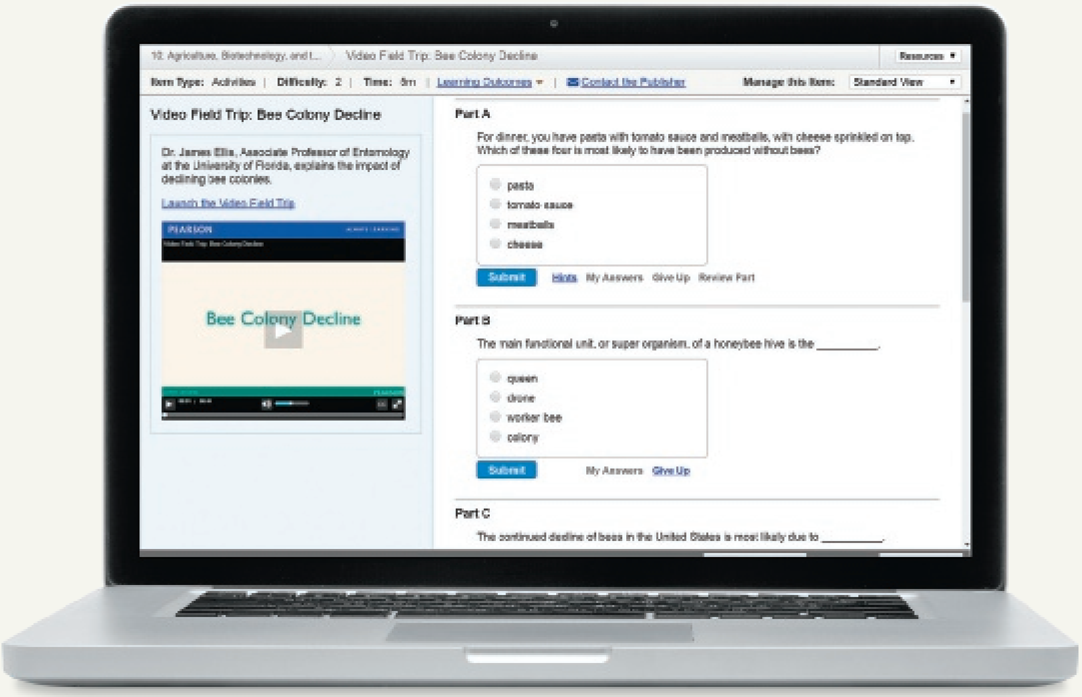
# with MasteringEnvironmentalScience

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.



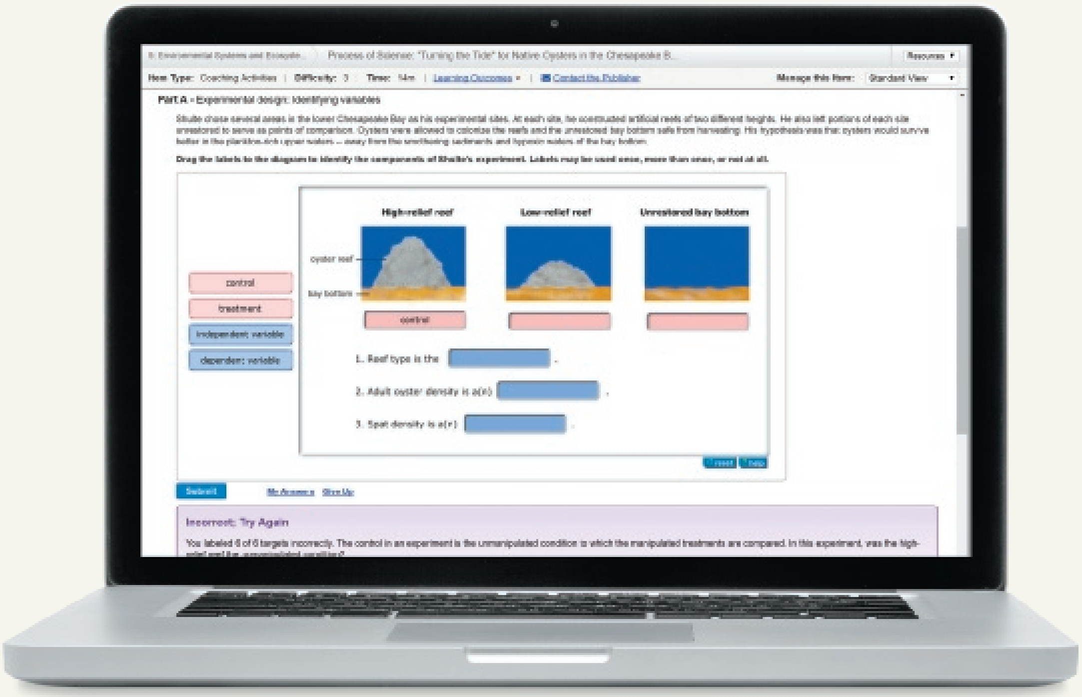


# Continuous Learning
## Before, During, and After Class

## 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.

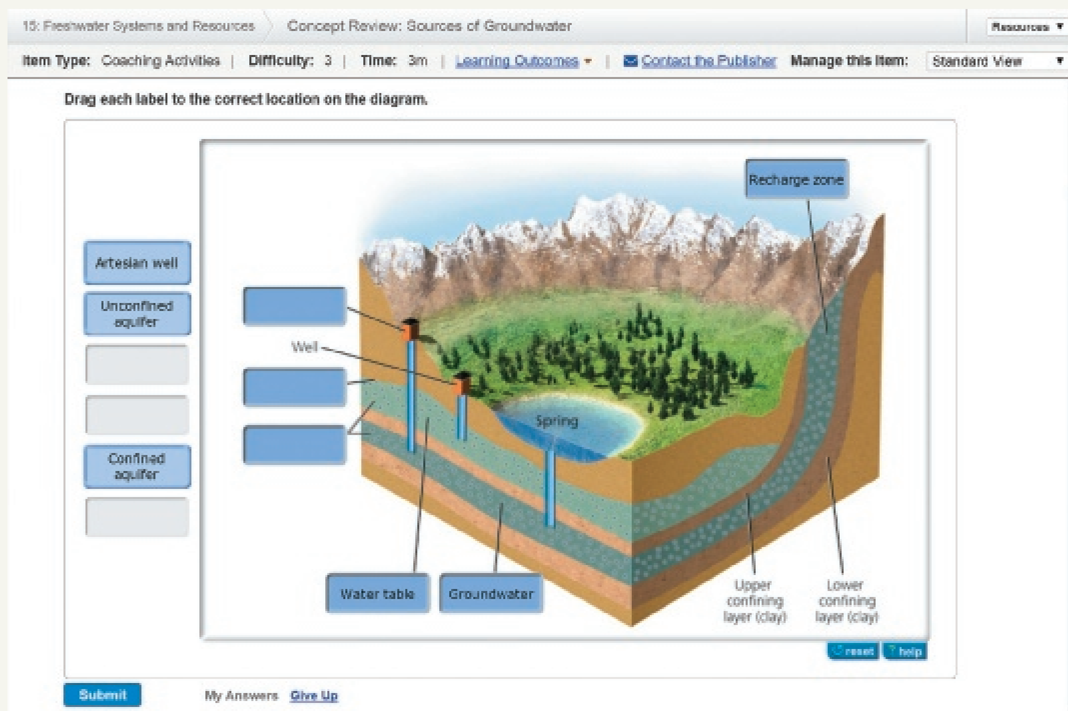
### GraphIt topics include:

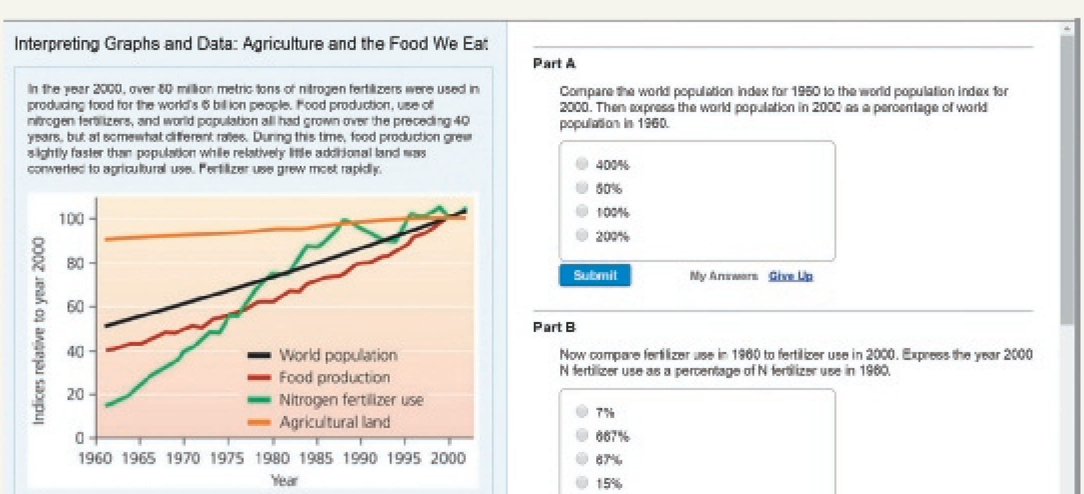
- Agriculture
- Freshwater Availability
- Nutrient Cycling
- Carrying Capacity
- Renewable Energy
- And more!

# with MasteringEnvironmentalScience

MasteringEnvironmentalScience®

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



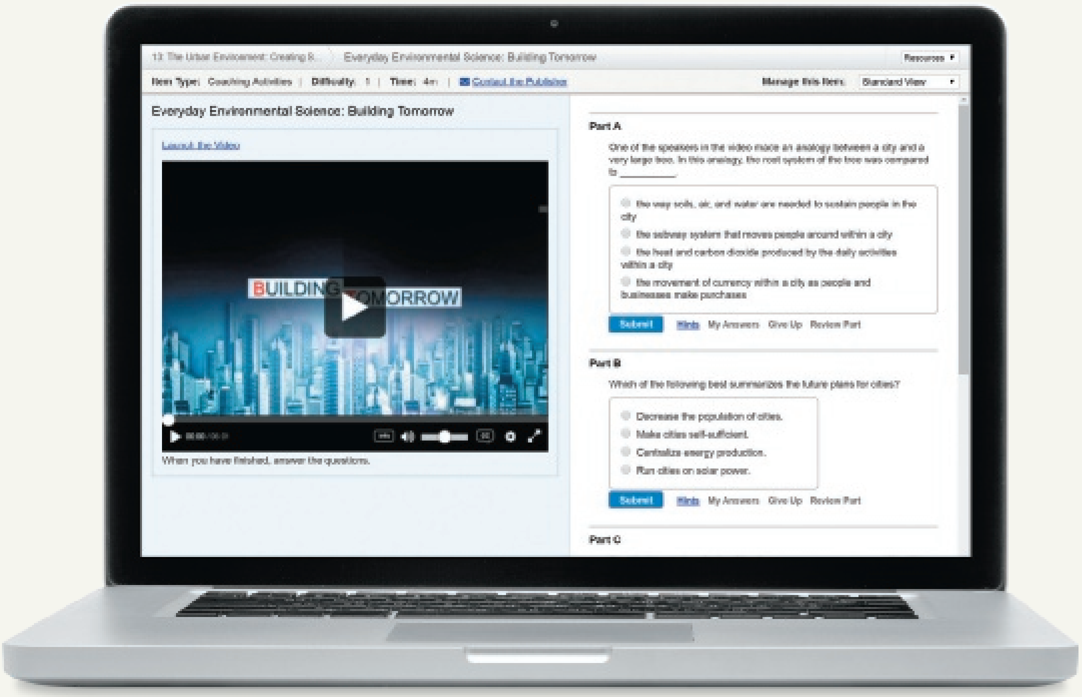

**NEW and EXPANDED! Interpreting Graphs and Data activities** help students practice quantitative literacy and scientific reasoning skills. Each activity includes personalized feedback for wrong answers.

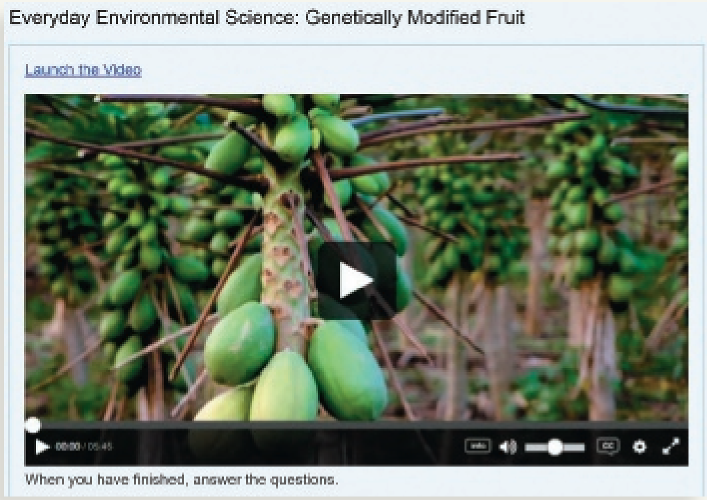
# MasteringEnvironmentalScience®

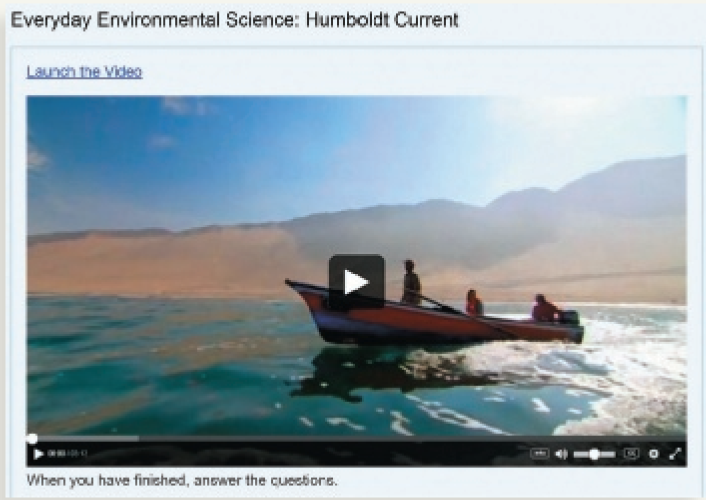
**MasteringEnvironmentalScience** delivers engaging, dynamic learning opportunities—focusing on course objectives and responsive to each student's progress—that are proven to help students absorb course material and understand challenging environmental processes and concepts.

## 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.

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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.

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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

PART 1

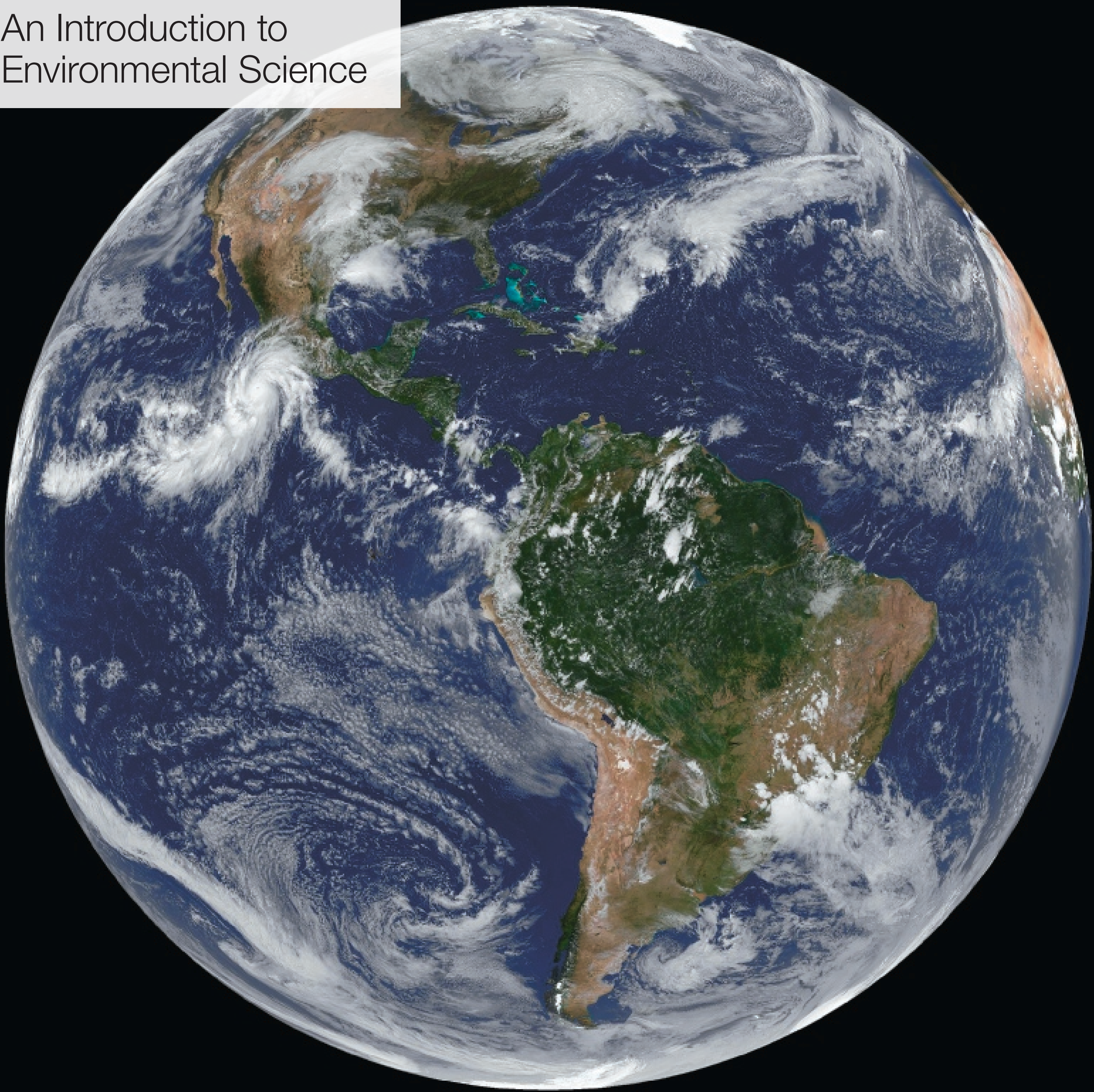
# Foundations of Environmental Science

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.

## 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.

**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

## 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.

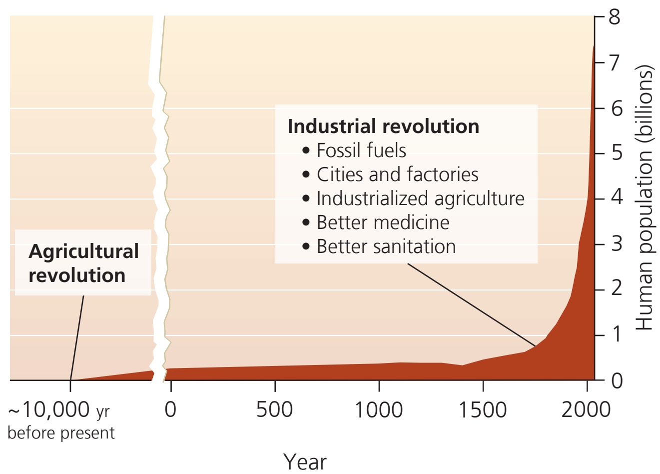



**FIGURE 1.3 The global human population increased after the agricultural revolution and then skyrocketed as a result of the industrial revolution.** Note that the tear in the graph represents the passage of time and a change in *x*-axis values. *Data compiled from U.S. Census Bureau, U.N. Population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

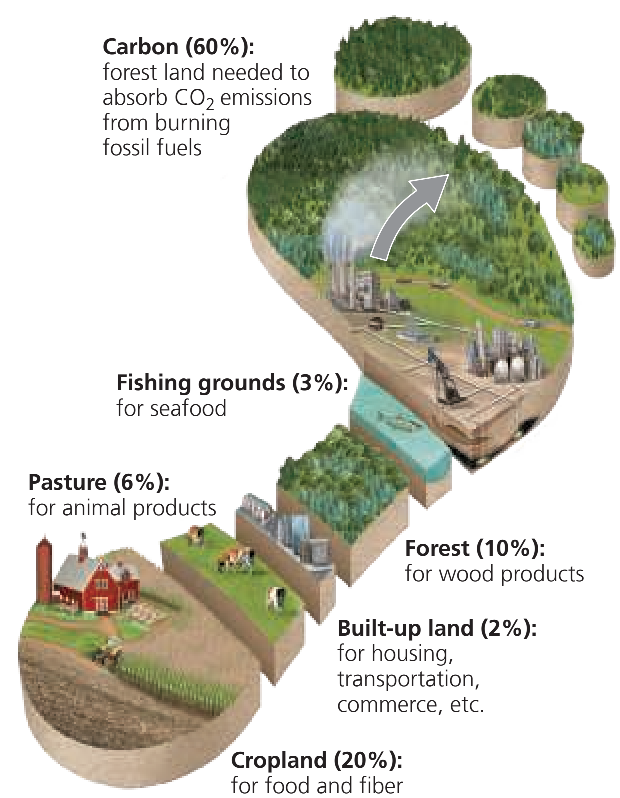



**FIGURE 1.4 An ecological footprint shows the total area of biologically productive land and water used by a given person or population.** Shown is a breakdown of major components of the average person's footprint. *Data from Global Footprint Network, 2016.*

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!

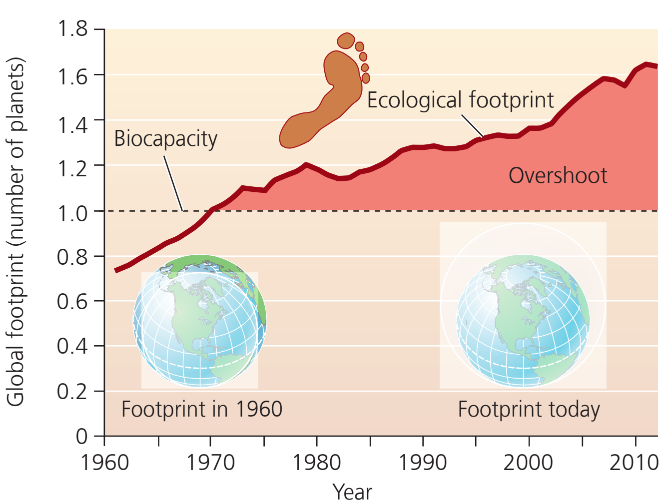



**FIGURE 1.5 Analyses by one research group indicate that we have overshot Earth's biocapacity—its capacity to support us—by 64%.** We are using renewable natural resources 64% faster than they are being replenished. *Data from Global Footprint Network, 2016.*

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

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## 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.

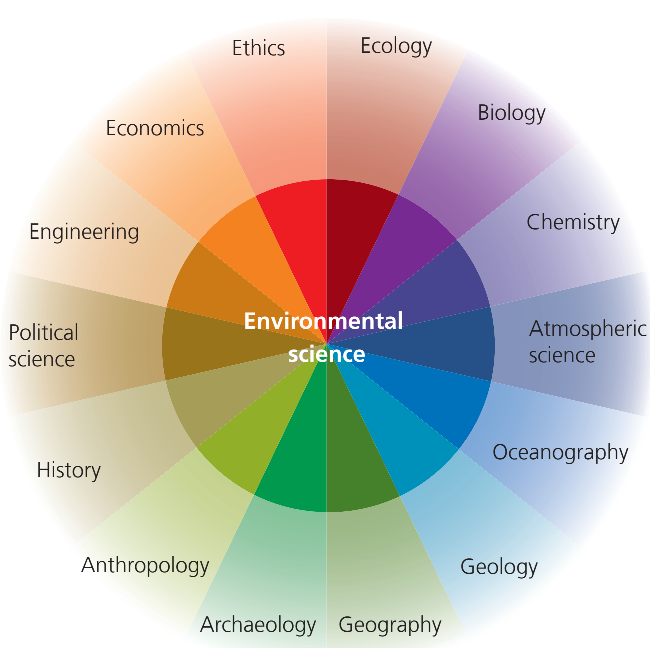


**FIGURE 1.6 Environmental science is an interdisciplinary pursuit.** It draws from many different established fields of study across the natural sciences and social sciences.

## 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?**