An aerial photograph of a vast, flat ice field, likely in Antarctica. The ice is white and textured, with numerous irregularly shaped melt ponds of varying sizes scattered across the surface. The water in the ponds is a deep, clear blue. In the middle ground, two researchers wearing bright orange and yellow safety gear are visible. One is standing and looking towards the left, while the other is crouching or kneeling, possibly collecting a sample. A thin line, possibly a rope or cable, stretches across the ice from the crouching researcher towards the left. The overall scene is bright and clear, suggesting a sunny day.

Essential Environment

The Science
Behind the Stories

5th Edition

JAY WITHGOTT

MATTHEW LAPOSATA

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The Science Behind the Stories

5TH EDITION

Jay Withgott
Matthew Laposata

PEARSON

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About the Authors



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

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

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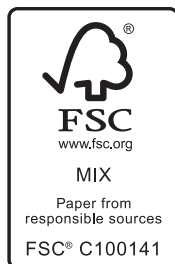
Matt is the coordinator of KSU's two-semester general education science sequence titled Science, Society, and the Environment, which enrolls over 5000 students per year. He focuses exclusively on introductory environmental science courses and has enjoyed teaching and interacting with thousands of nonscience majors during his career. He is an active scholar in environmental science education and has received grants from state, federal, and private sources to develop and evaluate innovative curricular materials. His scholarly work has received numerous awards, including the Georgia Board of Regents' highest award for the Scholarship of Teaching and Learning.

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ABOUT OUR SUSTAINABILITY INITIATIVES

This book is carefully crafted to minimize environmental impact. The materials used to manufacture this book originated from sources committed to responsible forestry practices. The paper is Forest Stewardship Council® (FSC®) certified. The printing, binding, cover, and paper come from facilities that minimize waste, energy consumption, and the use of harmful chemicals.

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The future holds great promise for reducing our impact on Earth's environment, and Pearson is proud to be leading the way. We strive to publish the best books with the most up-to-date and accurate content—and to do so in ways that minimize our environmental impact.

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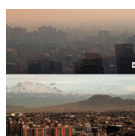


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Preface

Dear Student,

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

Today we live long lives enriched with astonishing technologies, in societies more free, just, and equal than ever before. We enjoy wealth on a scale our ancestors could hardly have dreamed of. Yet we have purchased these wonderful things at a price. By exploiting Earth's resources and ecological services, we are depleting our planet's bank account and running up its credit card. 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 face. Environmental science is not simply some subject you study in college. Rather, it provides you basic literacy in the foremost issues of the 21st century, and it relates to everything around you throughout your lifetime.

We have written this book because today's students will shape tomorrow's world. At this unique moment in history, the decisions and actions of your generation are key to achieving a sustainable future for our civilization. The many environmental challenges 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 *will* make a difference.

—Jay Withgott and Matthew Laposata

Dear Instructor,

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

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

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

New to This Edition

In this fifth edition of *Essential Environment*, we have incorporated the most current information from a fast-moving field. A number of major changes new to this edition enhance our presentation while strengthening our commitment to teach science in an engaging and accessible way.

■ CENTRAL CASE STUDY

Seven of our 17 Central Case Studies are new to this edition, providing a wealth of fresh stories and new ways to frame issues in environmental science. Students will travel from Pennsylvania to Hawaii and from Africa to Mexico to Costa Rica as they learn how debates over hydraulic fracturing, air pollution, deforestation, and biodiversity conservation are affecting people's lives. In addition, two new case studies focus on campus sustainability initiatives, showcasing some of the many innovative steps students are taking to advance sustainable solutions on campus.

- **Chapter 3:** Saving Hawaii’s Native Forest Birds
- **Chapter 5:** Costa Rica Values Its Ecosystem Services
- **Chapter 7:** Farm to Table—And Back Again—The Commons at Kennesaw State University
- **Chapter 8:** Will We Slice through the Serengeti?
- **Chapter 13:** Clearing the Air in L.A. and Mexico City
- **Chapter 15:** Hydrofracking the Marcellus Shale
- **Chapter 17:** A Mania for Recycling on Campus

■ THE SCIENCE BEHIND THE STORY

Eight of our 18 *Science Behind the Story* features are new to this edition, giving you a current and exciting selection of scientific studies to highlight. Students will follow researchers as they evaluate energy sources, design climate models, monitor animal populations, assess impacts of smog and forest fragmentation, and seek solutions to pollution from hydraulic fracturing and plastic in the ocean.

- **Chapter 3:** Monitoring Bird Populations at Hakalau Forest
- **Chapter 8:** Wildlife Declines in African Reserves
- **Chapter 9:** Forest Fragmentation in the Amazon
- **Chapter 11:** Can Acid Mine Drainage Reduce Fracking’s Environmental Impact?
- **Chapter 12:** Predicting the Oceans’ “Garbage Patches”
- **Chapter 13:** Measuring the Health Impacts of Mexico City’s Air Pollution
- **Chapter 14:** How Do Climate Models Work?
- **Chapter 16:** Comparing Energy Sources

Selected *Science behind the Story* features are now supported by new “Process of Science” exercises online in *MasteringEnvironmentalScience* that use these examples to help students explore how scientists conduct their work.

■ **DATA Q** Each chapter now contains *Data Q data-analysis questions* that help students to actively engage with graphs and other data-driven figures. This new 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 read, answers are provided in Appendix A, and students can practice data analysis skills further with new *Interpreting Graphs and Data: DataQs* in *MasteringEnvironmentalScience*.

■ **Currency and coverage of topical issues** To live up to our book’s hard-won reputation for currency, we have incorporated the most recent data possible and have enhanced coverage of issues now gaining prominence. As climate change and energy concerns play ever-larger roles in today’s world, our coverage continues to evolve. This edition highlights how renewable energy is growing, yet also how we are reaching further for fossil fuels with deep offshore drilling, Arctic exploration, oil sands extraction, and hydraulic fracturing for tight oil and shale gas. Climate change connections continue to proliferate throughout our text, and our climate change chapter includes new coverage of climate modeling, Hurricane Sandy, research into jet stream effects on extreme weather, the latest predictions for America and the world, and political responses at all levels.

This edition also expands coverage of a diversity of topics including the valuation of ecosystem services, introduced species and their ecological impacts on islands, prospects for nuclear power and safety after Fukushima, ocean acidification, advanced biofuels, sustainable agriculture, hormone-disrupting substances, impacts on coastal wetlands, marine plastic pollution, and green-collar jobs. We continue to use sustainability as an organizing theme, and we aid this by moving primary coverage of sustainable development to Chapter 5 and highlighting campus sustainability initiatives in several chapters.

■ **Enhanced style elements** We have updated and improved the look and clarity of our visual presentation throughout the text. A more open layout, more engaging photo treatments, and new designs for tables and for each feature all make the book more inviting and accessible for learning. This edition includes more than 30% entirely new photos, graphs, and illustrations, while most existing figures have been revised to reflect current data or for better clarity or pedagogy.

Existing Features

We have also retained the major features that made the first four 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 at the same time 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 numerous print and 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. We have aimed to counter this impression by highlighting innovative solutions being developed on campuses and 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.

■ **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* in each chapter. By guiding students through key research efforts, this feature shows not merely *what* scientists discovered, but *how* they discovered it.

■ **FAQ** The *FAQ* feature highlights questions frequently posed by students 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. A number of new *FAQs* have been added in this edition.

■ **Weighing the Issues** These questions aim to help develop the critical-thinking skills students need to navigate multifaceted issues at the juncture of science, policy, and ethics. They serve as stopping points for students to reflect on what they have read, wrestle with complex dilemmas, and engage in spirited classroom discussion.

■ **Diverse end-of-chapter features** *Testing Your Comprehension* provides concise study questions on main topics, while *Seeking Solutions* encourages broader creative thinking aimed at finding solutions. "Think It Through" questions place students in a scenario and empower them to make decisions to resolve problems. *Calculating Ecological Footprints* enables students to quantify the impacts of their choices and measure how individual impacts scale up to the societal level.

MasteringEnvironmental Science

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

■ **New to this edition** Informed by instructor feedback and motivated by the desire to help students to build science literacy skills, we have made the following additions to *MasteringEnvironmentalScience*. The first two were created specifically for the fifth edition by co-author Matthew Laposata:

- *Process of Science* activities help students navigate the scientific method, guiding them through explorations of experimental design using *Science Behind the Story* features from the fifth edition. These activities encourage students to think like a scientist and to practice basic skills in experimental design.
- *First Impressions Pre-Quizzes* help instructors determine their students' existing knowledge of core content areas in environmental science at the outset of the academic term, providing class-specific data that can then be employed for powerful teachable moments throughout the term. Assessment items in the Test Bank connect to each quiz item, so instructors can formally assess student understanding.
- *Interpreting Graphs and Data: Data Q* activities pair with the new in-text *Data Analysis Questions* and coach students to further develop skills related to presenting, interpreting, and thinking critically about environmental science data.
- Five more *Video Field Trips* have been added to the existing library in *MasteringEnvironmentalScience*. With these new videos, you can now kick off your class period with a field trip to a wind farm or a water desalination plant, a visit with researchers tackling invasive species or bee colony collapse disorder, or a tour of a sustainable college campus.

- **Existing features** *MasteringEnvironmentalScience* also retains its popular existing features. *Interpreting Graphs and Data* exercises and the interactive *GraphIt!* program each guide students in exploring how to present and interpret data and how to create graphs. Interactive *Causes and Consequences* exercises let students probe the causes behind major issues, their consequences, and possible solutions. *Viewpoints* offers paired essays authored by invited experts who present divergent points of view on topical questions.

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

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

—Jay Withgott and Matthew Laposata

Instructor Supplements

Instructor Resource Center on DVD with TestGen (0-133-89259-X)

This powerful media package is organized chapter-by-chapter and includes all teaching resources in one convenient location. You'll find Video Field Trips, PowerPoint presentations, Active Lecture questions to facilitate class discussions (for use with or without clickers), and an image library that includes all art and tables from the text.

Included on the IRDVD, the Test Bank includes hundreds of multiple-choice questions plus unique graphing, and scenario-based questions to test students' critical-thinking abilities.

Instructor Guide (0-133-90122-X)

This comprehensive resource provides chapter outlines, key terms, and teaching tips for lecture and classroom activities.

Blackboard Open Access (0-133-97474-X)

MasteringEnvironmentalScience™ for Essential Environment: The Science Behind the Stories (0-321-97688-6)

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

Acknowledgments

A textbook is the collective product of many minds and hearts. The two of us are exceedingly fortunate to be supported and guided by a tremendous publishing team.

Our acquisitions editor, Alison Rodal, coordinated our team's work for this fifth edition of *Essential Environment*. Alison's skills, focus, dedication, sound judgment, and experience in multiple aspects of publishing greatly enhanced our efforts. Project manager Margaret Young led us ably through the complex choreography of the textbook process. As program manager, Anna Amato lent her insight and her steady hand, building on her past contributions. Development editor Julia Osborne added perceptive and valuable feedback on our art program and the layout of our chapters. We appreciate their patience with us, and we admire their commitment to top-quality work.

We thank our editor-in-chief, Beth Wilbur, for her steady support of this book through its five editions, as well as Pearson's upper management for continuing to invest in the resources and top-notch personnel that our books have enjoyed for the past decade.

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As we expand our online offerings with *MasteringEnvironmentalScience*, we thank Tania Mlawer, Juliana Tringali, Sarah Jensen, Lee Ann Doctor, Daniel Ross, Jana Pratt, and Todd Brown for their work on the *Mastering* website and our media supplements. A special thanks to Jellyfish Smack Productions for their fabulous work on our *Video Field Trips*.

As always, a select number of top instructors have teamed with us to produce the supplementary materials, and we remain deeply grateful for their work. Our thanks go to Heidi Marcum for working on EnvSci dynamic study modules, Danielle DuCharme for updating our Instructor's Guide, Daniel Pavuk for his help with the Test Bank, Reggie Cobb for revising the PowerPoint lectures and clicker questions, Steve Fitzpatrick for revising the reading quizzes, and Donna Bivans for correlating the shared media.

We give a big thanks to marketing manager Amee Mosley, as well as to Lauren Harp. And of course, the many sales representatives who help communicate our vision, deliver our product, and work with instructors to ensure their satisfaction are absolutely vital, and we deeply admire and appreciate their tireless work and commitment.

Lastly, Jay thanks his parents and his many teachers and mentors over the years for making his own life and education so enriching. He gives loving thanks to his wife, Susan, who has patiently provided caring support throughout this book's writing and revision over the years. Matt thanks his family, friends, and colleagues, and he is grateful for his children, who give him three reasons to care passionately about the future. Most important, he thanks his wife, Lisa, for enriching his life with her keen insight, passion for life, unconscious grace, and effortless beauty—and for faithfully reminding him to treasure and cherish the truly valuable things in life. 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.

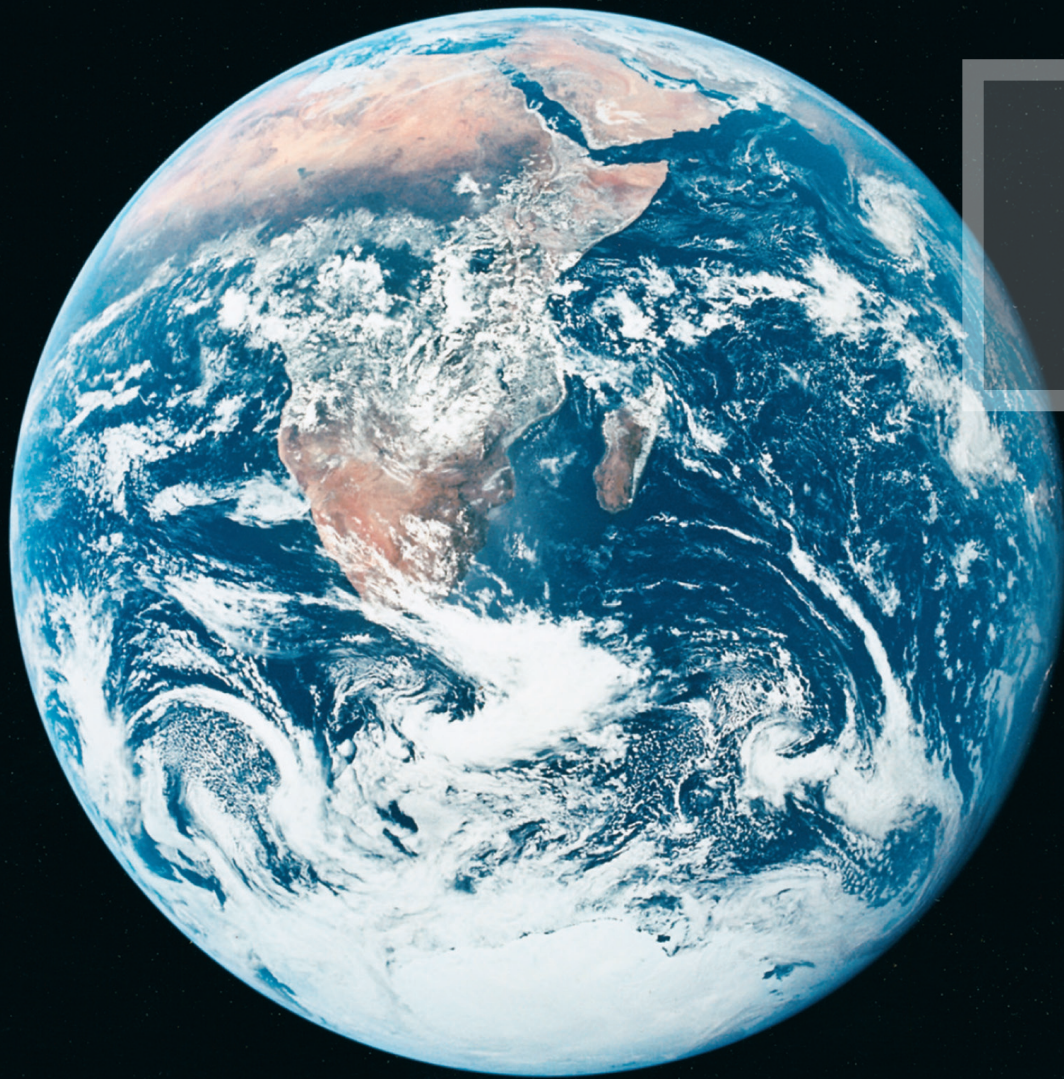
We dedicate this book to today's students, who will shape tomorrow's world.

—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 edition the best it could be. Over 600 instructors and outside experts have reviewed material for the previous four editions of this book and the five editions of this book's parent volume, where they are acknowledged in full. Below we thank those who contributed in particular to this fifth edition of *Essential Environment*—in most cases with multiple in-depth chapter reviews despite busy teaching schedules. Our sincere gratitude goes out to all of them. If the thoughtfulness and thoroughness of these reviewers are any indication, we feel confident that the teaching of environmental science is in excellent hands!

Marc Albrecht, *University of Nebraska at Kearney*
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Marie Trone, *Valencia College, Osceola Campus*
Candice Weber, *College of the Desert*
Nine (9) anonymous reviewers



1

Science and Sustainability: An Introduction to Environmental Science

Upon completing this chapter, you will be able to:

- ❑ Describe the field of environmental science
- ❑ Explain the importance of natural resources and ecosystem services to our lives
- ❑ Discuss the scale and consequences of population growth and resource consumption
- ❑ Describe the steps of the scientific method
- ❑ Comprehend the nature and importance of science, and characterize aspects of the process of science
- ❑ Appreciate the role of ethics in environmental science, and compare and contrast major approaches in environmental ethics
- ❑ Diagnose and illustrate major pressures on the global environment
- ❑ Articulate the concept of sustainability and describe campus sustainability efforts

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. Finding ways 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 the photo of Earth from space, as well as the animals, plants, forests, and farms of the landscapes surrounding us. In a more inclusive sense, it also encompasses the structures, urban centers, and living spaces that people have created. In its broadest sense, our environment includes the complex webs of social relationships and institutions that shape our daily lives.

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

Environmental science explores our interactions with the world

Understanding our relationship with the world around us is vital because we depend on our environment for air, water, food, shelter, and everything else essential for living. Moreover, we modify our environment. Many of our actions have enriched our lives, bringing us better health, longer life spans, and greater material wealth, mobility, and leisure time—yet they have often 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 build a society that will 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. By understanding these interactions, we may be able to devise solutions to our many pressing challenges. It can be daunting to reflect on the sheer magnitude of dilemmas that confront us today, but these problems also bring countless opportunities for creative solutions.

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

We rely on natural resources

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



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 time scales, 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.

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, or they may be depleted if we consume them faster than they are replenished. **Nonrenewable natural resources**, such as minerals and crude oil, 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 it is also true that Earth’s natural systems 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. 35, 97).

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 affluence and a human population that grows larger every day.



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

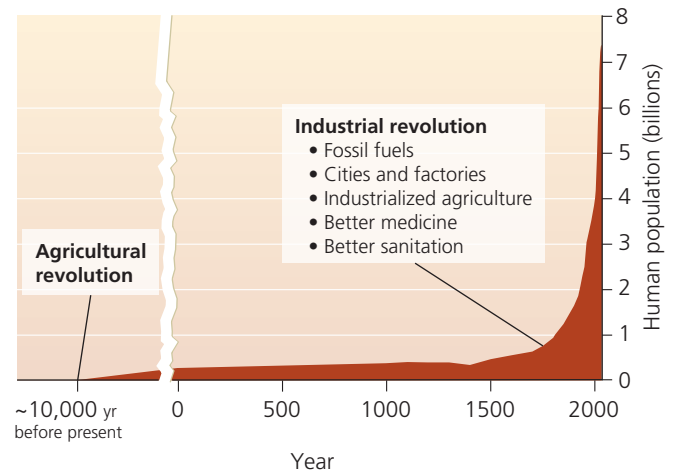


FIGURE 1.3 The global human population increased after the agricultural revolution and then skyrocketed as a result of the industrial revolution. Data from U.S. Census Bureau, U.N. Population Division, and other sources.

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

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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. For every one person who used to exist, several thousand people exist today! FIGURE 1.3 shows just how recently and suddenly this monumental change has taken place.

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

The second phenomenon, known as the **industrial revolution**, began in the mid-1700s. It entailed a shift from rural life, animal-powered agriculture, and handcrafted goods toward an urban society provisioned by the mass production of factory-made goods and powered by **fossil fuels** (nonrenewable energy sources such as coal, oil, and natural gas; pp. 337–338). 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. 137, 147).

The factors driving population growth have brought us better lives in many ways. Yet as our world fills with people, population growth has begun to threaten our well-being. We must ask how well the planet can accommodate the 9 billion people forecast by 2050. Already our sheer numbers, unparalleled in history, 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 biologically productive surface that a given person or population “uses” once all direct and indirect impacts are totaled up.

For humanity as a whole, Wackernagel and his colleagues at the Global Footprint Network calculate that we are now using 50% more of the planet's resources than are available on a sustainable basis. That is, we are depleting renewable resources by using them 50% faster than they are being replenished. This is like drawing the money out of a bank account rather than living off the interest the money

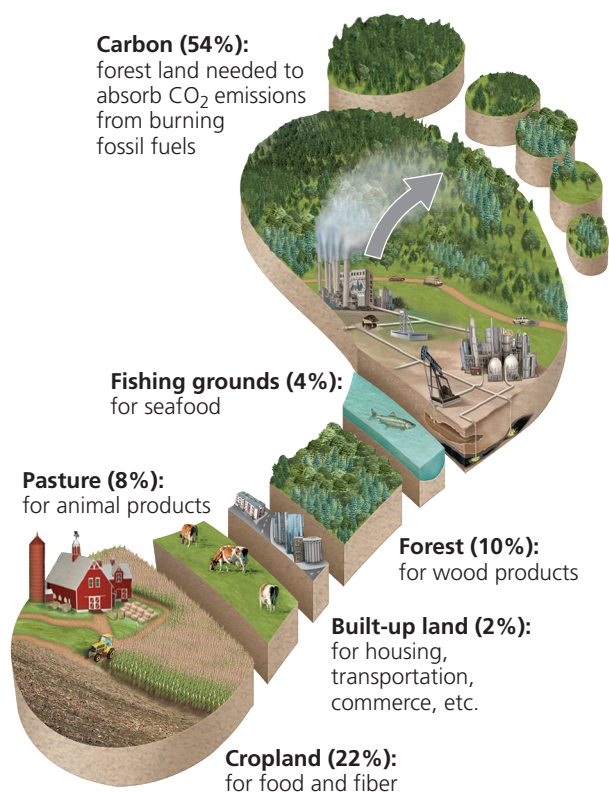


FIGURE 1.4 An ecological footprint shows the total area of biologically productive land and water used by a given person or population. Shown is a breakdown of major components of the average person's footprint. *Data from WWF, 2012. Living planet report 2012. WWF International, Gland, Switzerland.*

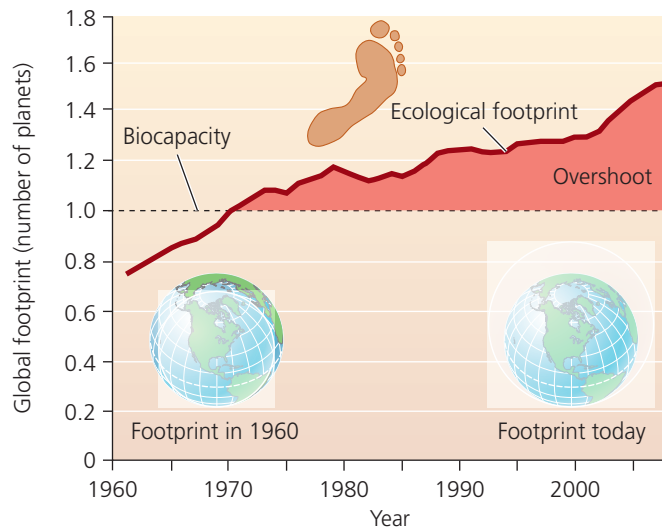


FIGURE 1.5 Analyses by one research group indicate that we have overshoot Earth's biocapacity—its capacity to support us—by 50%. We are using renewable natural resources 50% faster than they are being replenished. *Data from WWF, 2012. Living planet report 2012. WWF International, Gland, Switzerland.*

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

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makes. To look at this another way, it would take 1.5 years for the planet to regenerate the renewable resources that people use in 1 year. This excess use 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 complicated issues down 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, we would need the equivalent of four planet Earths!

Environmental science can help us avoid past 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 Iraq, Syria, 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. 6–7).

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 many changes happening around us and to think critically and creatively about ways to respond.

The Nature of Environmental Science

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

Environmental science is interdisciplinary

Studying our interactions with our environment is a complex endeavor that requires expertise from many 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. 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 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, 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

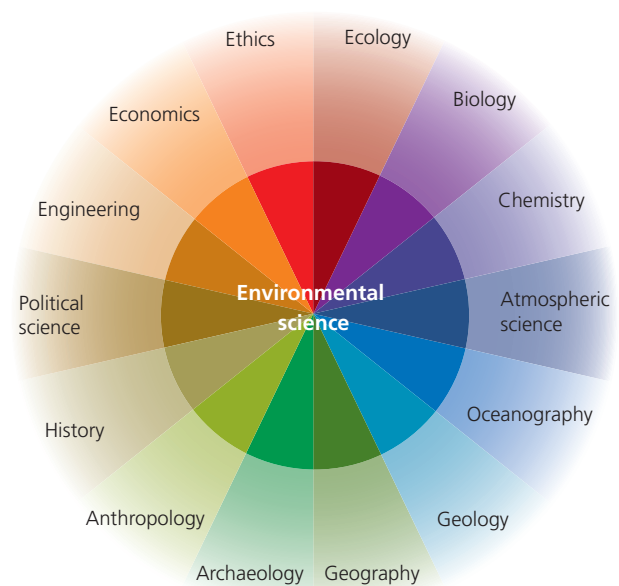


FIGURE 1.6 Environmental science is an interdisciplinary pursuit. It draws from many different established fields of study across the natural sciences and social sciences.

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.

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.

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. Yet, although personal values and social concerns may help shape the questions scientists ask, scientists do their utmost to carry out their work impartially and to interpret their results with wide-open minds. Remaining open to whatever conclusions the data demand is a hallmark of the effective scientist.

What Are the Lessons of Easter Island?



Easter Island's immense statues

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 can offer us. The debate shows how, in science, new information can challenge existing ideas—and also how interdisciplinary research helps us to tackle complex questions.

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

Researchers who set out to solve Rapa Nui's mysteries soon discovered that the island had once been lushly forested. Scientist John Flenley and his colleagues drilled cores deep into lake sediments and examined ancient pollen grains preserved there, seeking to reconstruct, layer by layer, the history of vegetation in the region. Finding a great deal of palm pollen, they inferred that when Polynesian people colonized the island (between A.D. 300–900, they estimated), it was covered with palm trees similar to the Chilean wine palm—which 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 showed that trees began declining after human arrival, and ferns and grasses became more common. Then between 1400 and 1600, pollen levels plummeted. Charcoal in the soil proved the forest had been burned, likely for slash-and-burn farming. Researchers concluded that the islanders, desperate for forest resources and cropland, had deforested their own island.

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

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

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

When Terry Hunt and Carl Lipo began research on Rapa Nui in 2001, they expected simply to help fill gaps in a well-understood history. But science is a process of discovery, and sometimes evidence leads researchers far from where they anticipated. For Hunt, an anthropologist at University of Hawaii 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. 28) indicated that people had not colonized the island until about A.D. 1200, suggesting that deforestation occurred rapidly after their arrival. How could so few people have destroyed so much forest so fast? Hunt and Lipo's answer: rats. When Polynesians settled new islands, they brought crop plants and chickens and other domestic animals.

They also brought rats—intentionally as a food source or unintentionally as stowaways. In either case, rats can multiply quickly, and they soon overran Rapa Nui.

Researchers find 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 over 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 statues were transported. It had been thought that a powerful central authority forced armies of laborers to roll them over countless palm logs, but Hunt and Lipo concluded that small numbers of people could move them by tilting and rocking them upright—the same way we move refrigerators today. 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, 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, its statues tumbling around it.



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

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 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. 12) in how we view Easter Island. Debate between the two camps over these complex issues remains heated, however, and interdisciplinary research continues as scientists look for new ways to test the differing hypotheses. This is 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. □

The Nature of Science

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

Knowledge gained from science can be applied to address society's needs—for instance, to develop technology or to inform policy and management decisions (FIGURE 1.7). From the food we eat to the clothing we wear to the health care we rely on, virtually everything in our lives has been improved by the application of science. Many scientists are motivated by the potential for developing useful applications. Others are motivated simply by a desire to understand how the world works.

Scientists test ideas by critically examining evidence

Science is all about asking and answering questions. Scientists examine how the world works by making observations, taking



(a) Chevy Volt, an electric hybrid car



(b) Prescribed burning

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

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. In these ways, scientists are good role models for the rest of us, because we can all benefit from learning to think critically in our everyday lives.

A great deal of scientific work is **observational science** or **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. Such research is common in traditional fields such as astronomy, paleontology, and taxonomy, and also in newer, fast-growing fields such as molecular biology and genomics.

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 they 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 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.

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

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

Scientific method

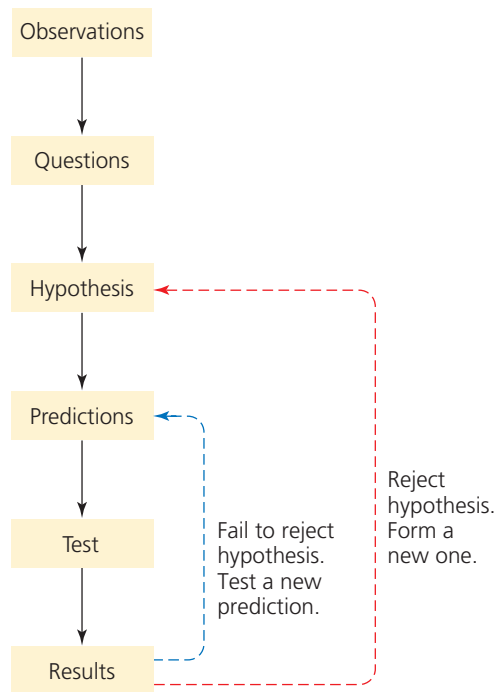


FIGURE 1.8 The scientific method is the traditional experimental approach that scientists use to learn how the world works.

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 them and thus disprove the hypothesis. The strongest form of evidence comes from experiments. An **experiment** is an activity designed to test the validity of a prediction or a hypothesis. It involves manipulating **variables**, or conditions that can change.

For example, a scientist could test the prediction linking algal growth to fertilizer by selecting two identical ponds and adding fertilizer to one of them. In this example, fertilizer input is an **independent variable**, a variable the scientist manipulates, whereas the quantity of algae that results is the **dependent variable**, a variable that depends on the fertilizer input. If the two ponds are identical except for a single independent variable (fertilizer input), then any differences that arise between the ponds

can be attributed to changes in the independent variable. Such an experiment is known as a **controlled experiment** because the scientist controls for the effects of all variables except the one he or she is testing. In our example, the pond left unfertilized serves as a **control**, an unmanipulated point of comparison for the manipulated **treatment** pond.

Whenever possible, it is best to replicate one’s experiment; that is, to stage multiple tests of the same comparison. Our scientist could perform a replicated experiment on, say, 10 pairs of ponds, adding fertilizer to one of each pair.

Analyze and interpret results Scientists record **data**, or information, from their studies (FIGURE 1.9). They 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 is representative.



FIGURE 1.9 Researchers gather data in order to test predictions in experiments. Here, Dr. Jennifer Smith of the Scripps Institution of Oceanography in San Diego photographs coral at a remote reef in the South Pacific. Data from analysis of the photos will help her test hypotheses about how human impacts affect the condition and community structure of coral reefs.