

Natural gas flares are visible at this fracking site in the Bakken Shale formation, North Dakota. *(Jim West/Alamy Stock Photo)*

Environmental Science: Studying the State of Our Earth

CHAPTER 1

MODULE 1 Environmental Science

MODULE 2 Environmental Indicators and Sustainability

MODULE 3 Scientific Method

CASE STUDY

Earthquakes, Leakage, and Wastewater: Modern-Day Consequences of Energy Production

The United States—like other developed countries—is highly dependent on **fossil fuels** such as coal, oil, and natural gas, which are derived from biological material that became fossilized millions of years ago. The use of these fossil fuels is the cause of many environmental problems including the release of pollutants into air and water and land degradation. Natural gas, also known as methane, is the least harmful producer of air pollution among the fossil fuels; it burns more completely and cleanly than coal or oil, and it contains fewer impurities.

Due to advances in technology, oil and mining companies have recently increased their reliance on *fracking*. **Fracking**, short for hydraulic fracturing, is a method of oil and gas extraction that uses high-pressure fluids to force open existing cracks in rocks deep underground. This technique allows extraction of natural gas from locations that were previously so difficult to reach that extraction was economically unfeasible. As a result, large quantities of natural gas are now available in the United States at a lower cost than before. And fracking has increased our reliance on a domestic energy source and created jobs. Roughly 40 percent of energy in the United States is used to generate electricity and from 1980 through 2000, 50 percent of that energy came from coal and only 15 percent came from natural gas. In 2017, as a result of greater natural gas availability and lower price due to fracking, 33 percent of electricity generated was from natural gas and only 30 percent from coal. Since coal emits more air pollutants—including carbon dioxide—than does natural gas, fracking and the increase in natural gas use for electricity generation initially appeared to be beneficial to the environment.

More and more studies have begun to suggest that significant quantities of natural gas escape as "leakage" during the fracking and gas extraction process.

However, reports gained attention both in the popular press and in scientific journals about the negative consequences of fracking. Large amounts of water are used in the fracking process, with millions of gallons of water taken out of local streams and rivers and pumped down or injected into each gas well. A portion of this water is later removed from the well and must be properly treated after use to avoid contaminating local water bodies.

A variety of chemicals are added to the fracking fluid to facilitate the release of natural gas. Mining companies are not required to publicly identify all of these chemicals. Environmental scientists and concerned citizens began to wonder if fracking was responsible for chemical contamination of underground water. Some drinking-water wells near fracking sites became contaminated with natural gas, and

Fossil fuel A fuel derived from biological material that became fossilized millions of years ago.

Fracking Hydraulic fracturing, a method of oil and gas extraction that uses high-pressure fluids to force open cracks in rocks deep underground.

homeowners and public health officials asked if fracking was the culprit. Water with high concentrations of natural gas can be flammable, and footage of flames shooting from kitchen faucets after someone ignited the water became popular on YouTube, in documentaries, and in feature films. However, it wasn't clear if fracking caused natural gas to contaminate well water or if some of these wells contained natural gas long before fracking began. Several reputable studies showed that drinking-water wells near some fracking sites were contaminated, with natural gas concentrations in the nearby wells being much higher than in more distant wells. In addition, there has been a higher frequency of earthquakes in the central and southwest United States and the U.S. Geological Survey, the primary government agency responsible for understanding and assessing earthquakes and other geological hazards, reported in 2016 that the injection of waste water from fracking is believed to be the primary cause. These issues need further study, which may take years.

In a direct connection to global climate change, more and more studies have begun to suggest that significant quantities of natural gas escape as "leakage" during the fracking and gas extraction process. It is not known how much of the natural gas extracted each year leaks into the atmosphere, but estimates range from 2 to10 percent. As we will learn in Chapter 19 methane is 25 times more efficient at trapping heat from Earth than carbon dioxide, the *greenhouse gas most* commonly produced by human activity. Due to its high heat trapping ability, the consequences of methane leakage are potentially substantial.

Almost certainly, using natural gas is better for the environment than using coal, though using less fossil fuel—or using no fossil fuel at all—would be even better. However, at present it is difficult to know whether the benefits of using natural gas outweigh the problems that extraction causes. Many years may pass before the extent and nature of harm from fracking is known.

The story of natural gas fracking provides a good introduction to the study of environmental science. It shows us that human activities that are initially perceived as causing little harm to the environment can in fact have adverse effects, and that we may not recognize these effects until we better understand the science surrounding the issue. It also illustrates the difficulty in obtaining absolute answers to questions about the environment and demonstrates that environmental science can be controversial. Finally, it shows us that making assessments and choosing appropriate actions in environmental science are not always as clear-cut as they first appear.

Sources: U.S. Geological Survey Induced Earthquakes Program. https://earthquake.usgs.gov/research/induced/,Drilling down. Multiple authors in 2011 and 2012. *New York Times*, http://www.nytimes.com/interactive/us/DRILLING_DOWN_SERIES.html.

The process of scientific inquiry builds on previous work and careful, sometimes lengthy, investigations. For example, we are still accumulating a body of knowledge on the effects of hydraulic fracturing of natural gas. Until we have this knowledge, we will not be able to make a fully informed decision about the policies of energy extraction. In the meantime, we may need to make interim decisions based on incomplete information. The urgency and lack of complete information are two particularly exciting aspects of environmental science.

To investigate topics such as the extraction and use of fossil fuels, environmental science relies on a number of indicators, methodologies, and tools. This chapter introduces you to the study of the environment and outlines some of the foundations and assumptions you will use throughout your study.

MODULE 1

Environmental Science

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

Learning Goals

After reading this module 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.

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 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 the study of **environmental science**, the discipline that examines interactions among human and natural science systems. By *system* we mean any set of interacting components that influence one another by exchanging energy, materials, or information. We have already seen that a change in one part of a system—for example, fracking in a particular geologic formation—can cause changes throughout the entire system, such as in a nearby well that supplies drinking water.

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 to even larger systems, such as the global climate system. Some environmental scientists are interested in regional problems. The case of fracking at a particular location in the United States, for example, is 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 with interacting components that include living, or **biotic**, components and nonliving, or **abiotic**, components.

As a student of environmental science, you should recognize that environmental science is different from **environmentalism**, which is a social movement that

Environment The sum of all the conditions surrounding us that influence life.

Environmental science The field of study that looks at interactions among human systems and those found in nature.

Ecosystem A particular location on Earth with interacting biotic and abiotic components.

Biotic Living.

Abiotic Nonliving.

Environmentalism A social movement that seeks to protect the environment through lobbying, activism, and education.

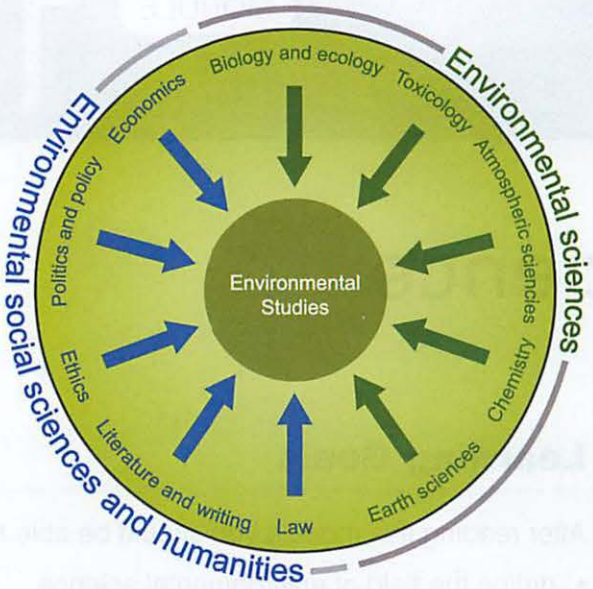


FIGURE 1.1 Environmental studies. The study of environmental science uses knowledge from many disciplines.

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 process of science 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. 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.

Environmental studies The field of study that includes environmental science and additional subjects such as environmental policy, economics, literature, and ethics.

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 factors interact with abiotic factors to influence the future of the forest. All of these factors are part of a system.

Systems can vary in size. A large system may contain many smaller systems within it. **FIGURE 1.2** shows an example of complex, interconnecting systems that operate at multiple space and time scales: the fisheries of the North Atlantic. A physiologist who wants to study how codfish survive in the North Atlantic's coldwaters must consider all the biological adaptations of the cod that enable it to be part of one system. In this case, the fish and its internal organs are the system being studied. In the same environment, a marine biologist might study the predator-prey relationship between cod and herring. That relationship constitutes another system, which includes two fish species and the environment they live in. At an even larger scale, a scientist might examine a system that includes all of these systems as well as people, fishing technology, policy, and law. The global environment is composed of both small-scale and large-scale systems.

Humans manipulate the systems in their environment more profoundly than any other species. We convert land from its natural state into urban, suburban, and agricultural areas. We change the chemistry of our air, water, and soil, both intentionally—for example, by adding fertilizers—and unintentionally—for example, by our activities that generate pollution. Even where we don't manipulate the environment directly, the simple fact that there are so many of us affects our surroundings.

Humans and our 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.

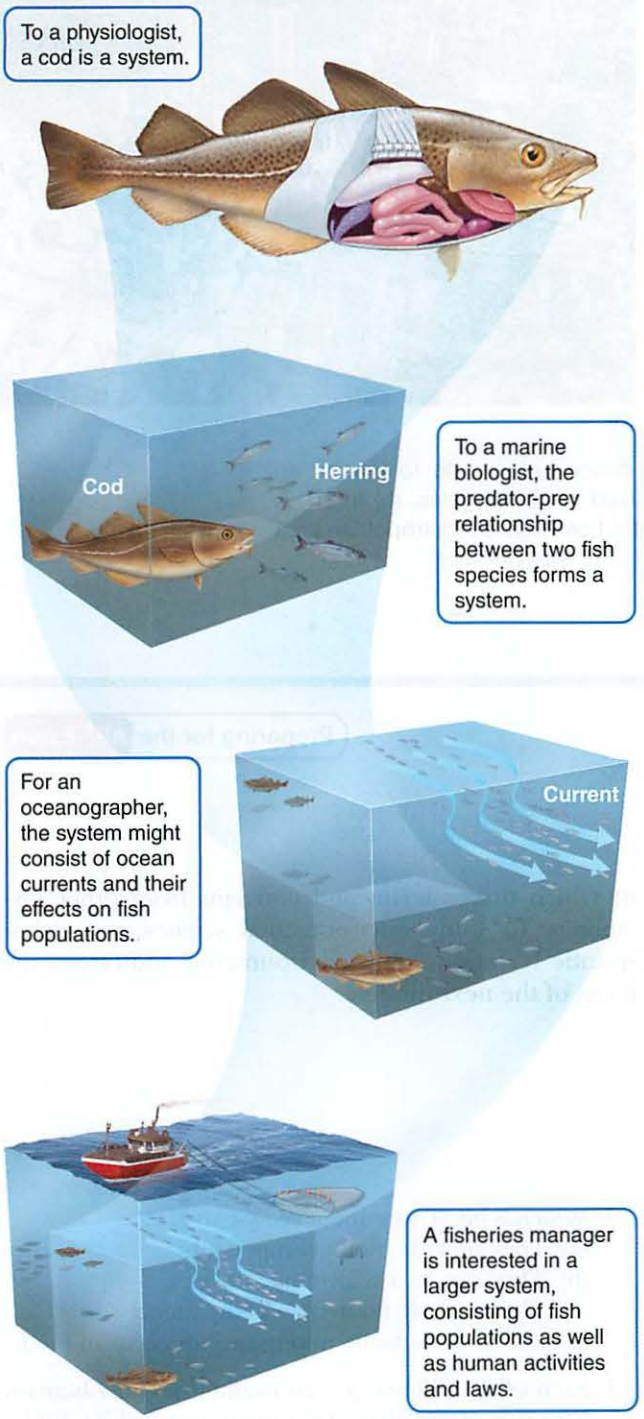


FIGURE 1.2 Systems within systems. The boundaries of an environmental system may be defined by the researcher's point of view. Physiologists, marine biologists, oceanographers, and fisheries managers would all describe the North Atlantic Ocean fisheries system differently.

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 and manipulation of the natural environment 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 substantially increased both the rate and the scale of our global environmental impact. 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. Because cities cover land that was once undisturbed by people, species that relied on the specific conditions of that land had to adapt or relocate, or they went 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 effects on the environment. But when roughly 4 million people live in a modern city like Los Angeles, their combined activity will cause environmental damage that will inevitably pollute the water, air, and soil as well as introduce other adverse consequences (**FIGURE 1.3** on page 6).



(a)



(b)

FIGURE 1.3 Human impact on Earth. 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 2017, Los Angeles had a population of 4 million people, and the greater Los Angeles metropolitan area was home to nearly 13 million people. *(a: The Granger Collection, New York; b: LA/AeroPhotos/Alamy)*

MODULE 1

Preparing for the AP® Exam

AP® Review

In this module we have seen that the study of environmental science helps us understand the role humans have played in the natural environment, and how that role has changed over time. There are specific approaches to the study of environmental science, some of which utilize terms and concepts from other disciplines. To study environmental science, we utilize specific techniques and environmental indicators, the focus of the next module.

AP® Practice Questions

Choose the best answer for the following.

1. Impacts of fracking include
   I. contamination of ground water.
   II. increased use of coal.
   III. lower natural gas prices.
   (a) I only
   (b) I and II
   (c) II and III
   (d) I and III

2. Which is an abiotic component?
   (a) an eagle
   (b) a rock
   (c) a tree
   (d) a human

3. Which is NOT true about ecosystems?
   (a) They include biotic components.
   (b) They can be a wide range of sizes.
   (c) They include no human components.
   (d) Many interactions among species occur in them.

4. Each of the following is an example of how humans have negatively affected the environment EXCEPT
   (a) hunting large mammals.
   (b) conversion of arid land to agricultural use.
   (c) the use of fire to create the Great Plains.
   (d) slash-and-burn forest clearing.

MODULE 2

Environmental Indicators and Sustainability

As we study the way humans have altered the natural world, it is important to have techniques for measuring and quantifying human impact. Environmental indicators allow us to assess the impact of humans on Earth. The use of these indicators helps us determine whether or not the quality of the natural environment is improving and informs discussions on the sustainability of humans on the planet.

Learning Goals

After reading this module you should be able to

- identify key environmental indicators and their trends over time.
- define sustainability and explain how it can be measured using the ecological footprint.

Environmental scientists use key environmental indicators to monitor natural systems for signs of stress

One critical question that environmental scientists investigate is whether the planet's natural life-support systems are being degraded by human-induced changes. Natural environments provide **ecosystem services**—the processes by which life-supporting resources such as clean water, timber, fisheries, and agricultural crops are produced. These are the resources necessary for organisms to survive, such as clean water and air, soil, woody plants, fisheries, and agricultural crops. Ecosystem services may benefit people directly, for example by providing the food that we eat. They may also benefit us indirectly, for example by providing a diversity of conditions, nutrients, and species, all of which make the ecosystem healthier for all organisms, including humans. Although we often take a healthy ecosystem for granted, we notice when an ecosystem is degraded or stressed because it is unable to provide the same services such as water purification or produce the same goods such as fruit or firewood.

To understand the extent of our effect on the environment, we need to be able to measure the health of Earth's ecosystems. 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 and the chapters in which they are covered are listed in TABLE 2.1 on page 8.

In this book we will focus on five global-scale environmental indicators:

- Biodiversity
- Food production
- Average global surface temperature and carbon dioxide concentrations in the atmosphere
- Human population
- Resource depletion

Throughout the text we will cover each of these five indicators in greater detail. Here we take a first look.

Ecosystem services The processes by which life-supporting resources such as clean water, timber, fisheries, and agricultural crops are produced.

Environmental indicator An indicator that describes the current state of an environmental system.

TABLE 2.1 Some common environmental indicators

Environmental indicator	Unit of measure	Chapter
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 extended	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 an infant born today can be expected to live under current conditions	7

Biodiversity

Biodiversity, a combination of the words "biological" and "diversity," is the diversity of life forms in an environment. It exists on three scales: ecosystem, species, and genetic, illustrated in **FIGURE 2.1**. Each level of biodiversity 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 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.

Biodiversity The diversity of life forms in an environment.

Genetic diversity A measure of the genetic variation among individuals in a population.

Species A group of organisms that is distinct from other groups in its morphology (body form and structure), behavior, or biochemical properties.

Species diversity The number of species in a region or in a particular ecosystem.

Species Diversity

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.

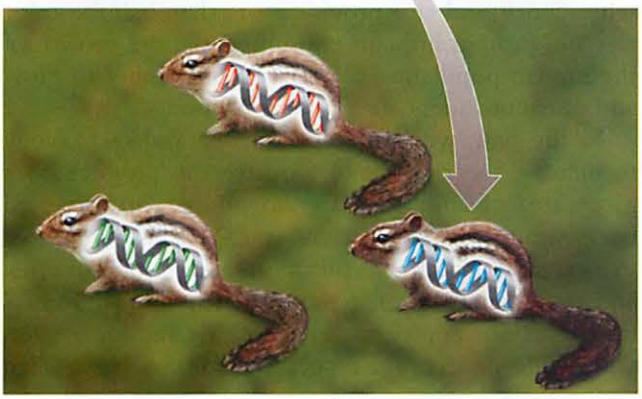
Species diversity indicates the number of species in a region or in a particular ecosystem. Scientists have observed that ecosystems with more species—that is, higher species diversity—are more productive and resilient—that is, better able to recover from disturbances



(a) Ecosystem diversity



(b) Species diversity



(c) Genetic diversity

FIGURE 2.1 Levels of biodiversity. Biodiversity exists at three scales. (a) Ecosystem diversity is the variety of ecosystems within a region. (b) Species diversity is the variety of species within an ecosystem. (c) Genetic diversity is the variety of genes among individuals of a species.

such as hurricanes or fires. For example, a tropical forest with a large number of plant species growing in the understory is likely to be more productive, and better able to withstand 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 ecosystems. 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 environmental problems on a larger scale. 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 is referred to as the **background extinction rate**. 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 2 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 1,000 species are currently going extinct each year—which is about 500 times the background rate of extinction. Destruction and degradation of the areas in which species live are the major causes of species extinction today, although climate change, overharvesting, and pressure from introduced species also contribute to species loss. In some situations, human pressures on the natural environment can lead to increased speciation. 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 tigris*), snow leopard (*Panthera uncia*), Siberian tiger (*Panthera tigris altaica*), and West Indian manatee (*Trichechus manatus*), remain endangered and may go extinct if present trends are not reversed (**FIGURE 2.2** on page 10). Overall, the number of species has been declining.

Ecosystem Diversity

Ecosystem diversity is a measure of the diversity of ecosystems that exist in a given region. A greater number of healthy and productive ecosystems means a healthier environment overall. As an environmental indicator, the current loss of biodiversity tells us that natural systems are facing strains unlike any in the recent past. We will look at this important topic in greater detail in Chapters 5 and 18.

Some measures of biodiversity are given in terms of land area, so becoming familiar with measurements of

Speciation The evolution of new species.

Background extinction rate The average rate at which species become extinct over the long term.



(a)



(b)

FIGURE 2.2 Species on the brink. Humans have saved some species from the brink of extinction, such as (a) the American bison. Other species, such as (b) the Siberian tiger remain endangered.
(a: David Osborn/Alamy Stock Photo, b: Jean-Louis Klein & Marie-Luce Hubert/Science Source)

land area is important to understanding them. A hectare (ha) is a unit of area used primarily in the measurement of land. It represents 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 hectares. "Do the Math: Converting Between Hectares and Acres" shows you how to do the conversion.

AP® Exam Tip

You are required to show all work for math problems on the AP® Environmental Science Exam. You will not get full credit for a correct answer unless you show each step, no matter how simple. Remember to include units. Develop the habit of showing your work from the beginning of the year. Start with the math practice in this chapter. ●

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 increased fairly steadily between 1950 and 2014 as a result of expanded irrigation, fertilization, new crop varieties, and other innovations. Since 2015, grain production has been approximately level. At the same time, worldwide production of grain *per person* has leveled

DO THE MATH **Converting Between Hectares and Acres** Preparing for the AP® Exam

In the metric system, land area is expressed in hectares. A hectare (ha) is 100 meters by 100 meters. In the United States, land area is most commonly expressed in acres. There are 2.47 acres in 1 ha. The conversion from hectares is relatively easy to do without a calculator; rounding to two significant figures gives us 2.5 acres in 1 ha. If a nature preserve is 100 ha, what is its size in acres?

$$100 \text{ ha} \times 2.5 \text{ acres} = 250 \text{ acres}$$

YOUR TURN A particular forest is 10,000 acres. Determine its size in hectares.

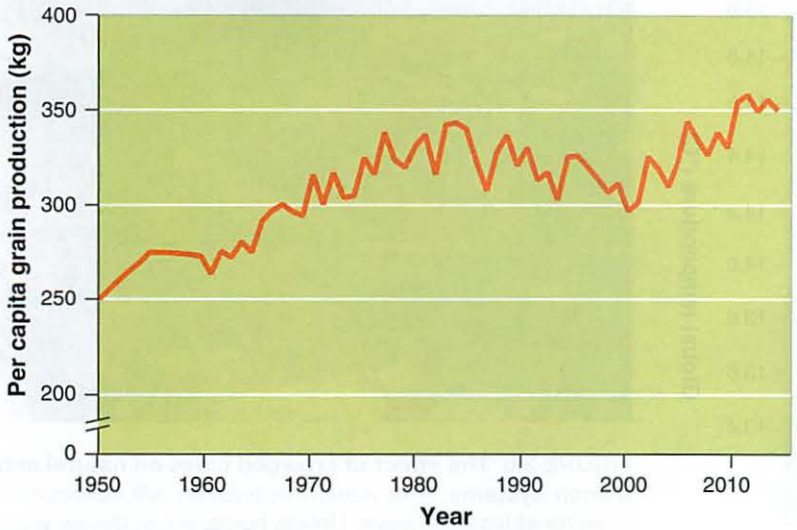


FIGURE 2.3 World grain production per person. Grain production has increased since the 1950s, but it has recently begun to level off. *(Data from: http://www.earth-policy.org/index.php?/indicators/C54)*

off as well. **FIGURE 2.3** shows the variation in per capita grain production through 2017.

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. Grain production may not be keeping up with population growth because in some areas the productivity of agricultural ecosystems has declined as a result of soil degradation, crop diseases, and unfavorable weather conditions such as drought or flooding. In addition, demand is outpacing supply. While the rate of human population growth has outpaced increases in food production, humans currently use more grain to feed livestock than they consume themselves. Finally, some government policies discourage food production by making it more profitable for 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 has 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. 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. "Working Toward Sustainability: Reducing Food Waste" on page 27 examines another approach to increasing the availability of food, by reducing the amount of food waste.

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 2.4** shows, our thick planetary atmosphere contains many gases. Some of these atmospheric gases, known as **greenhouse gases**, trap heat near Earth's surface. The gas that contributes most to warming of the atmosphere is carbon dioxide (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 2 centuries, however, the concentrations of CO_2 and other greenhouse gases in the atmosphere have risen. Today, atmospheric CO_2 concentrations are

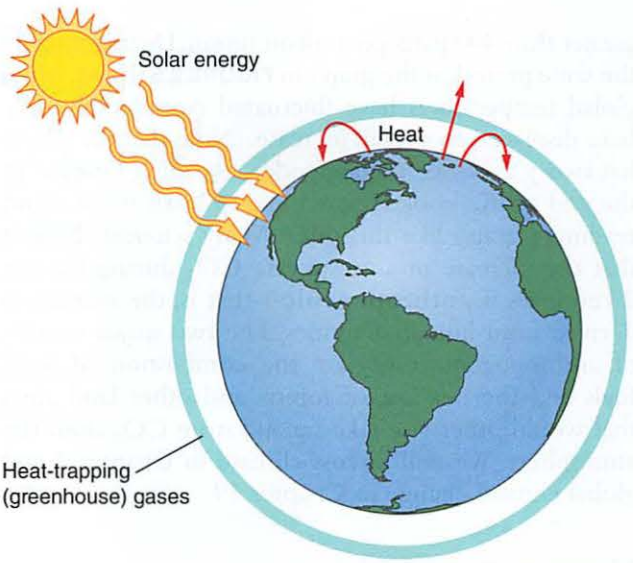


FIGURE 2.4 The Earth-surface energy balance. As Earth's surface is warmed by the Sun, it radiates heat outward. Heat-trapping gases absorb the outgoing heat and reradiate some of it back to Earth. Without these greenhouse gases, Earth would be much cooler.

Greenhouse gases Gases in Earth's atmosphere that trap heat near the surface.

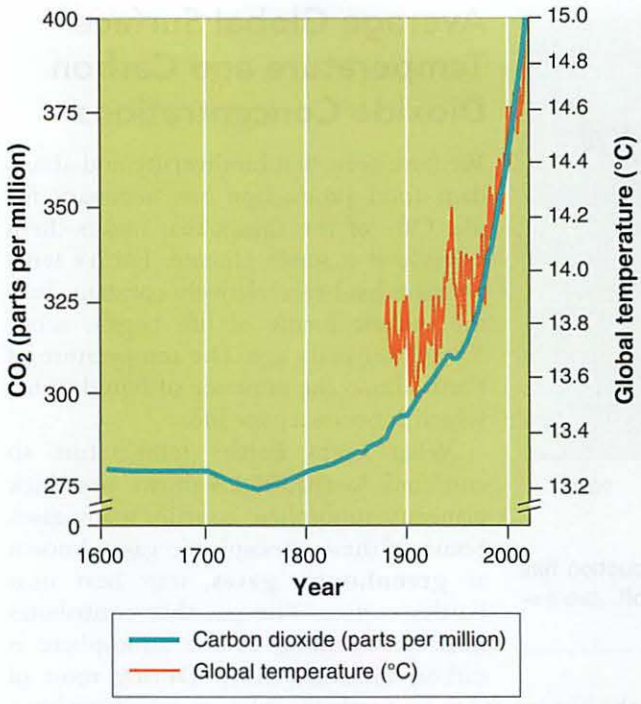


FIGURE 2.5 Changes in average global surface temperature and in atmospheric CO_2 concentrations. Earth's average global surface temperature has increased steadily for at least the past 100 years. Carbon dioxide concentrations in the atmosphere have varied over geologic time, but have risen steadily since 1960. *(Data from: http://data.giss.nasa.gov/gistemp/graphs_v3/and http://www.esrl.noaa.gov/gmd/ccgg/trends/#mlo_full)*

greater than 400 parts per million (ppm). During roughly the same period, as the graph in **FIGURE 2.5** shows, while global temperatures have fluctuated considerably, they have displayed an overall increase. (Note that this graph has two *y* axes. See the appendix "Reading Graphs" at the end of the book if you'd like to learn more about reading a graph like this one.) Many scientists believe that the increase in atmospheric CO_2 during the last 2 centuries is **anthropogenic**—that is, the increase is derived from human activities. The two major sources of anthropogenic CO_2 are the combustion of fossil fuels and the net loss of forests and other land areas that would otherwise take up and store CO_2 from the atmosphere. We will discuss climate in Chapter 4 and global climate change in Chapter 19.

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 7.6 billion and growing. The increasing world

Anthropogenic Derived from human activities.



FIGURE 2.6 The effect of crowded cities on natural and human systems. The human population will continue to grow for at least 50 years. Unless humans can devise ways to live more sustainably, these population increases will put additional strains on natural systems. Here, a street scene in Kolkata. *(Deshakalyan Chowdhury/AFP/Getty Images)*

population places additional demands on natural systems, since each new person requires food, water, and other resources. In any given 24-hour period, 380,000 infants are born and 155,000 people die. The net result is 225,000 new inhabitants on Earth each day, or over a million additional people every 5 days. Although the rate of population growth has been slowing since the 1960s, world population size will still continue to increase for at least another 50 to 100 years. Most population scientists project that the human population will be somewhere between 8 billion and 10 billion in 2050 and will stabilize between 7 billion and 11 billion by 2100.

Can the planet sustain so many people? 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 (**FIGURE 2.6**). 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 from 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,

DO THE MATH Rates of Forest Clearing

Preparing for the AP® Exam

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 Estimate 1 into hectares per year and Estimate 2 into hectares per day.

There are 2.47 acres per hectare. (See "Do the Math: Converting Between Hectares and Acres" on page 10.) Therefore, 1 acre = 0.40 ha.

Estimate 1: 1.0 acre/second × 0.40 ha/acre = 0.40 ha/second

0.40 ha/second × 60 seconds/minute × 60 minutes/hour × 24 hours/day × 365 days/year

= 12,614,400 ha cleared per year

Estimate 2: 80,000 acres/day × 0.40 ha/acre = 32,000 ha cleared per day

YOUR TURN Notice that Estimate 2, when converted to hectares, is identical to Estimate 3. Now convert the estimate of 32,000 ha/day into the amount cleared per year. How much larger is Estimate 1 than Estimate 2? Why might environmental organizations, or anyone else, choose to present similar information in different ways?

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 these resources are being used faster than they can be 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 **per capita** resource, which means the amount per each person in a country or other unit of population. Any quantity expressed "per capita" is the total quantity divided by the total number of people in the population unit being described, typically a country. The resulting value is the amount per each person.

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 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 a disproportionate share of the world's resources. **FIGURE 2.7** shows that the 17 percent of the global population that lives in developed nations

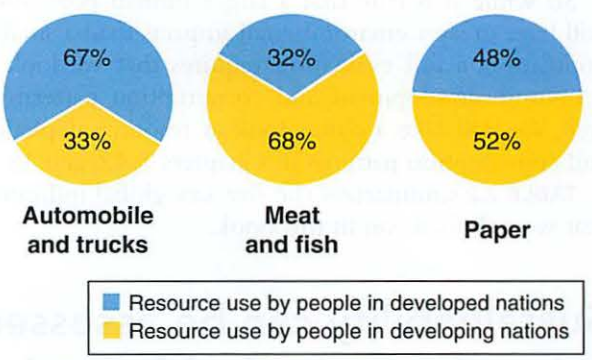


FIGURE 2.7 Fraction of resource use in developed and developing countries. Approximately 17 percent of the world's population lives in developed countries, but that 17 percent uses a disproportionate share of the world's resources. The remaining 83 percent of the population lives in developing countries and uses far fewer resources per capita. *(Data from http://www.oica.net/wp-content/uploads/total-inuse-2013.pdf; http://faostat.fao.org/site/610/DesktopDefault.aspx?PageID=610#ancor; http://www.paperonweb.com/Country.htm)*

Per capita Amount per each person in a country or unit of population.

Development Improvement in human well-being through economic advancement.

TABLE 2.2 Five key global indicators

Indicator	Recent trend	Outlook for the 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_2 concentration	CO_2 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 also a factor	Negative
Resource depletion	Many resources being depleted at rapid rate, but human ingenuity develops "new" resources, and efficiency of resource use is increasing in many cases	Unknown	Increased use of most resources has negative effects

owns 67 percent of the world's automobiles and consumes 32 percent of all meat and fish, and 48 percent of all paper. The poorest 20 percent of people in the world consume 5 percent or less of these resources. Thus, even though the number of people in the developing countries is much larger than the number in the developed countries, their total consumption of natural resources is smaller.

So while it is true that a larger human population will have greater environmental impacts than a smaller population, 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.

TABLE 2.2 summarizes the five key global indicators that we will focus on in this book.

Sustainability can be assessed using the ecological footprint

The five key environmental indicators that we have just discussed 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 people 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.

Sustainability Living on Earth in a way that allows humans to use its resources without depriving future generations of those resources.

The Impact of Consumption on the Environment

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 because there simply would not be enough people to do significant damage. Today, however, Earth's population is 7.6 billion people and growing.

There are numerous examples of human beings overexploiting forests, fisheries, and other resources. When humans initially settle an area, they typically increase in number in the hospitable environment. They cut down trees to build homes and other structures. Eventually they overuse soil and water resources and possibly fish and wildlife. Without trees to hold the soil in place, erosion can occur, and the loss of soil causes food production to decrease. The classic example of this type of overexploitation occurred on the Great Plains in the midwestern United States in the 1930s. Vast amounts of prairie land were converted to agricultural lands and that land was subject to subsequent droughts and strong winds. During this time, known as the Dust Bowl, dust storms across the entire Midwest carried away large quantities of soil.

Ultimately, consumption in the United States and in the world is related to the size of the human population. While people in some countries use more resources than those in other countries, the population has been growing since 1600. And resource use has grown since then as well. **FIGURE 2.8** shows world population change

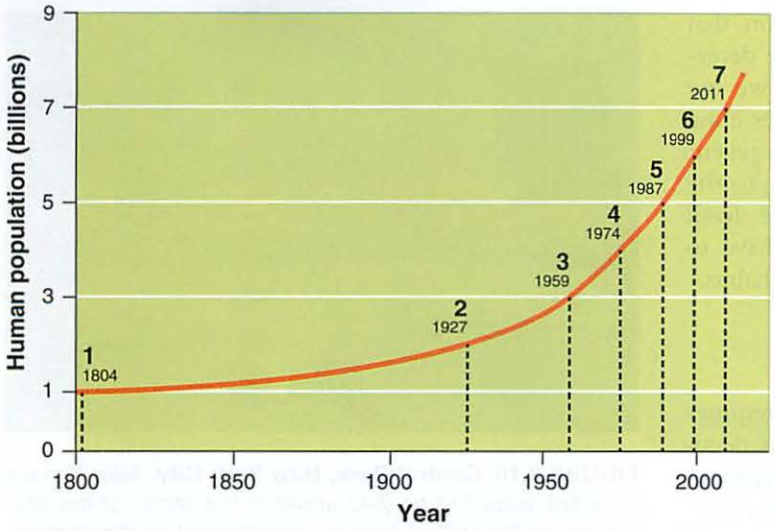


FIGURE 2.8 Adding 1 billion people. The number of years to add an additional billion people on Earth is shown since the first billion were added in 1800. It took 123 years to add 1 billion people from 1804 and only 12 years to add a billion people from 1999. *(Data from: http://www.un.org/esa/population/publications/sixbillion/sixbilpart1.pdf, http://www.pragcap.com/seven-billion-people/)*

since 1800. Each additional billion people on Earth are demanding and using resources, which clearly has an impact on the environment. 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? 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. They also believe there is 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 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 2.9**).

Consider iron, a nonrenewable resource derived from metal ore removed from the ground. Iron 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 increased demand, our current use of iron is unsustainable. What would happen if we ran out of iron? While not too long ago the depletion of iron ore might have been a catastrophe, 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 to increase sustainability.



FIGURE 2.9 Living sustainably. Sustainable choices such as bicycling to work or school can help protect the environment and conserve resources for future generations. *(Jim West/The Image Works)*

Sustainable development Development that balances current human well-being and economic advancement with resource management for the benefit of future generations.

The example of iron leads us to a question that environmental scientists often ask: How do we determine 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—indeed, cannot live without—electricity. In other parts of the world, however, people have never had these modern conveniences. So, when we speak of basic needs, we are referring only to the essentials that sustain human life, including air, water, food, health, 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, and so 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 2.10**).

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. Economic development can sometimes improve environmental conditions. For instance, wealthier countries may have the resources 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 have the financial resources to implement environmental protections.

Biophilia Love of life.

Ecological footprint A measure of how much an individual consumes, expressed in area of land.



FIGURE 2.10 Central Park, New York City. New Yorkers have set aside 341 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. *(Sylvain Sonnet /Getty Images)*

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 because we must consider the impacts of our activities and lifestyles on different aspects of our environment. We use land to grow food and to build structures on, and for parks and recreation. We require water for drinking, for cleaning, and for manufacturing products such as paper, and 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 E. 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. The output from the total amount of land required to support a person's lifestyle represents that person's ecological footprint as shown in **FIGURE 2.11**.

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 every 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. Other metrics for calculating our impact on Earth exist as well.

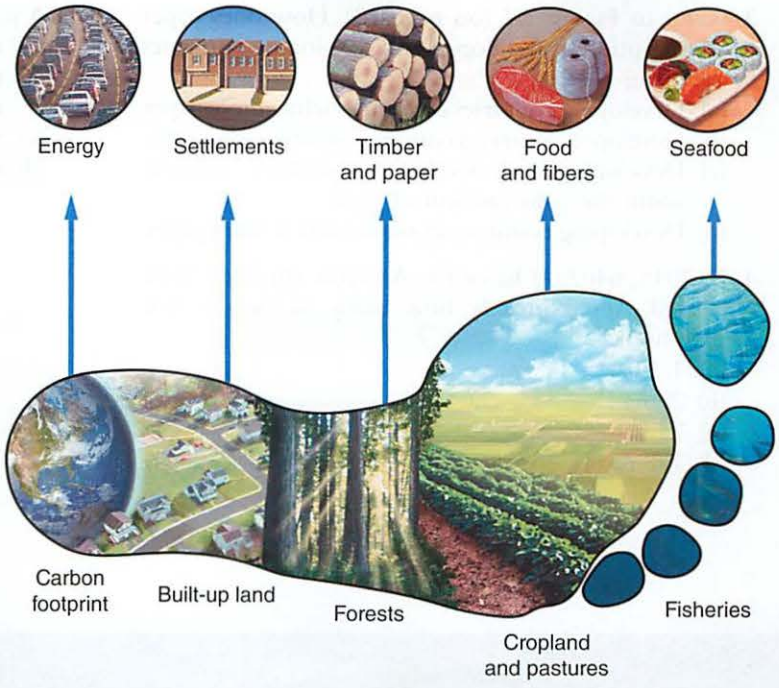


FIGURE 2.11 The ecological footprint. An individual's ecological footprint is a measure of how much land is needed to supply the goods and services that individual uses. Only some of the many factors that go into the calculation of the footprint are shown here. (The actual amount of land used for each resource is not drawn to scale.)

MODULE 2

AP® Review

Preparing for the AP® Exam

In this module we have identified global-scale indicators of environmental health that allow us to monitor specific parameters over time. Ultimately, these indicators contribute to a picture of the sustainability of human activities on Earth. We have identified that biodiversity is decreasing and that food production has leveled off. Atmospheric carbon dioxide concentrations are steadily increasing and global temperatures fluctuate, although the overall change is toward an increase. The human population continues to increase in size but the rate of increase has been declining. One measurement that allows us to assess the sustainability of these different parameters and how they change over time is the ecological footprint. The final module in this chapter introduces us to some of the scientific methods and techniques we will use in order to measure these indicators and make assessments about sustainability.

AP® Practice Questions

Choose the best answer for the following.

1. Common global-scale environmental indicators include all of the following EXCEPT
   (a) atmospheric carbon dioxide concentrations.
   (b) human population.
   (c) natural resource depletion.
   (d) pollution in a local stream.

2. How many hectares of land is a 500-acre park? (1 acre = 0.40 ha)
   (a) 200 ha
   (b) 250 ha
   (c) 500 ha
   (d) 750 ha

3. Refer to Figure 2.7 (on page 13). How does paper consumption in developed and developing countries compare?
   (a) Developing countries consume slightly more paper.
   (b) Developed countries consume slightly more paper.
   (c) Developing and developed countries consume about the same amount of paper.
   (d) Developing countries consume much more paper.
4. In 2015, 640,000 ha of the Amazon rainforest were cleared. Approximately how many hectares is that each hour?
   (a) 1.2 ha
   (b) 29 ha
   (c) 73 ha
   (d) 178 ha
5. A person's ecological footprint is
   (a) the land that a person lives on.
   (b) the amount of carbon dioxide a person contributes to climate change.
   (c) the land required to produce a person's food.
   (d) the land needed to support all of a person's activities.

MODULE 3

Scientific Method

Environmental indicators are important for understanding human impacts on Earth systems and the sustainability of those systems. In order to evaluate environmental indicators, we need to use reproducible scientific methods. An understanding of the *scientific method* is essential for environmental science.

Learning Goals

After reading this module you should be able to

- explain the scientific method and its application to the study of environmental problems.
- describe some of the unique challenges and limitations of environmental science.

The scientific method is an important process in environmental science

Humans during the past century 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 to determine how we can fix or prevent it from occurring. In this section we will look at the process scientists use to ask and answer questions about the environment.

The Scientific Method

To investigate the natural world, scientists, such as those who examined the effects of fracking as described at the beginning of this chapter, 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**, which is an objective way to explore the natural world, draw inferences from it, and predict the outcome of certain events, processes, or changes. The scientific method 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 3.1**, the scientific method has a number of steps, including observing and questioning, forming hypotheses, collecting data, interpreting results, and disseminating findings.

Observing and Questioning

In some areas where fracking occurred homeowners and scientists noticed that certain household wells contained high methane concentrations. They wanted to know whether fracking might be responsible. Such observing and questioning is where the process of scientific research begins.

Forming Hypotheses

Observing and generating questions 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 over time, certain plant species will be more likely to persist, and others will be less likely to persist.

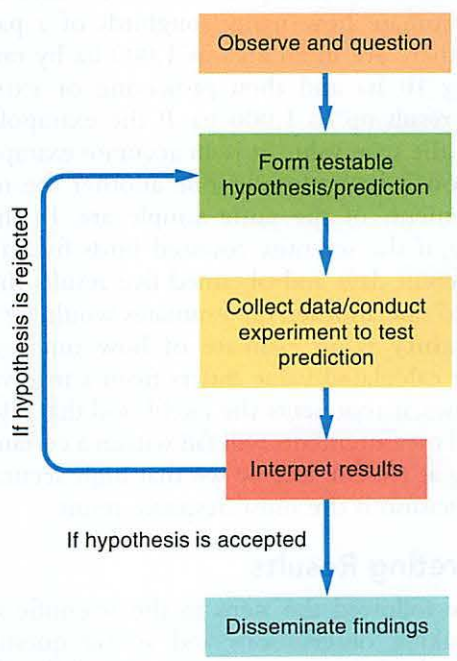


FIGURE 3.1 The scientific method. In an actual investigation, a researcher might reject a hypothesis and investigate further with a new hypothesis, several times if necessary, depending on the results of the experiment.

What makes a hypothesis testable? We can test the idea about the relationship between air temperature and plant species by conducting an experiment. In this case, that would require growing plants in a greenhouse at different temperatures. Consider this statement: "Fish kills are caused by something in the water." The statement is a testable hypothesis because it speculates that there is an interaction between something in the water and the observed dead fish. We can collect water from areas where fish have been found dead and identify harmful chemicals in the water. In a laboratory, we can add those harmful chemicals, one at a time, to fish tanks and determine which, if any, of the chemicals cause harm to fish. These are examples of testing hypotheses.

AP® Exam Tip

Make sure you understand the definition of a testable hypothesis and can give examples. ●

In each case, we are measuring **variables**, which are any categories, conditions, factors or traits that differ in various parts of the natural environment or experimental situation. An **independent variable** is one that is not dependent on factors. Age of an individual or elevation above sea level are examples of independent variables. A **dependent variable** is one that is influenced by other factors. Concentrations of a pollutant or number of deformities in a fish population are dependent variables.

It is almost always 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 prediction that there is no difference between the groups or treatments that are being compared. The statement "Fish deaths have no relationship to something in the water" is an example of a null hypothesis. Establishing absolute

Scientific method An objective method to explore the natural world, draw inferences from it, and predict the outcome of certain events, processes, or changes.

Hypothesis A testable conjecture about how something works.

Variable Any categories, conditions, factors, or traits that differ in the natural world or in experimental situations.

Independent variable A variable that is not dependent on other factors.

Dependent variable A variable that is dependent on other factors.

Null hypothesis A prediction that there is no difference between the groups or conditions that are being compared.

DO THE MATH Range of Electric Vehicles

Preparing for the AP® Exam

All-electric vehicles, which run on batteries only, are becoming more common. The range that a given vehicle can travel without being charged is a function of the efficiency of the vehicle and the storage capacity of the vehicle. The mileage ranges of five common electric vehicles are: 107 miles, 53 miles, 100 miles, 114 miles, and 237 miles. What is the average mileage range of these five electric vehicles? Round to the nearest whole number.

Add the mileage ranges together and divide by the number of electric vehicles:

107 miles + 53 miles + 100 miles + 114 miles + 237 miles = 611 miles

611 miles ÷ 5 vehicles = 122 miles average range per vehicle

YOUR TURN Five common hybrid-electric vehicles (which are powered by an internal combustion engine and batteries) have mileage ranges as follows: 409 miles, 702 miles, 513 miles, 583 miles, and 492 miles. What is the average mileage range of these five hybrid-electric vehicles? Round to the nearest whole number.

proof that a particular chemical killed fish in a river at some time in the past would be very difficult. So by generating a null hypothesis, scientists examine how easy or difficult it is to accept or reject the null hypothesis. If the null hypothesis is accepted, then they conclude that the pollutant, chemical, or process in question did not affect whatever factor they were measuring. They then move on to a different question or concern.

Collecting Data

Scientists typically take several, repeated sets of measurements of what they believe to be the same sample—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. We know that shoe size varies among men. However, if the scientist were studying an unknown population of earthworms, fish, or trees, she may not know whether or not they would have the same length, weight, or height. Therefore, she needs to collect data to obtain this information. Once data are collected, they can be analyzed, which may involve summing or averaging the data. "Do the Math: Range of Electric Vehicles" provides a data averaging exercise.

Proper procedures—testable hypotheses, appropriate sample size, careful measurements—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 3.2**, we see that high accuracy and high precision is the most desirable result.

Replication The data collection procedure of taking repeated measurements.

Sample size (*n*) The number of times a measurement is replicated in data collection.

Accuracy How close a measured value is to the actual or true value.

Precision How close the repeated measurements of a sample are to one another.

Uncertainty An estimate of how much a measured or calculated value differs from a true value.

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.

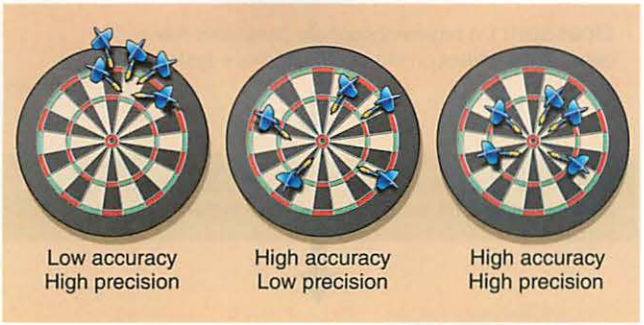


FIGURE 3.2 Accuracy and precision. Accuracy refers to how close a measured value is to the actual or true value. Precision is how close repeated measurements of the same sample are to one another.

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 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 or 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 with investigations of fracking. 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 scientific process. They help scientists refine their research to arrive at more consistent, reliable conclusions.

AP® Exam Tip

The free-response section of the AP® Environmental Science Exam regularly asks students to design an experiment that covers each step of the scientific method. Be sure you know how to do a lab write-up using the scientific method. ●

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, evaluate the journal or location where the information was published, and draw your own conclusions. This process, essential to all scientific endeavors, 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 (such as, "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 cannot 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 facts by the scientific community, but they remain subject to revision if contradictory data are found.

Theory A hypothesis that has been repeatedly tested and confirmed by multiple groups of researchers and has reached wide acceptance.

Scientific Method in Action: 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 problems such 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 Hypothesis

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 3.3.**

Testing the Hypothesis

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. In order to measure differences that will be ascribed to the experimental variable, in this case doses of chlorpyrifos, a second group was not fed any chlorpyrifos. 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 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—those 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.

Control group In a scientific investigation, a group that experiences exactly the same conditions as the experimental group, except for the single variable under study.

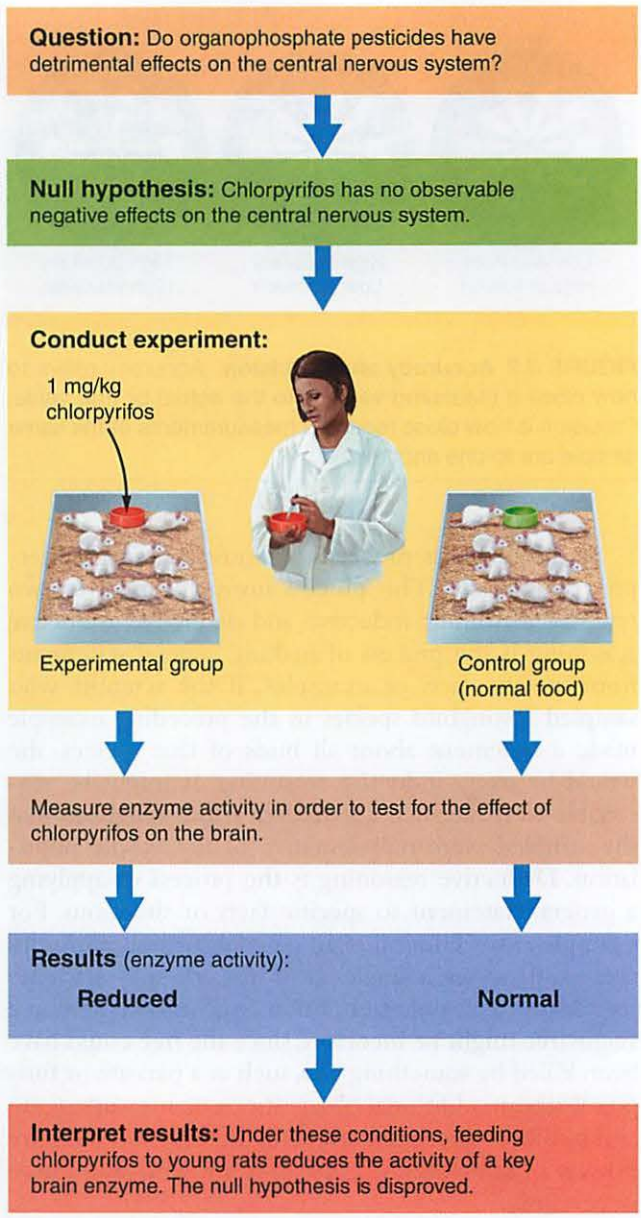


FIGURE 3.3 A typical experimental process. An investigation of the effects of chlorpyrifos on the central nervous system illustrates how the scientific method is used.

The Results

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

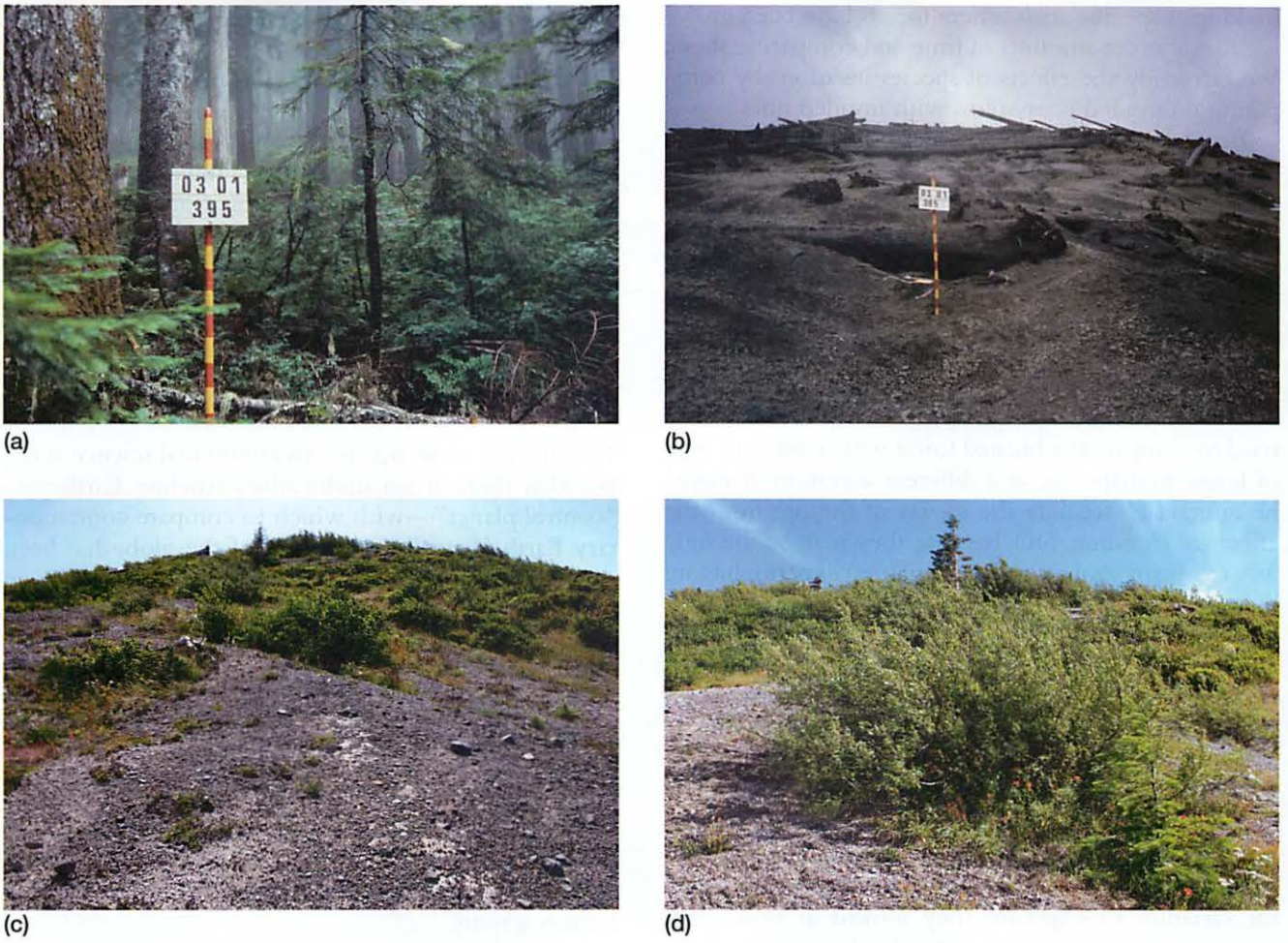


FIGURE 3.4 A natural experiment. The Mount St. Helens eruption in 1980 created a natural experiment for understanding large-scale forest regrowth. (a) A pre-eruption forest near Mount St. Helens in 1979; (b) the same location, post-eruption, in 1982; (c) the same location in 2009 begins to show forest regrowth; (d) the same location in 2014 showing further growth. *(a–d: US Forest Service)*

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 3.4**). We would never destroy that much forest just to study regrowth, but we can study such natural disasters when they occur. Still other cases of natural experiments do not involve disasters. For example, we can study the process of ecological succession by

Natural experiment A natural event that acts as an experimental treatment in an ecosystem.

looking at specific 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.

Let us return 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. Because researchers would never feed pesticides to humans to study their effects, for obvious ethical reasons, they conducted a natural experiment. They looked for groups of people who were similar in most ways—for example, income, age, level of education—but who varied in their exposure to chlorpyrifos. To gather data on variation of exposure they looked at how often people in each group used pesticides that contained the chemical, the brand they used, and the frequency and location of use. Researchers found that tissue concentrations of chlorpyrifos were highest in groups that were exposed to the chemical in their jobs 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 (that chlorpyrifos causes neurological disorders) and a null hypothesis (that there was no effect from chlorpyrifos). 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, and those that are especially popular with children, such as grapes.

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 Earth—no "control planet"—with which to compare contemporary Earth. Virtually every part of the globe has been altered by humans in some way (**FIGURE 3.5**). 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 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,



FIGURE 3.5 The global nature of human impacts. The trash that washed up onto the beach of this remote Pacific island vividly demonstrates the difficulty of finding any part of Earth unaffected by human activities. *(Ashley Cooper/Alamy)*

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. In the case of "Paper or plastic?" many of us would maintain that the best answer is "neither," if the bag is going to be thrown away, but rather a reusable bag made from a sturdier material.

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 affect environmental systems as much as the natural laws that describe them. For example, many people assume that if more efficient automobiles were available, 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. In previous decades, 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.

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? 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 3.6**).



FIGURE 3.6 Electronic waste recycling. The poor are exposed to a disproportionate amount of pollutants and other hazards. The people shown here, located in a small village on the outskirts of New Delhi, India, are recycling circuit boards from discarded electronics products. *(Aurora Photos/Alamy)*

MODULE 3

AP® Review

Preparing for the AP® Exam

In this module, we have seen how specific aspects of the scientific method are used to conduct field and laboratory evaluations of how human activity affects the natural environment. The scientific method follows a process of observations and questions, testable hypotheses and predictions, and data collection. Results are interpreted and shared with other researchers. Experiments can be either controlled (manipulated) experiments or natural experiments that make use of natural events. There are often challenges in environmental science including the lack of baseline data and the interactions with social factors such as human preferences.

AP® Practice Questions

Choose the best answer for the following.

1. The first step in the scientific process is
   (a) collecting data.
   (b) observations and questions.
   (c) forming a hypothesis.
   (d) forming a theory.

Use the following information for questions 2 and 3:
Two new devices for measuring lead contamination in water are tested for accuracy. Scientists test each device with seven samples of water known to contain 400 ppb of lead. Their data is shown in the table. Concentration is in parts per billion.

Water Sample	1	2	3	4	5	6	7
Device 1	415	417	416	417	415	416	416
Device 2	398	401	400	402	398	400	399

2. The data from device 1 is
   (a) accurate, but not precise.
   (b) precise, but not accurate.
   (c) both accurate and precise.
   (d) neither accurate nor precise.

3. Assuming the devices were used correctly, and assuming we want to choose a device that accurately reflects the true concentration of lead in the water samples, which conclusion does the data support?
   (a) Device 1 is superior to device 2 because it is more precise.
   (b) Device 2 is superior to device 1 because it is more precise.
   (c) Device 1 is superior to device 2 because it is more accurate.
   (d) Device 2 is superior to device 1 because it is more accurate.

4. Challenges in the study of environmental science include all of the following EXCEPT
   (a) dangers of studying natural systems.
   (b) lack of baseline data.
   (c) subjectivity of environmental impacts.
   (d) complexity of natural systems.

5. A control group is
   (a) a group with the same conditions as the experimental group.
   (b) a group with conditions found in nature.
   (c) a group with a randomly assigned population.
   (d) a group with the same conditions as the experimental group except for the study variable.

Working Toward Sustainability

Reducing Food Waste

Food is essential to life and food production has substantial impacts on the environment, including most of the indicators we discussed earlier in the chapter. For example, producing food involves clearing land, which impacts biodiversity. It also involves plowing and tilling soils, which leads to more oxygen in soils, which leads to more decomposition and release of carbon dioxide to the atmosphere. And virtually all food production involves fossil fuel energy which, when combusted, also releases carbon dioxide to the atmosphere.

The U.S. Department of Agriculture (USDA)—the primary agency in the United States responsible for overseeing farming, agriculture, forestry, and food—estimates that between 30 and 40 percent of the food supply is wasted. This estimate is based on the percentage of food at the retail and consumer level that is not eaten. It includes food that spoils before it reaches the consumer as well as food put on the plate and not eaten.

The USDA and the U.S. Environmental Protection Agency (EPA) recently announced a food waste challenge for farms, food processors, grocery stores, restaurants, and even colleges and universities. The stated objectives were to

- reduce food waste with better storage, ordering and cooking methods; and in "all you can eat" dining facilities, encouraging people to take less, or giving them smaller plates.
- recover food waste by connecting food donors to hunger relief organizations such as food banks.
- recycle food waste by feeding it to animals or composting it.

In 2015, the USDA and U.S. EPA established a food loss and waste goal for the United States, and targeted a 50 percent reduction by the 2030 goal. Although not enough time has passed to determine meaningful data on nationwide reductions, there are over 4,000 organizations, both companies and nonprofits, that have begun to help achieve these goals. Many of the nonprofits operate in universities, colleges, and high schools.

The Food Recovery Network was founded by a University of Maryland undergraduate and has recovered over 907,000 kilograms (2,000,000 pounds) of food and delivered it to people in need. The Campus Kitchens Project operates at 60 schools around the country from the University of Florida to Gonzaga College High School in Washington, D.C. They report that during the 2015–2016 academic year, they recovered 590,000 kilograms of food (1.3 million pounds) and prepared 350,000 nutritious meals to almost 20,000 people.



Students at the University of Hawaii are part of a Food Recovery Network that delivers unsold food from their dining facilities to food shelters. *(Courtesy Food Recovery Network)*

Because it takes so much energy to grow, process, and cook food, and because food disposed in the landfill generates methane, a greenhouse gas 25 times more potent than carbon dioxide, reducing, recovering, and recycling food is an excellent way to minimize the impact of people on the natural environment. And it appears to be off to a good start.

Sources: USDA Office of the Chief Economist. Food Waste Challenge viewed 20 July 2017. https://www.usda.gov/oce/foodwaste/foodtank: The Think Tank for Food https://foodtank.com/

Critical Thinking Questions

1. How are the 2013 food waste challenge objectives similar to those in the basic recycling slogan: Reduce, Reuse, Recycle?
2. Why do you think the goal for 50 percent food loss and waste reduction is 2030? Is that a long time from now or a short time?

Chapter 1 Review

Throughout this chapter, we have outlined principles, techniques, and methods that will allow us to approach environmental science from an interdisciplinary perspective as we evaluate the current condition of Earth and the ways that human beings have influenced it. We identified that we can use environmental indicators to show the status of specific environmental conditions in the past, at present, and, potentially, into the future. These indicators and other environmental metrics must be measured using the same scientific process used in other fields of science. Environmental science does contain some unique challenges because there is no undisturbed baseline—humans began manipulating Earth long before we have been able to study it.

Key Terms

Fossil fuel
Fracking
Environment
Environmental science
Ecosystem
Biotic
Abiotic
Environmentalism
Environmental studies
Ecosystem services
Environmental indicator
Biodiversity
Genetic diversity
Species
Species diversity
Speciation
Background extinction rate
Greenhouse gases
Anthropogenic
Per capita
Development
Sustainability
Sustainable development
Biophilia
Ecological footprint
Scientific method
Hypothesis
Variable
Independent variable
Dependent variable
Null hypothesis
Replication
Sample size (*n*)
Accuracy
Precision
Uncertainty
Theory
Control group
Natural experiment

Learning Goals Revisited

Module 1 Environmental Science

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.

Module 2 Environmental Indicators and Sustainability

Environmental scientists use key environmental indicators to monitor natural systems for signs of stress.

Five important global-scale environmental indicators are biological diversity, food production, average global surface temperature and atmospheric CO_2 concentrations, human population, and resource depletion. Biological diversity is decreasing as a result of human actions, most notably destruction and degradation of ecosystems. Food production appears to be leveling off and may be decreasing. Carbon dioxide concentrations are steadily increasing as a result of fossil fuel combustion and land conversion. Human population continues to increase and probably will continue to do so

throughout this century. Resource depletion for most natural resources continues to increase.

Sustainability can be assessed 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.

Module 3 Scientific Method

The scientific method is an important process in environmental science.

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 affect them as much as do natural laws.

Practice Math and Graphing

Preparing for the AP® Exam

Answer the following questions. Be sure to show all your work.

1. Practice Math

The table shows global average temperature in degrees centigrade from the year 2000 through 2016.

(a) What is the temperature difference between 2000 and 2016?

(b) What is the average temperature for the last 5 years of measurement (from 2012 through 2016)?

2. Practice Graphing

Using the data from the table, plot a graph of global temperature on the y axis and time from 2000 through 2016 on the x axis.

Year	Temperature °C
2000	14.42
2001	14.55
2002	14.64
2003	14.62
2004	14.55
2005	14.70
2006	14.63
2007	14.66
2008	14.54
2009	14.65
2010	14.72
2011	14.61
2012	14.64
2013	14.66
2014	14.75
2015	14.87
2016	14.99

Section 1: Multiple-Choice Questions

Choose the best answer for questions 1–11.

1. Which of the following events has increased the impact of humans on the environment?
   I. advances in technology
   II. reduced human population growth
   III. use of tools for hunting
   (a) I only
   (b) I and II
   (c) II and III
   (d) I and III

2. As described in this chapter, environmental indicators
   (a) always tell us what is causing an environmental change.
   (b) can be used to analyze the health of natural systems.
   (c) are useful only when studying large-scale changes.
   (d) do not provide information regarding sustainability.

3. Which statement regarding a global environmental indicator is NOT correct?
   (a) Concentrations of atmospheric carbon dioxide have been rising quite steadily since the Industrial Revolution.
   (b) World grain production has increased fairly steadily since 1950, but worldwide production of grain per capita has decreased dramatically over the same period.
   (c) For the past 130 years, average global surface temperatures have shown an overall increase that seems likely to continue.
   (d) World population is expected to be between 8 billion and 10 billion by 2050.

4. Figure 2.5 (on page 12) shows atmospheric carbon dioxide concentrations over time. The measured concentration of CO_2 in the atmosphere is an example of
   (a) a sample of air from over the Antarctic.
   (b) an environmental indicator.
   (c) replicate sampling.
   (d) how to study seasonal variation in Earth's temperatures.

5. Environmental metrics such as the ecological footprint are most informative when they are considered along with other environmental indicators. Which indicator, when considered in conjunction with the ecological footprint, would provide the most information about environmental impact?
   (a) biological diversity
   (b) food production
   (c) human population
   (d) CO_2 concentration

6. In science, which of the following is the most certain?
   (a) hypothesis
   (b) idea
   (c) natural law
   (d) observation

7. All of the following would be exclusively caused by anthropogenic activities EXCEPT
   (a) combustion of fossil fuels.
   (b) overuse of resources such as uranium.
   (c) forest clearing for crops.
   (d) forest fires.

8. Use Figure 2.3 (on page 11) to calculate the approximate percentage change in world grain production per person between 1950 and 2000.
   (a) 10 percent
   (b) 20 percent
   (c) 30 percent
   (d) 40 percent

9. A species of bat nearly went extinct due to the destruction of its forest habitat. However, conservationists preserved a small remnant population of the species in a large forested reserve. The population grew and it appeared that the species would rebound when a disease suddenly wiped out the entire population. What is the likely primary reason for why this occurred?
   I. the low genetic diversity of the population
   II. the reduced ecosystem diversity of the forest
   III. greater contact with humans, who passed on the disease
   (a) I only
   (b) II only
   (c) III only
   (d) I and II

10. The fraction of the global human population living in developed nations is currently 17 percent. If each person in the developed world consumes on average 100 kg of meat per year, how much meat will be consumed in the developed world in 1 year?
    (a) 102 billion kg
    (b) 130 billion kg
    (c) 500 billion kg
    (d) 630 billion kg

11. Which scenario would be most appropriate to study using a natural experiment?
    I. the effects of an herbicide on human health
    II. the influence of sleep on exam performance
    III. the effects of an earthquake on blood pressure
    (a) I only
    (b) II only
    (c) III only
    (d) I and III

Section 2: Free-Response Questions

Write your answer to each part clearly. Support your answers with relevant information and examples. Where calculations are required, show your work.

1. A company conducts an experiment to test whether their coffee or their energy drinks are more likely to keep people up at night. They have five male college students drink a cup of coffee at 5 PM one day, 6 PM the next day, 7 PM on the third day, and 8 PM on the fourth day. They have five other male college students do the same with energy drinks. Each night the researchers record how many minutes it takes for each student to fall asleep. With the results from their experiment, they produce the graphs shown below.

   The researchers conclude that energy drinks are more likely to keep people up at night than coffee.

   (a) Describe THREE problems with the company's experimental design. If you were designing a new experiment, how would you fix TWO of these problems? (5 points)

   (b) Describe ONE problem with the company's graphs. Without repeating anything from part (a) provide at least TWO reasons supporting or opposing the position that these graphs show energy drinks keep people awake later than coffee. (3 points)

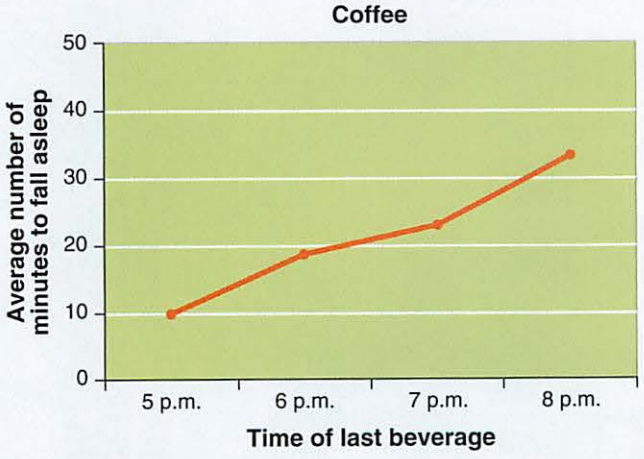
   (c) During this study, the researchers do a survey of the students at the university and notice that students who report drinking more coffee also tend to have higher grades. Can any conclusions be drawn from this observation? Why? (2 points)

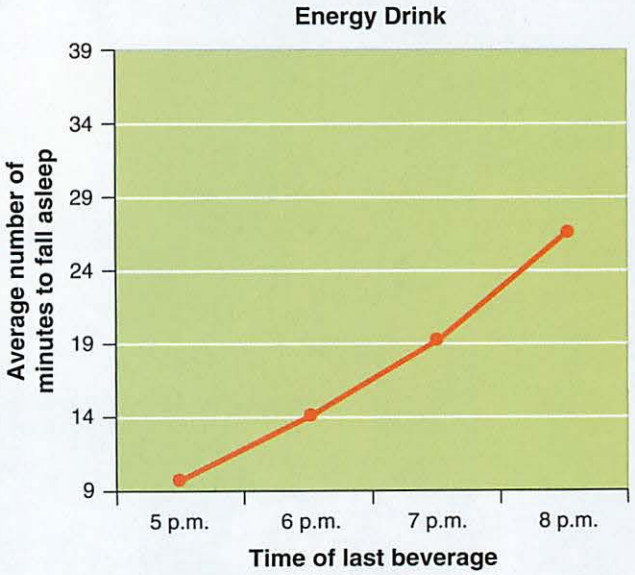
2. The study of environmental science sometimes involves examining the overuse of environmental resources.

   (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 a dust bowl, large-scale erosion, or other human-caused land deterioration might be indicative of environmental issues on Earth today. (4 points)







Tufa towers rise out of the salty water of Mono Lake. *(Don Smith/Getty Images)*