Our Island, Earth

1 SCIENCE AND SUSTAINABILITY: AN INTRODUCTION TO ENVIRONMENTAL SCIENCE

UPON COMPLETING THIS CHAPTER, YOU WILL BE ABLE TO:

- Define the term *environment* and describe the field of environmental science
- Explain the importance of natural resources and ecosystem services to our lives
- Discuss the effects of population growth and resource consumption
- Characterize the interdisciplinary nature of environmental science
- Understand the scientific method and the process of science
- Diagnose and illustrate some of the pressures on the global environment
- Articulate the concepts of sustainability and sustainable development

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 suggests that Earth and its systems are finite and limited. From this perspective, it becomes clear that as our population, technological powers, and consumption of resources increase, so does our capacity to alter our planet and damage the very systems that keep us alive.

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 that comprise the landscapes surrounding us. In a more inclusive sense, it encompasses our built environment as well—the structures, urban centers, and living spaces that people have created. In its broadest sense, our environment also 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 usage 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 with others the same 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 are separate and do not interact. However, the fundamental insight of environmental science is that we are part of the "natural" world and that our interactions with its other parts matter a great deal.

Environmental science explores our interactions with the world

Understanding our relationship with the world around us is vital because we depend utterly on our environment for air, water, food, shelter, and everything else essential for 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—but they have also often degraded the natural systems that sustain us. Impacts such as air and water pollution, soil erosion, and species extinction compromise our well-being, pose risks to human life, and jeopardize our ability to build a society that will survive and thrive in the long term.

Environmental science is the study of how the natural world works, how our environment affects us, and how we affect our environment. We need to understand our interactions with our environment in order to devise solutions to our most pressing challenges. It can be daunting to reflect on the sheer magnitude of environmental 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, through science, we are gaining knowledge more rapidly than ever. And right now, the window of opportunity for acting to solve problems is still open. With such bountiful challenges and opportunities, this particular moment in history is indeed an exciting time to be alive—and to be studying environmental science.

We rely on natural resources

An island by definition is finite and bounded, and its inhabitants must cope with limitations in the materials they need. On our island, Earth, human beings, like all living things, ultimately face environmental constraints. Specifically, there are limits to many of our **natural resources**, the various substances and energy sources that we take from our environment and that we need to survive. Natural resources that are replenished over short periods are known as **renewable natural resources**. Some renewable resources, such as sunlight, wind, and wave energy, are perpetually renewed and essentially inexhaustible. Others, such as timber, water, and soil, renew themselves over months, years, or decades. In contrast, resources such as mineral ores and crude oil are in finite supply and are formed much more slowly than we use them. These are known as **nonrenewable natural resources**. Once we deplete them, they are no longer available.

We can view the renewability of natural resources as a continuum (**FIGURE 1.1**). Renewable resources such as timber, water, and soil can be depleted if we use them faster than they are replenished. For example, pumping groundwater faster than it is restored can deplete underground aquifers and turn lush landscapes into deserts. Populations of animals and plants we take from the wild may vanish if we overharvest them.

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 receive and recycle our waste. Such essential services are commonly called **ecosystem services.** Ecosystem services arise from the normal functioning of natural systems, and although these processes are not meant for our benefit, we could not survive without them. Later in this book we will examine the countless and profound ways that ecosystem services support our lives and civilization (pp. 121–122, 160–161).

Just as we can deplete natural resources if we take too many of them, we can degrade ecosystem services by depleting resources, destroying habitat, or generating pollution. In recent years, our depletion of nature's goods and our disruption of nature's services have both intensified, driven by rising affluence and a human population that grows larger every day.

Population growth amplifies our impact

For nearly all of human history, less than a million people populated Earth at any one time. Today our population has grown beyond 6.9 *billion* people—several thousand times more! **FIGURE 1.2** shows just how recently and suddenly this monumental change has come about.

Two phenomena triggered remarkable increases in population size. The first was our transition from a hunter-gatherer

Renewable natural resources

- Sunlight
- Wind energy
- Wave energy
- Geothermal energy

- Fresh water
- Forest products
- Agricultural crops
- Soils

Nonrenewable natural resources

- Crude oil
- Natural gas
- Coal
- Copper, aluminum, and other metals

FIGURE 1.1 ▲ Natural resources lie along a continuum from perpetually renewable to nonrenewable. Perpetually renewable, or inexhaustible, resources, such as sunlight and wind energy, will always be there for us. Renewable resources, such as timber, soils, and fresh water, may be replenished on intermediate time scales, if we are careful not to deplete them. Nonrenewable resources, such as oil and coal, exist in limited amounts that could one day be gone.

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 found it easier to meet their nutritional needs. As a result, they began to live longer and to produce more children.

The second notable phenomenon, known as the **industrial revolution**, began in the mid-1700s. It entailed a shift from rural life, animal-powered agriculture, and handcrafted goods to an urban society (**FIGURE 1.3**) provisioned by the mass production of factory-made goods and powered by **fossil fuels** (nonrenewable energy sources including oil, coal, and natural gas; pp. 533–545). In the wake of industrialization, our technological advances have brought improvements in sanitation and medicine, and we have enhanced agricultural production with fossil-fuel-powered equipment and synthetic pesticides and fertilizers (pp. 254–255).

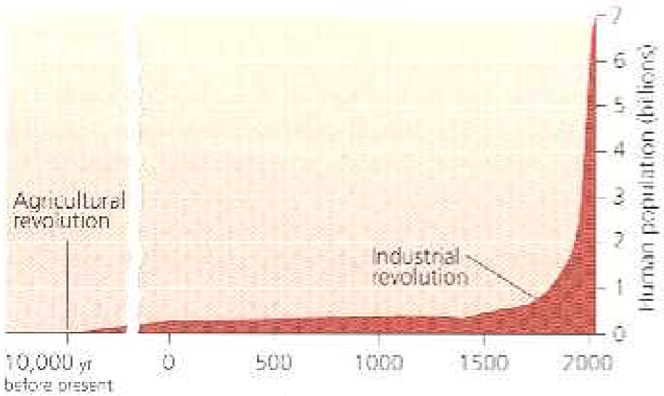


FIGURE 1.2 ▲ For almost all of human history, our population was low and relatively stable. It increased after the agricultural revolution and then skyrocketed as a result of the industrial revolution. Data compiled from U.S. Census Bureau, U.N. Population Division, and other sources.

The factors driving population growth have brought us better lives in many ways. But as our world fills up 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 for 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

Population growth is unquestionably at the root of many environmental problems. However, the growth in our exploitation and consumption of resources is also to blame. The industrial revolution enhanced the material affluence of many of the world's people by considerably increasing our consumption of natural resources and manufactured goods.

FIGURE 1.3 ▲ As our population swells and as nations industrialize, people are streaming to cities, creating congested urban areas such as this one in Java, Indonesia.

The "tragedy of the commons" When publicly accessible resources are open to unregulated exploitation, they inevitably become overused and, as a result, are damaged or depleted. So argued the late Garrett Hardin of the University of California at Santa Barbara in his 1968 essay in the journal *Science*, titled "The Tragedy of the Commons."

Basing his argument on a scenario described in a 19th-century pamphlet, Hardin explained that in a public pasture (or "common") open to unregulated grazing, each person who grazes animals will be motivated by self-interest to increase the number of his or her animals in the pasture. Because no single person owns the pasture, no one has incentive to expend effort taking care of it, and everyone takes what he or she can until the resource is depleted. This is known as the **tragedy of the commons**. Ultimately, overgrazing will cause the pasture's food production to collapse.

Some have argued that private ownership best addresses this problem. Others point to cases in which people sharing a common resource have voluntarily organized and cooperated to enforce its responsible use. Still others maintain that the dilemma justifies government regulation of the private use of resources held in common by the public, from grazing land and forests to clean air and water.

WEIGHING THE ISSUES

The Tragedy of the Commons Imagine you make your living by fishing. You are free to boat anywhere and set out as many lines and traps as you like, and your catches have been good. However, the fishing grounds are getting crowded, and you find yourself competing with more and more people for fewer and fewer fish. Catches decline year by year, leaving you and the other fishers with catches too meager to support your families. Some call for dividing the waters and selling access to individuals plot by plot. Others implore the government to regulate how many fish can be caught. Still others want to team up, set quotas themselves, and prevent newcomers from entering the market. What do you think is the best way to combat this tragedy of the commons and restore the fishery, and why?

Our ecological footprint As global affluence has increased, human society has consumed more and more of the planet's limited resources. We can quantify resource consumption using the concept of the "ecological footprint," developed in the 1990s by environmental scientists Mathis Wackernagel and William Rees. An **ecological footprint** expresses environmental impact in terms of 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 calculate that our ecological footprint now surpasses Earth's productive capacity by about 30%. That is, we are running a global deficit, depleting renewable resources by using them 30% faster than they are being replenished. This is essentially like drawing the principal out of a bank account rather than living off the interest. This global deficit has been termed **overshoot**, because we have overshot, or surpassed, Earth's capacity to sustainably support us (**FIGURE 1.5**). Moreover,

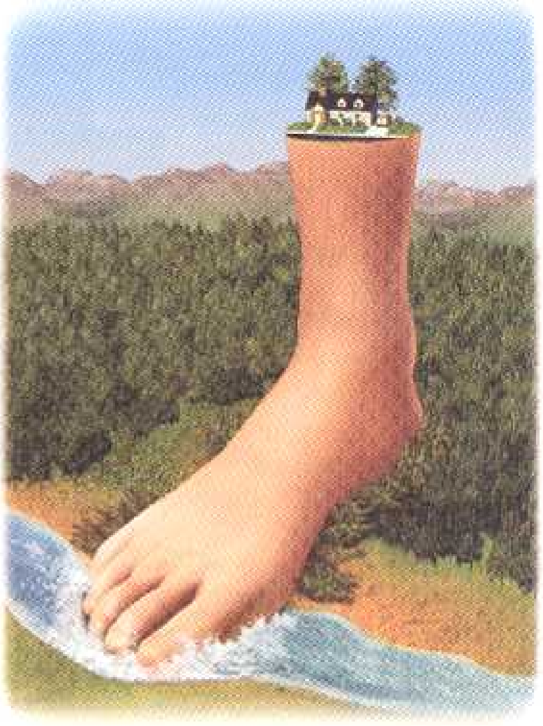


FIGURE 1.4 ▲ An "ecological footprint" represents the total area of biologically productive land and water needed to produce the resources and dispose of the waste for a given person or population. The footprint of an average citizen of an affluent nation is much larger than the physical area in which the person lives day to day. Adapted from an illustration by Philip Testemale in Wackernagel, M., and W. Rees, 1996. *Our ecological footprint: Reducing human impact on the Earth*. Gabriola Island, British Columbia: New Society Publishers.

FIGURE 1.5 ▲ The global ecological footprint of the human population is over 2.5 times larger than it was a half-century ago and now exceeds what Earth can bear in the long run, scientists have calculated. Data indicate that we have already overshot Earth's biocapacity—its capacity to support us—by 30%; that is, we are using renewable natural resources 30% faster than they are being replenished. Data from WWF International, 2008. *Living planet report 2008*. Published in October 2008 by WWF-World Wide Fund for Nature. (c) 2008 WWF (panda.org).

The SCIENCE behind the Story

The Lesson of Easter Island

The immense moai (statues) of Easter Island

Easter Island is one of the most remote spots on the globe, located in the Pacific Ocean 3,750 km (2,325 mi) from South America and 2,250 km (1,395 mi) from the nearest inhabited island. When the first European explorers reached the island (today called Rapa Nui) in 1722, they found a barren landscape populated by fewer than 2,000 people, who lived in caves and eked out a marginal existence from a few meager crops. However, explorers also noted that the desolate island featured hundreds of gigantic statues of carved stone, evidence that a sophisticated civilization had once inhabited the island.

Historians and anthropologists long wondered how people without wheels or ropes, on an island without trees, could have moved statues 10 m (33 ft) high weighing 90 metric tons (99 tons) as far as 10 km (6.2 mi) from the quarries where they were chiseled to the coastal sites where they were erected. The explanation, scientists discovered, was that the island did not always lack trees.

Indeed, scientific research tells us that the island had once been lushly forested and had supported a prosperous society of 6,000 to 30,000 people. Tragically, this once-flourishing civilization overused its resources and cut down all its trees, destroying itself in a downward spiral of starvation and conflict. Today Easter Island stands as a parable and a warning for what can happen when a population consumes too much of the limited resources that support it.

To solve the mystery of Easter Island's past, scientists have used various methods. Some, such as British scientist John Flenley, have excavated sediments from the bottom of the island's lakes, drilling cores deep into the mud and examining ancient grains of pollen preserved there. Pollen grains vary from one plant species to another, so scientists can reconstruct, layer by layer, the history of vegetation in a region through time. By analyzing pollen grains under scanning electron microscopes, Flenley and other researchers found that when Polynesian people arrived (likely between A.D. 300 and 900), the island was covered with a species of palm tree related to the Chilean wine palm, a tall and thick-trunked tree.

Adding to this evidence, archaeologists located ancient palm nut casings in caves and crevices, and a geologist found carbon-lined channels in the soil that matched root channels typical of the Chilean wine palm. Scientists deciphering the island people's script on stone tablets discerned characters etched in the form of palm trees.

By studying pollen and the remains of wood from charcoal, scientists, among them French archaeologist Catherine Orliac, found that at least 21 other species of plants, many of them trees, had also been common but are now completely gone. The island had clearly supported a diverse forest. However, starting around A.D. 750, tree populations declined and ferns and grasses became more common, according to pollen analysis from one lake site. By A.D. 950, the trees were largely gone, and around A.D. 1400 overall pollen levels plummeted, indicating a dearth of vegetation.

The same sequence of events occurred two centuries later at the other two lake sites, which were higher and more remote from village areas.

people from wealthy nations such as the United States have much larger ecological footprints than do people from poorer nations. If all the world's people consumed resources at the rate of U.S. citizens, we would need the equivalent of four and one-half planet Earths.

Environmental science can help us avoid past mistakes

It remains to be seen what consequences resource consumption and population growth will have for today's

The haunting statues of Easter Island (Rapa Nui) were erected by a sophisticated civilization that collapsed after depleting its resource base and devastating its island environment.

Researchers first hypothesized that the forest loss was due to climate change, but evidence instead supported the hypothesis that the people had gradually denuded their own island.

The trees provided fuelwood, building material for houses and canoes, fruit to eat, fiber for clothing—and, presumably, logs with which to move the stone statues. By hiring groups of men to recreate the feat, anthropologists have experimentally tested hypotheses about how the islanders moved their monoliths down from the quarries. The methods that have worked involve using numerous tree trunks as rollers or sleds, along with great quantities of rope. The only likely source of rope on the island would have been the fibrous inner bark of the hauhau tree, a species that today is near extinction.

With the trees gone, soil would have eroded away—a phenomenon confirmed by data from the lake bottoms, where large quantities of sediment accumulated. Faster runoff of rainwater would have meant less fresh water available for drinking. Runoff and erosion would have degraded the islanders' agricultural land, lowering yields of bananas, sugarcane, and sweet potatoes. Reduced agricultural production would have led to starvation and population decline.

Archaeological evidence supports a scenario of environmental degradation and civilization decline. Analysis of 6,500 bones by archaeologist David Steadman showed that at least 31 species of birds nested on Easter Island and provided food for the islanders. Today, only one native bird species is left.

Remains from charcoal fires aged using radioisotopes of carbon (p. 26) show that besides crops and birds, early islanders feasted on the bounty of the sea, including porpoises, fish, sharks, turtles, octopus, and shellfish. But analysis of islanders' diets in the later years indicated that the people consumed little seafood. With the trees gone, the islanders could no longer build the great double canoes their proud Polynesian ancestors had used for centuries to fish and travel among islands.

As resources declined, archaeologists found, the islanders began keeping their main domesticated food animal, chickens, in stone fortresses with entrances designed to prevent theft. The once prosperous and peaceful civilization fell into clan warfare, as revealed by unearthed weapons, skeletons, and skulls with head wounds.

Is the story of Easter Island as unique and isolated as the island itself, or does it hold lessons for our world today? Like the Easter Islanders, we are all stranded together on an island with limited resources. Earth may be vastly larger and richer in resources than Easter Island, but Earth's human population is also much greater.

The Easter Islanders must have seen that they were depleting their resources, but it seems that they could not stop. Whether we can learn from the history of Easter Island and act more wisely to conserve the resources on our island, Earth, is entirely up to us.

global society, but we have historical evidence that civilizations can crumble when pressures from population and consumption overwhelm resource availability. Easter Island is a classic case (see **THE SCIENCE BEHIND THE STORY**, above).

Many great civilizations have fallen after degrading their environments, and each has left devastated landscapes in its wake. Historians have concluded that environmental degradation contributed in part to the fall of the Greek and Roman empires; the Angkor civilization of Southeast Asia;

and the Maya, Anasazi, and other civilizations of the New World. In Iraq and other regions of the Middle East, areas that are barren desert today were lush enough to support the origin of agriculture when great ancient civilizations thrived there. In his 2005 book *Collapse*, scientist and author Jared Diamond synthesized existing research and formulated general reasons why civilizations succeed and persist, or fail and collapse. Success and persistence, he argued, depend largely on how societies interact with their environments and on how they respond to problems.

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 changes happening around us and to think critically and creatively about actions to take in response.

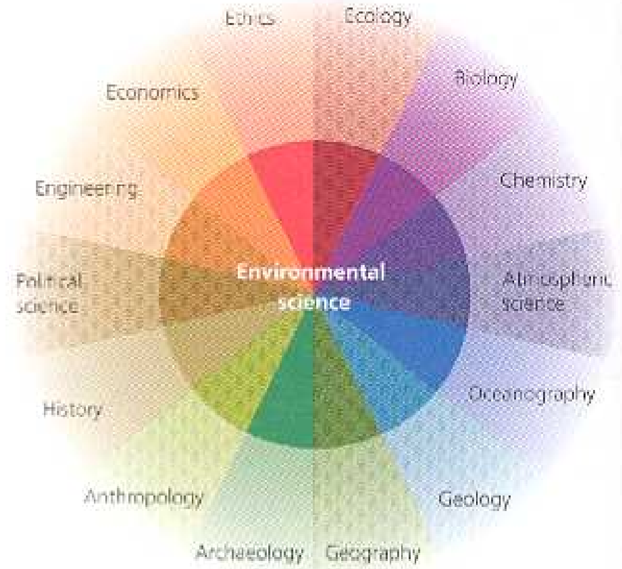


FIGURE 1.6 ▲ Environmental science is an interdisciplinary pursuit, involving input from many different established fields of study across the natural sciences and social sciences.

THE NATURE OF ENVIRONMENTAL SCIENCE

Environmental scientists aim to comprehend how Earth's natural systems function, how these systems affect people, and how we are influencing 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, in turn, also part of environmental science.

Environmental science is an interdisciplinary pursuit

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 thus an **interdisciplinary** field—one that borrows techniques from multiple disciplines and brings their research results together into a broad synthesis (**FIGURE 1.6**).

Traditional established disciplines are valuable because their scholars delve deeply into topics, uncovering new knowledge and developing expertise in particular areas. In contrast, interdisciplinary fields are valuable because their practitioners consolidate and synthesize the specialized knowledge from many different 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). The natural sciences provide us the means to obtain and interpret information about the world around us. However, to fully comprehend our interactions with our environment, we also need to weigh values and understand human behavior—and this requires the social sciences. Most environmental science programs focus predominantly on the natural sciences, whereas programs that incorporate the social sciences extensively often use the term **environmental studies**. Whichever approach one takes, these fields reflect many diverse perspectives and sources of knowledge.

Just as an interdisciplinary approach to studying issues can help us better understand them, an integrated approach to addressing environmental problems can produce effective solutions for society. As one example, we used to add lead to gasoline to make cars run more smoothly, even though researchers knew 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. Over the following years, environmental scientists, engineers, medical researchers, and policymakers all merged their knowledge and skills into a process that eventually resulted in 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 emissions had been completely eliminated.

People vary in their perception of environmental problems

Environmental science arose in the latter half of the 20th century as people sought to better understand environmental problems, their origins, and their solutions. However, the perception of what constitutes a problem may vary from one person to another, or from one situation to another. A person's age, gender, class, race, nationality, employment, income, and educational background can all affect whether he or she considers a given environmental condition or change to be a "problem."

For instance, people today are more likely to view the spraying of the pesticide DDT as a problem than they did in the 1950s, because today more is known about the health risks of pesticides (**FIGURE 1.7**). However, a person living today in a malaria-infested village in Africa or India may welcome the use of DDT if it kills mosquitoes that transmit malaria, because he or she may view malaria as a more immediate health threat. Thus an African and an American who have each knowledgeably assessed the pros and cons may, because of differences in their circumstances, differ in their judgment of DDT's severity as an environmental problem.

People may also vary in their awareness of problems. For example, in many cultures women are responsible for collecting water and fuelwood. As a result, they are often the first to perceive environmental degradation that affects these resources, whereas men simply might not "see" the problem. As another example, in most societies information about environmental health risks tends to reach wealthy people more readily than poor people. Thus, who you are, where you live, and what you do influences how you perceive your environment, how change affects you, and how you react to change. In Chapter 6 we will examine the diversity of human values and philosophies and consider their consequences for how we define environmental problems.

FIGURE 1.7 ▲ How a person or a society defines an environmental problem can vary with time and circumstance. In 1945, health hazards of the pesticide DDT were not yet known, so children were doused with the chemical to treat head lice. Today, knowing of its toxicity to people and wildlife, many developed nations have banned DDT. However, in developing countries where malaria is a threat, DDT is welcomed as a means of eradicating mosquitoes that transmit the disease.

FIGURE 1.8 ▲ Environmental scientists play roles very different from those of environmental activists, such as the protestors shown here. Although many environmental scientists search for solutions to environmental problems, they generally aim to keep their research rigorously objective and free from advocacy.

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 *not* the same. **Environmentalism** is a social movement dedicated to protecting the natural world—and, by extension, people—from undesirable changes brought about by human actions (**FIGURE 1.8**). Environmental science, in contrast, is the pursuit of knowledge about the workings of the environment and our interactions with it.

Although environmental scientists study many of the same issues environmentalists care about, as scientists they aim to maintain an objective approach in how they conduct their work. Like any other human endeavor, science can never be entirely free of social or political influence—and like all people, scientists are motivated by personal values and interests. Yet although personal values and social concerns may shape how scientists choose their goals, scientists try to avoid undue influence from outside pressures and preconceptions when carrying out their work. Remaining free from bias, and open to whatever conclusions the data reveal, is a hallmark of the effective scientist.

THE NATURE OF SCIENCE

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

Knowledge gained from science can be applied to address societal needs. Among the applications of science is its use in developing technology and in informing policy and management decisions (**FIGURE 1.9**). Many scientists are motivated by the potential for developing such useful applications, whereas others are motivated simply by a desire to understand how the world works.

Why does science matter? The late astronomer and author Carl Sagan wrote the following in his 1995 treatise, *The Demon Haunted World: Science as a Candle in the Dark*:

> We've arranged a global civilization in which the most crucial elements—transportation, communications, and all other industries; agriculture, medicine, education, entertainment, protecting the environment; and even the key democratic institution of voting—profoundly depend on science and technology. . . . Science is an attempt, largely successful, to understand the world, to get a grip on things, to get hold of ourselves, to steer a safe course.

Sagan and many other thinkers have argued that science is essential if we hope to sort fact from fiction and develop solutions to the challenges we face. Moreover, making science accessible and understandable to as many people as possible is also vital if we are to make informed decisions as a society.

(a) Prescribed burning

(b) Chevy Volt, an electric hybrid car

FIGURE 1.9 ▲ Scientific knowledge can be applied in policy and management decisions and in engineering and technology. Prescribed burning **(a)**, shown here in the Ouachita National Forest, Arkansas, is a management practice to restore healthy forests that is informed by scientific research into forest ecology. Energy-efficient automobiles such as the Chevy Volt **(b)**, an electric car due for release in late 2010, are technological advances made possible by materials and energy research.

Scientists test ideas by critically examining evidence

Science is all about asking and answering questions. Scientists examine how the world works by making observations, taking measurements, and designing tests to determine whether ideas are supported by evidence. If a particular explanation is testable and resists repeated attempts to disprove it, scientists will come to accept it as a true explanation. Scientific inquiry thus consists of an incremental approach to the truth.

The effective scientist thinks critically and does not simply accept the conventional wisdom that he or she hears from others. The scientist becomes excited by novel ideas but is a skeptic 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 every one of us can benefit from learning to think critically in our everyday lives.

Science advances in different ways

A great deal of scientific work is **observational science** or **descriptive science**, types of research in which scientists gather basic information about organisms, materials, systems, or processes that are not well known or that cannot be manipulated in experiments. In these approaches, researchers explore new frontiers of knowledge by observing and measuring phenomena to gain a better understanding of the world. Such research is common in traditional fields such as astronomy, paleontology, and taxonomy, as well as in newer and expanding fields such as molecular biology and genomics.

Once enough general information is known about a subject, scientists can begin posing more specific questions that ask 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 naturally use logic to resolve a question.

Because science is an active, creative process, an innovative researcher may find good reason to stray from the traditional scientific method when a particular situation demands it. Moreover, scientists in different fields approach their work differently because they deal with dissimilar types of information. A natural scientist, such as a chemist, will conduct research quite differently from a social scientist, such as a sociologist. However, scientists of all persuasions broadly agree on fundamental elements of the process of scientific inquiry.

The scientific method relies on the following assumptions:

- The universe functions in accordance with fixed natural laws that do not change from time to time or from place to place.
- All events arise from some cause or causes and, in turn, cause other events.
- We can use our senses and reasoning abilities to detect and describe natural processes that underlie the cause-and-effect relationships we observe in nature.

As practiced by individual researchers or research teams, the scientific method (**FIGURE 1.10**) typically consists of the steps outlined below.

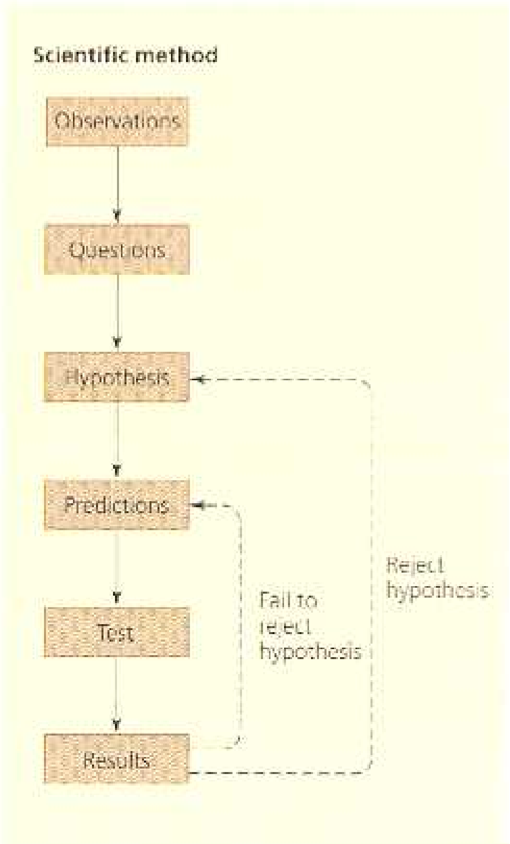


FIGURE 1.10 ▲ The scientific method is the traditional experimental approach that scientists use to learn how the world works. This diagram is a simplified generalization that, although useful for instructive purposes, cannot convey the true dynamic and creative nature of science. Moreover, researchers from different disciplines may pursue their work in ways that vary legitimately from this model.

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

Ask questions Curiosity is a fundamental human characteristic—just observe the explorations of a young child in a new environment. Babies want to touch, taste, watch, and listen to anything that catches their attention, and as soon as they can speak, they begin asking questions. Scientists, in this respect, are kids at heart. Why are certain plants or animals less common today than they once were? Why are storms becoming more severe and flooding more frequent? What is causing excessive growth of algae in local ponds? When pesticides poison fish or frogs, does that indicate that people may also be affected? All of these are questions environmental scientists ask.

Develop a hypothesis Scientists attempt to answer 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 the question of why algae are growing excessively in local ponds might observe chemical fertilizers being applied on farm fields nearby. The scientist might then state a hypothesis as follows: "Agricultural fertilizers running into ponds cause the amount of algae in the ponds to increase." Sometimes a scientist begins with a *null hypothesis*, which postulates no relationship between variables (such as between fertilizer and algal growth), and tests this against *alternative hypotheses* that propose particular relationships.

Make predictions The scientist next uses his or her 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 one at a time by gathering evidence that could potentially refute the prediction and thus disprove the hypothesis (**FIGURE 1.11**). The strongest form of evidence comes from experimentation. 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 while leaving the other in its natural state. 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**, one 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 that variable. Such an experiment is known as a **controlled experiment** because the scientist controls for the effects of all variables except the one whose effect 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.

FIGURE 1.11 ▲ Here Dr. Jennifer Smith of the Scripps Institution of Oceanography in San Diego uses a quadrat with a digital camera to photograph sites along a transect of a coral reef at a remote atoll 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.

Whenever possible, it is best to replicate one's experiment; that is, to stage multiple tests of the same comparison of control and treatment. 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. They particularly value quantitative data (information expressed using numbers), because numbers provide precision and are easy to compare. The scientist running 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.

However, even with the precision that numbers provide, a scientist's results may not be clear-cut. Data from treatments and controls may vary only slightly, or replicates may yield different results. The researcher must therefore analyze the data using statistical tests. With these mathematical methods, scientists can determine objectively and precisely the strength and reliability of patterns they find.

Some research, especially in the social sciences, involves data that is qualitative, or not expressible in terms of numbers. Research involving historical texts, personal interviews, surveys, case studies, or descriptive observation of behavior can include qualitative data on which quantitative statistical analysis may not be possible.

If experiments disprove a hypothesis, the scientist will reject it and may formulate a new hypothesis to replace it. If experiments fail to disprove a hypothesis, this result lends support to the hypothesis but does not *prove* it is correct. The scientist may choose to generate new predictions to test the hypothesis in different ways and further assess its likelihood of being true. Thus, the scientific method loops back on itself, often giving rise to repeated rounds of hypothesis revision, prediction, and testing (see Figure 1.10). If repeated tests fail to reject a particular hypothesis, evidence in favor of it accumulates, and the researcher may eventually conclude that the hypothesis is well supported.

Ideally, the scientist would want to test all possible explanations for the question of interest. For instance, our researcher might propose two alternative hypotheses for why algae increase in fertilized ponds: Is it because the chemical nutrients spur algal growth directly, or is it because fertilizer contamination decreases the numbers of fish or invertebrate animals that eat algae? It is possible, of course, that both hypotheses could be correct and that each may explain some portion of the initial observation that local ponds were experiencing algal blooms.

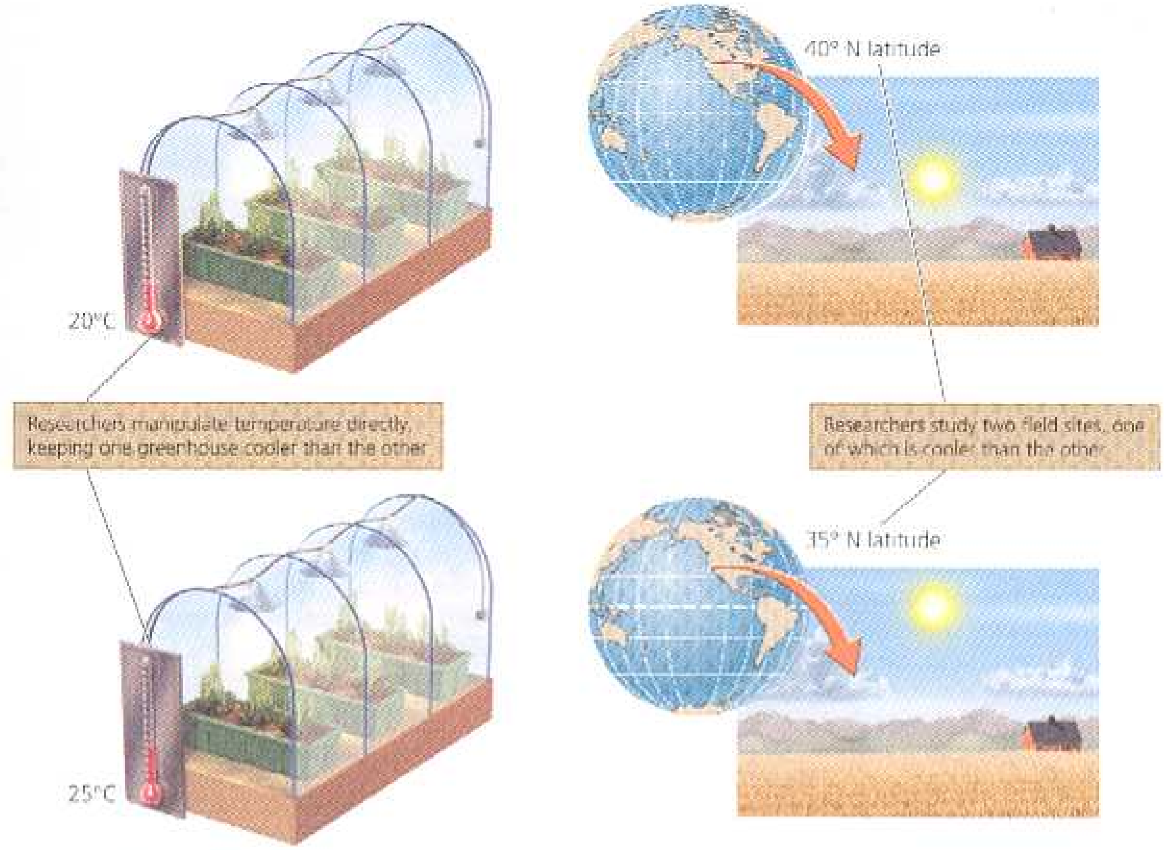
We can test hypotheses in different ways

An experiment in which the researcher actively chooses and manipulates the independent variable is known as a **manipulative experiment** (**FIGURE 1.12A**). A manipulative experiment provides the strongest type of evidence a scientist can obtain, because it can reveal causal relationships, showing that changes in an independent variable cause changes in a dependent variable. In practice, however, we cannot run manipulative experiments for all questions, especially for processes that operate at large spatial scales or on long time scales. For example, in studying the effects of global climate change (Chapter 18), we cannot run a manipulative experiment adding carbon dioxide to 10 treatment planets and 10 control planets and then compare the results!

Thus, in environmental science, it is common for researchers to run **natural experiments** (**FIGURE 1.12B**), which compare how dependent variables are expressed in naturally different contexts. In such experiments, the independent variable varies naturally, and researchers test their hypotheses by searching for **correlation**, or a statistical relationship among variables.

For instance, let's suppose our scientist studying algae surveys 50 ponds, 25 of which happen to be fed by fertilizer runoff from nearby farm fields and 25 of which are not. Let's say he or she finds seven times more algal growth in the fertilized ponds than in the unfertilized ponds. The scientist would conclude that algal growth is correlated with fertilizer input; that is, that one tends to increase along with the other.

This type of evidence is weaker than the causal demonstration that manipulative experiments can provide, but sometimes



(a) Manipulative experiment **(b) Natural experiment, or correlational study**

FIGURE 1.12 ▲ A researcher wishing to test how temperature affects the growth of a crop might run a manipulative experiment **(a)**, in which the crop is grown in two identical greenhouses, one kept at 20 °C (68 °F) and the other kept at 25 °C (77 °F). Alternatively, the researcher might run a "natural experiment" **(b)**, in which he or she compares the growth of the crop in two fields at different latitudes, a cool northerly location and a warm southerly one. Because it would be difficult to hold all variables besides temperature constant in the natural experiment, the researcher might want to study a number of northern and southern fields and correlate data on temperature and crop growth.

a natural experiment is the only feasible approach for a subject of immense scale, such as an ecosystem or a planet. Because of their large scale and complexity, many questions in environmental science must be addressed with correlative data. As such, environmental scientists cannot always provide clear-cut, black-and-white answers to questions from policymakers and the public. Nonetheless, good correlative studies can make for strong science, and they preserve the real-world complexity that manipulative experiments often sacrifice.

The scientific process does not stop with the scientific method

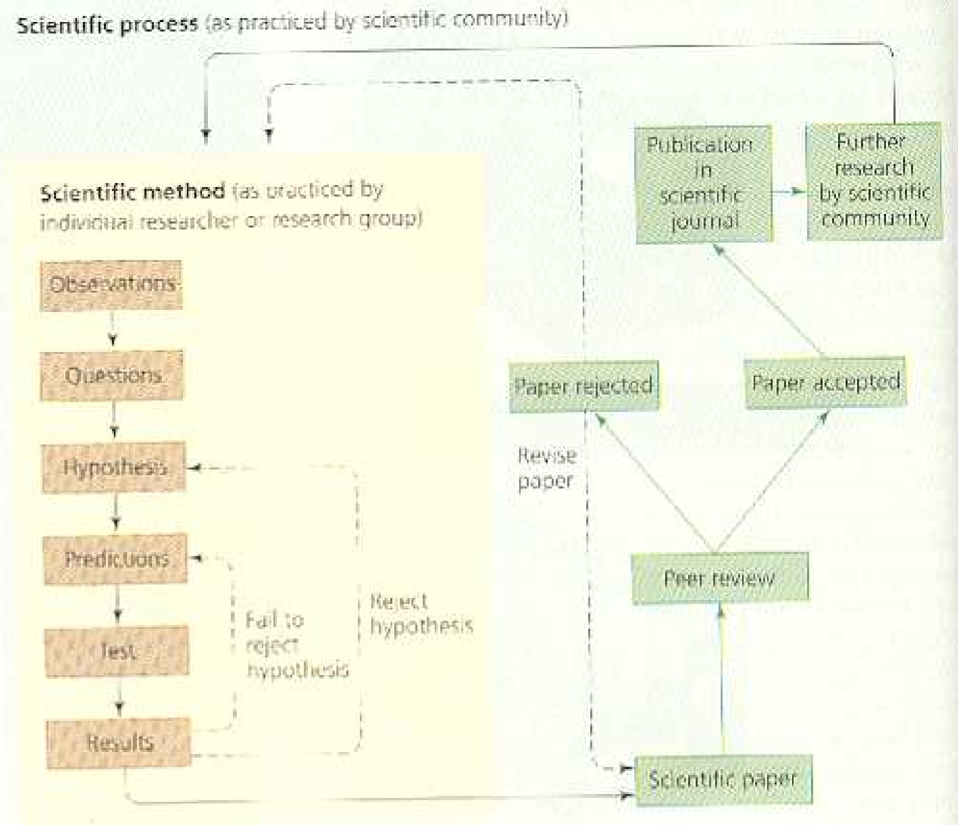
Scientific work takes place within the context of a community of peers. To have impact, a researcher's work must be published and made accessible to this community. Thus, the scientific method is embedded within a larger process involving the scientific community as a whole (**FIGURE 1.13**).

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

Peer review is a valuable guard against faulty research contaminating the literature on which all scientists rely. However, because scientists are human and may have their own personal biases and agendas, politics can sometimes creep into the review process. Fortunately, just as individual scientists strive to remain objective in conducting their research, the scientific community does its best to ensure fair review of all work. Winston Churchill once called democracy the worst form of government, except for all the others that had been tried. The same might be said about peer review; it is an imperfect system, yet no one has come up with a better one.

Conference presentations Scientists frequently present their work at professional conferences, where they interact with colleagues and receive informal comments on their research. Such feedback can help improve a scientist's work before it is submitted for publication.

FIGURE 1.13 ▶ The scientific method (inner yellow box) followed by individual researchers or research teams exists within the context of the overall process of science at the level of the scientific community (outer green box). This process includes peer review and publication of research, acquisition of funding, and the elaboration of theory through the cumulative work of many researchers.



Grants and funding To fund their research, most scientists are forced to spend enormous amounts of time writing grant applications to request money from private foundations or from government agencies such as the National Science Foundation. Grant applications undergo peer review just as scientific papers do, and competition for funding is generally intense.

Scientists' reliance on funding sources can occasionally lead to conflicts of interest. A researcher who obtains data showing his or her funding source in an unfavorable light may be reluctant to publish the results for fear of losing funding — or worse yet, may be tempted to doctor the results. This situation can arise, for instance, when an industry funds research to test its products for safety or environmental impact. Few scientists succumb to these temptations, but some funding sources have been known to pressure their researchers for certain results. This is why as a student or informed citizen, when critically assessing a scientific study, you should always try to find out where the researchers obtained funding.

WEIGHING THE ISSUES

Follow the Money Let us say you are a research scientist, and you want to study the impacts of chemicals released by pulp-and-paper mills on nearby lakes. Obtaining research funding has been difficult. Then a representative from a large pulp-and-paper company contacts you. The company also is interested in how its chemical effluents affect water bodies, and it would like to fund your research. What are the benefits and drawbacks of this offer? Would you accept the offer?

Repeatability Even when a hypothesis appears to explain an observed phenomenon, scientists are inherently wary of accepting it. The careful scientist may test a hypothesis repeatedly in various ways before submitting the findings for publication. Following publication, other scientists may attempt to reproduce the results in their own experiments and analyses.

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

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

For example, Darwin's theory of evolution by natural selection (pp. 52–55) has been supported and elaborated by many thousands of studies over 150 years of intensive research. Research has shown repeatedly and in great detail how plants and animals change over generations, or evolve, to express characteristics that best promote survival and reproduction. Because of its strong support and explanatory power, evolutionary theory is the central unifying principle of modern biology. Other prominent scientific theories include atomic theory, cell theory, the big bang theory, plate tectonics, and general relativity.

Applications Knowledge gained from scientific research may be applied to help fulfill society's needs and address society's problems. As discussed earlier (see Figure 1.9), scientific research informs and facilitates new technologies, engineering approaches, policy decisions, and management strategies. However, even when research is able to provide clear information, deciding on the optimal social response to a problem can still be difficult. Moreover, many predicaments addressed by environmental science are so-called *wicked problems*: problems complex enough to have no simple solution and whose very nature changes over time. As a result, we need scientists to continue studying such problems as they evolve.

Science goes through "paradigm shifts"

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

Another paradigm shift occurred in the 1960s, when geologists accepted plate tectonics (pp. 35–37). By this time, evidence for the movement of continents and the action of tectonic plates had accumulated and become overwhelmingly convincing. Such paradigm shifts demonstrate the strength and vitality of science, showing it to be a process that refines and improves itself through time.

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

SUSTAINABILITY AND THE FUTURE OF OUR WORLD

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

Achieving sustainable solutions is vital

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

We can think of our planet's resources as a bank account. If we deplete resources, we draw down the bank account. However, we can choose instead to use the interest and leave the principal intact so that we can continue using the interest far into the future. Presently we are drawing down Earth's **natural capital**—its accumulated wealth of resources. Recall (p. 5) that researchers estimate that we are withdrawing our planet's natural capital 30% faster than it is being replenished. To live off nature's interest—its replenishable resources—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—and we cannot get away with this for long.

Sustainability is a concept you will encounter throughout this book, infused through issue after issue. Our final chapter (Chapter 24) rounds out our discussion by presenting a broad summary of approaches to sustainability—on college and university campuses and in the world at large. Along the way, we will explore a wide array of issues in our far-reaching search for sustainable solutions.

Population and consumption drive environmental impact

We modify our environment in diverse ways, but the steep and sudden rise in human population (Chapter 8) has amplified nearly all of our impacts. We add about 80 million people to the planet each year—that's over 200,000 per day. Today, the rate of population growth is slowing, but our absolute numbers continue to increase.

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

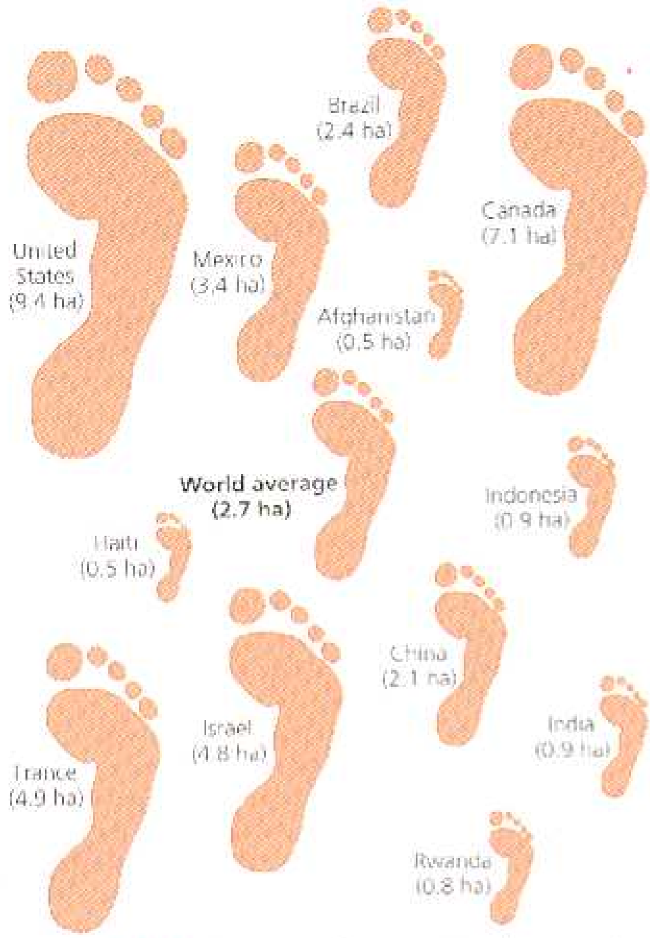


FIGURE 1.14 ▲ The citizens of some nations have much larger ecological footprints than the citizens of others. Shown here are ecological footprints for average citizens of several developed and developing nations, along with the world's average per capita footprint of 2.7 hectares. One hectare (ha) = 2.47 acres. Data are for 2005, from Global Footprint Network, 2008.

Moreover, the world's citizens have not benefited equally from our overall rise in affluence. Today the 20 wealthiest nations boast over 55 times the per capita income of the 20 poorest nations—nearly three times the gap that existed just four decades ago. The ecological footprint of the average citizen of a developed nation such as the United States is considerably larger than that of the average resident of a developing country (**FIGURE 1.14**). Within the United States, the richest 10% of people claim fully half the income, and the richest 1% claim nearly a quarter of all income.

WEIGHING THE ISSUES

Ecological Footprints What do you think accounts for the variation in sizes of per capita ecological footprints among societies? Do you think that nations with larger footprints have a moral obligation to reduce their environmental impact, so as to leave more resources available for nations with smaller footprints?

We face challenges with agriculture, pollution, and biodiversity

Our dramatic growth in population and consumption is due in part to our success in expanding and intensifying the production of food (Chapters 9 and 10). Since the origin of agriculture and the industrial revolution, progressively more powerful technologies have enabled us to grow more and more food per unit of land. These advances in agriculture must be counted as one of humanity's great achievements, but they have come at some cost. We have converted nearly half the planet's land surface for agriculture, and our extensive use of chemical fertilizers and pesticides poisons organisms and alters natural systems. Erosion, climate change, and poorly managed irrigation destroy 5–7 million ha (hectares; 12.5–17.5 million acres) of productive cropland each year. Together, agriculture, urban sprawl, and various other land uses have substantially affected most of the landscape of the United States and all other nations (**FIGURE 1.15**).

Meanwhile, pollution from our farms, industries, households, and vehicles dirties our land, water, and air. Outdoor air pollution, indoor air pollution, and water pollution contribute to the deaths of millions of people each year (Chapters 15–17). Environmental toxicologists are chronicling the impacts on people and wildlife of the many synthetic chemicals and other pollutants we emit into the environment (Chapter 14).

Perhaps our most pressing pollution challenge is to address the looming specter of global climate change (Chapter 18). Scientists have firmly concluded that human activity is altering the composition of the atmosphere and that these changes are affecting Earth's climate. Since the start of the industrial revolution, our combustion of fossil fuels and our deforestation of the landscape have boosted atmospheric carbon dioxide concentrations by 39%, to a level not present in at least 800,000 years, and probably 20 million years. Carbon dioxide and several other gases absorb and emit radiation and warm Earth's surface, which in turn causes glacial melting; sea level rise; changes in rainfall patterns; increased storms; and impacts on crops, forests, wildlife, and health.

The combined impact of human actions—climate change, overharvesting, pollution, the introduction of non-native species, and particularly habitat alteration—has driven many species toward extinction (Chapter 11). Today Earth's biological diversity, or **biodiversity**, the cumulative number and diversity of living things (pp. 55, 282–287), is declining dramatically (**FIGURE 1.16**). Biologists say we are setting in motion a mass extinction event (pp. 59–61, 288–290) comparable to only five others documented in all of Earth's history. Biologist Edward O. Wilson has warned that the loss of biodiversity is our most threatening dilemma because extinction is irreversible; once a species has become extinct, it is lost forever.

The most comprehensive scientific assessment of the condition of the world's ecological systems and their ability to continue supporting our civilization was completed in 2005, when over 2,000 of the world's leading environmental scientists from nearly 100 nations completed the **Millennium Ecosystem Assessment**. The main findings of this exhaustive project are summarized in **TABLE 1.1**. The Millennium Ecosystem Assessment makes it clear that our degradation

FIGURE 1.15 ▲ Human activity has heavily influenced much of the United States, especially in cities, on farms, and across the eastern portion of the nation. This map summarizes influence on terrestrial ecosystems by human settlement, roads and transportation networks, nighttime light pollution, and agriculture and other land use. It demonstrates that we live in a highly modified environment and suggests we would be wise to carefully nurture natural systems and manage remaining resources. Used by permission of the Center for International Earth Science Information Network (CIESIN), The Earth Institute, Columbia University. (c) 2008.

FIGURE 1.16 ▲ Human activities are pushing many organisms, including the panda, toward extinction. Efforts to save endangered species and reduce the loss of biodiversity include many approaches, but all require that adequate areas of appropriate habitat be preserved in the wild.

of the world's environmental systems is having negative impacts on all of us, but that with care and diligence we can still turn many of these trends around.

Our energy choices will influence our future enormously

Our reliance on fossil fuels to power our civilization has intensified virtually every impact we have on our environment, from habitat alteration to air pollution to climate change. Fossil fuels have also brought us the material affluence we enjoy. By exploiting the richly concentrated energy in coal, oil, and natural gas, we have been able to power the machinery of the industrial revolution, produce the chemicals that boost agricultural yields, run the vehicles and transportation networks of our mobile society, and manufacture and distribute our countless consumer products. The lifestyles we lead today are a direct result of the availability of fossil fuels (Chapter 19).

However, in extracting fossil fuels, we are splurging on a one-time bonanza. Scientists calculate that we have depleted roughly half the world's oil supplies and that we are in for a rude awakening soon, once supply begins to decline while demand continues to rise (pp. 539–544). We are also approaching peak production of natural gas, and coal is also nonrenewable and in finite supply. How we handle the imminent crises of fossil fuel depletion will largely determine the nature of our lives in the 21st century.

Sustainable solutions abound

Humanity's challenge is to develop solutions that enhance our quality of life while protecting and restoring the environment

TABLE 1.1 Main Findings of the Millennium Ecosystem Assessment

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

Adapted from *Millennium ecosystem assessment. 2005 ecosystems and human well-being: biodiversity synthesis.* World Resources Institute, Washington, DC.

that supports us. Fortunately, many workable solutions are at hand. For instance:

- A multitude of renewable energy sources (Chapters 20 and 21) are being developed to take the place of fossil fuels (**FIGURE 1.17**), and energy-efficiency efforts are gaining ground.
- In response to agricultural impacts, scientists and others have developed and promoted soil conservation, high-efficiency irrigation, and organic agriculture.
- Legislation and technological advances have reduced the pollution emitted by industry and automobiles in wealthier countries.
- Amid deep concern over the state of global biodiversity, advances in conservation biology (pp. 300–309) are helping to protect habitat, slow extinction, and safeguard endangered species.
- Recycling is helping to mitigate our waste disposal problems (Chapter 22).
- Nations, states, municipalities, businesses, and individuals are beginning to take steps to reduce emissions of the greenhouse gases that drive climate change.

FIGURE 1.17 ▼ We can develop clean and renewable energy sources, for our sustainable use now and in the future. Just as a flowering plant gathers energy from the sun, we can use rooftop panels like these to harness solar energy.

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

Are things getting better or worse?

Despite the myriad challenges we face, some people maintain that the general conditions of human life and the environment are in fact getting better, not worse. A well-known proponent of this view, Danish statistician Bjorn Lomborg, wrote the following in his 2001 book *The Skeptical Environmentalist*:

> We are not running out of energy or natural resources. There will be more and more food per head of the world's population. Fewer and fewer people are starving. In 1900 we lived for an average of 30 years; today we live for 67. . . . The air and water around us are becoming less and less polluted. Mankind's lot has actually improved in terms of practically every measurable indicator.

Furthermore, some people maintain that we will find ways to make Earth's natural resources meet all of our needs indefinitely and that human ingenuity will see us through any difficulty. Such views are sometimes characterized as **Cornucopian.** In Greek mythology, *cornucopia*—literally "horn of plenty"—is the name for a magical goat's horn that overflowed with grain, fruit, and flowers. In contrast, people who predict doom and disaster have been called **Cassandras**, after the mythical princess of Troy with the gift of prophecy, whose dire predictions were not believed.

At least three questions are worth asking each time you are confronted with seemingly conflicting statements from Cornucopians and Cassandras:

1. Do the impacts being debated pertain only to people or also to other organisms and to natural systems?
2. Are the proponents of each view thinking in the short term or in the long term?
3. Are they considering all costs and benefits relevant for the question at hand, or only some?

As you proceed through this book and encounter countless contentious issues, consider how a person's perception of them may be influenced by these three factors.

Sustainable development involves environmental protection, economic well-being, and social equity

Environmental protection often is portrayed as threatening people's economic and social needs, but environmental scientists have long recognized that our civilization cannot exist without an intact and functional natural environment. In recent years, people of all persuasions have increasingly realized how environmental quality supports human quality of life.

Moreover, we now recognize that it is society's poorer people who suffer the most from environmental degradation. This realization has led advocates of environmental protection, economic development, and social justice to begin working together toward common goals. This cooperative approach has given rise to the modern drive for sustainable development.

Economists employ the term *development* to describe the use of natural resources for economic advancement (as opposed to simple subsistence, or survival). More broadly, development involves making purposeful changes intended to improve the quality of human life. Construction of homes, schools, hospitals, power plants, factories, and transportation networks are all examples of development. **Sustainable development** is the use of resources in a manner that satisfies our current needs but does not compromise the future availability of resources. The United Nations (p. 189) defines sustainable development as development that "meets the needs of the present without sacrificing the ability of future generations to meet their own needs." This definition is taken from the United Nations–sponsored Brundtland Commission (named after its chair, Norwegian prime minister Gro Harlem Brundtland), which published an influential 1987 report titled *Our Common Future*.

Prior to the Brundtland Report, most people aware of human impact on the environment might have thought "sustainable development" to be an oxymoron—a phrase that contradicts itself. Environmental advocates had long pointed out that development often so degrades the natural environment that it threatens the very improvements for human life that were intended. Conversely, many people remain under the impression that protecting the environment is incompatible with serving people's economic needs.

People also vary in how they interpret the phrase "sustainable development." Some businesspeople use it to mean ever-increasing economic gain, regardless of social or ecological well-being—whereas most environmental advocates use it to mean a novel kind of development that values and prioritizes environmental protection. Proponents of a school of thought called "weak sustainability" feel that we can allow natural capital to decline over time as long as human-made capital increases to compensate for it. In contrast, proponents of "strong sustainability" insist that human-made capital cannot substitute for natural capital and that therefore we must not allow natural capital to degrade.

In part because of the ambiguity resulting from differing interpretations of the term, just about everyone claims to support sustainable development these days. Sustainable development efforts are being undertaken by governments, businesses, industries, organizations, and individuals everywhere—from students on campus (Chapter 24) to international representatives at the United Nations (**FIGURE 1.18**). Many of these efforts truly are innovative and call for business and development interests to satisfy a **triple bottom line**, in which the goal is not simply the maximization of profit or economic advancement, but also environmental protection and the promotion of social equity. Solutions that meet environmental, economic, and social goals simultaneously, addressing the triple bottom line, can help pave the way for a truly sustainable society that promotes economic and social well-being while limiting environmental impact.

These aims require us to make an ethical commitment to our fellow citizens and to future generations. They also require that we apply knowledge from the sciences to help us devise ways to limit our impact and maintain the functioning environmental systems on which we depend. The question "How can we develop in a sustainable way?" may well be the single most important question in the world today. Environmental science holds the key to addressing this question.

FIGURE 1.18 ▲ Former South African President Thabo Mbeki hugs a boy who performed in the welcoming ceremony of the United Nations–sponsored World Summit on Sustainable Development, held in Johannesburg, South Africa, in 2002, where 10,000 delegates from 200 nations set sustainable development goals. Sustainability requires that each generation leave enough resources for future generations to live as well or better.

➤ CONCLUSION

Finding effective ways of living peacefully, healthfully, and sustainably on our diverse and complex planet will require a thorough scientific understanding of both natural and social systems. Environmental science helps us understand our intricate relationship with our environment and informs our attempts to solve and prevent environmental problems. Identifying a problem is the first step in devising a solution to it. Many of the trends detailed in this book may cause us worry, but others give us reason to hope. Solving environmental problems can move us toward health, longevity, peace, and prosperity. Science in general, and environmental science in particular, can aid us in our efforts to develop balanced and workable solutions to the many challenges we face today and to create a better world for ourselves and our children.

REVIEWING OBJECTIVES

You should now be able to:

DEFINE THE TERM *ENVIRONMENT* AND THE FIELD OF ENVIRONMENTAL SCIENCE

- Our environment consists of everything around us, including living and nonliving things. (p. 3)
- Humans are part of the environment and are not separate from nature. (p. 3)
- Environmental science is the study of how the natural world works, how our environment affects us, and how we affect our environment. (p. 3)

EXPLAIN THE IMPORTANCE OF NATURAL RESOURCES AND ECOSYSTEM SERVICES TO OUR LIVES

- Some resources are inexhaustible or perpetually renewable, others are nonrenewable, and still others are renewable if we do not overexploit them. (pp. 3–4)
- Ecosystem services are benefits we receive from the processes and normal functioning of natural systems. (p. 3)
- Resources and ecosystem services are essential to human life and civilization, yet we are depleting and degrading them. (p. 3)

DISCUSS THE EFFECTS OF POPULATION GROWTH AND RESOURCE CONSUMPTION

- Rapid growth of the human population magnifies our environmental impacts. (pp. 3–4)
- The tragedy of the commons can lead to resource depletion. (p. 5)
- The ecological footprint concept quantifies a person's or nation's resource consumption in terms of area of biologically productive land and water. (pp. 5–6)

CHARACTERIZE THE INTERDISCIPLINARY NATURE OF ENVIRONMENTAL SCIENCE

- Environmental science employs approaches and insights from numerous disciplines in the natural sciences and social sciences. (p. 8)

UNDERSTAND THE SCIENTIFIC METHOD AND THE PROCESS OF SCIENCE

- Science is a process of using observations to test ideas. (p. 10)
- The scientific method consists of a series of steps that include making observations, formulating questions, stating a hypothesis, generating predictions, testing predictions, and analyzing results obtained from the tests. (pp. 10–12)
- There are different ways to test questions scientifically (for example, with manipulative experiments to determine causation or with natural experiments and correlation). (pp. 12–13)
- Scientific research occurs within a larger process that includes peer review of work, journal publication, and interaction with colleagues. (pp. 13–15)
- Science goes through paradigm shifts. This openness to change is what gives science its strength. (p. 15)

DIAGNOSE AND ILLUSTRATE SOME OF THE PRESSURES ON THE GLOBAL ENVIRONMENT

- Rising human population and intensifying per capita consumption magnify human impacts on the environment. (pp. 15–16)
- Human activities such as industrial agriculture and fossil fuel use are having diverse impacts, including resource depletion, air and water pollution, climate change, habitat destruction, and biodiversity loss. (pp. 16–17)
- We are striving to develop sustainable solutions to our environmental challenges. (pp. 18–19)

ARTICULATE THE CONCEPTS OF SUSTAINABILITY AND SUSTAINABLE DEVELOPMENT

- Sustainability means living within the planet's means, such that Earth's resources can sustain us—and other species—for the future. (p. 15)
- Sustainable development means pursuing environmental, economic, and social goals in a coordinated way, and it is the most important pursuit in our society today. (p. 19)

TESTING YOUR COMPREHENSION

1. What do renewable resources and nonrenewable resources have in common? How are they different? Identify two renewable and two nonrenewable resources.
2. How and why did the agricultural revolution affect human population size? How and why did the industrial revolution affect human population size? Explain what environmental impacts have resulted.
3. What is *the tragedy of the commons?* Explain how the concept might apply to an unregulated industry that is a source of water pollution.
4. What is *environmental science*? Name several disciplines involved in environmental science.
5. What are the two meanings of *science*? Name three applications of science.
6. Describe the scientific method. What is its typical sequence of steps?
7. Explain the difference between correlation and causation, and state how these concepts relate to manipulative and natural experiments.
8. What needs to occur before a researcher's results are published? Why is this process important?
9. Give examples of three major environmental problems in the world today, along with their causes. How are these problems interrelated? Can you name a potential solution for each?
10. How can *sustainable development* be defined? What is meant by the *triple bottom line*? Why is it important to pursue sustainable development?

SEEKING SOLUTIONS

1. Many resources are renewable if we use them in moderation but can become nonrenewable if we overexploit them. Order the following resources on a continuum of renewability (see Figure 1.1), from most renewable to least renewable: soils, timber, fresh water, food crops, and biodiversity. What factors influenced your choices? For each resource, what might constitute overexploitation, and what might constitute sustainable use?
2. Why do you think the Easter Islanders did not or could not stop themselves from stripping their island of all its trees? What similarities do you perceive between the history of Easter Island and the modern history of our society? What differences do you see between their predicament and ours?
3. What environmental problem do *you* feel most acutely yourself? Do you think there are people in the world who do not view your issue as an environmental problem? Who might they be, and why might they take a different view?
4. If the human population were to stabilize tomorrow and never surpass 7 billion people, would that solve our environmental problems? Which types of problems might be alleviated, and which might continue to worsen?
5. Consider the historic expansion of agriculture and our ability to feed increasing numbers of people, as described in this chapter. Now ask yourself, "Are things getting better or worse?" Ask this question from four points of view: (1) the human perspective, (2) the perspective of other organisms, (3) a short-term perspective, and (4) a long-term perspective. Do your answers to this question change? If so, how?
6. **THINK IT THROUGH** You have become head of a major funding agency that disburses funding to researchers pursuing work in environmental science. You must give your staff several priorities to determine what types of scientific research to fund. What environmental problems would you most like to see addressed with research? Describe the research you think would need to be completed so that workable solutions to these problems can be developed. Would more than science be needed to develop sustainable solutions?

CALCULATING ECOLOGICAL FOOTPRINTS

Mathis Wackernagel and his many colleagues at the Global Footprint Network (www.footprintnetwork.org) have continued to refine the method of calculating ecological footprints—the amount of biologically productive land and water required to produce the energy and natural resources we consume and to absorb the wastes we generate. According to their most recent data, there are nearly 2.1 hectares (5.2 acres) available for every person in the world, yet we use on average more than 2.7 ha (6.7 acres) per person, creating a global ecological deficit, or overshoot (p. 5), of about 30%.

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

Nation	Ecological footprint (hectares per person)	Proportion relative to world average footprint	Proportion relative to world area available
Bangladesh	0.6	0.2 (0.6 ÷ 2.7)	0.3 (0.6 ÷ 2.1)
Tanzania	1.1		
Colombia	1.8		
Thailand	2.1		
Mexico	3.4		
Sweden	5.1		
United States	9.4		
World average	2.7	1.0 (2.7 ÷ 2.7)	1.29 (2.7 ÷ 2.1)
Your personal footprint (see Question 4)			

Data from *Living planet report 2008.* WWF International, Zoological Society of London, and Global Footprint Network.

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

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