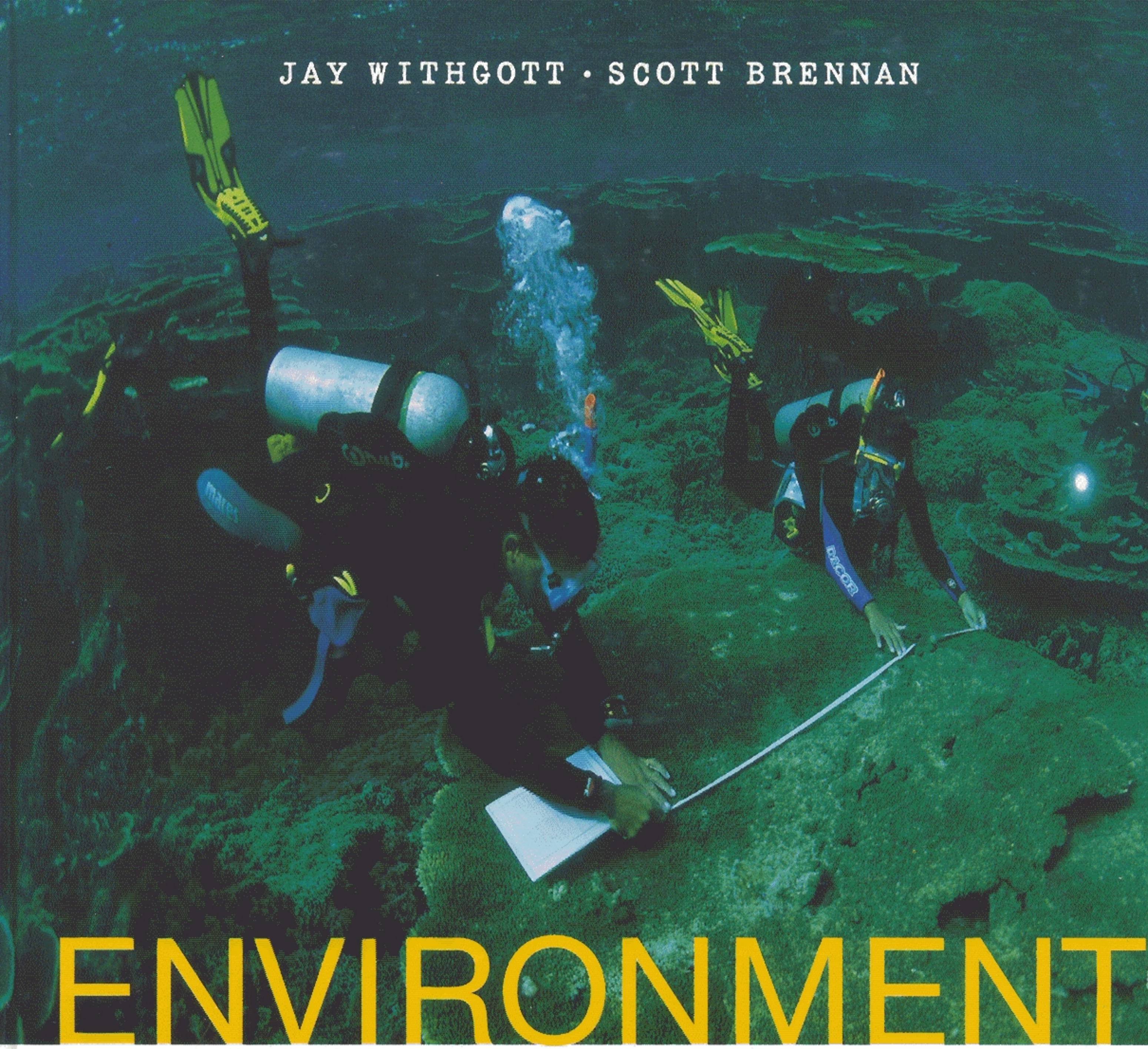
JAY WITHGOTT · SCOTT BRENNAN



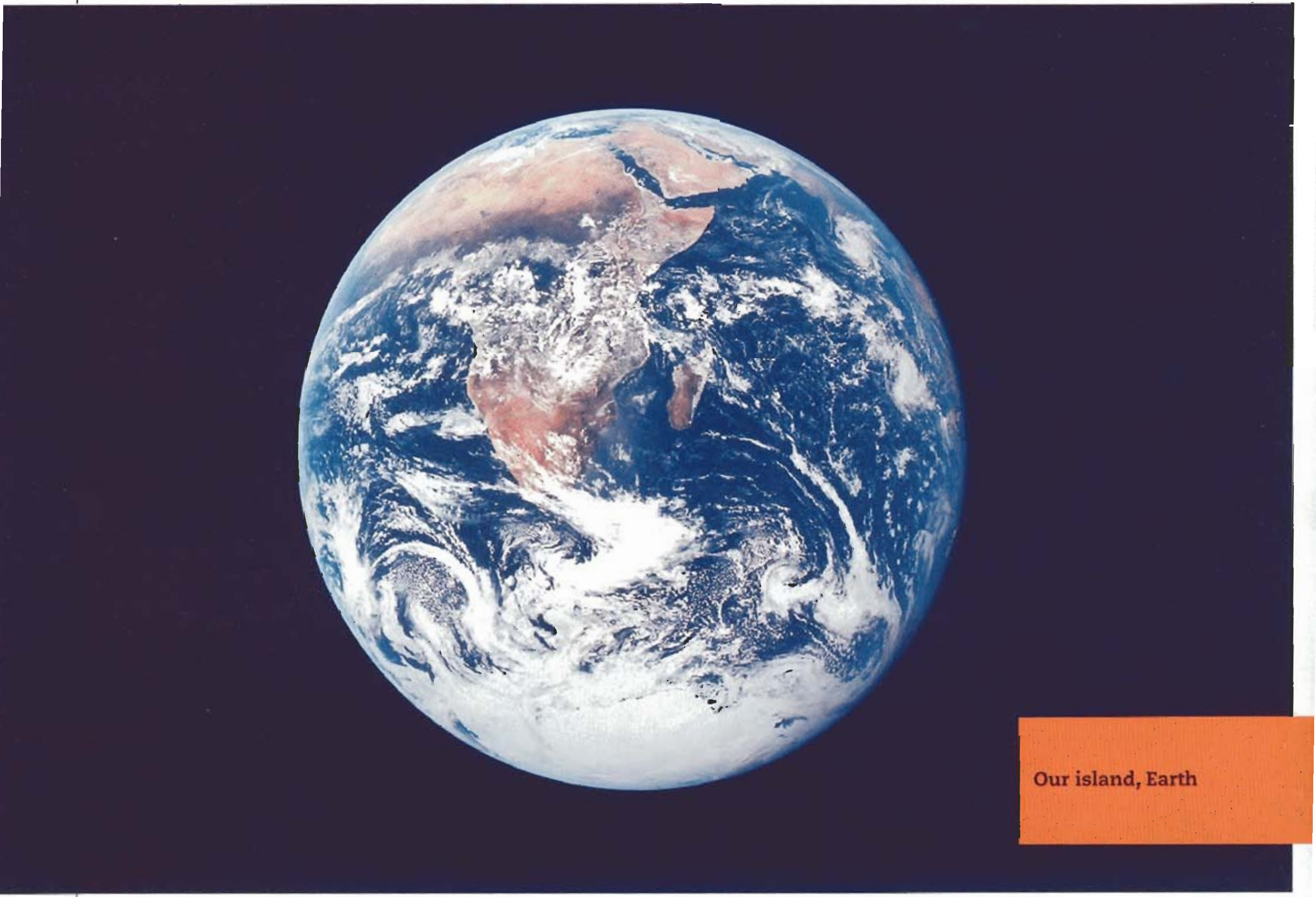
ENVIRONMENT

THE SCIENCE BEHIND THE STORIES

SECOND EDITION

1

An Introduction to Environmental Science



Our island, Earth

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

- Define the term *environment*
- Describe natural resources and explain their importance to human life
- Characterize the interdisciplinary nature of environmental science
- Understand the scientific method and how science operates
- Diagnose and illustrate some of the pressures on the global environment
- Evaluate the concepts of sustainability and sustainable development

Our Island, Earth

Viewed from space, our home planet resembles a small blue marble suspended against a vast inky-black backdrop. Although few of us will ever get to witness that sight directly, photographs taken by astronauts convey a sense that Earth is small, isolated, and fragile. It may seem vast to us as we go about our lives on its surface, but from the astronaut's perspective it is apparent that Earth and its natural systems are not unlimited. From this perspective, it becomes clear that as our population, our technological powers, and our consumption of resources increase, so do our abilities to alter our planet and damage the very systems that keep us alive.

Our environment is the sum total of our surroundings

A photograph of Earth reveals a great deal, but it does not convey the complexity of our environment. Our **environment** (a term that comes from the French *environner,* "to surround") is more than water, land, and air; it is the sum total of our surroundings. It includes all of the **biotic factors,** or living things, with which we interact. It also includes the **abiotic factors,** or nonliving things, with which we interact. Our environment 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 around us. In a more inclusive sense, it also encompasses our built environment, the structures, urban centers, and living spaces humans have created. In its most inclusive sense, our environment also includes the complex webs of scientific, ethical, political, economic, and social relationships and institutions that shape our daily lives.

From day to day, people most commonly use the term *environment* in the first, narrow sense—of a nonhuman or "natural" world apart from human society. This connotation is unfortunate, because it masks the very important fact that humans exist within the environment and are a part of nature. As one of many species of animals 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 "human society 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 other parts of it matter a great deal.

Environmental science explores interactions between humans and our environment

Appreciating how we interact with our environment is crucial for a well-informed view of our place in the world and for a mature awareness that we are one species among many on a planet full of life. Understanding our relationship with the environment is also vital because we are altering the very natural systems we need, in ways we do not yet fully comprehend.

We depend utterly on our environment for air, water, food, shelter, and everything else essential for living. However, our actions modify our environment, whether we intend them to or not. Many of these actions have enriched our lives, bringing us longer life spans, better health, and greater material wealth, mobility, and leisure time. However, these improvements have often degraded the natural systems that sustain us. Impacts such as air and water pollution, soil erosion, and species extinction can compromise human well-being, pose risks to human life, and threaten our ability to build a society that will survive and thrive in the long term. The elements of our environment were functioning long before the human species appeared, and we would be wise to realize that we need to keep these elements in place.

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 because such knowledge is the essential first step toward devising solutions to our most pressing environmental problems. Many environmental scientists are taking this next step, trying to apply their knowledge to develop solutions to the many environmental challenges we face.

It can be daunting to reflect on the sheer magnitude of environmental dilemmas that confront us today, but with these problems also come countless opportunities for devising creative solutions. The topics studied by environmental scientists are the most centrally important issues to our world and its future. Right now, global conditions are changing more quickly than ever. Right now, through science, we as a civilization 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 studying environmental science.

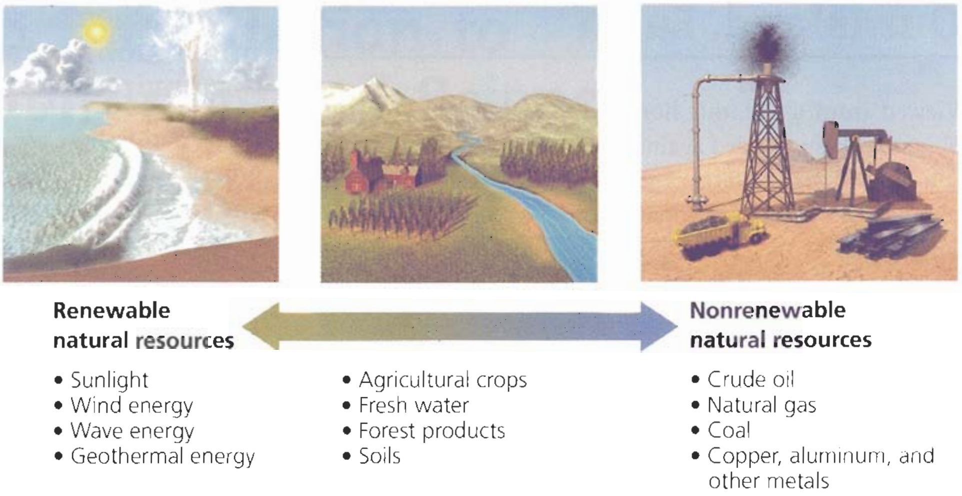


FIGURE 1.1 Natural resources lie along a continuum from perpetually renewable to nonrenewable. Perpetually renewable resources, such as sunlight, will always be there for us. Nonrenewable resources, such as oil and coal, exist in limited amounts that could one day be gone. Other resources, such as timber, soils, and food crops, can be renewed on intermediate time scales, if we are careful not to deplete them.

Natural resources are vital to our survival

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 we need to survive. Natural resources that are virtually unlimited or that are replenished over short periods are known as **renewable natural resources.** Some renewable resources, such as sunlight, wind, and wave energy, are perpetually available. Others, such as timber, food crops, water, and soil, renew themselves over months, years, or decades, if we are careful not to use them up too quickly or destructively. 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 use them up, they are no longer available.

We can view the renewability of natural resources as a continuum (Figure 1.1). Some renewable resources may turn nonrenewable if we overuse them. For example, overpumping groundwater can deplete underground aquifers and turn a lush landscape into a desert. Populations of animals and plants we harvest from the wild may be renewable if we do not overharvest them but may vanish if we do. In recent years, our consumption of natural resources has increased greatly, driven by rising affluence and the growth of the largest human population in history.

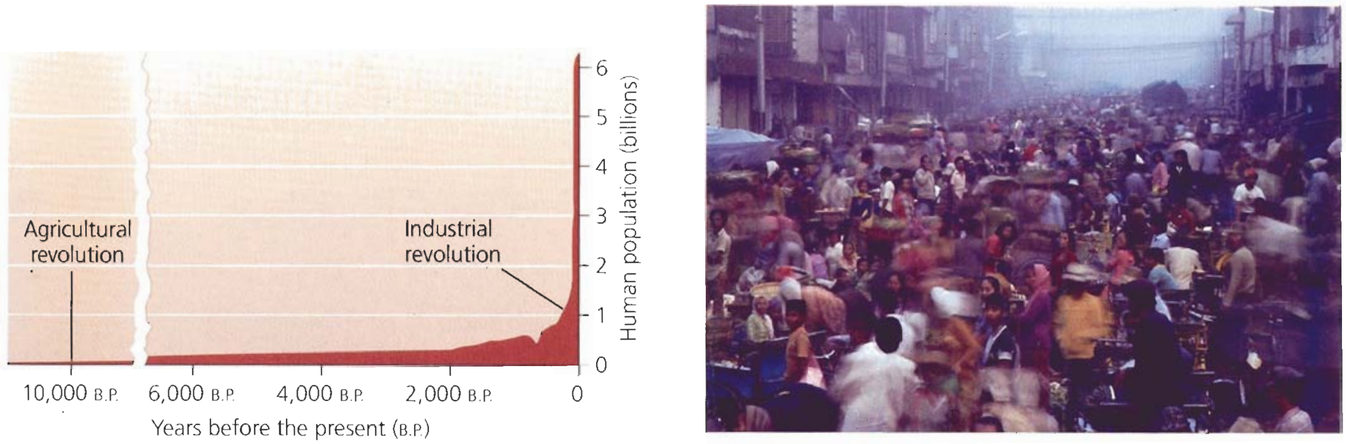
Human population growth has shaped our relationship with natural resources

For nearly all of human history, only a few million people populated Earth at any one time. Although past populations cannot be calculated precisely, Figure 1.2 gives some idea of just how recently and suddenly our population has grown beyond 6 billion people.

Two phenomena triggered remarkable increases in population size. The first was our transition from a hunter-gatherer lifestyle to an agricultural way of life. This change began to occur around 10,000 years ago and is known as the **agricultural revolution.** As people began to grow their own crops, raise domestic animals, and live sedentary lives in villages, they found it easier to meet their nutritional needs. As a result, they began to live longer and to produce more children who survived to adulthood. 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 manufacturing by craftsmen, to an urban society powered by **fossil fuels** (nonrenewable energy sources, such as oil, coal, and natural gas, produced by the decomposition and fossilization of ancient life). The industrial revolution introduced improvements in sanitation and medical technology, and it enhanced agricultural production with fossil-fuel-powered equipment and synthetic fertilizer (▸ pp. 278–282).

Thomas Malthus and population growth At the outset of the industrial revolution in England, population growth was regarded as a good thing. For parents, high birth rates meant more children to support them in old age. For society, it meant a greater pool of labor for factory work.

British economist **Thomas Malthus** (1766–1834) had a different opinion. Malthus claimed that unless population growth were controlled by laws or other social strictures, the number of people would outgrow the available food



(a) World population growth

(b) Urban society

FIGURE 1.2 For almost all of human history, our population was low and relatively stable. It increased significantly as a result first of the agricultural revolution and then of the industrial revolution **(a)**. Our skyrocketing population has given rise to congested urban areas, such as this city in Java, Indonesia **(b)**.

supply until starvation, war, or disease arose and reduced the population (Figure 1.3). Malthus's most influential work, *An Essay on the Principle of Population*, published in 1798, argued that a growing population would eventually be checked either by limits on births or increases in deaths. If limits on births (such as abstinence and contraception) were not implemented soon enough, Malthus wrote, deaths would increase through famine, plague, and war.

Malthus's thinking was shaped by the rapid urbanization and industrialization he witnessed during the early years of the industrial revolution, but debates over his views continue today. As we will see in Chapter 8 and throughout this book, global population growth has indeed helped spawn famine, disease, and social and political conflict. However, increasing material prosperity has also helped bring down birth rates—something Malthus did not foresee.

Paul Ehrlich and the "population bomb" In our day, biologist Paul Ehrlich of Stanford University has been called a "neo-Malthusian" because he too has warned that population growth will have disastrous effects on human welfare. In his 1968 book, *The Population Bomb*, Ehrlich predicted that the rapidly increasing human population would unleash widespread famine and conflict that would consume civilization by the end of the 20th century. Like Malthus, Ehrlich argued that population was growing much faster than our ability to produce and distribute food, and he maintained that population control was the only way to prevent massive starvation and civil strife.

Although human population nearly quadrupled in the past 100 years—the fastest it has ever grown (see Figure 1.2a)—Ehrlich's predictions have not materialized on the scale he predicted. This is due, in part, to agricultural advances made in recent decades (►pp. 278–279). As

(a) 18th-century London, England

(b) Thomas Malthus

FIGURE 1.3 The England of Thomas Malthus's era (1766–1834), shown in this engraving **(a)**, favored population growth as society industrialized. Malthus **(b)** argued that population growth could lead to disaster.

a result, Ehrlich and other neo-Malthusians have revised their predictions accordingly and now warn of a postponed, but still impending, global crisis.

Resource consumption exerts social and environmental impacts

Population growth affects resource availability and is unquestionably at the root of many environmental problems. However, the growth in consumption 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.

Garrett Hardin and the "tragedy of the commons"

The late Garrett Hardin of the University of California, Santa Barbara, disputed the economic theory that unfettered exercise of individual self-interest will serve the public interest. According to Hardin's best-known essay, "The Tragedy of the Commons," published in the journal *Science* in 1968, resources that are open to unregulated exploitation will eventually be depleted.

Hardin based his argument on a scenario described in a pamphlet published in 1833. In a public pasture, or "common," that is open to unregulated grazing, Hardin argued, each person who grazes animals will be motivated to increase the number of his or her animals in the pasture. Ultimately, overgrazing will cause the pasture's food production to collapse (Figure 1.4). 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.

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

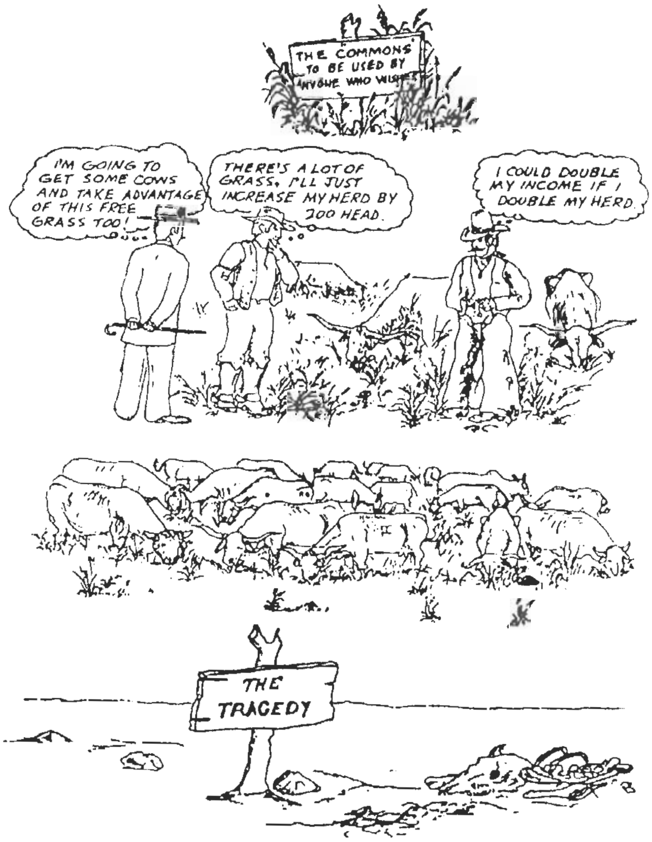


FIGURE 1.4 Unregulated areas that offer limited resources freely to the public are prone to be depleted by the process that Garrett Hardin dubbed "the tragedy of the commons."

Weighing the Issues: The Tragedy of the Commons

Imagine you make your living fishing for lobster. You are free to boat anywhere and set out as many traps as you like. Your harvests have been good, and nothing is stopping you from increasing the number of your traps. However, all the other lobster fishers are thinking the same thing, and the fishing grounds are getting crowded. Catches decline year by year, until one year the fishery crashes, leaving you and all the others with catches too meager to support your families. Some of your fellow fishers call for dividing the waters and selling access to individuals plot-by-plot. Others urge the fishers to team up, set quotas among themselves, and prevent newcomers from entering the market. Still others are imploring the government to get involved and pass laws regulating how much fishers can catch. What do you think is the best way to combat this tragedy of the commons and restore the fishery? Why?

Wackernagel, Rees, and the 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. The **ecological footprint** expresses the environmental impact of an individual or population in terms of the cumulative amount of land and water required to provide the

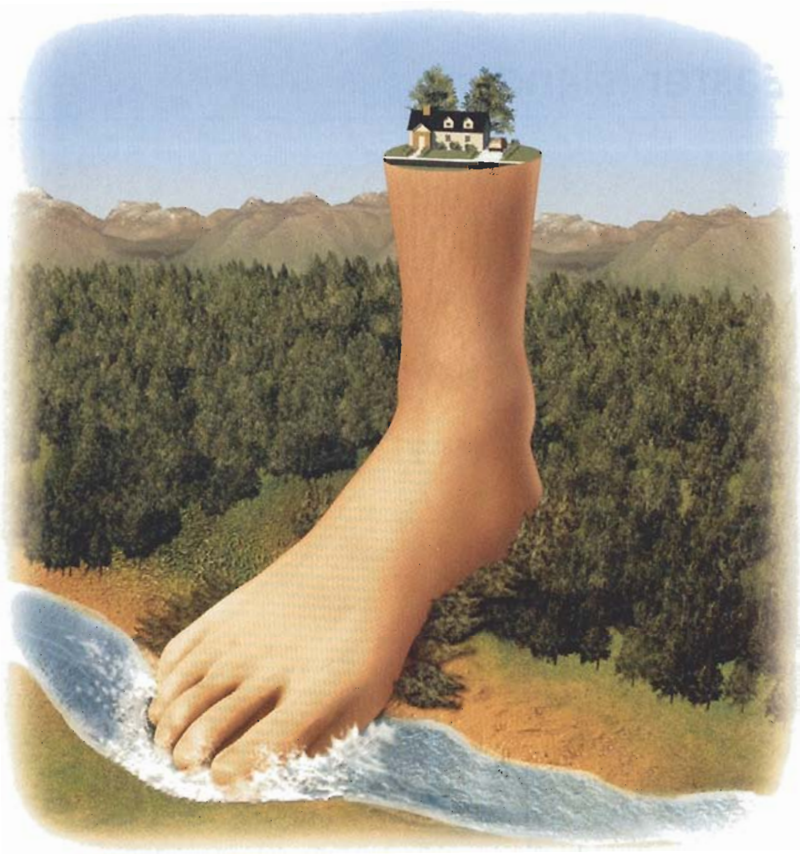


FIGURE 1.5 The "ecological footprint" represents the total area of land and water needed to produce the resources a given person or population uses, together with the total amount of land and water needed to dispose of their waste. The footprints of the urbanized and affluent societies of today's developed nations tend to be much larger than the geographic areas these societies take up directly. Adapted from Wackernagel, M., and W. Rees. 1996. *Our ecological footprint: Reducing human impact on the Earth.* Gabriola Island, British Columbia: New Society Publishers.

raw materials the person or population consumes and to dispose of or recycle the waste the person or population produces (Figure 1.5). It measures the total amount of Earth's surface "used" by a given person or population, once all direct and indirect impacts are totaled up.

For humanity as a whole, Wackernagel and Rees have calculated that our species is using 30% more resources than are available on a sustainable basis from all the land on the planet. That is, we are depleting renewable resources 30% faster than they are being replenished—like drawing the principal out of a bank account rather than living off the interest. Furthermore, people from wealthy nations have much larger ecological footprints than do people from poorer nations. If all the world's people consumed resources at the rate of North Americans, these researchers concluded, we would need the equivalent of two additional planet Earths.

Environmental science can help us avoid mistakes made by past civilizations

It remains to be seen whether the direst predictions of Malthus, Ehrlich, and others will come to pass for today's global society, but we already have historical evidence that civilizations can crumble when pressures from population and consumption overwhelm resource availability. Easter Island is the classic case (see "The Science behind the Story," ▸ pp. 8–9), but it is not the only example. Many great civilizations have fallen after depleting resources from their environments, and each has left devastated landscapes in its wake. The Greek and Roman empires show evidence of such a trajectory, as do the Maya, the Anasazi, and other civilizations of the New World. Plato wrote of the deforestation and environmental degradation accompanying ancient Greek cities, and today further evidence is accumulating from research by archaeologists, historians, and paleoecologists who study past societies and landscapes. The arid deserts of today's Middle Eastern countries were far more vegetated when the great ancient civilizations thrived there; at that time these regions were lush enough to support the very origin of agriculture. While deforestation created deserts in temperate regions, in more tropical climates, the ancient cities of fallen civilizations became overgrown by jungle. The gigantic stone monuments of the Angkor civilization in Southeast Asia, like those of the Maya in Mexico and Central America, remained unknown to Westerners until the

The Science behind the Story

The Lesson of Easter Island

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

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 have discovered, lay in the fact that the island did not always lack trees, and its people were not always without rope.

Indeed, scientific research tells us that the island had once been lushly forested, with all the appeal of a South Pacific paradise, and had supported a prosperous society with a population 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 grows too large and 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 volcanic crater lakes, drilling cores deep into the mud and examining ancient grains of pollen preserved there. Because pollen grains vary from one plant species to another, scientists, by identifying specific pollen grains, 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 A.D. 900), the island was covered with a species of palm tree related to the Chilean wine palm, a tall and thick-trunked tree. 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. Furthermore, 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 such as French archaeologist Catherine Orliac have found that at least 21 other species of plants, many of them trees, had also been common, and 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 about two centuries later at the other two lake sites, which were higher and more remote from village areas. 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 palms and other trees provided fuelwood, building material for houses and canoes, fruit to eat and fiber for clothing, and presumably, logs to move the stone statues. Several anthropologists in recent years have experimentally tested hypotheses about how the islanders moved their monoliths down from the quarries, by hiring groups of men to recreate the feat. The methods that have worked involve using numerous tree trunks as rollers or sleds, as well as 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 bottom of Easter Island lakes, 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 crops, such as bananas, sugar cane, and sweet potatoes. Reduced agricultural production would have led to starvation and subsequent population decline.

Archaeological evidence supports the scenario of environmental degradation and civilization decline. Analysis of 6,500 bones by archaeologist David Steadman has shown that at least 6 species of land birds and 25 species of seabirds nested on Easter Island and were eaten by islanders. Today no native land birds and only 1 seabird are left. Remains from charcoal fires can be aged by radiocarbon dating (▸ pp. 94–95), and show that islanders' diets shifted over the years. Besides their crops and the island's birds, early islanders feasted on the bounty of the sea, including porpoises, fish, sharks, turtles, octopus, and shellfish. Analysis of islanders' diets in the later years indicated that little seafood was consumed. 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. Indeed, the Europeans who visited Easter Island in the 1700s observed only a few old small canoes and flimsy rafts made of reeds. As resources declined, the islanders' main domesticated food animal, the chicken, became more valuable. Archaeologists found that later islanders kept their chickens in stone fortresses with entrances designed to prevent theft. The once prosperous and peaceful civilization fell into clan warfare, as revealed by unearthed skeletons, skulls with head wounds, and artifacts of weapons made of obsidian, a hard volcanic rock.

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 was 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.

19th century, and most of these cities remain covered by rainforest. Researchers have learned enough by now, however, that scientist and author Jared Diamond in his 2005 book, *Collapse,* could synthesize this information and formulate sets of reasons why civilizations succeed and persist, or fail and collapse. Success and persistence, it turns out, depend largely on how societies interact with their environments.

Today we are confronted with news and predictions of environmental catastrophes on a regular basis, but it can be difficult to assess the reliability of such reports. It is even harder to evaluate the causes and effects of environmental change. Perhaps most difficult is to devise solutions to environmental problems. Studying environmental science will outfit you with the tools that can help you evaluate information on environmental change and think critically and creatively about possible actions to take in response. Let us examine this broad field we call environmental science, and then explore the process and methods of science in general.

The Nature of Environmental Science

Environmental scientists aim to comprehend how Earth's natural systems function, how humans are influenced by those systems, and how we are influencing those systems. In addition, many environmental scientists are motivated by a desire to develop solutions to environmental quandaries. The solutions themselves (such as new technologies, policy decisions, or resource management strategies) are applications of environmental science. However, the study of such applications and their consequences is, in turn, also part of environmental science.

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 and their origins. An *environmental problem,* stated simply, is any undesirable change in the environment. However, the perception of what constitutes an undesirable change may vary from one person or group of people to another, or from one context or situation to another. A person's age, gender, class, race, nationality, employment, and educational background can all affect whether he or she considers a given environmental change to be a "problem."

FIGURE 1.6 How a person or a society defines an environmental problem can vary with time and circumstance. In Germany 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 some developing countries where malaria is a threat, DDT is welcomed to combat mosquitoes that transmit the disease.

For instance, today's industrial societies are more likely to view the spraying of the pesticide DDT as a problem than those societies viewed it in the 1950s, because today more is known about the health risks of pesticides (Figure 1.6). At the same time, 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 malaria is viewed 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.

Different types of 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 affecting these resources, whereas men in the same area 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 can have a huge effect on how you perceive your environment, how you perceive and react to change, and what impact those changes may have on how you live your life. In Chapter 2, we will examine the diversity of human values and philosophies and consider their effects on how we define environmental problems.

Environmental science provides interdisciplinary solutions

Studying and addressing environmental problems is a complex endeavor that requires expertise from many disciplines, including ecology, earth science, chemistry, biology, economics, political science, demography, ethics, and others. Environmental science is thus an **interdisciplinary** field—one that borrows techniques from numerous disciplines and brings research results from these disciplines together into a broad synthesis (Figure 1.7). Traditional established disciplines are valuable because their scholars delve deeply into topics, uncovering new knowledge and developing expertise in particular areas. Interdisciplinary fields are valuable because their practitioners take specialized knowledge from different disciplines, consolidate it, synthesize it, and make sense of it in a broad context to better serve the multifaceted interests of society.

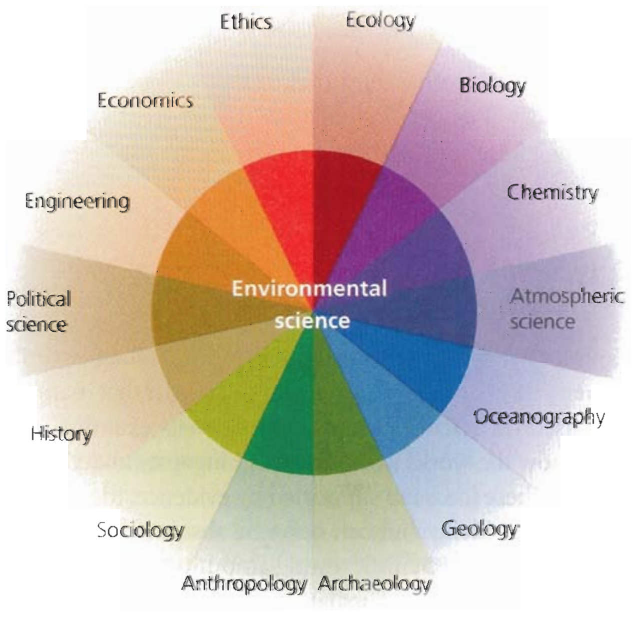


FIGURE 1.7 Environmental science is a highly interdisciplinary pursuit, involving input from many different established fields of study across the natural sciences and social sciences.

Environmental science is especially broad because it encompasses not only the **natural sciences** (disciplines that study the natural world), but also the **social sciences** (disciplines that study human interactions and institutions). The natural sciences provide us the means to gain accurate information about our environment and to interpret it reasonably. Addressing environmental problems, however, also involves weighing values and understanding human behavior, and this requires the social sciences. Most environmental science programs focus predominantly on the natural sciences as they pertain to environmental issues. In contrast, programs incorporating the social sciences heavily often prefer using the term **environmental studies** to describe their academic umbrella. 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 problems can produce effective and lasting solutions. One example is the dramatic improvement in one aspect of air quality in the United States over the past few decades. Ever since automobiles were invented, lead had been added to gasoline to make cars run more smoothly, even though medical professionals knew that lead emissions from tailpipes could cause 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. But over the following years, engineers, physicians, atmospheric scientists, and politicians 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.

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. Environmental science is the pursuit of knowledge about the workings of the environment and our interactions with it. **Environmentalism** is a social movement dedicated to protecting the natural world—and, by extension, humans—from undesirable changes brought about by human choices (Figure 1.8). Although environmental scientists may study many of the same issues environmentalists care about, as scientists

FIGURE 1.8 Environmental scientists and environmental activists play very different roles. Some scientists have become activists to promote particular solutions to environmental problems. However, most have not, and those who have generally try hard to keep their advocacy separate from their pursuit of objective scientific work.

they attempt to maintain an objective approach in their work. Remaining free from personal or ideological bias, and open to whatever conclusions the data demand, is a hallmark of the effective scientist. We will now proceed with a brief overview of how science works and how scientists go about this enterprise that brings our society so much valuable knowledge.

The Nature of Science

Modern scientists describe **science** (from the Latin *scire*, "to know") 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 observation, testing, and discovery.

Knowledge gained from science can be applied to address societal problems. Among the applications of science are its use in developing technology and its use in informing policy and management decisions (Figure 1.9). These pragmatic applications in themselves are not science, but they must be informed by science in order to be effective. Many scientists are motivated simply by a desire to know how the world works, and others are motivated by the potential for developing useful applications.

Environmental science is a dynamic yet systematic way of studying the world, and it is also the body of knowledge accumulated from this process. Like science in general, environmental science informs its practical applications and often is motivated by them.

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*:

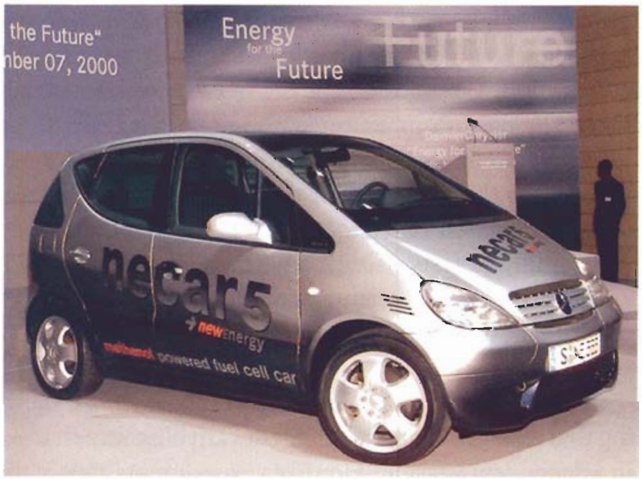
> We've arranged a global civilization in which the most crucial elements—transportation, communications, and all other industries; agriculture, medicine, education, entertainment, protecting the environment; and even the key democratic institution of voting—profoundly depend on science and technology. We have also arranged things so that almost no one understands science and technology. This is a prescription for disaster. We might get away with it for a while, but sooner or later this combustible mixture of ignorance and power is going to blow up in our faces. . . . 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 before and since have argued that science is essential if we hope to sort fact from fiction and develop solutions to the problems—environmental and otherwise—that we face today.

Scientists test ideas by weighing evidence

How can we tell whether warnings of impending environmental catastrophes—or any other claims, for that matter—are based on scientific thinking? Scientists examine ideas about how the world works by designing tests to determine whether these ideas are supported by evidence. Ideas can be refuted by evidence but can never be absolutely proven, so, strictly speaking, scientific testing amounts to attempting to disprove ideas. If a particular statement or explanation is testable and resists repeated attempts to disprove it, scientists are likely to accept it as a useful and true explanation. Scientific inquiry thus consists of an incremental approach to the truth.

(a) Prescribed burning



(b) Methanol-powered fuel-cell car

FIGURE 1.9 Scientific knowledge can be applied in policy and management decisions and in technology. Prescribed burning, shown here in the Ouachita National Forest, Arkansas (**a**), is a management practice to restore healthy forests, and is informed by scientific research into forest ecology. Energy-efficient automobiles, like this methanol-powered fuel-cell car from Daimler-Chrysler (**b**), are technological advances made possible by materials and energy research.

The scientific method is the key element of science

Scientists generally follow a process called the **scientific method.** A technique for testing ideas with observations, it involves several assumptions and a series of interrelated steps. There is nothing mysterious about the scientific method; it is merely a formalized version of the procedure any of us might naturally take, using common sense, to resolve a question.

The scientific method is a theme with variations, however, and scientists pursue their work in many different ways. Because science is an active, creative, imaginative process, an innovative scientist may find good reason to stray from the traditional scientific method when a particular situation demands it. Moreover, scientists from 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. Because environmental science includes both natural and social sciences, in our discussion here we use the term *science* in its broad sense, to include both. Despite their many differences, 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 laws 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.

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. This is evident to anyone who has observed 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,

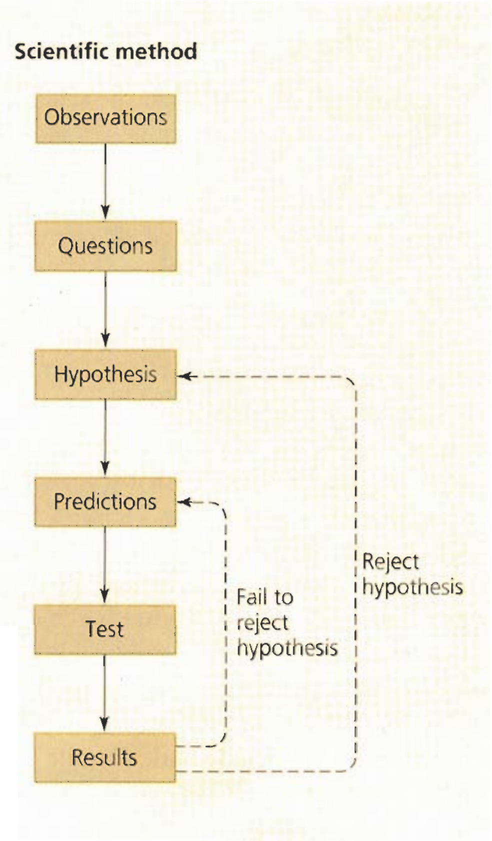


FIGURE 1.10 The scientific method is the observation-based hypothesis-testing approach that scientists use to learn how the world works. This diagram is a simplified generalization that, although useful for instructive purposes, cannot convey the true dynamic and creative nature of science. Moreover,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

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? Do pesticide impacts on fish or frogs indicate that people may be affected in the same ways? All of these are questions environmental scientists have asked and attempted to answer.

Develop a hypothesis Scientists attempt to answer their questions by devising explanations that they can test. A **hypothesis** is an educated guess that explains a phenomenon or answers 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."

Make predictions The scientist next uses the hypothesis to generate **predictions,** which are specific statements that can be directly and unequivocally tested. In our algae example, a prediction might be: "If agricultural fertilizers are added to a pond, the quantity of algae in the pond will increase."

Test the predictions Predictions are tested one at a time by gathering evidence that could potentially refute the prediction and thus refute the hypothesis. The strongest form of evidence comes from experimentation. An **experiment** is an activity designed to test the validity of a hypothesis. It involves manipulating **variables,** or conditions that can change. For example, a scientist could test the hypothesis 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. 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.

Experiments can establish causal relationships, showing that changes in an independent variable cause changes in a dependent variable. However, experiments are not the only way of testing a hypothesis. Sometimes a hypothesis can be convincingly addressed through **correlation,** searching for relationships among variables. Let's suppose our scientist surveys 50 ponds, 20 of which happen to be fed by fertilizer runoff from nearby farm fields and 30 of which are not. Let's also say he or she finds seven times as much algal growth in the fertilized ponds as 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. Although this type of evidence is weaker than the causal demonstration that controlled experiments can provide, sometimes it is the best approach, or the only feasible one. For example, in studying the effects of global climate change (Chapter 18), we could hardly run an experiment adding carbon dioxide to 10 treatment planets and comparing the result to 10 control planets.

Analyze and interpret results Scientists record **data,** or information, from their studies. They particularly value *quantitative* data, which is 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 different replicates may yield different results. The scientist 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, detailed examination of case studies, or descriptive observation of behavior can include qualitative data on which statistical analyses may not be possible. Such studies are still scientific in the broad sense, because their data can be interpreted systematically using other accepted methods of analysis.

Weighing the Issues: Replicates and Data Analysis

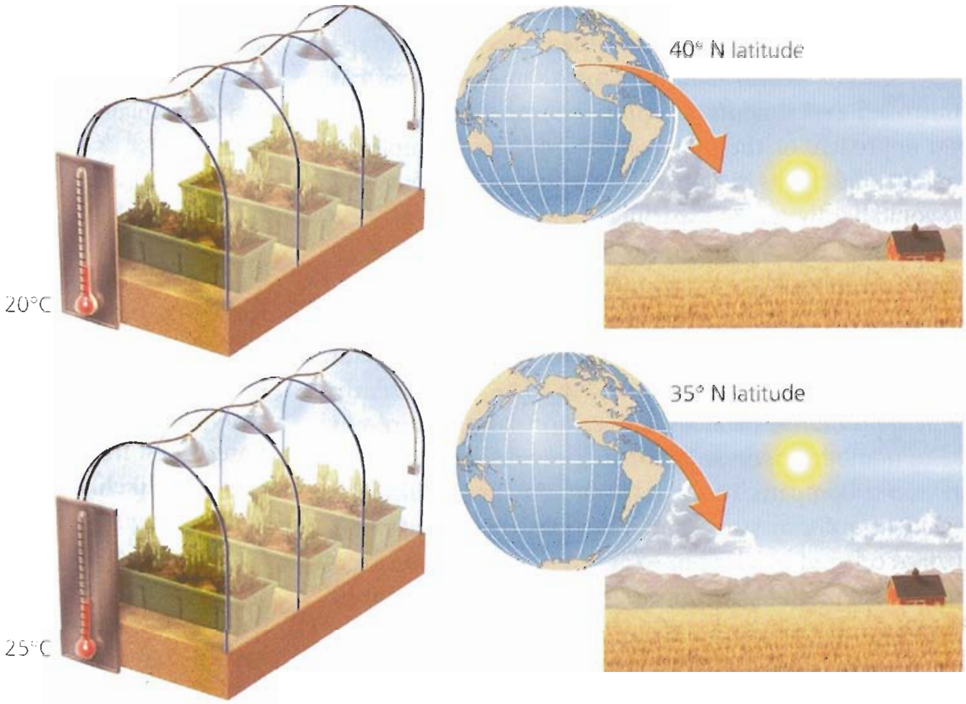
Let's say our scientist who is testing for the effects of agricultural fertilizer on algal growth uses experimental replicates, testing 10 pairs of ponds. If 5 of the 10 treatments grow more algae than controls while 5 grow less, what do you think the scientist should conclude? What if all 10 treatments grow more algae than do controls? What if 8 do? If 8 treatment ponds show 10% more growth than the control ponds they are paired with, but the remaining 2 control ponds show 300% more growth than their paired treatments, then what should the scientist conclude? Such cases require statistical analysis so that we can judge levels of confidence to assign to our conclusions. Given possibilities like this, can you explain why scientists believe replicates are important?

If experiments refute a hypothesis, the scientist will reject it and may develop a new hypothesis to replace it. If experiments fail to reject the hypothesis, this outcome 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 a different way 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 and new experimentation (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 idea is well supported. One would ideally also want to test different potential explanations for the question of interest. For instance, our scientist might propose an additional hypothesis that algae increase in fertilized ponds because numbers of fish or invertebrate animals that eat algae decrease. 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.

There are different ways to test hypotheses

An experiment in which the researcher actively chooses and manipulates the independent variable is known as a **manipulative experiment** (Figure 1.11a). A manipulative experiment provides the strongest type of evidence a scientist can obtain. In practice, however, some modes of scientific inquiry are more amenable to manipulative experimentation than others. Physics and chemistry tend to involve manipulative experiments, but many other fields deal with entities less easily manipulated than physical forces and chemical reagents. This is true of *historical sciences* such as cosmology, which deals with the history of the universe, and paleontology, which explores the history of past life. It is difficult to manipulate experimentally a star thousands of light years away, or the fossil tooth from a mastodon. Moreover, many of the most interesting questions in these fields center on the causes and consequences



(a) Manipulative experiment

(b) Natural experiment, or correlational study

FIGURE 1.11 A researcher wishing to test how temperature affects the growth of wheat might run a manipulative experiment in which wheat is grown in two identical greenhouses, one kept at 20°C (68°F) and the other kept at 25°C (77°F) **(a)**. Alternatively, the researcher might run a "natural experiment" in which he or she compares the growth of wheat in two fields at different latitudes, a cool northerly location and a warm southerly one **(b)**. Because it would be difficult to hold all variables besides temperature constant, the researcher might want to collect data on a number of northern and southern fields and correlate temperature and wheat growth using statistical methods.

of particular historical events, rather than the behavior of general constants.

Disciplines that do not quite fit the so-called physics model of science sometimes rely on **natural experiments** rather than manipulative ones (Figure 1.11b). For instance, an evolutionary biologist might want to test whether animal species isolated on oceanic islands tend to evolve large body size over time. The biologist cannot run a manipulative experiment by placing animals on islands and continents and waiting long enough for evolution to do its work. However, this is exactly what nature has already done. The biologist might test the idea by comparing pairs of closely related species, in which one of each pair lives on an island and the other on a continental mainland. The experiment has in essence been conducted naturally, and it is up to the scientist to interpret the results.

In ecology, both manipulative and natural experimentation is used. The science of **ecology** deals with the distribution and abundance of **organisms** (living things), the interactions among them, and the interactions between organisms and their abiotic environments. When possible, ecologists try to run manipulative experiments. An ecologist wanting to measure the importance of a certain insect in pollinating the flowers of a given crop plant might, for example, fit some flowers with a device to keep the insects out while leaving other flowers accessible, and later measure the fruit output of each group. Other questions that involve large spatial scales or long time scales may instead require natural experiments.

The social sciences generally involve less experimentation than the natural sciences, depending more on careful observation and interpretation of patterns in data. A sociologist studying how people from different cultures conceive the notion of wilderness might conduct a survey and analyze responses to its questions, looking for similarities and differences among respondents. Such analyses may be either quantitative or qualitative, depending on the nature of the data and the researchers' particular questions and approaches.

Descriptive observational studies and natural experiments can show correlation between variables, but they cannot demonstrate that one variable *causes* change in another, as manipulative experiments can. Not all variables are controlled for in a natural experiment, so a single result could give rise to several interpretations. However, correlative studies, when done well, can make for very convincing science, and they preserve the real-world complexity that manipulative experiments often sacrifice. Moreover, sometimes correlation is all we have. Because manipulations are difficult at large scales, some of the most important questions in environmental science tend to be addressed with correlative data. The large scale and complexity of many questions in environmental science also mean that few studies, manipulative or correlative, come up with neat and clean results. As such, scientists are not always able to give policymakers and society black-and-white answers to questions.

The scientific process does not stop with the scientific method

Individual researchers or teams of researchers follow the scientific method as they investigate questions that interest them. However, scientific work takes place within the context of a community of peers, and to have any impact, a researcher's work must be published and made accessible to this community. Thus, the scientific method is embedded within a larger process that takes place at the level of the scientific community as a whole (Figure 1.12).

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. Several other scientists specializing in the topic of the paper 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 science 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 their best 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.

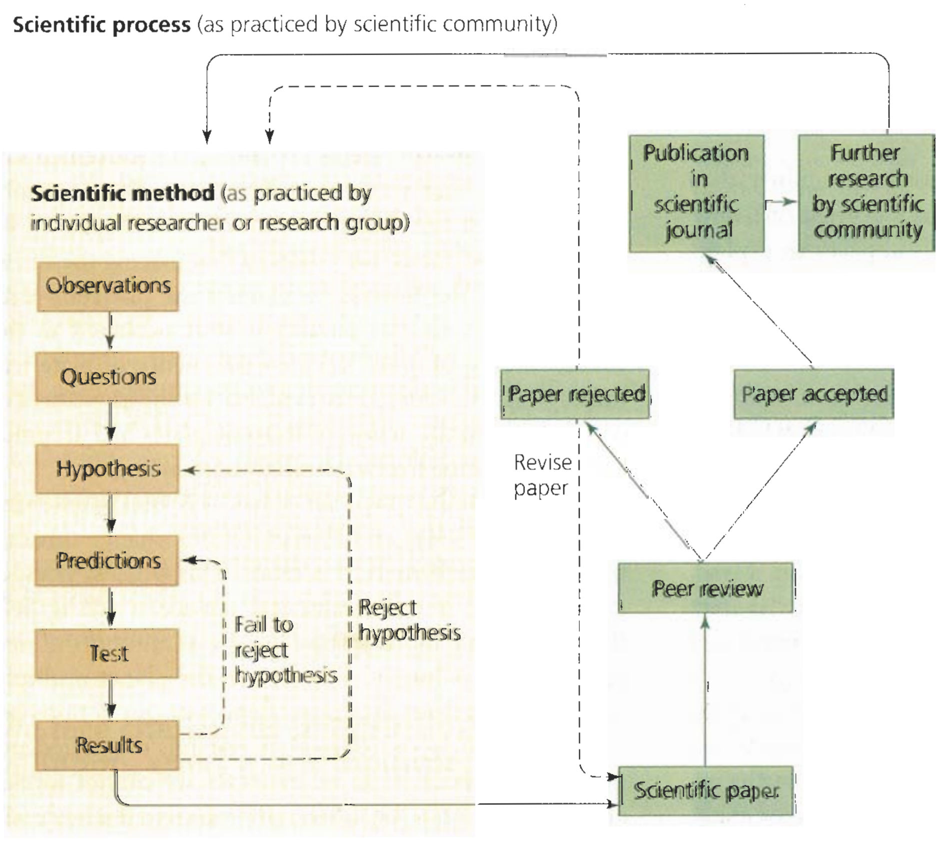


FIGURE 1.12 The scientific method (inner box) followed by individual researchers or research teams exists within the context of the overall process of science at the level of the scientific community (outer box). This process includes peer review and publication of research, acquisition of funding, and the development of theory through the cumulative work of many researchers.

Conference presentations Scientists frequently present their work at professional conferences, where they interact with colleagues and often receive informal comments on their research. When research has not yet been published, feedback from colleagues can help improve the quality of a scientist's work before it is submitted for publication.

Grants and funding Research scientists spend large portions of their time writing grant applications requesting money to fund their research from private foundations or government agencies such as the National Science Foundation. Grant applications undergo peer review just as scientific papers do, and competition for funding is often intense. Scientists' reliance on funding sources can also lead to potential conflicts of interest. A scientist 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. Most scientists do not succumb to these temptations, but some funding sources have been known to pressure their scientists 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 their funding.

Repeatability Sound science is based on doubt rather than certainty and on repeatability rather than one-time occurrence. Even when a hypothesis appears to explain observed phenomena, 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 refuted by a single experiment, a theory consolidates many related hypotheses that have been tested and have not been refuted.

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. 118–121) has been supported and elaborated by many thousands of studies over 150 years of intensive research. Such 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.

Science may go through "paradigm shifts"

It is crucial to realize that results obtained by the scientific method may sometimes later be reinterpreted to show that earlier interpretations were incorrect. Thomas Kuhn's 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, and some made elaborate and accurate measurements explaining the movements of planets from that viewpoint. Their data fit the theory quite well, yet the theory eventually was disproved by Nicolaus Copernicus, who showed that placing the sun at the center of the universe explained the planetary data even better. A similar paradigm shift occurred in the 1960s, when geologists accepted the theory of plate tectonics (▸pp. 207–209), once evidence for the movement of continents and the action of tectonic plates had accumulated and become overwhelmingly convincing.

Understanding how science works is vital to assessing how scientific ideas and interpretations change through time as new 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 lessons from the consequences of our actions become apparent. Because so much remains unstudied and undone, and because so many issues we cannot foresee are likely to arise in the future, environmental science will remain an exciting frontier for you to explore as a student and as an informed citizen throughout your life.

Sustainability and the Future of Our World

Throughout this book you will see examples of environmental scientists asking questions, developing 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 studying the most centrally important issues of our time.

Population and consumption lie at the root of many environmental changes

We modify our environment in diverse ways, but the steep and sudden rise in human population has amplified nearly all of our impacts (Chapter 8). Our numbers have nearly quadrupled in the past 100 years, passing 6 billion in 1999 and 6.5 billion in 2006. We add about 78 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 and to shape our interactions with one another and with our environment.

Our consumption of resources has risen even faster than our population growth. The 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 amplifies the demands we make on our environment. Moreover, affluence and consumption have not grown equally for all the world's citizens. Today the 20 wealthiest nations boast 40 times the income of the 20 poorest nations—twice the gap that existed four decades earlier. 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 1.13). Within the United States, the richest fifth of people claim nearly half the income, whereas the poorest fifth receive only 5%.

We face challenges in agriculture, pollution, energy, and biodiversity

The dramatic growth in human population and consumption is due in part to our successful efforts to expand and intensify the production of food (Chapters 9 and 10).

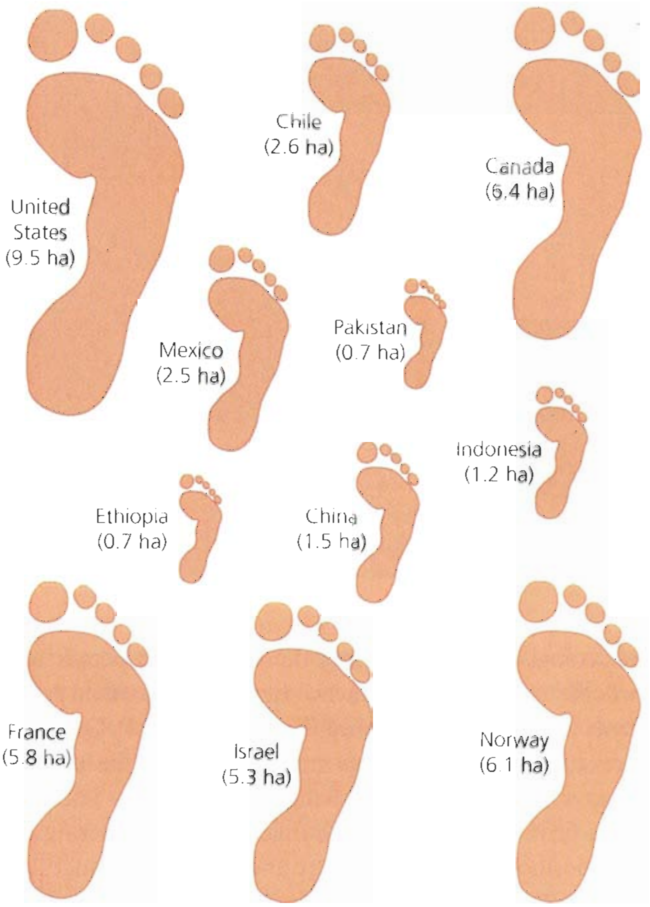


FIGURE 1.13 The citizens of some nations have larger ecological footprints than the citizens of others. U.S. residents consume more resources—and thus use more land—than residents of any other nation. Shown here are ecological footprints for average citizens of several developed and developing nations, as of 2001. Data from Global Footprint Network, 2005.

Since the agricultural revolution, new technologies have enabled us to grow increasingly 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; our extensive use of chemical fertilizers and pesticides poisons organisms and alters natural systems; and erosion, climate change, and poorly managed irrigation are destroying 5–7 million hectares (ha; 12.5–17.5 million acres) of productive cropland each year.

Meanwhile, pollution from our farms, industries, households, and individual actions dirties our land, water, and air (Figure 1.14). Outdoor air pollution, indoor air pollution, and water pollution contribute to the deaths of millions of people each year (Chapters 15–17). Environmental

FIGURE 1.14 Indoor and outdoor air pollution contribute to millions of premature deaths each year, and environmental scientists and policymakers are working to reduce this problem in a variety of ways.

toxicologists are chronicling the impacts on people and wildlife of the many synthetic chemicals and other pollutants we emit into the environment (Chapter 14). Our most pressing pollution challenge may be 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, atmospheric carbon dioxide concentrations have risen by 31%, to a level not present in at least 420,000 years. This increase results from our reliance on burning fossil fuels to power our civilization. Carbon dioxide and several other gases absorb heat and warm Earth's surface, which is likely responsible for glacial melting, sea-level rise, impacts on wildlife and crops, and increased episodes of destructive weather.

The combined impact of human actions such as climate change, overharvesting, pollution, the introduction of non-native species, and particularly habitat alteration, has driven many aquatic and terrestrial species out of large parts of their ranges and toward the brink of extinction (Chapter 11). Today Earth's biological diversity, or **biodiversity,** the cumulative number and diversity of living things, is declining dramatically. Many biologists say we are already at the outset of a mass extinction event 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 serious and threatening environmental dilemma, because it is not the kind of problem that responsible human action can remedy. Rather, the extinction of species is irreversible; once a species has become extinct, it is lost forever.

Solutions to environmental problems must be global and sustainable

The nature of virtually all of these environmental issues is being changed by the set of ongoing phenomena commonly dubbed *globalization*. Our increased global interconnectedness in trade, politics, and the movement of people and of other species poses many challenging problems, but it also sets the stage for novel and effective solutions.

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

Table 1.1 Main Findings of the Millennium Ecosystem Assessment

- Over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history, largely to meet rapidly growing demands for food, freshwater, timber, fiber, and fuel. This has resulted in a substantial and largely irreversible loss in the diversity of life on Earth.
- The changes made to ecosystems have contributed to substantial net gains in human well-being and economic development, but these gains have been achieved at growing costs. These costs include the degradation of ecosystems and the services they provide for us, and the exacerbation of poverty for some groups of people.
- This degradation could grow significantly worse during the first half of this century.
- The challenge of reversing the degradation of ecosystems while meeting increasing demands for their services can be partially overcome, but doing so will involve significantly changing many policies, institutions, and practices.

Adapted from *Millennium Ecosystem Assessment, Synthesis Report*, 2005.

FIGURE 1.15 Human activities are pushing many organisms, including the panda, toward extinction. Efforts to save endangered species and reduce biodiversity loss include many approaches, but all require that adequate areas of appropriate habitat be preserved in the wild.

Fortunately, potential solutions abound

We cannot, of course, live without exerting any impact on Earth's systems. We face trade-offs with many environmental issues, and the challenge is to develop solutions that further our quality of life while minimizing harm to the environment that supports us. Fortunately, there are many workable solutions at hand, and many more potential solutions we can achieve with further effort.

In response to agricultural problems, scientists and others have developed and promoted soil conservation, high-efficiency irrigation, and organic agriculture. Technological advances and new laws have greatly reduced the pollution emitted by industry and automobiles in wealthier countries. Although the U.S. government has resisted international efforts to rein in pollutants to halt climate change, American scientists have been at the forefront of climate change science, and other nations are beginning to address the problem, as are the governments of some U.S. states. Amid ample reasons for concern about the state of global biodiversity, advances in conservation biology are enabling scientists and policymakers in many cases to work together to protect habitat, slow extinction, and safeguard endangered species (Figure 1.15). Recycling is helping relieve our waste disposal problems, and alternative renewable energy sources are being developed to take the place of fossil fuels (Figure 1.16). These are but a few of the many solutions we will explore in the course of this book.

Are things getting better or worse?

Despite the myriad challenges we review in this book, many people maintain that the general conditions of human life and the environment are in fact getting better, not worse. A recent proponent of this view, Danish statistician Bjorn Lomborg, wrote in his 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 for the world because of our impact upon it 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 Cassandras and Cornucopians. One question is whether the impacts being debated pertain only to humans or also to other organisms and natural systems. The second question is whether the debaters are thinking in the short term or the long term. The third question is whether they are considering all costs and

FIGURE 1.16 Our dependence on fossil fuels has caused a wide array of environmental impacts. Although fossil fuels have powered our civilization since the industrial revolution, many renewable energy sources exist, such as solar energy that can be collected with panels like these. Such alternative energy sources could be further developed for sustainable use now and in the future.

benefits relevant for the question at hand, or only some. As you proceed through this book and encounter countless contentious issues, consider how one's perception of them may be influenced by these three factors.

Sustainability is a goal for the future

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 the rest of Earth's biota for the foreseeable 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 not depleting Earth's natural capital, so that after we are gone our descendants will enjoy the use of resources as we have. It means developing solutions that are able to 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.

Sustainability is a concept you will encounter throughout this book. Our final chapter (Chapter 23) takes a wide-ranging look at emerging sustainable solutions—on college and university campuses and in the world at large.

Sustainability need not require great sacrifice of us. We will naturally always desire to enhance our quality of life, and as we will see, there are many ways we can do so while also encouraging a more sustainable lifestyle. Economists employ the term *development* to describe the use of natural resources for economic advancement (as opposed to simple subsistence, or survival). Logging, farming, mining, and building homes and factories are all types of development, and each of them affects the environment and gives rise to changes that environmental scientists study. **Sustainable development** is the use of renewable and nonrenewable resources in a manner that satisfies our current needs without compromising future availability of resources. The United Nations defines sustainable development as development that ". . . meets the needs of the present without sacrificing the ability of future generations to meet theirs." Answering a simple question—"Can this activity continue forever?"—indicates whether a particular activity is sustainable.

Sustainability depends, in large part, on the ability of the current human population to limit its environmental impact. Doing so will require us to make an ethical commitment, while also applying information we gain from the sciences. Science can help us devise ways to limit our impact and maintain the functioning of the environmental systems on which we depend.

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 the environment and informs our attempts to solve and prevent environmental problems.

It is important to keep in mind that 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. One often-heard criticism of environmental science courses and textbooks is that too often they emphasize the negative. Recognizing the validity of this criticism, in this book we attempt to balance the discussion of environmental problems with a corresponding focus on potential solutions. 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 environmental dilemmas 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*

- Our environment consists of everything around us, including living and nonliving things. (p. 3)
- Humans are a part of the environment and are not separate from nature. (p. 3)

Describe natural resources and explain their importance to human life

- Resources from nature are essential to human life and civilization. (p. 4)
- Some resources are perpetually renewable, others are nonrenewable, and still others are renewable if we are careful not to exploit them at too fast a rate. (p. 4)
- Malthus and Ehrlich pointed out risks of human population growth, while Hardin and Wackernagel and Rees pioneered important concepts in resource consumption. (pp. 4–7)

Characterize the interdisciplinary nature of environmental science

- Environmental science uses the approaches and insights of numerous disciplines from the natural sciences and the social sciences. (p. 11)

Understand the scientific method and how science operates

- Science is a process of using observations to test ideas. (p. 12)
- The scientific method consists of a series of steps, including making observations, formulating questions, stating a hypothesis, generating predictions, testing predictions, and analyzing the results obtained from the tests. (pp. 13–15)
- The scientific method is not always followed strictly, and there are different ways to test questions scientifically. (pp. 15–17)
- Scientific research occurs within a larger process that includes peer review of work, journal publication, and interaction with colleagues. (pp. 17–18)

Diagnose and illustrate some of the pressures on the global environment

- Increasing human population and increasing per capita consumption exacerbate human impacts on the environment. (p. 19)
- Human activities such as industrial agriculture and the use of fossil fuels for energy are having diverse environmental impacts, including resource depletion, air and water pollution, habitat destruction, and the diminishment of biodiversity. (pp. 19–20)

Evaluate 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 foreseeable future. (pp. 20–22)
- Sustainable development is possible; we need not decrease our quality of life to establish sustainable lifestyles. (p. 22)

TESTING YOUR COMPREHENSION

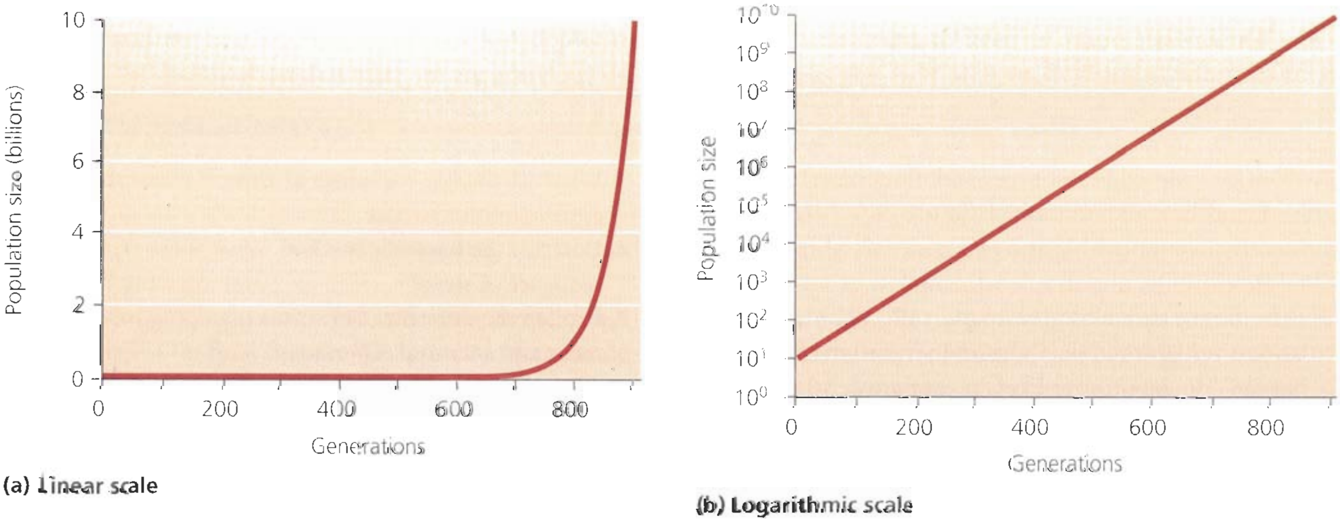
1. What do renewable resources and nonrenewable resources have in common? How are they different? Identify two renewable and two nonrenewable resources.
2. How did the agricultural revolution affect human population size? How did the industrial revolution affect human population size? Explain your answers.
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 the typical sequence of steps?
7. Explain the difference between a manipulative experiment and a natural experiment.
8. What needs to occur before a researcher's results are published? Why is this important?
9. Give examples of three major environmental problems in the world today, along with their causes.
10. What is 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 decision? For each of these resources, 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? Do you see similarities between the history of the Easter Islanders and the modern history of our society? Why or why not?
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. Name an environmental problem you would like to see solved or mitigated. Describe the scientific research you think would need to be completed so that workable solutions to this problem can be developed. Would more than science be needed?
5. 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 become worse?
6. 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) from the human perspective, (2) from the perspective of other organisms, (3) from a short-term perspective, and (4) from a long-term perspective. Do your answers to this question change? If so, how?

INTERPRETING GRAPHS AND DATA

Environmental scientists study phenomena that range in size from individual molecules (Chapter 4) to the entire Earth (Chapter 7), and that occur over time periods lasting from fractions of a second to billions of years. To simultaneously and meaningfully represent data covering so many orders of magnitude, scientists have devised a variety of mathematical and graphical techniques, such as exponential notation and logarithmic scales. Below are two graphical representations *of the same data,* representing the growth of a hypothetical population from an initial size of 10 individuals at a rate of increase of approximately 2.3% per generation. The graph in part (a) uses a conventional linear scale for the population size; the graph in part (b) uses a logarithmic scale.



(a) Linear scale

(b) Logarithmic scale

Hypothetical population growth curves, assuming an initial size of 10 and a constant rate of increase of approximately 2.3% per generation.

1. Using the graph in part (a), what would you say was the population size after 200 generations? After 400? After 600? After 800? How would you answer the same questions using the graph in part (b)? What impression does the graph in part (a) give about population change for the first 600 generations? What impression does the graph in part (b) give?
2. Compare these graphs to Figure 1.2a in the text. What does the human population appear to be doing between 10,000 B.P. and 2,000 B.P.?
3. The size of a population that is growing by a constant rate of increase will plot as a straight line on a logarithmically scaled graph like the one in part (b) above, but if the annual rate of increase changes, the line will curve. Do you think the data for the human population over the past 12,000 years would plot as a straight line on a logarithmically scaled graph? If not, when and why do you think the line would bend?

CALCULATING ECOLOGICAL FOOTPRINTS

Mathis Wackernagel and his colleagues have continued to refine the method of calculating ecological footprints—the amount of land and water required to produce the energy and natural resources we consume. In a 1999 paper, they applied their method to 52 nations that together account for 80% of the world's population and 95% of the World Domestic Product. According to their study, there are 4.9 acres available for every person in the world.

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

Country	Ecological footprint (acres per person)	Proportion relative to world average footprint	Proportion relative to world land available
Bangladesh	1.2		
Colombia	4.9		1.0 (4.9/4.9)
Mexico	6.4		
Sweden	14.6		
Thailand	6.9		
United States	25.4		
World Average	6.9	1.0 (6.9/6.9)	1.4 (6.9/4.9)

Data from Wackernagel, M., et al. 1999. National natural capital accounting with the ecological footprint concept. *Ecological Economics* 29: 375–390.

1. Why is the ecological footprint for people in Bangladesh so low?
2. Why is it so high in the United States?
3. The population of the United States is expected to grow to 349 million by 2025. What impact, if any, do you think this growth will have on the average global ecological footprint?
4. Based on the data in the table, what impacts do you think average family income has on ecological footprints?

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