

# Studying the State of Our Earth

## The Mysterious Neuse River Fish Killer

Over the course of a few days in 1991, roughly a billion fish died in North Carolina's Neuse River. Researchers at North Carolina State University (NCSU), led by Professor JoAnn Burkholder, identified the cause of this disaster as a microscopic free-living aquatic organism in the river water. This particular organism, of the genus *Pfiesteria* (fis-TEER-ee-uh), emits a potent toxin that rapidly kills fish. When members of the research team working with the organism began to develop skin sores and experience nausea, vomiting, memory impairment, and confusion, they became concerned that people using the river for fishing, crabbing, or recreation could also be in danger.

killer. But where did these nutrients come from, and how did they get into the river? The answer probably lies in human activities along the river's banks. The Neuse flows through a region dominated by large industrial-scale hog farms, agricultural fields, and rapidly growing suburban areas, all of which contribute fertilizer runoff and nutrient-rich waste to the river water. A sudden increase in nutrient concentrations caused by these various human activities apparently started a "bloom," or rapid proliferation, of *Pfiesteria*.

The discovery of *Pfiesteria* in North Carolina rivers created panic among the area's recreation and fishing industries. The organism was subsequently found in many other locations from Delaware to Florida, where it infected fisheries and

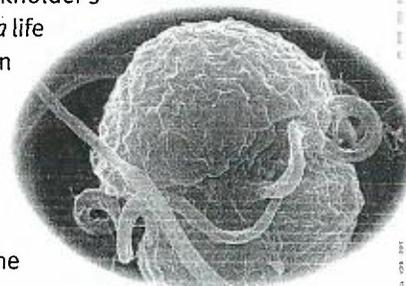
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As researchers continued to study *Pfiesteria*, they found that, depending on environmental conditions, the organism could have up to 24 different life stages—an incredibly large number for any organism. They found that under most conditions, swimming *Pfiesteria* fed harmlessly on algae. However, in the presence of high concentrations of nutrients and large populations of fish, *Pfiesteria* rapidly changed into a carnivore. During this carnivorous life stage, *Pfiesteria* emitted a toxin that stunned fish, then burrowed into a fish's body to feed. Once the fish died, *Pfiesteria* transformed into yet another life stage, a free-floating amoeba that engulfed the tissue sloughed off from fish corpses. Finally, when food became scarce, it could develop a protective casing and sink to the river bottom as a cyst, able to remain dormant for decades awaiting a new influx of nutrients.

Burkholder's group deduced that large influxes of nutrients into the Neuse River had triggered *Pfiesteria*'s metamorphosis from harmless algae eater into carnivorous fish

discouraged tourism. Concern over *Pfiesteria* led to a \$40 million loss in seafood sales in the Chesapeake Bay region alone.

While the NCSU researchers proceeded with their investigations, other investigators suggested that the "*Pfiesteria* hysteria" was overblown. Studies of humans exposed to *Pfiesteria* along rivers were inconclusive, despite additional anecdotal evidence of the symptoms that the initial researchers had experienced. Some investigators were unable to replicate the findings of Burkholder's team regarding certain *Pfiesteria* life stages. A few researchers even argued that *Pfiesteria* did not produce toxins at all. It wasn't until 2007—16 years after the fish kill that drew so much attention—that other investigators confirmed the identity of the toxin released by *Pfiesteria*. ▶



*Pfiesteria* cell.

◀ Despite the beautiful appearance of North Carolina's Neuse River, shown here, runoff from agriculture and housing development contributed to an environmental catastrophe in 1991.

The *Pfiesteria* story is a particularly good introduction to the study of environmental science. It shows us that human activities—for example, releasing waste material into a river—can affect the environment in complex and unexpected ways. Such unintended consequences of human activities are a key concern for environmental scientists.

The case of *Pfiesteria* also tells us that environmental science can be controversial. Following a new discovery, individuals, commercial interests, and the media may overstate the problem, understate it, or disagree with the initial report. Many years may pass before scientists understand the true nature and extent of the problem. Because the findings of environmental science often have an impact on industry, tourism, or recreation, they can create conflicts between scientific study and economic interests.

Finally, the story shows us that findings in environmental science are not always as clear-cut, as they first appear. As we begin our study of environmental science, it's important to recognize that the process of scientific inquiry always builds on the work of previous investigators. In this way we accumulate a body of knowledge that eventually resolves important questions—such as what killed the fish in the Neuse River. Only with this knowledge in hand can we begin to make informed decisions on questions of appropriate policy. ■

Sources: P. D. R. Moeller et al., Metal complexes and free radical toxins produced by *Pfiesteria piscicida*, *Environmental Science and Technology* 41 (2006): 1166–1172; Nicholas Wade, Deadly or dull? Up roar over a microbe, *New York Times*, August 6, 2000.

## KEY IDEAS

Humans are dependent on Earth's air, water, and soil for our existence. However, we have altered the planet in many ways, large and small. The study of environmental science can help us understand how humans have changed the planet and identify ways of responding to those changes.

After reading this chapter you should be able to

- define the field of environmental science and discuss its importance.
- identify ways in which humans have altered and continue to alter our environment.

- describe key environmental indicators that help us evaluate the health of the planet.
- define sustainability and explain how it can be measured using the ecological footprint.
- explain the scientific method and its application to the study of environmental problems.
- describe some of the unique challenges and limitations of environmental science.

## Environmental science offers important insights into our world and how we influence it

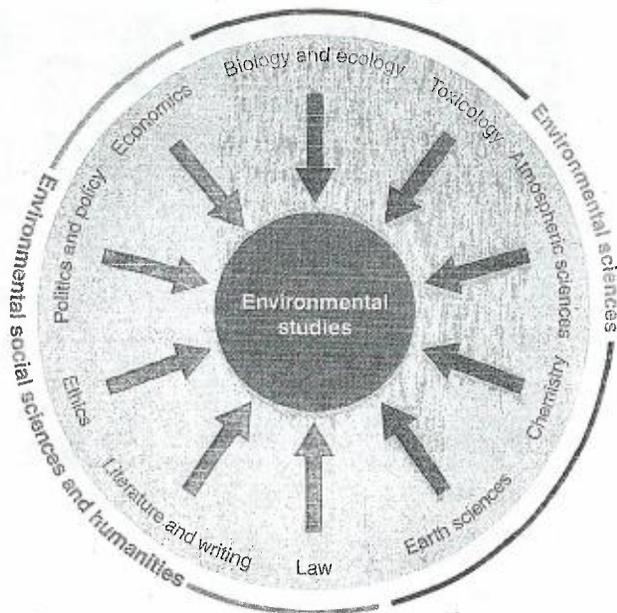
Stop reading for a moment and look up to observe your surroundings. Consider the air you breathe, the heating or cooling system that keeps you at a comfortable temperature, and the natural or artificial light that helps you see. Our **environment** is the sum of all the conditions surrounding us that influence life. These conditions include living organisms as well as nonliving components such as soil, temperature, and the availability of water. The influence of humans is an important part of the environment as well. The environment we live in determines how healthy we are, how fast we grow, how easy it is to move around, and even how much food we can obtain. One environment may be strikingly different from another—a hot, dry desert versus a cool, humid tropical rainforest, or a coral reef teeming with marine life versus a crowded city street.

We are about to begin a study of **environmental science**, the field that looks at interactions among

human *systems* and those found in nature. By **system** we mean any set of interacting components that influence one another by exchanging energy or materials. We have already seen that a change in one part of a system—for example, nutrients released into the Neuse River—can cause changes throughout the entire system.

An environmental system may be completely human-made, like a subway system, or it may be natural, like weather. The scope of an environmental scientist's work can vary from looking at a small population of individuals, to multiple populations that make up a species, to a community of interacting species, or even larger systems, such as the global climate system. Some environmental scientists are interested in regional problems. The specific case of *Pfiesteria* in the Neuse River, for example, was a regional problem. Other environmental scientists work on global issues, such as species extinction and climate change.

Many environmental scientists study a specific type of natural system known as an *ecosystem*. An **ecosystem** is a particular location on Earth whose interacting components include living, or **biotic**, components and nonliving, or **abiotic**, components.



**FIGURE 1.1** Environmental studies. The study of environmental science uses knowledge from many disciplines.

It is important for students of environmental science to recognize that environmental science is different from *environmentalism*, which is a social movement that seeks to protect the environment through lobbying, activism, and education. An **environmentalist** is a person who participates in environmentalism. In contrast, an environmental scientist, like any scientist, follows the process of observation, hypothesis testing, and field and laboratory research. We'll learn more about the scientific method later in this chapter.

So what does the study of environmental science actually include? As **FIGURE 1.1** shows, environmental science encompasses topics from many scientific disciplines, such as chemistry, biology, and Earth science. And environmental science is itself a subset of the broader field known as **environmental studies**, which includes additional subjects such as environmental policy, economics, literature, and ethics. Throughout the course of this book you will become familiar with these and many other disciplines.

We have seen that environmental science is a deeply interdisciplinary field. It is also a rapidly growing area of study. As human activities continue to affect the environment, environmental science can help us understand the consequences of our interactions with our planet and help us make better decisions about our actions.

#### CHECKPOINT

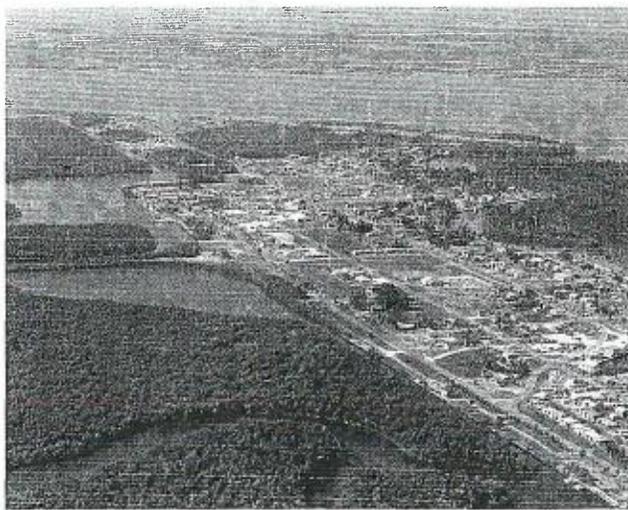
- ✓ What factors make up an organism's environment?
- ✓ In what ways is the field of environmental studies interdisciplinary?
- ✓ Why is environmental science research important?

## Humans alter natural systems

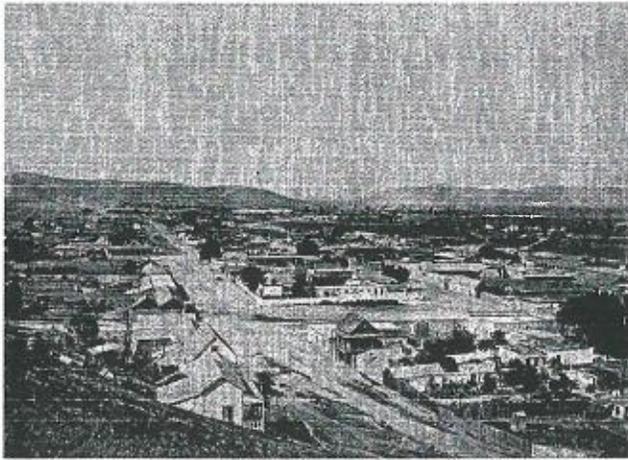
Think of the last time you walked in a wooded area. Did you notice any dead or fallen trees? Chances are that even if you did, you were not aware that living and nonliving components were interacting all around you. Perhaps an insect pest killed the tree you saw and many others of the same species. Over time, dead trees in a forest lose moisture. The increase in dry wood makes the forest more vulnerable to intense wildfires. But the process doesn't stop there. Wildfires trigger the germination of certain tree seeds, some of which lie dormant until after a fire. And so what began with the activity of insects leads to a transformation of the forest. In this way, *biotic*, or living, factors interact with *abiotic*, or non-living, factors to influence the future of the forest.

The global environment is composed of small-scale and large-scale systems. Within a given system, biotic and abiotic components can interact in surprisingly complex ways. In the forest example, the species of trees that are present in the forest, the insect pests, and the wildfires interact with one another: they form a system. This small forest system is part of many larger systems and, ultimately, one global system that generates, circulates, and utilizes oxygen and carbon dioxide, among other things.

Humans manipulate their environment more than any other species. We convert land from its natural state into urban, suburban, and agricultural areas (**FIGURE 1.2**). We change the chemistry of our air, water, and soil, both intentionally—for example, by adding fertilizers—and unintentionally, as a consequence of activities that generate pollution. Even where we don't manipulate the environment directly, the simple fact that we are so abundant affects our surroundings.



**FIGURE 1.2** The impact of humans on Earth. Housing development is one example of the many ways in which humans convert land from its natural state.



(a)



(b)

**FIGURE 1.3** It is impossible for millions of people to inhabit an area without altering it. (a) In 1880, fewer than 6,000 people lived in Los Angeles. (b) In 2009, Los Angeles had a population of 3.8 million people, and the greater Los Angeles metropolitan area was home to nearly 13 million people.

Humans and their direct ancestors (other members of the genus *Homo*) have lived on Earth for about 2.5 million years. During this time, and especially during the last 10,000 to 20,000 years, we have shaped and influenced our environment. As tool-using, social animals, we have continued to develop a capacity to directly alter our environment in substantial ways. *Homo sapiens*—genetically modern humans—evolved to be successful hunters: when they entered a new environment, they often hunted large animal species to extinction. In fact, early humans are thought to be responsible for the extinction of mammoths, mastodons, giant ground sloths, and many types of birds. More recently, hunting in North America led to the extinction of the passenger pigeon (*Ectopistes migratorius*) and nearly caused the loss of the American bison (*Bison bison*).

But the picture isn't all bleak. Human activities have also created opportunities for certain species to thrive. For example, for thousands of years Native Americans on the Great Plains used fire to capture animals for food. The fires they set kept trees from encroaching on the plains, which in turn created a window for an entire ecosystem to develop. Because of human activity, this ecosystem—the tallgrass prairie—is now home to numerous unique species.

During the last two centuries, the rapid and widespread development of technology, coupled with dramatic human population growth, has increased both the rate and the scale of our global environmental impact substantially. Modern cities with electricity, running water, sewer systems, Internet connections, and public transportation systems have improved human well-being, but they have come at a cost. Cities cover land that was once natural habitat. Species relying on that habitat must adapt, relocate, or go extinct. Human-induced changes

in climate—for example, in patterns of temperature and precipitation—affect the health of natural systems on a global scale. Current changes in land use and climate are rapidly outpacing the rate at which natural systems can evolve. Some species have not “kept up” and can no longer compete in the human-modified environment.

Moreover, as the number of people on the planet has grown, their effect has multiplied. Six thousand people can live in a relatively small area with only minimal environmental effects. But when 4 million people live in a modern city like Los Angeles, their combined activity will cause greater environmental damage that will inevitably pollute the water, air, and soil and introduce other consequences as well (FIGURE 1.3).

#### CHECKPOINT

- ✓ In what ways do humans change the environment?
- ✓ What is the relationship between the development of technology and environmental impacts?
- ✓ How does human development have an impact on natural systems?

## Environmental scientists monitor natural systems for signs of stress

One of the critical questions that environmental scientists investigate is whether the planet's natural

TABLE 1.1 Some common environmental indicators

Environmental indicator	Unit of measure	Chapter where indicator is discussed
Human population	Individuals	7
Ecological footprint	Hectares of land	1
Total food production	Metric tons of grain	11
Food production per unit area	Kilograms of grain per hectare of land	11
Per capita food production	Kilograms of grain per person	11
Carbon dioxide	Concentration in air (parts per million)	19
Average global surface temperature	Degrees centigrade	19
Sea level change	Millimeters	19
Annual precipitation	Millimeters	4
Species diversity	Number of species	5, 18
Fish consumption advisories	Present or absent; number of fish allowed per week	17
Water quality (toxic chemicals)	Concentration	14
Water quality (conventional pollutants)	Concentration; presence or absence of bacteria	14
Deposition rates of atmospheric compounds	Milligrams per square meter per year	15
Fish catch or harvest	Kilograms of fish per year or weight of fish per effort expended	11
Extinction rate	Number of species per year	5
Habitat loss rate	Hectares of land cleared or "lost" per year	18
Infant mortality rate	Number of deaths of infants under age 1 per 1,000 live births	7
Life expectancy	Average number of years a newborn infant can be expected to live under current conditions	7

life-support systems are being degraded by human-induced changes. Natural environments provide what we refer to as **ecosystem services**—the processes by which life-supporting resources such as clean water, timber, fisheries, and agricultural crops are produced. We often take a healthy ecosystem for granted, but we notice when an ecosystem is degraded or stressed because it is unable to provide the same services or produce the same goods. To understand the extent of our effect on the environment, we need to be able to measure the health of Earth's ecosystems.

To describe the health and quality of natural systems, environmental scientists use *environmental indicators*. Just as body temperature and heart rate can indicate whether a person is healthy or sick, **environmental indicators** describe the current state of an environmental system. These indicators do not always tell us what is causing a change, but they do tell us when we might need to look more deeply into a particular issue. Environmental indicators provide valuable information about natural systems on both small and large scales. Some of these indicators are listed in Table 1.1.

In this book we will focus on the five global-scale environmental indicators listed in Table 1.2: biological diversity, food production, average global surface temperature and carbon dioxide concentrations in the

atmosphere, human population, and resource depletion. These key environmental indicators help us analyze the health of the planet. We can use this information to guide us toward **sustainability**, by which we mean living on Earth in a way that allows us to use its resources without depriving future generations of those resources. Many scientists maintain that achieving sustainability is the single most important goal for the human species. It is also one of the most challenging tasks we face.

## Biological Diversity

Biological diversity, or **biodiversity**, is the diversity of life forms in an environment. It exists on three scales: *genetic*, *species*, and *ecosystem* diversity. Each of these is an important indicator of environmental health and quality.

**GENETIC DIVERSITY** Genetic diversity is a measure of the genetic variation among individuals in a population. Populations with high genetic diversity are better able to respond to environmental change than populations with lower genetic diversity. For example, if a population of fish possesses high genetic diversity for disease resistance, at least some individuals are likely to survive

**TABLE 1.2** Five key global environmental indicators

Indicator	Recent trend	Outlook for future	Overall impact on environmental quality
Biological diversity	Large number of extinctions, extinction rate increasing	Extinctions will continue	Negative
Food production	Per capita production possibly leveling off	Unclear	May affect the number of people Earth can support
Average global surface temperature and CO <sub>2</sub> concentrations	CO <sub>2</sub> concentrations and temperatures increasing	Probably will continue to increase, at least in the short term	Effects are uncertain and varied, but probably detrimental
Human population	Still increasing, but growth rate slowing	Population leveling off Resource consumption rates are also a factor	Negative
Resource depletion	Many resources are being depleted at rapid rates. But human ingenuity frequently develops "new" resources, and efficiency of resource use is increasing in many cases	Unknown	Increased use of most resources has negative effects

whatever diseases move through the population. If the population declines in number, however, the amount of genetic diversity it can possess is also reduced, and this reduction increases the likelihood that the population will decline further when exposed to a disease.

**SPECIES DIVERSITY** Species diversity indicates the number of *species* in a region or in a particular type of habitat. A **species** is defined as a group of organisms that is distinct from other groups in its morphology (body form and structure), behavior, or biochemical properties. Individuals within a species can breed and produce fertile offspring. Scientists have identified and cataloged approximately 2 million species on Earth. Estimates of the total number of species on Earth range between 5 million and 100 million, with the most common estimate at 10 million. This number includes a large array of organisms with a multitude of sizes, shapes, colors, and roles (FIGURE 1.4). Scientists have observed that ecosystems with more species, that is, higher species diversity, are more resilient and productive. For example, a tropical forest with a large number of plant species growing in the understory is likely to be more productive, and more resilient to change, than a nearby tropical forest plantation with one crop species growing in the understory.

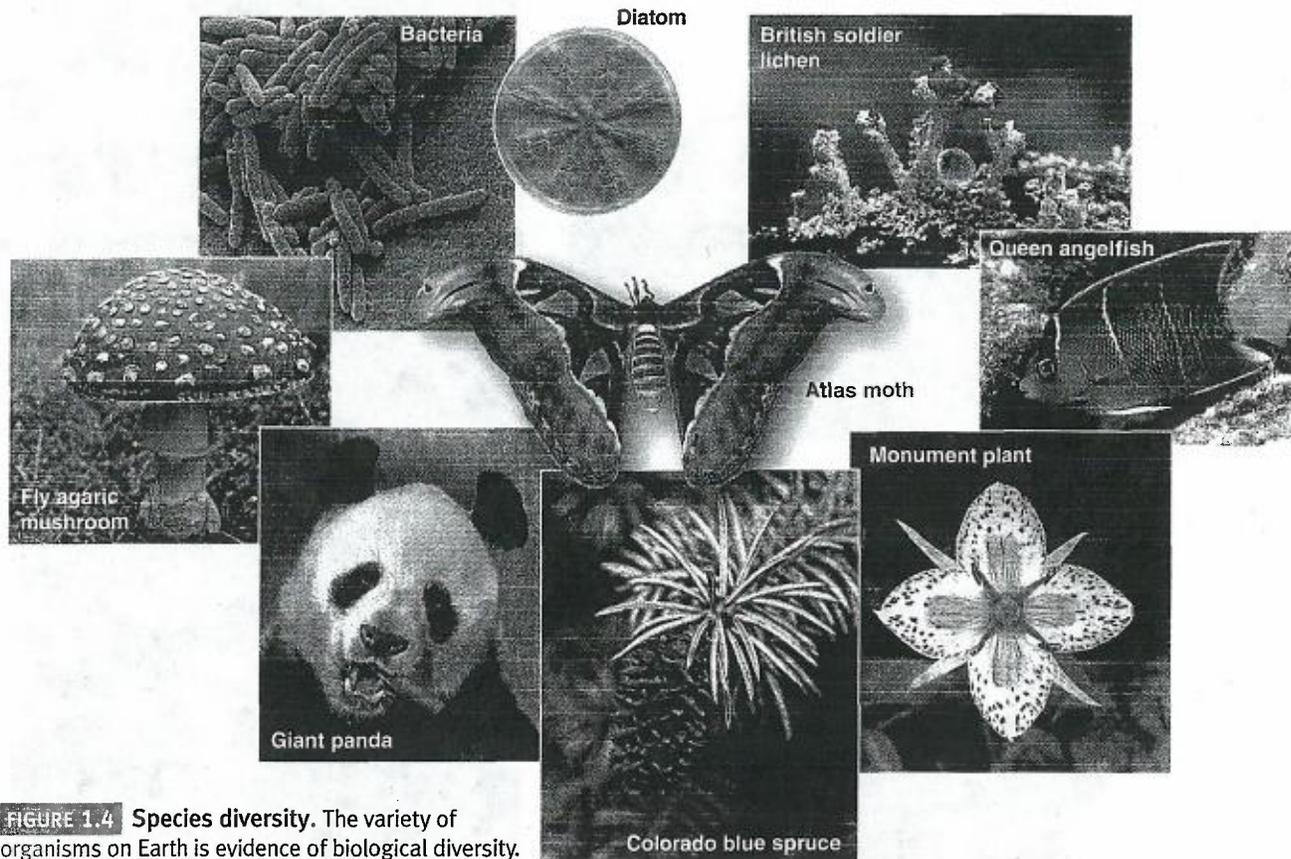
Environmental scientists often focus on species diversity as a critical environmental indicator. The number of frog species, for example, is used as an indicator of regional environmental health because frogs are exposed to both the water and the air in their ecosystem. A decrease in the number of frog species in a particular ecosystem may be an indicator of environmental problems there. Species losses in several ecosystems can indicate larger-scale environmental problems.

Not all species losses are indicators of environmental problems, however. Species arise and others go extinct as part of the natural evolutionary process. The evolution of new species, known as **speciation**, typically happens very slowly—perhaps on the order of one to three new species per year worldwide. The average rate at which species go extinct over the long term, referred to as the **background extinction rate**, is also very slow: about one species in a million every year. So with 2 million identified species on Earth, the background extinction rate should be about two species per year.

Under conditions of environmental change or biological stress, species may go extinct faster than new ones evolve. Some scientists estimate that more than 10,000 species are currently going extinct each year—5,000 times the background rate of extinction. Habitat destruction and habitat degradation are the major causes of species extinction today, although climate change, overharvesting, and pressure from introduced species also contribute to species loss. Human intervention has saved certain species, including the American bison, peregrine falcon (*Falco peregrinus*), bald eagle (*Haliaeetus leucocephalus*), and American alligator (*Alligator mississippiensis*). But other large animal species, such as the Bengal tiger (*Panthera tigris*), snow leopard (*Panthera uncia*), and West Indian manatee (*Trichechus manatus*), remain endangered and may go extinct if present trends are not reversed. Overall, the number of species has been declining (FIGURE 1.5).

**ECOSYSTEM DIVERSITY** Ecosystem diversity is a measure of the diversity of ecosystems or habitats that exist in a given region. A greater number of healthy and productive ecosystems means a healthier environment over

As an environmental indicator, the current loss of biodiversity tells us that natural systems are facing strains



**FIGURE 1.4** Species diversity. The variety of organisms on Earth is evidence of biological diversity.

unlike any in the recent past. It is clearly an important topic in the study of environmental science, and we will look at it in greater detail in Chapters 5 and 18 of this book.

Some measures of biodiversity are given in terms of land area, so becoming familiar with measurements of land area is important to understanding them. As Do the Math “What Is a Hectare?” describes, a hectare

**DO THE MATH**

**What Is a Hectare?**

Some environmental indicators are expressed in hectares. A hectare is a measure of land area, abbreviated “ha,” that represents an area that is 100 meters by 100 meters. In the United States we measure land area in terms of square miles and acres. However, the rest of the world measures land in terms of hectares. Let’s see how the two systems compare:

$$1 \text{ mile}^2 = 640 \text{ acres}$$

Given that there are 5,280 feet in a mile:

$$1 \text{ mi}^2 = (5,280 \text{ ft})^2 = 27,878,400 \text{ ft}^2$$

Using this information, we can determine the number of square feet in 1 acre, as follows:

$$\left( \frac{1 \text{ mi}^2}{640 \text{ acres}} \right) \times \left( \frac{27,878,400 \text{ ft}^2}{1 \text{ mi}^2} \right) = 43,560 \text{ ft}^2/\text{acre}$$

So—what is a hectare?

1 ha = 10,000 m<sup>2</sup>—that is, a square that is 100 m on each side, and 1 kilometer (km) = 1,000 m. Thus:

$$1 \text{ km}^2 = (1,000 \text{ m})^2 = 1,000,000 \text{ m}^2$$

Using this information, we can determine the number of hectares in 1 square kilometer.

$$\left( \frac{1,000,000 \text{ m}^2}{1 \text{ km}^2} \right) \times \left( \frac{1 \text{ ha}}{10,000 \text{ m}^2} \right) = 100 \text{ ha}/\text{km}^2$$

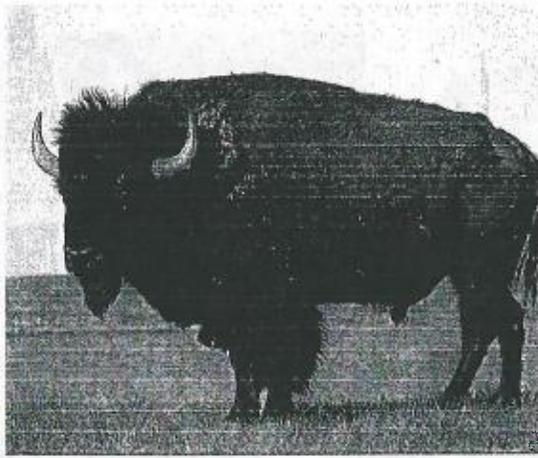
Notice how neatly the metric system handles all these calculations. Everything is in powers of 10—unlike feet, miles, acres, and sections.

How can we compare hectares to acres? To do so, we first need to use common units. Let’s convert square kilometers to square feet. If 1 km = 0.6214 mi, then:

$$1 \text{ km}^2 = (0.6214 \text{ mi})^2 \times \left( \frac{27,878,400 \text{ ft}^2}{1 \text{ mi}^2} \right) = 10,764,908 \text{ ft}^2$$

Now, finally, we can determine the number of acres in 1 hectare, as follows:

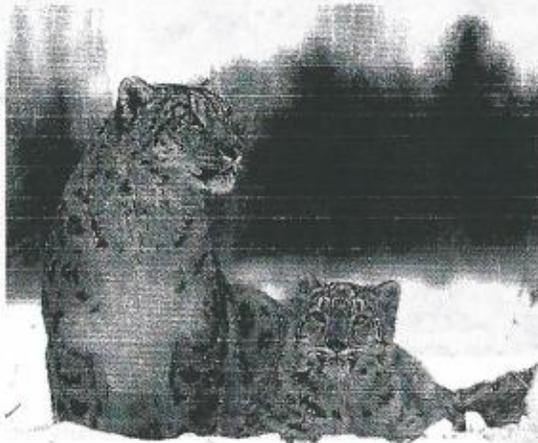
$$\left( 10,764,908 \text{ ft}^2/\text{km}^2 \right) \times \left( \frac{1 \text{ km}^2}{100 \text{ ha}} \right) \times \left( \frac{1 \text{ acre}}{43,560 \text{ ft}^2} \right) = 2.47 \text{ acres}/\text{ha}$$



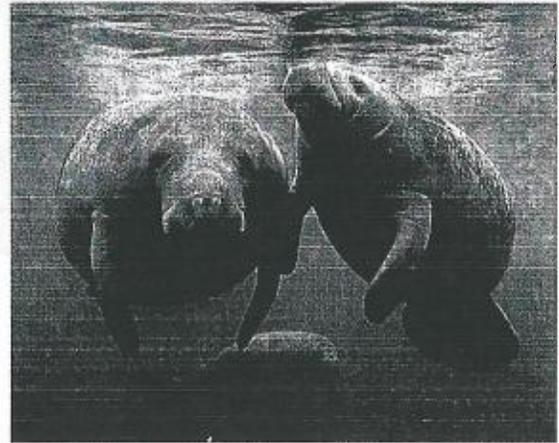
(a)



(b)



(c)



(d)

**FIGURE 1.5** Species on the brink. Humans have saved some species from the brink of extinction, such as (a) the American bison and (b) the peregrine falcon. Other species, such as (c) the snow leopard and (d) the West Indian manatee, continue to decline toward extinction.

is a unit of area used primarily in the measurement of land.

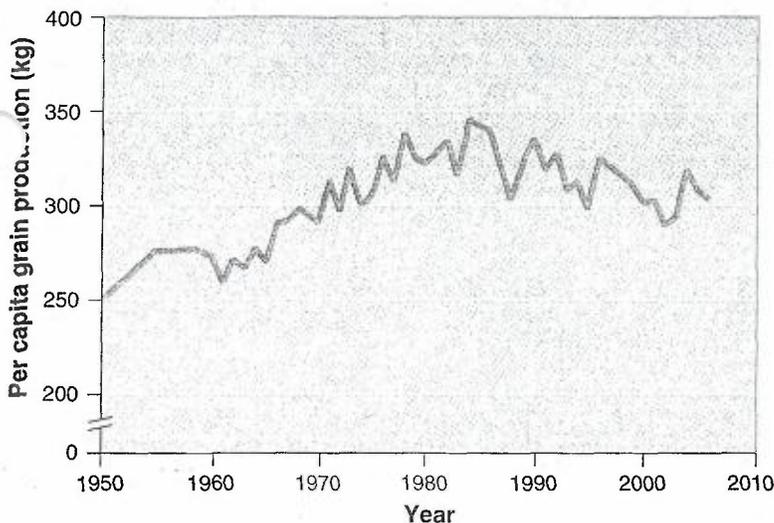
## Food Production

The second of our five global indicators is food production: our ability to grow food to nourish the human population. Just as a healthy ecosystem supports a wide range of species, a healthy soil supports abundant and continuous food production. Food grains such as wheat, corn, and rice provide more than half the calories and protein humans consume. Still, the growth of the human population is straining our ability to grow and distribute adequate amounts of food.

In the past we have used science and technology to increase the amount of food we can produce on a given area of land. World grain production has increased fairly steadily since 1950 as a result of expanded irrigation, fertilization, new crop varieties, and other innovations.

At the same time, worldwide production of grain *per person*, also called *per capita* world grain production, has leveled off. FIGURE 1.6 shows a downward trend in wheat production since about 1985.

In 2008, food shortages around the world led to higher food prices and even riots in some places. Why did this happen? The amount of grain produced worldwide is influenced by many factors. These factors include climatic conditions, the amount and quality of land under cultivation, irrigation, and the human labor and energy required to plant, harvest, and bring the grain to market. Why is grain production not keeping up with population growth? In some areas, the productivity of agricultural ecosystems has declined because of soil degradation, crop diseases, and unfavorable weather conditions such as drought or flooding. In addition, demand is outpacing supply. The rate of human population growth has outpaced increases in food production. Furthermore, humans currently u



**FIGURE 1.6** World grain production per person. Grain production has increased since the 1950s, but it has recently begun to level off. [After <http://www.earth-policy.org/index.php?/indicators/C54>.]

more grain to feed livestock than they consume themselves. Finally, some government policies discourage food production by making it more profitable to allow land to remain uncultivated, or by encouraging farmers to grow crops for fuels such as ethanol and biodiesel instead of food.

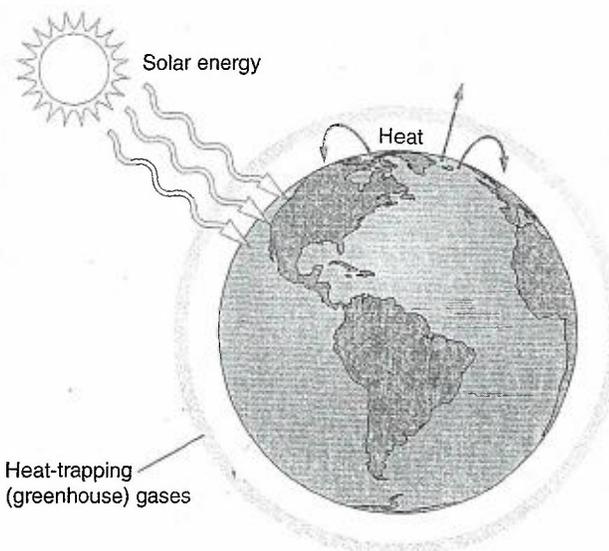
Will there be sufficient grain to feed the world's population in the future? In the past, whenever a shortage of food loomed, humans have discovered and employed technological or biological innovations to increase production. However, these innovations often put a strain on the productivity of the soil. Unfortunately, if we continue to overexploit the soil, its ability to sustain food production may decline dramatically. We will take a closer look at soil quality in Chapter 8 and food production in Chapter 11.

### Average Global Surface Temperature and Carbon Dioxide Concentrations

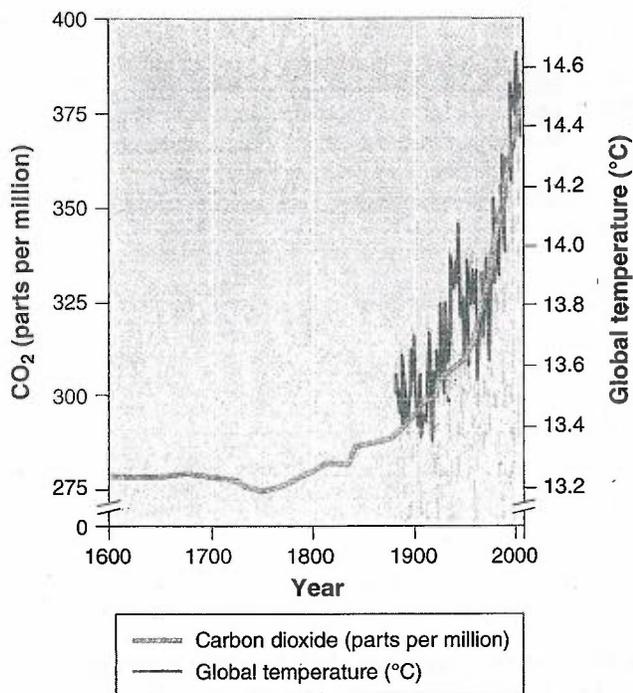
We have seen that biodiversity and abundant food production are necessary for life. One of the things that makes them possible is a stable climate. Earth's temperature has been relatively constant since the earliest forms of life began, about 3.5 billion years ago. The temperature of Earth allows the presence of liquid water, which is necessary for life.

What keeps Earth's temperature so constant? As **FIGURE 1.7** shows, our thick planetary atmosphere contains many gases, some of which act like a blanket trapping heat near Earth's surface. The most important of these heat-trapping gases, called **greenhouse gases**, is carbon dioxide ( $\text{CO}_2$ ). During most of the history of life on Earth, greenhouse gases have been present in the atmosphere at fairly constant concentrations for relatively long periods. They help keep Earth's surface within the range of temperatures at which life can flourish.

In the past two centuries, however, the concentrations of  $\text{CO}_2$  and other greenhouse gases in the atmosphere have risen. During roughly the same period, as the graph in **FIGURE 1.8** shows, global temperatures have fluctuated considerably, but have shown an overall increase. Many scientists believe that the increase in atmospheric  $\text{CO}_2$  during the last two centuries is **anthropogenic**—derived from human activities. The two major sources of anthropogenic  $\text{CO}_2$  are the combustion of fossil fuels and the net loss of forests and other habitat types that would otherwise take up and store  $\text{CO}_2$  from the atmosphere. We will discuss climate in Chapter 4 and global climate change in Chapter 19.



**FIGURE 1.7** The greenhouse effect. As Earth's surface is warmed by the Sun, it radiates heat outward. Heat-trapping gases absorb the outgoing heat and re-radiate some of it back to Earth. Without these greenhouse gases, Earth would be much cooler.



**FIGURE 1.8** Changes in average global surface temperature and in atmospheric CO<sub>2</sub> concentrations. Earth's average global surface temperature has increased steadily for at least the past 100 years. Carbon dioxide concentrations in the atmosphere have varied over geologic time, but have risen steadily since 1960. [After <http://data.giss.nasa.gov/gistemp/2008/>. <http://mb-soft.com/public3/co2hist.gif>.]

## Human Population

In addition to biodiversity, food production, and global surface temperature, the size of the human population can tell us a great deal about the health of our global environment. The human population is currently 6.8 billion and growing. The increasing world population places additional demands on natural systems, since each new person requires food, water, and other resources. In any given 24-hour period, 364,000 infants are born and 152,000 people die. The net result is 212,000 new inhabitants on Earth each day, or *over a million additional people every 5 days*. The rate of population growth has been slowing since the 1960s, but world population size will continue to increase for at least 50 to 100 years. Most population scientists project that the human population will be somewhere between 8.1 billion and 9.6 billion in 2050 and will stabilize between 6.8 billion and 10.5 billion by 2100.

Can the planet sustain so many people (FIGURE 1.9)? Even if the human population eventually stops growing, the billions of additional people will create a greater demand on Earth's finite resources, including food, energy, and land. Unless humans work to reduce these pressures, the human population will put a rapidly growing strain on natural systems for at least the first half of this century. We discuss human population issues in Chapter 7.

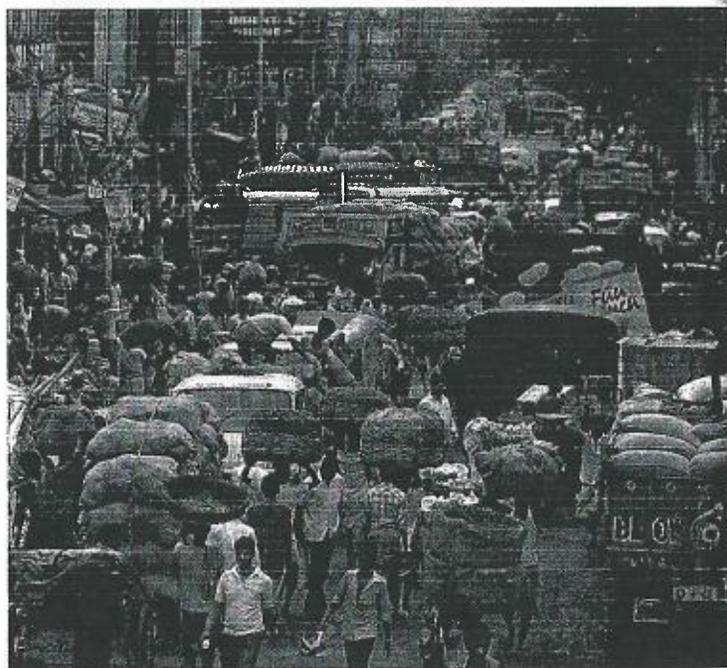
## Resource Depletion

Natural resources provide the energy and materials that support human civilization. But as the human population grows, the resources necessary for our survival become increasingly depleted. In addition, extracting these natural resources can affect the health of our environment in many ways. Pollution and land degradation caused by mining, waste from discarded manufactured products, and air pollution caused by fossil fuel combustion are just a few of the negative environmental consequences of resource extraction and use.

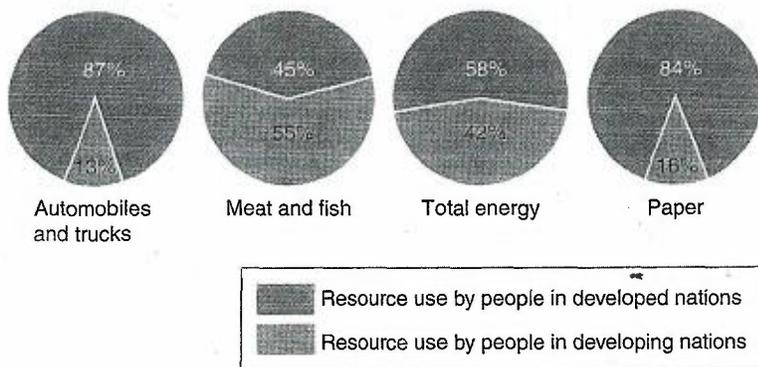
Some natural resources, such as coal, oil, and uranium, are finite and cannot be renewed or reused. Others, such as aluminum or copper, also exist in finite quantities, but can be used multiple times through reuse or recycling. Renewable resources, such as timber, can be grown and harvested indefinitely, but in some locations they are being used faster than they are naturally replenished. Do the Math "Rates of Forest Clearing" provides an opportunity to calculate rates of one type of resource depletion.

Sustaining the global human population requires vast quantities of resources. However, in addition to the total amounts of resources used by humans, we must consider resource use per capita.

Patterns of resource consumption vary enormously among nations depending on their level of development. What exactly do we mean by *development*? **Development** is defined as improvement in human well-being



**FIGURE 1.9** Kolkata, India. The human population will continue to grow for at least 50 years. Unless humans can devise ways to live sustainably, these population increases will put additional strains on natural systems.



**FIGURE 1.10** Resource use in developed and developing countries. Only 20 percent of the world's population lives in developed countries, but that 20 percent uses most of the world's resources. The remaining 80 percent of the population lives in developing countries and uses far fewer resources per capita.

through economic advancement. Development influences personal and collective human lifestyles—things such as automobile use, the amount of meat in the diet, and the availability and use of technologies such as cell phones and personal computers. As economies develop, resource consumption also increases: people drive more automobiles, live in larger homes, and purchase more goods. These increases can often have implications for the natural environment.

According to the United Nations Development Programme, people in developed nations—including the United States, Canada, Australia, most European countries, and Japan—use most of the world's resources. FIGURE 1.10 shows that the 20 percent of the global population that lives in developed nations owns 87 percent of the world's automobiles and consumes 58 percent of all energy, 84 percent of all paper, and 45 percent of all fish and meat. The poorest 20 percent of the world's people consume 5 percent or less of these resources. Thus, even though the number of people in the developing countries is much larger than the num-

ber in the developed countries, their total consumption of natural resources is relatively small.

So while it is true that a larger human population has greater environmental impacts, a full evaluation requires that we look at economic development and consumption patterns as well. We will take a closer look at resource depletion and consumption patterns in Chapters 7, 12, and 13.

**CHECKPOINT**

- ✓ What is an environmental indicator and what does it tell us?
- ✓ What are the five global-scale environmental indicators we focus on in this book, and how do they help us monitor the health of the environment?
- ✓ How do human activities contribute to changes in the five global-scale environmental indicators?

**DO THE MATH**

**Rates of Forest Clearing**

A Web search of environmental organizations yielded a range of estimates of the amount of forest clearing that is occurring worldwide:

- Estimate 1: 1 acre per second
- Estimate 2: 80,000 acres per day
- Estimate 3: 32,000 ha per day

Convert all three estimates into hectares per year and compare them.

There are 2.47 acres per hectare (see Do the Math "What Is a Hectare?"). Therefore, 1 acre = 0.40 ha.

$$\begin{aligned} \text{Estimate 1: } & 1.0 \text{ acre/second} \times 0.40 \text{ ha/acre} = \\ & 0.40 \text{ ha/second} \\ & 0.40 \text{ ha/second} \times 60 \text{ seconds/minute} \times \\ & 60 \text{ minutes/hour} \times 24 \text{ hours/day} \times 365 \text{ days/year} = \\ & 12,614,400 \text{ ha cleared per year} \end{aligned}$$

$$\text{Estimate 2: } 80,000 \text{ acres/day} \times 0.40 \text{ ha/acre} = 32,000 \text{ ha cleared per day}$$

$$\text{Estimate 3: } 32,000 \text{ ha/day} \times 365 \text{ days/year} = 11,680,000 \text{ ha cleared per year}$$

The second and third estimates are exactly the same. Both are equivalent to 32,000 ha per day (as seen in the intermediate step of the conversion above).

There is a difference of less than 1,000,000 ha per year, or roughly 9%, between the estimates, suggesting that they are similar in scope.

Why might environmental organizations choose to present similar information in different ways?

## Human well-being depends on sustainable practices

We have seen that people living in developed nations consume a far greater share of the world's resources than do people in developing countries. What effect does this consumption have on our environment? It is easy to imagine a very small human population living on Earth without degrading its environment: there simply would not be enough people to do significant damage. Today, however, Earth's population is 6.8 billion people and growing. Many environmental scientists ask how we will be able to continue to produce sufficient food, build needed infrastructure, and process pollution and waste. Our current attempts to sustain the human population have already modified many environmental systems. Can we continue our current level of resource consumption without jeopardizing the well-being of future generations?

Easter Island, in the South Pacific, provides a cautionary tale (FIGURE 1.11). This island, also called Rapa Nui, was once covered with trees and grasses. When humans settled the island hundreds of years ago, they quickly multiplied in its hospitable environment. They cut down trees to build homes and canoes for fishing, and they overused the island's soil and water resources. By the 1870s, almost all of the trees were gone. Without the trees to hold the soil in place, massive erosion occurred, and the loss of soil caused food production to decrease. While other forces, including diseases introduced by European visitors, were also involved in the



**FIGURE 1.11** Easter Island. The overuse of resources by the people of Easter Island is probably the primary cause for the demise of that civilization.

destruction of the population, the unsustainable use of natural resources on Easter Island appears to be the primary cause for the collapse of its civilization.

Most environmental scientists believe that there are limits to the supply of clean air and water, nutritious foods, and other life-sustaining resources our environment can provide, as well as a point at which Earth will no longer be able to maintain a stable climate. We must meet several requirements in order to live sustainably:

- Environmental systems must not be damaged beyond their ability to recover.
- Renewable resources must not be depleted faster than they can regenerate.
- Nonrenewable resources must be used sparingly.

**Sustainable development** is development that balances current human well-being and economic advancement with resource management for the benefit of future generations. This is not as easy as it sounds. The issues involved in evaluating sustainability are complex, in part because sustainability depends not only on the number of people using a resource, but also on how that resource is being used. For example, eating chicken is sustainable when people raise their own chickens and allow them to forage for food on the land. However, if all people, including city dwellers, wanted to eat chicken six times a week, the amount of resources needed to raise that many chickens would probably make the practice of eating chicken unsustainable.

Living sustainably means *acting in a way such that activities that are crucial to human society can continue*. It includes practices such as conserving and finding alternatives to nonrenewable resources as well as protecting the capacity of the environment to continue to supply renewable resources (FIGURE 1.12).

Iron, for example, is a nonrenewable resource derived from ore removed from the ground. It is the major constituent of steel, which we use to make many things, including automobiles, bicycles, and strong frames for tall buildings. Historically, our ability to smelt iron for steel limited our use of that resource. But as we have improved steel manufacturing technology, steel has become more readily available, and the demand for it has grown. Because of this, our current use of iron is unsustainable. What would happen if we ran out of iron? Not too long ago the depletion of iron ore might have been a catastrophe. But today we have developed materials that can substitute for certain uses of steel—for example, carbon fiber—and we also know how to recycle steel. Developing substitutes and recycling materials are two ways to address the problem of resource depletion and increase sustainability.

The example of iron leads us to a question that environmental scientists often ask: How do we determine



**FIGURE 1.12** Living sustainably. Sustainable choices such as bicycling to work or school can help protect the environment and conserve resources for future generations.

the importance of a given resource? If we use up a resource such as iron for which substitutes exist, it is possible that the consequences will not be severe. However, if we are unable to find an alternative to the resource—for example, something to replace fossil fuels—people in the developed nations may have to make significant changes in their consumption habits.

### Defining Human Needs

We have seen that sustainable development requires us to determine how we can meet our current needs without compromising the ability of future generations to meet their own needs. Let's look at how environmental science can help us achieve that goal. We will begin by defining *needs*.

If you have ever experienced an interruption of electricity to your home or school, you know how frustrating it can be. Without the use of lights, computers, televisions, air-conditioning, heating, and refrigeration, many people feel disconnected and uncomfortable. Almost everyone in the developed world would insist that they need—cannot live without—electricity. But in other parts of the world, people have never had these modern conveniences. When we speak of *basic needs*, we are referring to the essentials that sustain human life, including air, water, food, and shelter.

But humans also have more complex needs. Many psychologists have argued that we require meaningful human interactions in order to live a satisfying life; therefore, a community of some sort might be

considered a human need. Biologist Edward O. Wilson wrote that humans exhibit **biophilia**—that is, love of life—which is a *need* to make “the connections that humans subconsciously seek with the rest of life.” Thus our needs for access to natural areas, for beauty, and for social connections can be considered as vital to our well-being as our basic physical needs and must be considered as part of our long-term goal of global sustainability (FIGURE 1.13).

### The Ecological Footprint

We have begun to see the multitude of ways in which human activities affect the environment. As countries prosper, their populations use more resources. But economic development can sometimes improve environmental conditions. For instance, wealthier countries may be able to afford to implement pollution controls and invest money to protect native species. So although people in developing countries do not consume the same quantity of resources as those in developed nations, they may be less likely to use environmentally friendly technologies or to have the financial resources to implement environmental protections.

How do we determine what lifestyles have the greatest environmental impact? This is an important question for environmental scientists if we are to understand the effects of human activities on the planet and develop sustainable practices. Calculating sustainability, however, is more difficult than one might think. We have to consider the impacts of our activities and lifestyles on different aspects of our environment. We use land to grow food, to build on, and for parks and recreation. We require



**FIGURE 1.13** Central Park, New York City. New Yorkers have set aside 2,082 ha (843 acres) in the center of the largest city in the United States—a testament to the compelling human need for interactions with nature.

water for drinking, for cleaning, and for manufacturing products such as paper. We need clean air to breathe. Yet these goods and services are all interdependent: using or protecting one has an effect on the others. For example, using land for conventional agriculture may require water for irrigation, fertilizer to promote plant growth, and pesticides to reduce crop damage. This use of land reduces the amount of water available for human use: the plants consume it and the pesticides pollute it.

One method used to assess whether we are living sustainably is to measure the impact of a person or country on world resources. The tool many environmental scientists use for this purpose, the *ecological footprint*, was developed in 1995 by Professor William Rees and his graduate student Mathis Wackernagel. An individual's **ecological footprint** is a measure of how much that person consumes, expressed in area of land. That is, the output from the total amount of land required to support a person's lifestyle represents that person's ecological footprint (FIGURE 1.14).

Rees and Wackernagel maintained that if our lifestyle demands more land than is available, then we must be living unsustainably—using up resources more quickly than they can be produced, or producing wastes more quickly than they can be processed. For example, each person requires a certain number of food calories each day. We know the number of calories in a given amount

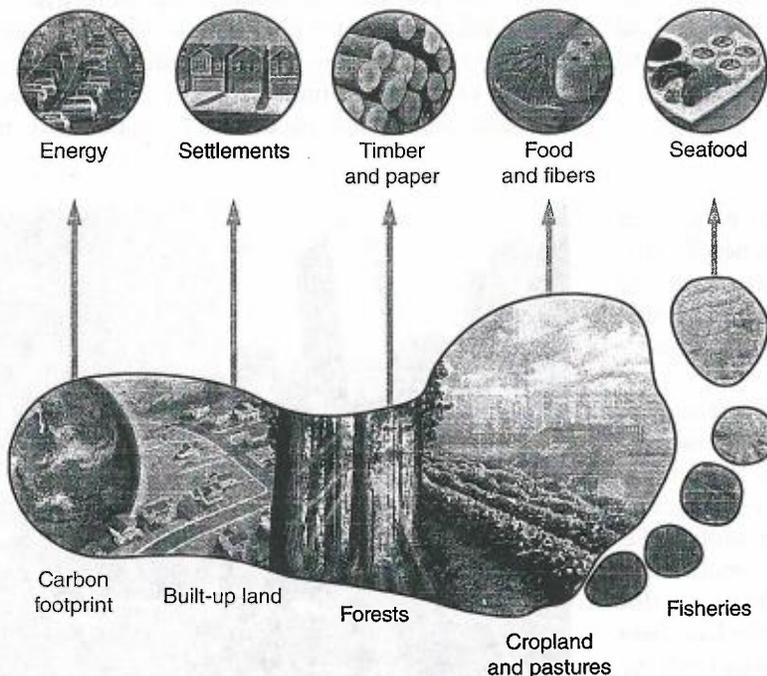
of grain or meat. We also know how much farmland or rangeland is needed to grow the grain to feed people or livestock such as sheep, chickens, or cows. If a person eats only grains or plants, the amount of land needed to provide that person with food is simply the amount of land needed to grow the plants they eat. If that person eats meat, however, the amount of land required to feed that person is greater, because we must also consider the land required to raise and feed the livestock that ultimately become meat. Thus one factor in the size of a person's ecological footprint is the amount of meat in the diet. Meat consumption is a lifestyle choice, and per capita meat consumption is much greater in developed countries.

We can calculate the ecological footprint of the food we eat, the water and energy we use, and even the activities we perform that contribute to climate change. All of these impacts determine our ecological footprint on the planet as individuals, cities, states, or nations. Calculating the ecological footprint is complex, and the details are subject to debate, but it has at least given scientists a concrete measure to discuss and refine.

Scientists at the Global Footprint Network, where Wackernagel is now president, have calculated that the human ecological footprint has reached 14 billion hectares (34.6 billion acres), or 125 percent of Earth's total usable land area. Furthermore, they have calculated

that if every person on Earth lived the average lifestyle of people in the United States, we would require the equivalent of five Earths (FIGURE 1.15). Even to support the entire human population with the lifestyles we have now, we would need more than one Earth. Clearly, this level of resource consumption is not sustainable.

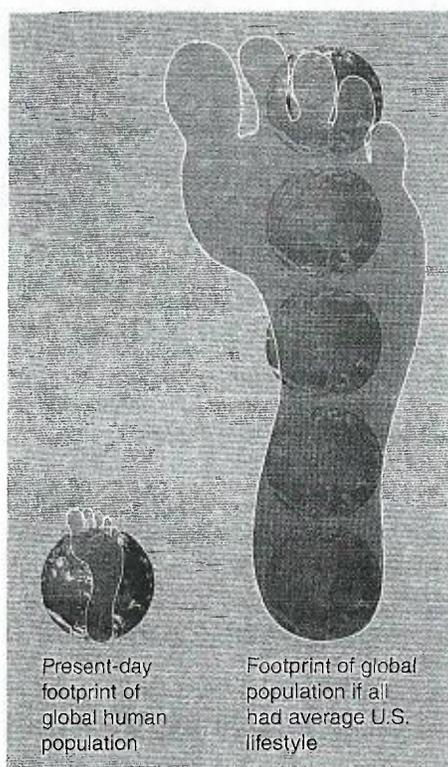
According to Wackernagel and Rees, if we are to sustain human life, we must ensure that our total consumption leads to an ecological footprint of no more than 11 billion hectares (27.2 billion acres). This number will need to be significantly less if we wish to preserve land for species other than humans. In order to achieve this goal, humans will have some important choices to make.



**FIGURE 1.14** The ecological footprint. An individual's ecological footprint is a measure of how much land is needed to supply the goods and services that individual uses. Only some of the many factors that go into the calculation of the footprint are shown here. (The actual amount of land used for each resource is not drawn to scale.)

#### CHECKPOINT

- ✓ What is meant by basic human needs?
- ✓ What does it mean to live sustainably?
- ✓ What does an ecological footprint tell us? Why is it important to calculate?



**FIGURE 1.15** The human footprint. If all people worldwide lived the lifestyle of the average U.S. citizen, the human population would need five Earths to support its resource use.

## Science is a process

In the past century humans have learned a lot about the impact of their activities on the natural world. Scientific inquiry has provided great insights into the challenges we are facing and has suggested ways to address those challenges. For example, a hundred years ago, we did not know how significantly or rapidly we could alter the chemistry of the atmosphere by burning fossil fuels. Nor did we understand the effects of many common materials, such as lead and mercury, on human health. Much of our knowledge comes from the work of researchers who study a particular problem or situation to understand why it occurs and how we can fix or prevent it. We will now look at the process scientists use to ask and answer questions about the environment.

### The Scientific Method

To investigate the natural world, scientists like JoAnn Burkholder and her colleagues, who examined the large-scale fish kill in the Neuse River, have to be as objective and methodical as possible. They must conduct their research in such a way that other researchers can understand how their data were collected and agree on the validity of their findings. To do this, scientists

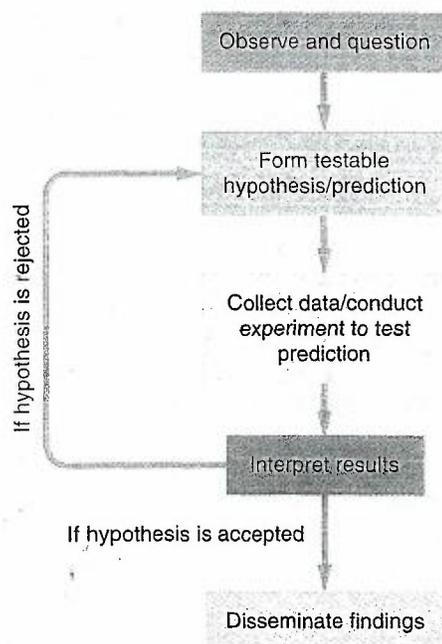
follow a process known as the *scientific method*. The **scientific method** is an objective way to explore the natural world, draw inferences from it, and predict the outcome of certain events, processes, or changes. It is used in some form by scientists in all parts of the world and is a generally accepted way to conduct science.

As we can see in **FIGURE 1.16**, the scientific method has a number of steps, including *observations and questions, forming hypotheses, collecting data, interpreting results, and disseminating findings*.

**OBSERVATIONS AND QUESTIONS** JoAnn Burkholder and her team observed a mass die-off of fish in the Neuse River and wanted to know why it happened. Such observing and questioning is where the process of scientific research begins.

**FORMING HYPOTHESES** Observation and questioning lead a scientist to formulate a *hypothesis*. A **hypothesis** is a *testable* conjecture about how something works. It may be an idea, a proposition, a possible mechanism of interaction, or a statement about an effect. For example, we might hypothesize that when the air temperature rises, certain plant species will be more likely, and others less likely, to persist.

What makes a hypothesis testable? We can test the idea about the relationship between air temperature and plant species by growing plants in a greenhouse at different temperatures. “Fish kills are caused by something



**FIGURE 1.16** The scientific method has a number of steps. In an actual investigation, a researcher might reject a hypothesis and investigate further with a new hypothesis, several times if necessary, depending on the results of the experiment.

in the water” is a testable hypothesis: it speculates that there is an interaction between something in the water and the observed dead fish.

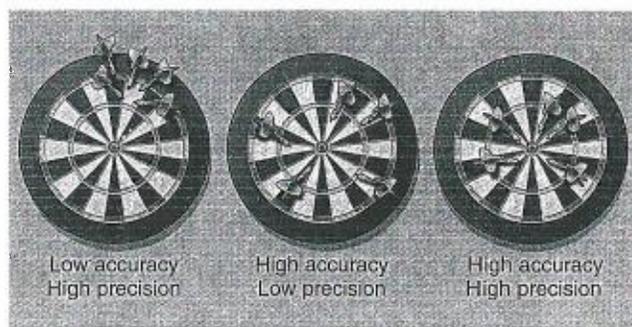
Sometimes it is easier to prove something wrong than to prove it is true beyond doubt. In this case, scientists use a *null hypothesis*. A **null hypothesis** is a statement or idea that can be falsified, or proved wrong. The statement “Fish deaths have no relationship to something in the water” is an example of a null hypothesis.

**COLLECTING DATA** Scientists typically take several sets of measurements—a procedure called **replication**. The number of times a measurement is replicated is the **sample size** (sometimes referred to as  $n$ ). A sample size that is too small can cause misleading results. For example, if a scientist chose three men out of a crowd at random and found that they all had size 10 shoes, she might conclude that all men have a shoe size of 10. If, however, she chose a larger sample size—100 men—it is very unlikely that all 100 individuals would happen to have the same shoe size.

Proper procedures yield results that are accurate and precise. They also help us determine the possible relationship between our measurements or calculations and the true value. **Accuracy** refers to how close a measured value is to the actual or true value. For example, an environmental scientist might estimate how many songbirds of a particular species there are in an area of 1,000 ha by randomly sampling 10 ha and then projecting or extrapolating the result up to 1,000 ha. If the extrapolation is close to the true value, it is an accurate extrapolation. **Precision** is how close to one another the repeated measurements of the same sample are. In the same example, if the scientist counted birds five times on five different days and obtained five results that were similar to one another, the estimates would be precise. **Uncertainty** is an estimate of how much a measured or calculated value differs from a true value. In some cases, it represents the likelihood that additional repeated measurements will fall within a certain range. Looking at **FIGURE 1.17**, we see that high accuracy and high precision is the most desirable result.

**INTERPRETING RESULTS** We have followed the steps in the scientific method from making observations and asking questions, to forming a hypothesis, to collecting data. What happens next? Once results have been obtained, analysis of data begins. A scientist may use a variety of techniques to assist with data analysis, including summaries, graphs, charts, and diagrams.

As data analysis proceeds, scientists begin to interpret their results. This process normally involves two types of reasoning: *inductive* and *deductive*. **Inductive reasoning** is the process of making general statements from specific facts or examples. If the scientist who sampled a songbird species in the preceding example



**FIGURE 1.17 Accuracy and precision.** Accuracy refers to how close a measured value is to the actual or true value. Precision is how close repeated measurements of the same sample are to one another.

made a statement about all birds of that species, she would be using inductive reasoning. It might be reasonable to make such a statement if the songbirds that she sampled were representative of the whole population. **Deductive reasoning** is the process of applying a general statement to specific facts or situations. For example, if we know that, in general, air pollution kills trees, and we see a single, dead tree, we may attribute that death to air pollution. But a conclusion based on a single tree might be incorrect, since the tree could have been killed by something else, such as a parasite or fungus. Without additional observations or measurements, and possibly experimentation, the observer would have no way of knowing the cause of death with any degree of certainty.

The most careful scientists always maintain multiple working hypotheses; that is, they entertain many possible explanations for their results. They accept or reject certain hypotheses based on what the data show and do not show. Eventually, they determine that certain explanations are the most likely, and they begin to generate conclusions based on their results.

**DISSEMINATING FINDINGS** A hypothesis is never confirmed by a single experiment. That is why scientists not only repeat their experiments themselves, but also present papers at conferences and publish the results of their investigations. This dissemination of scientific findings allows other scientists to repeat the original experiment and verify or challenge the results. The process of science involves ongoing discussion among scientists, who frequently disagree about hypotheses, experimental conditions, results, and the interpretation of results. Two investigators may even obtain different results from similar measurements and experiments, as happened in the *Pfiesteria* case. Only when the same results are obtained over and over by different investigators can we begin to trust that those results are valid. In the meantime, the disagreements and discussion about contradictory findings are a valuable part of the scien-

tific process. They help scientists refine their research to arrive at more consistent, reliable conclusions.

Like any scientist, you should always read reports of “exciting new findings” with a critical eye. Question the source of the information, consider the methods or processes that were used to obtain the information, and draw your own conclusions. This process, essential to all scientific endeavor, is known as **critical thinking**.

A hypothesis that has been repeatedly tested and confirmed by multiple groups of researchers and has reached wide acceptance becomes a **theory**. Current theories about how plant species distributions change with air temperature, for example, are derived from decades of research and evidence. Notice that this sense of *theory* is different from the way we might use the term in everyday conversation (“But that’s just a theory!”). To be considered a theory, a hypothesis must be consistent with a large body of experimental results. A theory can not be contradicted by any replicable tests.

Scientists work under the assumption that the world operates according to fixed, knowable laws. We accept this assumption because it has been successful in explaining a vast array of natural phenomena and continues to lead to new discoveries. When the scientific process has generated a theory that has been tested multiple times, we can call that theory a *natural law*. A **natural law** is a theory to which there are no known exceptions and which has withstood rigorous testing. Familiar examples include the law of gravity and the laws of thermodynamics, which we will look at in the next chapter. These theories are accepted as fact by the scientific community, but they remain subject to revision if contradictory data are found.

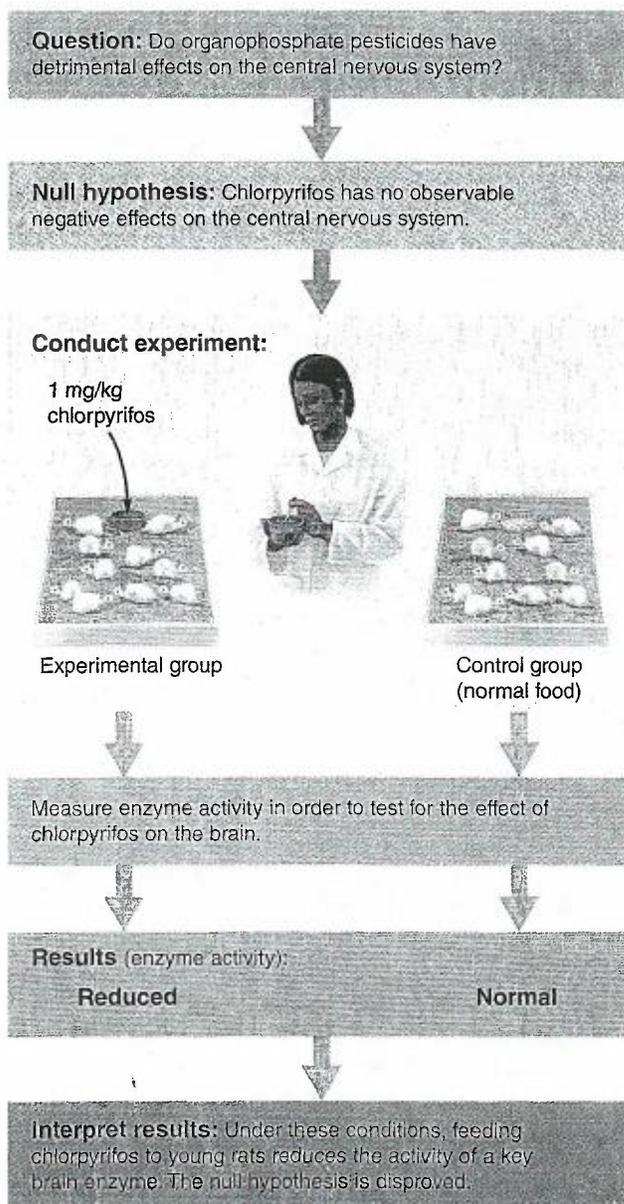
### Case Study: The Chlorpyrifos Investigation

Let’s look at what we have learned about the scientific method in the context of an actual scientific investigation. In the 1990s, scientists suspected that organophosphates—a group of chemicals commonly used in insecticides—might have serious effects on the human central nervous system. By the early part of the decade, scientists suspected that organophosphates might be linked to such problems as neurological disorders, birth defects, ADHD, and palsy. One of these chemicals, chlorpyrifos (klor-PEER-i-fos), was of particular concern because it is among the most widely used pesticides in the world, with large amounts applied in homes in the United States and elsewhere.

The researchers investigating the effects of chlorpyrifos on human health formulated a hypothesis: *chlorpyrifos causes neurological disorders and negatively affects human health*. Because this hypothesis would be hard to prove conclusively, the researchers also proposed a null hypothesis: *chlorpyrifos has no observable negative effects on the central*

*nervous system*. We can follow the process of their investigation in **FIGURE 1.18**.

To test the null hypothesis, the scientists designed experiments using rats. One experiment used two groups of rats, with 10 individuals per group. The first group—the *experimental group*—was fed small doses of chlorpyrifos for each of the first 4 days of life. No chlorpyrifos was fed to the second group. That second group was a **control group**: a group that experiences exactly the same conditions as the experimental group, except for the single variable under study. In this experiment, the only difference between the control group and the



**FIGURE 1.18** A typical experimental process. An investigation of the effects of chlorpyrifos on the central nervous system illustrates how the scientific method is used.

experimental group was that the control group was not fed any chlorpyrifos. By designating a control group, scientists can determine whether an observed effect is the result of the experimental treatment or of something else in the environment to which all the subjects are exposed. For example, if the control rats—those that were not fed chlorpyrifos—and the experimental rats—that were exposed to chlorpyrifos—showed no differences in their brain chemistry, researchers could conclude that the chlorpyrifos had no effect. If the control group and experimental group had very different brain chemistry after the experiment, the scientists could conclude that the difference must have been due to the chlorpyrifos. At the end of the experiment, the researchers found that the rats exposed to chlorpyrifos had much lower levels of the enzyme choline acetyltransferase in their brains than the rats in the control group. But without a control group for comparison, the researchers would never have known whether the chlorpyrifos or something else caused the change observed in the experimental group.

The discovery of the relationship between ingesting chlorpyrifos and a single change in brain chemistry might seem relatively small. But that is how most scientific research works: very small steps establish that an effect occurs and, eventually, how it occurs. In this way, we progress toward a more thorough understanding of how the world works. This particular research on chlorpyrifos, combined with numerous other experiments testing specific aspects of the chemical's effect on rat brains, demonstrated that chlorpyrifos was capable of damaging developing rat brains at fairly low doses. The results of this research have been important for our understanding of human health and toxic substances in the environment.

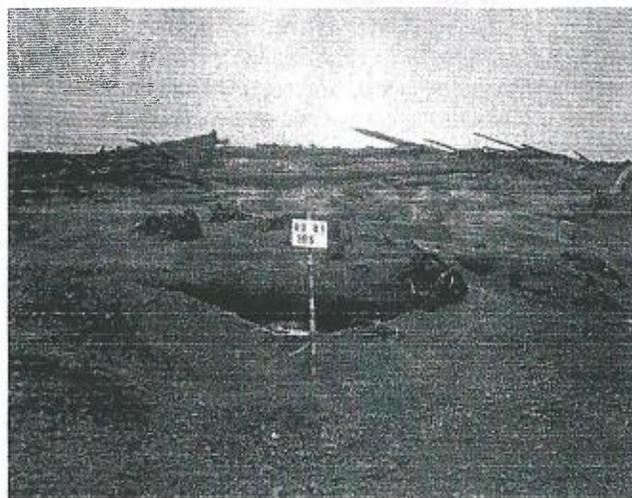
## Controlled Experiments and Natural Experiments

The chlorpyrifos experiment we have just described was conducted in the controlled conditions of a laboratory. However, not all experiments can be done under such controlled conditions. For example, it would be difficult to study the interactions of wolves and caribou in a controlled setting because both species need large amounts of land and because their behavior changes in captivity. Other reasons that a controlled laboratory experiment may not be possible include prohibitive costs and ethical concerns.

Under these circumstances, investigators look for a *natural experiment*. A **natural experiment** occurs when a natural event acts as an experimental treatment in an ecosystem. For example, a volcano that destroys thousands of hectares of forest provides a natural experiment for understanding large-scale forest regrowth (FIGURE 1.19). We would never destroy that much forest just to study regrowth, but we can study such natural disasters



(a)



(b)



(c)

**FIGURE 1.19** A natural experiment. The Mount St. Helens eruption in 1980 created a natural experiment for understanding large-scale forest regrowth. (a) A pre-eruption forest near Mount St. Helens in 1979; (b) the same location, post-eruption, in 1982; (c) the same location in 2009 begins to show forest regrowth.

when they occur. Still other cases of natural experiments do not involve disasters. For example, we can study the process of ecological succession by looking at areas where forests have been growing for different amounts of time and comparing them. We can study the effects of species invasions by comparing uninvaded ecosystems with invaded ones.

Because a natural experiment is not controlled, many variables can change at once, and results can be difficult to interpret. Ideally, researchers compare multiple examples of similar systems in order to exclude the influences of different variables. For example, after a forest fire, researchers might not only observe how a burned forest responds to the disturbance, but also compare it with a nearby forest that did not burn. In this case, the researchers are comparing similar forests that differ in only one variable: fire. If, however, they tried to compare the burned forest with a different type of forest, perhaps one at a different elevation, it would be difficult to separate the effects of the fire from the effects of elevation. Still, because they may be the only way to obtain vital information, natural experiments are indispensable.

Returning to the study of chlorpyrifos, researchers wanted to know if human brains that were exposed to the chemical would react in the same way as rat brains. For obvious ethical reasons, researchers would never feed pesticides to humans to study their effects. Instead, they conducted a natural experiment. They looked for groups of people in similar circumstances (income, age, level of education) that varied mostly in their exposure to chlorpyrifos. That variation came from their use of pesticides containing chlorpyrifos, the frequency and location of that use, and the brand used. Researchers found that tissue concentrations of chlorpyrifos were highest in groups that worked with the chemical and among poor urban families whose exposure to residential pesticides was high. Among these populations, a number of studies connected exposure to chlorpyrifos with low birth weight and other developmental abnormalities.

## Science and Progress

The chlorpyrifos experiment is a good example of the process of science. Based on observations, the scientists proposed a hypothesis and null hypothesis. The null hypothesis was tested and rejected. Multiple rounds of additional testing gave researchers confidence in their understanding of the problem. Moreover, as the research progressed, the scientists informed the public, as well as the scientific community, about their results. Finally, in 2000, as a result of the step-by-step scientific investigation of chlorpyrifos, the U.S. Environmental Protection Agency (EPA) decided to prohibit its use for most residential applications. It also prohibited agricultural use on fruits that are eaten without peeling, such as apples and pears, or those that are especially popular with children, such as grapes.

### CHECKPOINT

- ✓ What is the scientific method, and how do scientists use it to address environmental problems?
- ✓ What is a hypothesis? What is a null hypothesis?
- ✓ How are controlled and natural experiments different? Why do we need each type?

## Environmental science presents unique challenges

Environmental science has many things in common with other scientific disciplines. However, it presents a number of challenges and limitations that are not usually found in most other scientific fields. These challenges and limitations are a result of the nature of environmental science and the way research in the field is conducted.

### Lack of Baseline Data

The greatest challenge to environmental science is the fact that there is no undisturbed baseline—no “control planet”—with which to compare the contemporary Earth. Virtually every part of the globe has been altered by humans in some way (FIGURE 1.20). Even though some remote regions appear to be undisturbed, we can still find quantities of lead in the Greenland ice sheet, traces of the anthropogenic compound PCB in the fatty tissue of penguins in Antarctica, and invasive species from many locations carried by ship to remote tropical



**FIGURE 1.20** Human impacts are global. The trash washed up onto the beach of this remote Pacific island vividly demonstrates the difficulty of finding any part of Earth unaffected by human activities.

islands. This situation makes it difficult to know the original levels of contaminants or numbers of species that existed before humans began to alter the planet. Consequently, we can only speculate about how the current conditions deviate from those of pre-human activity.

## Subjectivity

A second challenge unique to environmental science lies in the dilemmas raised by subjectivity. For example, when you go to the grocery store, the bagger may ask, "Paper or plastic?" How can we know for certain which type of bag has the least environmental impact? There are techniques for determining what harm may come from using the petrochemical benzene to make a plastic bag and from using chlorine to make a paper bag. However, different substances tend to affect the environment differently: benzene may pose more of a risk to people, whereas chlorine may pose a greater risk to organisms in a stream. It is difficult, if not impossible, to decide which is better or worse for the environment overall. There is no single measure of environmental quality. Ultimately, our assessments and our choices involve value judgments and personal opinions.

## Interactions

A third challenge is the complexity of natural and human-dominated systems. All scientific fields examine interacting systems, but those systems are rarely as complex and as intertwined as they are in environmental science. Because environmental systems have so many interacting parts, the results of a study of one system cannot always be easily applied to similar systems elsewhere.

There are also many examples in which human preferences and behaviors have as much of an effect on environmental systems as the natural laws that describe them. For example, many people assume that if we built more efficient automobiles, the overall consumption of gasoline in the United States would decrease. To decrease gas consumption, however, it is necessary not only to build more efficient automobiles, but also to get people to purchase those vehicles and use them in place of less efficient ones. During the 1990s and early 2000s, even though there were many fuel-efficient cars available, the majority of buyers in the United States continued to purchase larger, heavier, and less fuel-efficient cars, minivans, light trucks, and sport-utility vehicles. Environmental scientists thought they knew how to reduce gasoline consumption, but they neglected to account for consumer behavior. Science is the search for natural laws that govern the world around us, whereas environmental science may involve politics, law, and economics as well as the traditional natural sciences. This complexity often makes environmental science challenging and its findings the subject of vigorous and lively debate.

## Human Well-Being

As we continue our study of environmental science, we will see that many of its topics touch on human well-being. In environmental science, we study how humans impact the biological systems and natural resources of the planet. We also study how changes in natural systems and the supply of natural resources affect humans.

We know that people who are unable to meet their basic needs are less likely to be interested in or able to be concerned about the state of the natural environment. The principle of *environmental equity*—the fair distribution of Earth's resources—adds a moral issue to questions raised by environmental science. Pollution and environmental degradation are inequitably distributed, with the poor receiving much more than an equal share. Is this a situation that we, as fellow humans, can tolerate? The ecological footprint and other environmental indicators show that it would be unsustainable for all people on the planet to live like the typical North American. But as more and more people develop an ability to improve their living conditions, how do we think about apportioning limited resources? Who has the right and the responsibility to make such decisions? **Environmental justice** is a social movement and field of study that works toward equal enforcement of environmental laws and the elimination of disparities, whether intended or unintended, in how pollutants and other environmental harms are distributed among the various ethnic and socioeconomic groups within a society (FIGURE 1.21).

Our society faces many environmental challenges. The loss of biodiversity, the growing human demand for



**FIGURE 1.21** A village on the outskirts of New Delhi, India. The poor are exposed to a disproportionate amount of pollutants and other hazards. The people shown here are recycling circuit boards from discarded electronics products.

resources, and climate change are all complex problems. To solve them, we will need to apply thoughtful analysis, scientific innovation, and strategies that consider human behavior. Around the globe today, we can find people who are changing the way their governments work, changing the way they do business, and changing the way they live their lives, all with a common goal: they are working toward sustainability. Here, and at the end of each chapter of this book, we will tell a few of their stories.

#### CHECKPOINT

- ✓ In what ways is environmental science different from other sciences?
- ✓ Why (or when) is the lack of baseline data a problem in environmental science?
- ✓ What makes environmental systems so complex?



## WORKING TOWARD SUSTAINABILITY

**W**e have seen that environmental indicators can be used to monitor conditions across a range of scales, from local to global. They are also being used by people looking for ways to apply environmental science to the urban planning process in countries as diverse as China, Brazil, and the United States.

San Francisco, California, is one example. In 1997, the city adopted a sustainability plan to go along with its newly formed Department of the Environment. The San Francisco Sustainability Plan focuses on 10 environmental concerns:

- Air quality
- Biodiversity
- Energy, climate change, and ozone depletion
- Food and agriculture
- Hazardous materials
- Human health
- Parks, open spaces, and streetscapes
- Solid waste
- Transportation
- Water and wastewater

Although some of these topics may not seem like components of urban planning, the drafters of the plan recognized that the everyday choices of city dwellers can have wide-ranging environmental impacts, both in and beyond the city. For example, purchasing local produce or organic food affects the environments and economies of both San Francisco and the agricultural areas that serve it.

For each of the 10 environmental concerns, the sustainability plan sets out a series of 5-year and long-term

### Using Environmental Indicators to Make a Better City

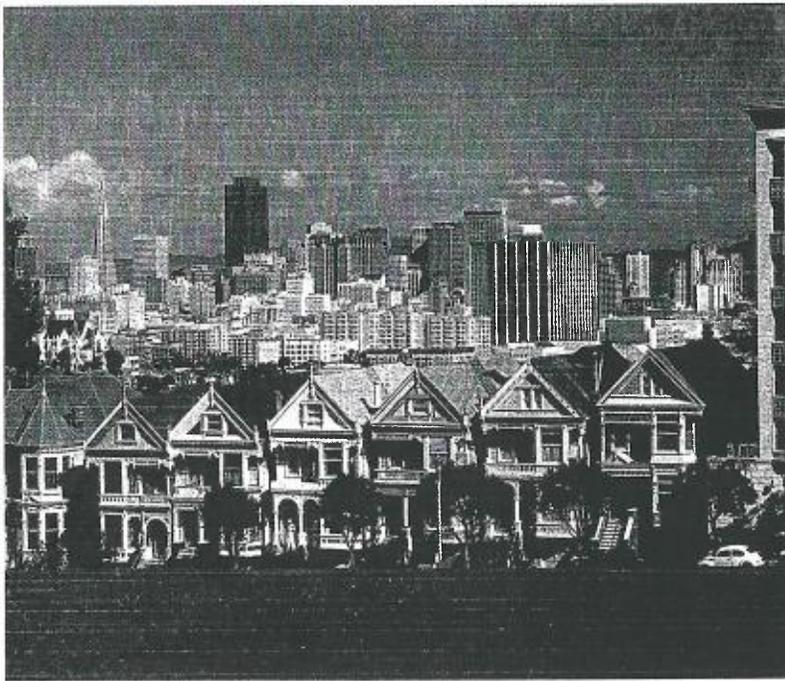
objectives as well as specific actions required to achieve them. These actions include public education through information sources such as Web sites and newsletters and hands-on activities such as replacing non-native plants with native trees and shrubs.

To monitor the effectiveness of the various actions, San Francisco chose specific environmental indicators for each of the 10 environmental concerns. These indicators had to indicate a clear trend toward or away from environmental sustainability, demonstrate cost-effectiveness, be understandable to the nonscientist, and be easily presented to the media. For example, to evaluate biodiversity, San Francisco uses four indicators:

Environmental indicator	Desired trend
Number of volunteer hours dedicated to managing, monitoring, and conserving San Francisco's biodiversity	INCREASING
Number of square feet of the worst non-native species removed from natural areas	INCREASING
Number of surviving native plant species planted in developed parks, private landscapes, and natural areas	INCREASING
Abundance and species diversity of birds, as indicated by the Golden Gate Audubon Society's Christmas bird counts	INCREASING

Together, these indicators provide a relatively inexpensive and simple way to summarize the level of biodiversity, the threat to native biodiversity from non-native species, and the amount of effort going into biodiversity protection.

More than 13 years later, what do the indicators show? In general, there has been a surprising amount of improvement. For example, in the category of solid waste, San Francisco has increased the amount of waste



**FIGURE 1.22** A “green” city. San Francisco’s adoption of environmental indicators has helped it achieve many of its sustainability goals.

recycled from 30 to 70 percent, with a goal of 75 percent by 2020, and it now has the largest urban composting program in the country. San Francisco has also improved its air quality, reducing the number of days in which fine particulate matter exceeded the EPA air quality safe level, from 27 days in 2000 to 10 days in 2006. These and other successes have won the city numerous accolades: it has been selected as one of “America’s Top Five Cleanest Cities” by *Reader’s Digest* and as one of the “Top 10 Green Cities” by *The Green Guide*. In 2005, San Francisco was named the most sustainable city in the United States by SustainLane (FIGURE 1.22).

**Reference**

[www.sustainlane.com](http://www.sustainlane.com).

**KEY IDEAS REVISITED**

- **Define the field of environmental science and discuss its importance.**

Environmental science is the study of the interactions among human-dominated systems and natural systems and how those interactions affect environments. Studying environmental science helps us identify, understand, and respond to anthropogenic changes.

- **Identify ways in which humans have altered and continue to alter our environment.**

The impact of humans on natural systems has been significant since early humans hunted some large animal species to extinction. However, technology and population growth have dramatically increased both the rate and the scale of human-induced change.

- **Describe key environmental indicators that help us evaluate the health of the planet.**

Five important global-scale environmental indicators are biological diversity, food production, average global surface temperature and atmospheric CO<sub>2</sub> concentrations, human population, and resource depletion.

- **Define sustainability and explain how it can be measured using the ecological footprint.**

Sustainability is the use of Earth’s resources to meet our current needs without jeopardizing the ability of future

generations to meet their own needs. The ecological footprint is the land area required to support a person’s (or a country’s) lifestyle. We can use that information to say something about how sustainable that lifestyle would be if it were adopted globally.

- **Explain the scientific method and its application to the study of environmental problems.**

The scientific method is a process of observation, hypothesis generation, data collection, analysis of results, and dissemination of findings. Repetition of measurements or experiments is critical if one is to determine the validity of findings. Hypotheses are tested and often modified before being accepted.

- **Describe some of the unique challenges and limitations of environmental science.**

We lack an undisturbed “control planet” with which to compare conditions on Earth today. Assessments and choices are often subjective because there is no single measure of environmental quality. Environmental systems are so complex that they are poorly understood, and human preferences and policies may have as much of an effect on them as natural laws.

## PREPARING FOR THE AP EXAM

### MULTIPLE-CHOICE QUESTIONS

- Which of the following events has increased the impact of humans on the environment?
  - Advances in technology
  - Reduced human population growth
  - Use of tools for hunting
  - I only
  - I and II only
  - II and III only
  - I and III only
  - I, II, and III
- As described in this chapter, environmental indicators
  - always tell us what is causing an environmental change.
  - can be used to analyze the health of natural systems.
  - are useful only when studying large-scale changes.
  - do not provide information regarding sustainability.
  - take into account only the living components of ecosystems.
- Which statement regarding a global environmental indicator is *not* correct?
  - Concentrations of atmospheric carbon dioxide have been rising quite steadily since the Industrial Revolution.
  - World grain production has increased fairly steadily since 1950, but worldwide production of grain per capita has decreased dramatically over the same period.
  - For the past 130 years, average global surface temperatures have shown an overall increase that seems likely to continue.
  - World population is expected to be between 8.1 billion and 9.6 billion by 2050.
  - Some natural resources are available in finite amounts and are consumed during a one-time use, whereas other finite resources can be used multiple times through recycling.
- Figure 1.8 (on page 10) shows atmospheric carbon dioxide concentrations over time. The measured concentration of CO<sub>2</sub> in the atmosphere is an example of
  - a sample of air from over the Antarctic.
  - an environmental indicator.
  - replicate sampling.
  - calculating an ecological footprint.
  - how to study seasonal variation in Earth's temperatures.
- In science, which of the following is the most certain?
  - Hypothesis
  - Idea
  - Natural law
  - Observation
  - Theory
- All of the following would be exclusively caused by anthropogenic activities *except*
  - combustion of fossil fuels.
  - overuse of resources such as uranium.
  - forest clearing for crops.
  - air pollution from burning oil.
  - forest fires.
- Use Figure 1.6 (on page 9) to calculate the approximate percentage change in world grain production per person between 1950 and 2000.
  - 10 percent
  - 20 percent
  - 30 percent
  - 40 percent
  - 50 percent
- The populations of some endangered animal species have stabilized or increased in numbers after human intervention. An example of a species that is still endangered and needs further assistance to recover is the
  - American bison.
  - peregrine falcon.
  - bald eagle.
  - American alligator.
  - snow leopard.

Questions 9 and 10 refer to the following experimental scenario:

An experiment was performed to determine the effect of caffeine on the pulse rate of five healthy 18-year-old males. Each was given 250 mL of a beverage with or without caffeine. The men had their pulse rates measured before they had the drink (time 0 minutes) and again after they had been sitting at rest for 30 minutes after consuming the drink. The results are shown in the following table.

Subject	Beverage	Caffeine content (mg/serving)	Pulse rate at time 0 minutes	Pulse rate at time 30 minutes
1	Water	0	60	59
2	Caffeine-free soda	0	55	56
3	Caffeinated soda	10	58	68
4	Coffee, decaffeinated	3	62	67
5	Coffee, regular	45	58	81

9. Before the researchers began the experiment, they formulated a null hypothesis. The best null hypothesis for the experiment would be that caffeine
- (a) has no observable effect on the pulse rate of an individual.
  - (b) will increase the pulse rates of all test subjects.
  - (c) will decrease the pulse rates of all test subjects.
  - (d) has no observable effects on the pulse rates of 18-year-old males.
  - (e) from a soda will have a greater effect on pulse rates than caffeine from coffee.
10. After analyzing the results of the experiment, the most appropriate conclusion would be that caffeine
- (a) increased the pulse rates of the 18-year-old males tested.
  - (b) decreased the pulse rates of the 18-year-old males tested.
  - (c) will increase the pulse rate of any individual that is tested.
  - (d) increases the pulse rate and is safe to consume.
  - (e) makes drinks better than decaffeinated beverages.

## FREE-RESPONSE QUESTIONS

1. Your neighbor has fertilized her lawn. Several weeks later, she is alarmed to see that the surface of her ornamental pond, which sits at the bottom of the sloping lawn, is covered with a green layer of algae.
- (a) Suggest a feasible explanation for the algal bloom in the pond. (2 points)
  - (b) Design an experiment that would enable you to validate your explanation. (7 points) Include and label in your answer:
    - (i) a testable hypothesis. (2 points)
    - (ii) the variable that you will be testing. (1 point)
    - (iii) the data to be collected. (1 point)
    - (iv) a description of the experimental procedure. (2 points)
    - (v) a description of the results that would validate your hypothesis. (1 point)
  - (c) Based on the data from your experiment and your explanation of the problem, think of, and suggest, one action that your neighbor could take to help the pond recover. (1 point)
2. The study of environmental science sometimes involves examining the overuse of environmental resources.
- (a) Identify one general effect of overuse of an environmental resource. (3 points)
  - (b) For the effect you listed above, describe a more sustainable strategy for resource utilization. (3 points)
  - (c) Describe how the events from Easter Island can be indicative of environmental issues on Earth today. (4 points)