Learning Skills

Students who can begin early in their lives to think of things as connected, even if they revise their views every year, have begun the life of learning.

MARK VAN DOREN

Why Is It Important to Study Environmental Science?

Welcome to **environmental science**—an *interdisciplinary* study of how the earth works, how we interact with the earth, and how we can deal with the environmental problems we face. Because environmental issues affect every part of your life, the concepts, information, and issues discussed in this book and the course you are taking will be useful to you now and throughout your life.

Understandably, we are biased, but *we strongly believe that environmental science is the single most important course in your education.* What could be more important than learning how the earth works, how we are affecting its life support system, and how we can reduce our environmental impact?

We live in an incredibly challenging era. We are becoming increasingly aware that during this century we need to make a new cultural transition in which we learn how to live more sustainably by sharply reducing the degradation of our life-support system. We hope this book will inspire you to become involved in this change in the way we view and treat the earth, which sustains us and our economies and all other living things.

You Can Improve Your Study and Learning Skills

Maximizing your ability to learn should be one of your most important lifetime educational goals. It involves continually trying to *improve your study and learning skills.* Here are some suggestions for doing so:

Develop a passion for learning. As the famous physicist and philosopher Albert Einstein put it, "I have no special talent. I am only passionately curious."

Get organized. Becoming more efficient at studying gives you more time for other interests.

Make daily to-do lists in writing. Put items in order of importance, focus on the most important tasks, and assign a time to work on these items. Because life is full of uncertainties, you might be lucky to accomplish half of the items on your daily list. Shift your schedule as needed to accomplish the most important items.

Set up a study routine in a distraction-free environment. Develop a written daily study schedule and stick to it. Study in a quiet, well-lighted space. Work while sitting at a desk or table—not lying down on a couch or bed. Take breaks every hour or so. During each break, take several deep breaths and move around; this will help you to stay more alert and focused.

Avoid procrastination—putting work off until another time. Do not fall behind on your reading and other assignments. Set aside a particular time for studying each day and make it a part of your daily routine.

Do not eat dessert first. Otherwise, you may never get to the main meal (studying). When you have accomplished your study goals, reward yourself with dessert (play or leisure).

Make hills out of mountains. It is psychologically difficult to climb a mountain, which is what reading an entire book, reading a chapter in a book, writing a paper, or cramming to study for a test can feel like. Instead, break these large tasks (mountains) down into a series of small tasks (hills). Each day, read a few pages of a book or chapter, write a few paragraphs of a paper, and review what you have studied and learned. As American automobile designer and builder Henry Ford put it, "Nothing is particularly hard if you divide it into small jobs."

Look at the big picture first. Get an overview of an assigned reading in this book by looking at the *Key Questions and Concepts* box at the beginning of each chapter. It lists key questions explored in the chapter sections and the corresponding key concepts, which are the critical lessons to be learned in the chapter. Use this list as a chapter roadmap. When you finish a chapter you can also use it to review.

Ask and answer questions as you read. For example, "What is the main point of a particular subsection or paragraph?" Relate your own questions to the key questions and key concepts being addressed in each major chapter section. In this way, you can flesh out a chapter outline to help you understand the chapter material. You may even want to do such an outline in writing.

Focus on key terms. Use the glossary in this textbook to look up the meanings of terms or words you do not understand. This book shows all key terms in **boldface** type and lesser, but still important, terms in *italicized* type. The review

Environmental Problems, Their Causes, and Sustainability

1

Living in an Exponential Age

CORE CASE STUDY

Two ancient kings enjoyed playing chess. The winner claimed a prize from the loser. After one match, the winning king asked the losing king to pay him by placing one grain of wheat on the first square of the chessboard, two grains on the second square, four on the third, and so on, with the number doubling on each square until all 64 squares were filled.

The losing king, thinking he was getting off easy, agreed with delight. It was the biggest mistake he ever made. He bankrupted his kingdom because the number of grains of wheat he had promised was probably more than all the wheat that has ever been harvested!

This fictional story illustrates the concept of **exponential growth,** by which a quantity increases at a *fixed percentage* per unit of time, such as 2% per year. Exponential growth is deceptive. It starts off slowly, but after only a few doublings, it grows to enormous numbers because each doubling is more than the total of all earlier growth.

Here is another example. Fold a piece of paper in half to double its thickness. If you could continue doubling the thickness of the paper 42 times, the stack would reach from the earth to the moon—386,400 kilometers (240,000 miles) away. If you could double it 50 times, the folded paper would almost reach the sun—149 million kilometers (93 million miles) away!

Because of exponential growth in the human population (Figure 1-1), in 2008 there were 6.7 billion people on the planet. Collectively, these people consume vast amounts of food, water, raw materials, and energy and in the process produce huge amounts of pollution and wastes. Unless death rates rise sharply, there will probably be 9.3 billion of us by 2050 and perhaps as many as 10 billion by the end of this century.

The exponential rate of global population growth has declined since 1963. Even so, each day we add an average of 225,000 more people to the earth's population. This is roughly equivalent to adding a new U.S. city of Los Angeles, California, every 2 months, a new France every 9 months, and a new United States—the world's third most populous country—about every 4 years.

No one knows how many people the earth can support, and at what level of resource consumption or affluence, without seriously degrading the ability of the planet to support us and other forms of life and our economies. But there are some disturbing warning signs. Biologists estimate that, by the end of this century, our exponentially increasing population and resource consumption could cause the irreversible loss of one-third to one-half of the world's known different types of plants and animals.

There is also growing evidence and concern that continued exponential growth in human activities such as burning *fossil fuels* (carbon-based fuels such as coal, natural gas, and gasoline) and clearing forests will change the earth's climate during this century. This could ruin some areas for farming, shift water supplies, eliminate many of the earth's unique forms of life, and disrupt economies in various parts of the world.

Great news: We have solutions to these problems that we could implement within a few decades, as you will learn in this book.

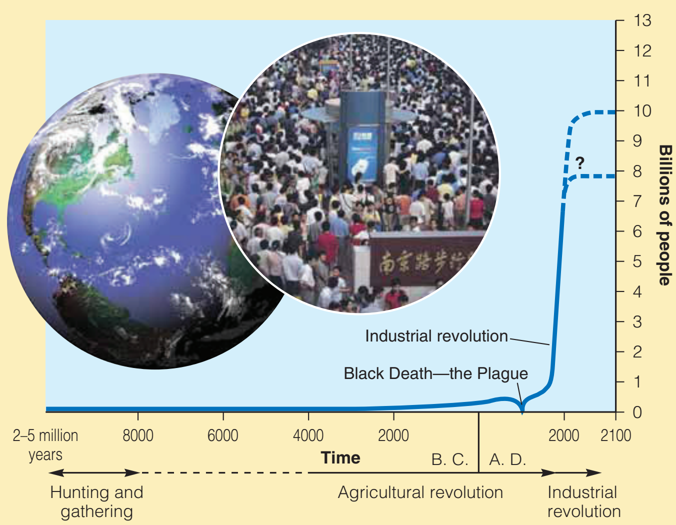


Figure 1-1 *Exponential growth:* the J-shaped curve of past exponential world population growth, with projections to 2100 showing possible population stabilization with the J-shaped curve of growth changing to an S-shaped curve. (This figure is not to scale.) (Data from the World Bank and United Nations; photo L. Yong/UNEP/Peter Arnold, Inc)

Key Questions and Concepts*

1-1 **What is an environmentally sustainable society?**

CONCEPT 1-1A Our lives and economies depend on energy from the sun (*solar capital*) and on natural resources and natural services (*natural capital*) provided by the earth.

CONCEPT 1-1B Living sustainably means living off the earth's natural income without depleting or degrading the natural capital that supplies it.

1-2 **How can environmentally sustainable societies grow economically?**

CONCEPT 1-2 Societies can become more environmentally sustainable through economic development dedicated to improving the quality of life for everyone without degrading the earth's life support systems.

1-3 **How are our ecological footprints affecting the earth?**

CONCEPT 1-3 As our ecological footprints grow, we are depleting and degrading more of the earth's natural capital.

1-4 **What is pollution, and what can we do about it?**

CONCEPT 1-4 Preventing pollution is more effective and less costly than cleaning up pollution.

1-5 **Why do we have environmental problems?**

CONCEPT 1-5A Major causes of environmental problems are population growth, wasteful and unsustainable resource use, poverty, exclusion of environmental costs of resource use from the market prices of goods and services, and attempts to manage nature with insufficient knowledge.

CONCEPT 1-5B People with different environmental worldviews often disagree about the seriousness of environmental problems and what we should do about them.

1-6 **What are four scientific principles of sustainability?**

CONCEPT 1-6 Nature has sustained itself for billions of years by using solar energy, biodiversity, population control, and nutrient cycling—lessons from nature that we can apply to our lifestyles and economies.

*This is a *concept-centered* book, with each major chapter section built around one to three key concepts derived from the natural or social sciences. Key questions and concepts are summarized at the beginning of each chapter. You can use this list as a preview and as a review of the key ideas in each chapter.

Note: Supplements 2 (p. S4), 3 (p. S10), 4 (p. S20), 5 (p. S31), and 6 (p. S39) can be used with this chapter.

Alone in space, alone in its life-supporting systems,
powered by inconceivable energies,
mediating them to us through the most delicate adjustments,
wayward, unlikely, unpredictable, but nourishing, enlivening, and enriching
in the largest degree—is this not a precious home for all of us?
Is it not worth our love?

BARBARA WARD AND RENÉ DUBOS

1-1 What Is an Environmentally Sustainable Society?

▶ **CONCEPT 1-1A** **Our lives and economies depend on energy from the sun (*solar capital*) and on natural resources and natural services (*natural capital*) provided by the earth.**

▶ **CONCEPT 1-1B** **Living sustainably means living off the earth's natural income without depleting or degrading the natural capital that supplies it.**

Environmental Science Is a Study of Connections in Nature

The **environment** is everything around us. It includes all of the living and the nonliving things with which we interact. And it includes a complex web of relationships that connect us with one another and with the world we live in.

Despite our many scientific and technological advances, we are utterly dependent on the environment for air, water, food, shelter, energy, and everything else we need to stay alive and healthy. As a result, we are part of, and not apart from, the rest of nature.

This textbook is an introduction to **environmental science,** an *interdisciplinary* study of how humans interact with the environment of living and nonliving

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. CONCEPT LINK indicates links to key concepts in earlier chapters.

Table 1-1

Major Fields of Study Related to Environmental Science

Major Fields	Subfields
Biology: study of living things (organisms)	**Ecology:** study of how organisms interact with one another and with their nonliving environment **Botany:** study of plants **Zoology:** study of animals
Chemistry: study of chemicals and their interactions	**Biochemistry:** study of the chemistry of living things
Earth science: study of the planet as a whole and its nonliving systems	**Climatology:** study of the earth's atmosphere and climate **Geology:** study of the earth's origin, history, surface, and interior processes **Hydrology:** study of the earth's water resources **Paleontology:** study of fossils and ancient life
Social sciences: studies of human society	**Anthropology:** study of human cultures **Demography:** study of the characteristics of human populations **Geography:** study of the relationships between human populations and the earth's surface features **Economics:** study of the production, distribution, and consumption of goods and services **Political Science:** study of the principles, processes, and structure of government and political institutions
Humanities: study of the aspects of the human condition not covered by the physical and social sciences	**History:** study of information and ideas about humanity's past **Ethics:** study of moral values and concepts concerning right and wrong human behavior and responsibilities **Philosophy:** study of knowledge and wisdom about the nature of reality, values, and human conduct

things. It integrates information and ideas from the *natural sciences,* such as biology, chemistry, and geology, the *social sciences,* such as geography, economics, political science, and demography (the study of populations), and the *humanities,* including philosophy and ethics (Table 1-1 and Figure 1-2). The goals of environmental science are to learn *how nature works, how the environment affects us, how we affect the environment, and how to deal with environmental problems and live more sustainably.*

A key subfield of environmental science is **ecology,** the biological science that studies how **organisms,** or living things, interact with their environment and with each other. Every organism is a member of a certain **species:** a group of organisms with distinctive traits and, for sexually reproducing organisms, can mate and produce fertile offspring. For example, all humans are members of a species that biologists have named *Homo sapiens sapiens.* A major focus of ecology is the study of ecosystems. An **ecosystem** is a set of

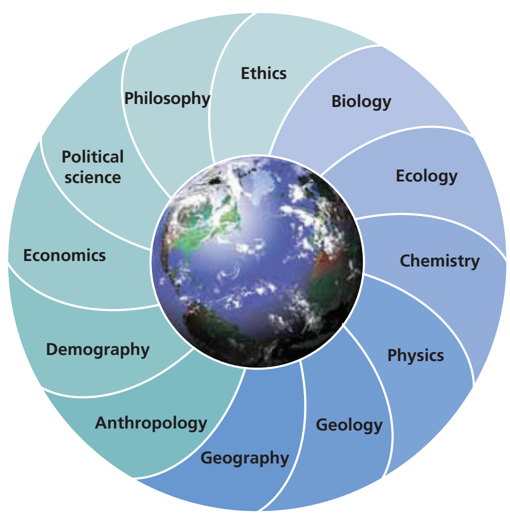


Figure 1-2 Environmental science is an interdisciplinary study of connections between the earth's life-support system and human activities.

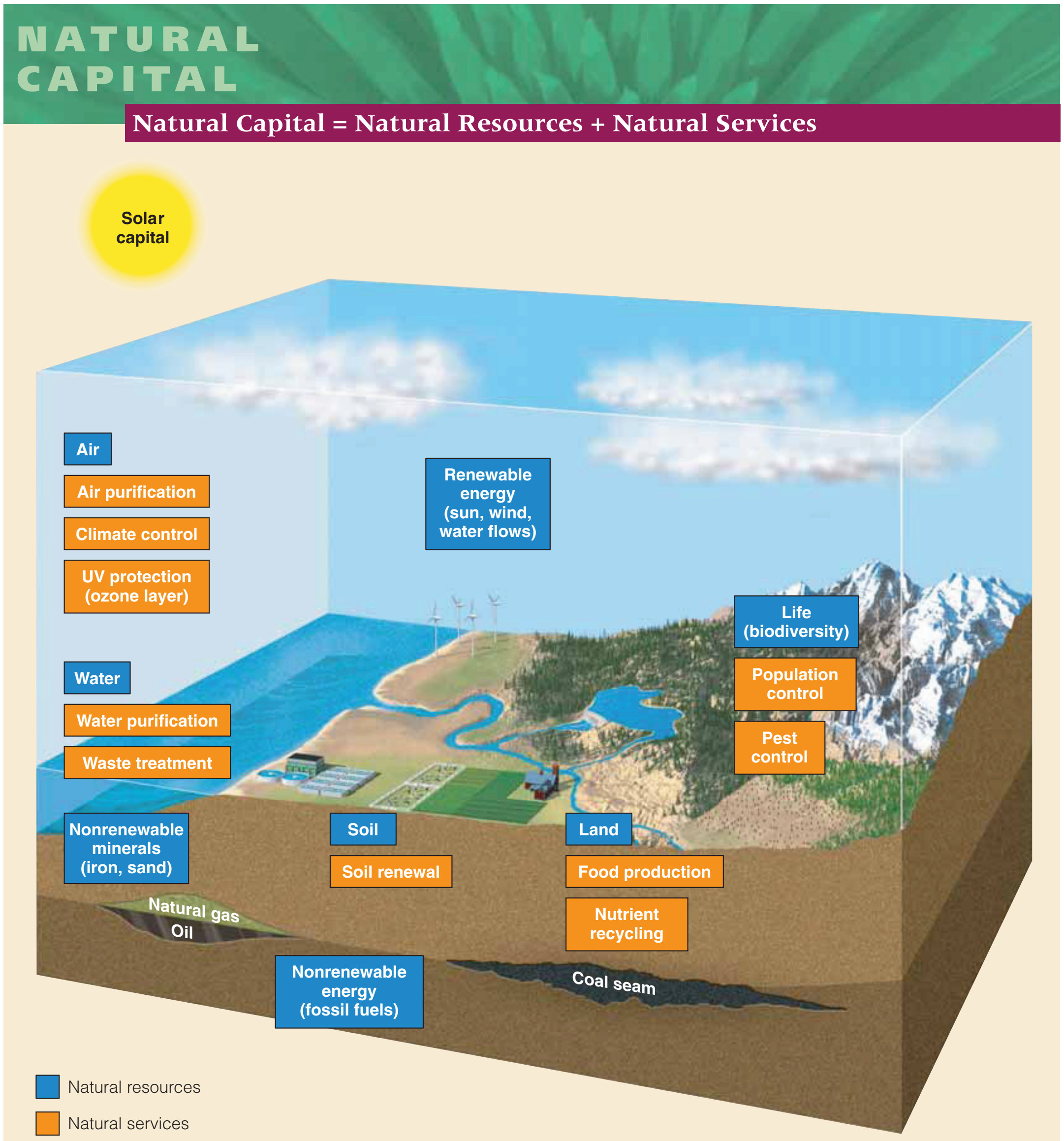


Figure 1-3 Key *natural resources* (blue) and *natural services* (orange) that support and sustain the earth's life and economies (**Concept 1-1A**).

organisms interacting with one another and with their environment of nonliving matter and energy within a defined area or volume.

We should not confuse environmental science and ecology with **environmentalism,** a social movement dedicated to protecting the earth's life-support systems for us and all other forms of life. Environmentalism is practiced more in the political and ethical arenas than in the realm of science.

Sustainability Is the Central Theme of This Book

Sustainability is the ability of the earth's various natural systems and human cultural systems and economies to survive and adapt to changing environmental conditions indefinitely. It is the central theme of this book, and its components provide the subthemes of this book.

A critical component of sustainability is **natural capital**—the natural resources and natural services that keep us and other forms of life alive and support our economies (Figure 1-3). **Natural resources** are materials and energy in nature that are essential or useful to humans. These resources are often classified as *renewable* (such as air, water, soil, plants, and wind) or *nonrenewable* (such as copper, oil, and coal). **Natural services** are functions of nature, such as purification of air and water, which support life and human economies. Ecosystems provide us with these essential services at no cost.

One vital natural service is **nutrient cycling,** the circulation of chemicals necessary for life, from the environment (mostly from soil and water) through organisms and back to the environment (Figure 1-4). For example, *topsoil,* the upper layer of the earth's crust, provides the nutrients that support the plants, animals, and microorganisms that live on land; when they die and decay, they resupply the soil with these nutrients. Without this service, life as we know it could not exist.

Natural capital is supported by **solar capital:** energy from the sun (Figure 1-3). Take away solar energy, and all natural capital would collapse. Solar energy warms the planet and supports *photosynthesis*—a complex chemical process that plants use to provide food for themselves and for us and most other animals. This direct input of solar energy also produces indirect forms of renewable solar energy such as wind, flowing water, and biofuels made from plants and plant residues. Thus, our lives and economies depend on energy from the sun (*solar capital*) and natural resources and natural services (*natural capital*) provided by the earth (**Concept 1-1A**).

A second component of sustainability—and another sub-theme of this text—is to recognize that many human activities can *degrade natural capital* by using normally renewable resources faster than nature can renew them. For example, in parts of the world, we are clearing mature forests much faster than nature can replenish them. We are also harvesting many species of ocean fish faster than they can replenish themselves.

This leads us to a third component of sustainability. Environmental scientists search for *solutions* to problems such as the degradation of natural capital. However, their work is limited to finding the scientific solutions, while the political solutions are left to political processes. For example, scientific solutions might be to stop chopping down biologically diverse, mature forests, and to harvest fish no faster than they can replenish themselves. But implementing such solutions could require government laws and regulations.

The search for solutions often involves conflicts. When scientists argue for protecting a diverse natural forest to help prevent the premature extinction of various life forms, for example, the timber company that had planned to harvest trees in that forest might protest. Dealing with such conflicts often involves making *trade-offs,* or compromises—a fourth component of sustainability. In the case of the timber company, it might be persuaded to plant a tree farm in an area that had already been cleared or degraded, in exchange for preserving the natural forest.

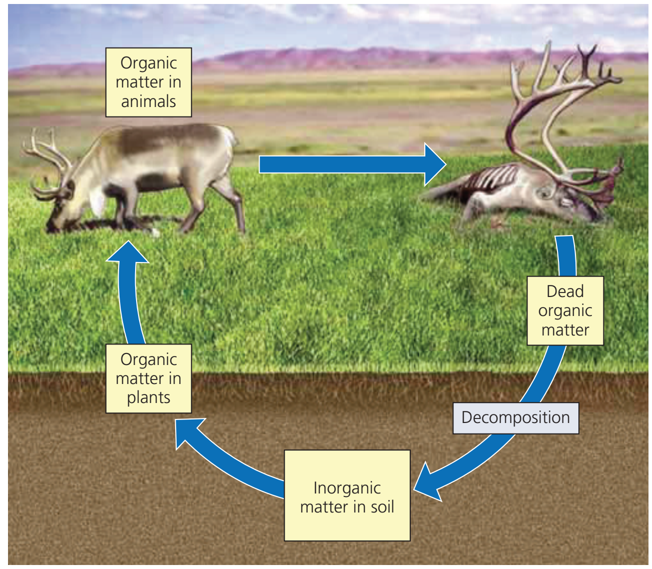


Figure 1-4 *Nutrient cycling:* an important natural service that recycles chemicals needed by organisms from the environment (mostly from soil and water) through organisms and back to the environment.

Any shift toward environmental sustainability should be based on scientific concepts and results that are widely accepted by experts in a particular field, as discussed in more detail in Chapter 2. In making such a shift, *individuals matter*—another subtheme of this book. Some people are good at thinking of new ideas and inventing innovative technologies or solutions. Others are good at putting political pressure on government officials and business leaders, acting either alone or in groups to implement those solutions. In any case, a shift toward sustainability for a society ultimately depends on the actions of individuals within that society.

Environmentally Sustainable Societies Protect Natural Capital and Live Off Its Income

SUSTAINABILITY

The ultimate goal is an **environmentally sustainable society**—one that meets the current and future basic resource needs of its people in a just and equitable manner without compromising the ability of future generations to meet their basic needs.

Imagine you win $1 million in a lottery. If you invest this money and earn 10% interest per year, you will have a sustainable income of $100,000 a year that you can live off of indefinitely, while allowing interest to accumulate on what is left after each withdrawal, without depleting your capital. However, if you spend

$200,000 per year, even while allowing interest to accumulate, your capital of $1 million will be gone early in the seventh year. Even if you spend only $110,000 per year and still allow the interest to accumulate, you will be bankrupt early in the eighteenth year.

The lesson here is an old one: *Protect your capital and live off the income it provides.* Deplete or waste your capital, and you will move from a sustainable to an unsustainable lifestyle.

The same lesson applies to our use of the earth's natural capital—the global trust fund that nature provides for us. *Living sustainably* means living off **natural income,** the renewable resources such as plants, animals, and soil provided by natural capital. This means preserving the earth's natural capital, which supplies this income, while providing the human population with adequate and equitable access to this natural income for the foreseeable future (**Concept 1-1B**).

The bad news is that, according to a growing body of scientific evidence, we are living unsustainably by wasting, depleting, and degrading the earth's natural capital at an exponentially accelerating rate (**Core Case Study**).* In 2005, the United Nations (U.N.) released its *Millennium Ecosystem Assessment.* According to this 4-year study by 1,360 experts from 95 countries, human activities are degrading or overusing about 62% of the earth's natural services (Figure 1-3). In its summary statement, the report warned that "human activity is putting such a strain on the natural functions of Earth that the ability of the planet's ecosystems to sustain future generations can no longer be taken for granted." The good news is that the report suggests we have the knowledge and tools to conserve the planet's natural capital, and it describes commonsense strategies for doing this.

*The opening Core Case Study is used as a theme to connect and integrate much of the material in each chapter. The logo indicates these connections

RESEARCH FRONTIER*

A crash program to gain better and more comprehensive information about the health of the world's life-support systems. See **academic.cengage.com/biology/miller**.

HOW WOULD YOU VOTE?**

Do you believe that the society you live in is on an unsustainable path? Cast your vote online at **academic .cengage.com/biology/miller**.

*Environmental science is a developing field with many exciting research frontiers that are identified throughout this book.

**To cast your vote, go the website for this book and then to the appropriate chapter (in this case, Chapter 1). In most cases, you will be able to compare how you voted with others using this book.

1-2 How Can Environmentally Sustainable Societies Grow Economically?

CONCEPT 1-2 Societies can become more environmentally sustainable through economic development dedicated to improving the quality of life for everyone without degrading the earth's life support systems.

There Is a Wide Economic Gap between Rich and Poor Countries

Economic growth is an increase in a nation's output of goods and services. It is usually measured by the percentage of change in a country's **gross domestic product (GDP):** the annual market value of all goods and services produced by all firms and organizations, foreign and domestic, operating within a country. Changes in a country's economic growth per person are measured by **per capita GDP:** the GDP divided by the total population at midyear.

The value of any country's currency changes when it is used in other countries. Because of such differences, a basic unit of currency in one country can buy more of a particular thing than the basic unit of currency of another country can buy. Consumers in the first country are said to have more *purchasing power* than consumers in the second country have. To help compare countries, economists use a tool called *purchasing power parity* (*PPP*). By combining per capita GDP and PPP, for any given country, they arrive at a **per capita GDP PPP**—a measure of the amount of goods and services that a country's average citizen could buy in the United States.

While economic growth provides people with more goods and services, **economic development** has the goal of using economic growth to improve living standards. The United Nations classifies the world's countries as economically developed or developing based primarily on their degree of industrialization and their per capita GDP PPP. The **developed countries** (with 1.2 billion people) include the United States, Canada, Japan, Australia, New Zealand, and most countries of

Europe. Most are highly industrialized and have a high per capita GDP PPP.

All other nations (with 5.5 billion people) are classified as **developing countries,** most of them in Africa, Asia, and Latin America. Some are *middle-income, moderately developed countries* such as China, India, Brazil, Turkey, Thailand, and Mexico. Others are *low-income, least developed countries* where per capita GDP PPP is steadily declining. These 49 countries with 11% of the world's population include Angola, Congo, Belarus, Nigeria, Nicaragua, and Jordan. Figure 2 on p. S10 in Supplement 3 is a map of high-, upper middle-, lower middle-, and low-income countries.

Figure 1-5 compares some key characteristics of developed and developing countries. About 97% of the projected increase in the world's population between 2008 and 2050 is expected to take place in developing countries, which are least equipped to handle such large population increases.

We live in a world of haves and have-nots. Despite a 40-fold increase in economic growth since 1900, *more than half of the people in the world live in extreme poverty and try to survive on a daily income of less than $2. And one of every six people, classified as desperately poor, struggle to survive on less than $1 a day.* (All dollar figures are in U.S. dollars.) (Figure 1-6)

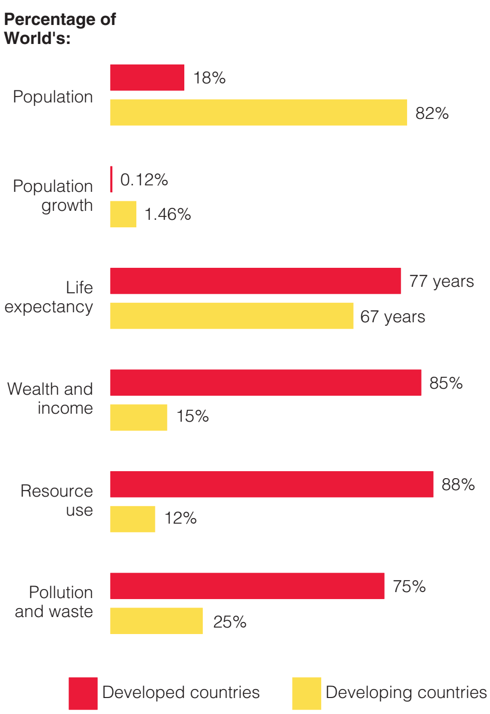


Figure 1-5 *Global outlook:* comparison of developed and developing countries, 2008. (Data from the United Nations and the World Bank)

Sean Sprague/Peter Arnold, Inc.

Figure 1-6 *Extreme poverty:* boy searching for items to sell in an open dump in Rio de Janeiro, Brazil. Many children of poor families who live in makeshift shantytowns in or near such dumps often scavenge all day for food and other items to help their families survive. This means that they cannot go to school.

Some economists call for continuing conventional economic growth, which has helped to increase food supplies, allowed people to live longer, and stimulated mass production of an array of useful goods and services for many people. They also see such growth as a cure for poverty, maintaining that some of the resulting increase in wealth trickles down to countries and people near the bottom of the economic ladder.

Other economists call for us to put much greater emphasis on **environmentally sustainable economic development.** This involves using political and economic systems to *discourage* environmentally harmful and unsustainable forms of economic growth that degrade natural capital, and to *encourage* environmentally beneficial and sustainable forms of economic development that help sustain natural capital (**Concept 1-2**).

THINKING ABOUT
Economic Growth and Sustainability

SUSTAINABILITY

Is exponential economic growth incompatible with environmental sustainability? What are three types of goods whose exponential growth would promote environmental sustainability?

1-3 How Are Our Ecological Footprints Affecting the Earth?

▶ **CONCEPT 1-3** **As our ecological footprints grow, we are depleting and degrading more of the earth's natural capital.**

Some Resources Are Renewable

From a human standpoint, a **resource** is anything obtained from the environment to meet our needs and wants. **Conservation** is the management of natural resources with the goal of minimizing resource waste and sustaining resource supplies for current and future generations.

Some resources, such as solar energy, fresh air, wind, fresh surface water, fertile soil, and wild edible plants, are directly available for use. Other resources such as petroleum, iron, water found underground, and cultivated crops, are not directly available. They become useful to us only with some effort and technological ingenuity. For example, petroleum was a mysterious fluid until we learned how to find, extract, and convert (refine) it into gasoline, heating oil, and other products that could be sold.

Solar energy is called a **perpetual resource** because it is renewed continuously and is expected to last at least 6 billion years as the sun completes its life cycle.

On a human time scale, a **renewable resource** can be replenished fairly quickly (from hours to hundreds of years) through natural processes as long as it is not used up faster than it is renewed. Examples include forests, grasslands, fisheries, freshwater, fresh air, and fertile soil.

The highest rate at which a renewable resource can be used *indefinitely* without reducing its available supply is called its **sustainable yield.** When we exceed a renewable resource's natural replacement rate, the available supply begins to shrink, a process known as **environmental degradation,** as shown in Figure 1-7.

We Can Overexploit Commonly Shared Renewable Resources: The Tragedy of the Commons

There are three types of property or resource rights. One is *private property* where individuals or firms own

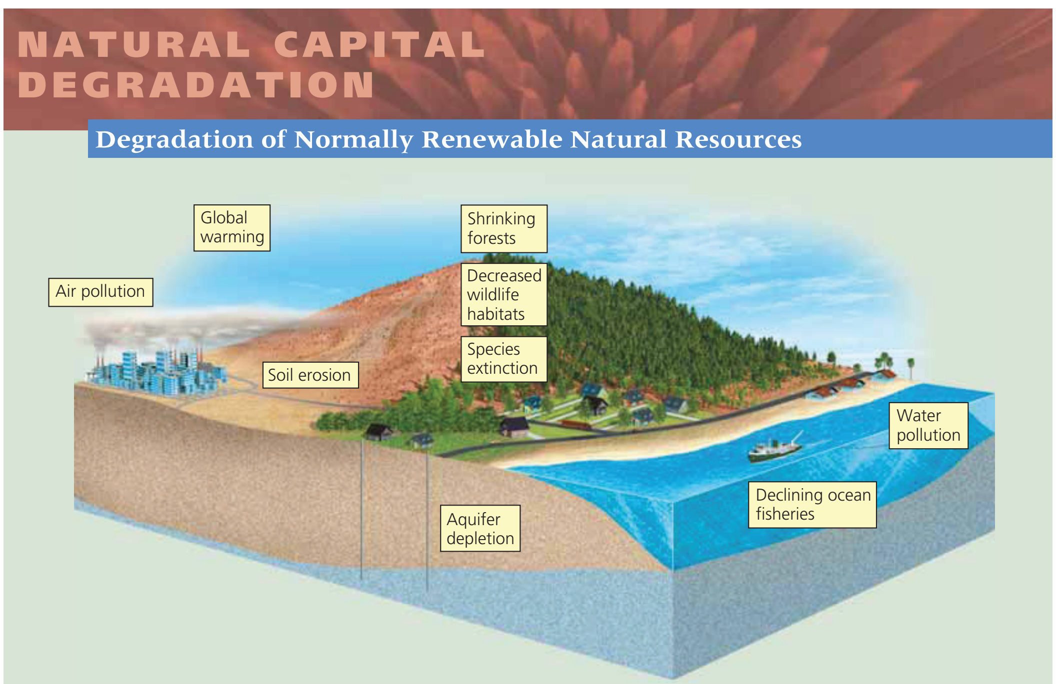


Figure 1-7 Degradation of normally renewable natural resources and services in parts of the world, mostly as a result of rising population and resource use per person.

the rights to land, minerals, or other resources. Another is *common property* where the rights to certain resources are held by large groups of individuals. For example, roughly one-third of the land in the United States is owned jointly by all U.S. citizens and held and managed for them by the government. Another example is land that belongs to a whole village and can be used by anyone for activities such as grazing cows or sheep.

A third category consists of *open access renewable resources,* owned by no one and available for use by anyone at little or no charge. Examples of such shared renewable resources include clean air, underground water supplies, and the open ocean and its fish.

Many common property and open access renewable resources have been degraded. In 1968, biologist Garrett Hardin (1915–2003) called such degradation the *tragedy of the commons.* It occurs because each user of a shared common resource or open-access resource reasons, "If I do not use this resource, someone else will. The little bit that I use or pollute is not enough to matter, and anyway, it's a renewable resource."

When the number of users is small, this logic works. Eventually, however, the cumulative effect of many people trying to exploit a shared resource can exhaust or ruin it. Then no one can benefit from it. Such resource degradation results from the push to satisfy the short-term needs and wants of a growing number of people. It threatens our ability to ensure the long-term economic and environmental sustainability of open-access resources such as clean air or an open-ocean fishery.

One solution is to *use shared resources at rates well below their estimated sustainable yields* by reducing use of the resources, regulating access to the resources, or doing both. For example, the most common approach is for governments to establish laws and regulations limiting the annual harvests of various types of ocean fish that are being harvested at unsustainable levels in their coastal waters. Another approach is for nations to enter into agreements that regulate access to open-access renewable resources such as the fish in the open ocean.

Another solution is to *convert open-access resources to private ownership.* The reasoning is that if you own something, you are more likely to protect your investment. That sounds good, but this approach is not practical for global open-access resources—such as the atmosphere, the open ocean, and most wildlife species—that cannot be divided up and converted to private property.

THINKING ABOUT
Degradation of Commonly Shared Resources

CORE CASE STUDY

How is the degradation of shared renewable resources related to exponential growth (**Core Case Study**) of the world's population and economies? What are three examples of how most of us contribute to this environmental degradation?

Some Resources Are Not Renewable

Nonrenewable resources exist in a fixed quantity, or *stock,* in the earth's crust. On a time scale of millions to billions of years, geological processes can renew such resources. But on the much shorter human time scale of hundreds to thousands of years, these resources can be depleted much faster than they are formed. Such exhaustible resources include *energy resources* (such as coal and oil), *metallic mineral resources* (such as copper and aluminum), and *nonmetallic mineral resources* (such as salt and sand).

As such resources are depleted, human ingenuity can often find substitutes. For example, during this century, a mix of renewable energy resources such as wind, the sun, flowing water, and the heat in the earth's interior could reduce our dependence on nonrenewable fossil fuels such as oil and coal. Also, various types of plastics and composite materials can replace certain metals. But sometimes there is no acceptable or affordable substitute.

Some nonrenewable resources, such as copper and aluminum, can be recycled or reused to extend supplies. **Reuse** is using a resource over and over in the same form. For example, glass bottles can be collected, washed, and refilled many times (Figure 1-8). **Recycling** involves collecting waste materials and processing them into new materials. For example, discarded aluminum cans can be crushed and melted to make new

Mark Edwards/Peter Arnold, Inc.

Figure 1-8 *Reuse:* This child and his family in Katmandu, Nepal, collect beer bottles and sell them for cash to a brewery where they will be reused.

aluminum cans or other aluminum products. But energy resources such as oil and coal cannot be recycled. Once burned, their energy is no longer available to us.

Recycling nonrenewable metallic resources takes much less energy, water, and other resources and produces much less pollution and environmental degradation than exploiting virgin metallic resources. Reusing such resources takes even less energy and other resources and produces less pollution and environmental degradation than recycling does.

Both photos by Peter Menzel

Figure 1-9 *Consumption of natural resources.* The top photo shows a family of five subsistence farmers with all their possessions. They live in the village of Shingkhey, Bhutan, in the Himalaya Mountains, which are sandwiched between China and India in South Asia. The bottom photo shows a typical U.S. family of four living in Pearland, Texas, with their possessions .

Our Ecological Footprints Are Growing

Many people in developing countries struggle to survive. Their individual use of resources and the resulting environmental impact is low and is devoted mostly to meeting their basic needs (Figure 1-9, top). By contrast, many individuals in more affluent nations consume large amounts of resources way beyond their basic needs (Figure 1-9, bottom).

Supplying people with resources and dealing with the resulting wastes and pollution can have a large environmental impact. We can think of it as an **ecological footprint**—the amount of biologically productive land and water needed to supply the people in a particular country or area with resources and to absorb and recycle the wastes and pollution produced by such resource use. The **per capita ecological footprint** is the average ecological footprint of an individual in a given country or area.

If a country's, or the world's, total ecological footprint is larger than its *biological capacity* to replenish its renewable resources and absorb the resulting waste products and pollution, it is said to have an *ecological deficit.* The World Wildlife Fund (WWF) and the Global Footprint Network estimated that in 2003 (the latest data available) humanity's global ecological footprint exceeded the earth's *biological capacity* by about 25% (Figure 1-10, right). That figure was about 88% in the world's high-income countries, with the United States having the world's largest total ecological footprint. If the current exponential growth in the use of renewable resources continues, the Global Footprint Network estimates that by 2050 humanity will be trying to use twice as many renewable resources as the planet can supply (Figure 1-10, bottom) (**Concept 1-3**). See Figure 3 on p. S24 and Figure 5 on pp. S27 in Supplement 4 for maps of the human ecological footprints for the world and the United States, and Figure 4 on p. S26 for a map of countries that are ecological debtors and those that are ecological creditors.

The per capita ecological footprint is an estimate of how much of the earth's renewable resources an individual consumes. After the oil-rich United Arab Emirates, the United States has the world's second largest per capita ecological footprint. In 2003 (the latest data available), its per capita ecological footprint was about 4.5 times the average global footprint per person, 6 times larger than China's per capita footprint, and 12 times the average per capita footprint in the world's low-income countries.

According to William Rees and Mathis Wackernagel, the developers of the ecological footprint concept, it would take the land area of about *five more planet earths* for the rest of the world to reach current U.S. levels of consumption with existing technology. Put another way, if everyone consumed as much as the average American does today, the earth's natural capital could support only about 1.3 billion people—not

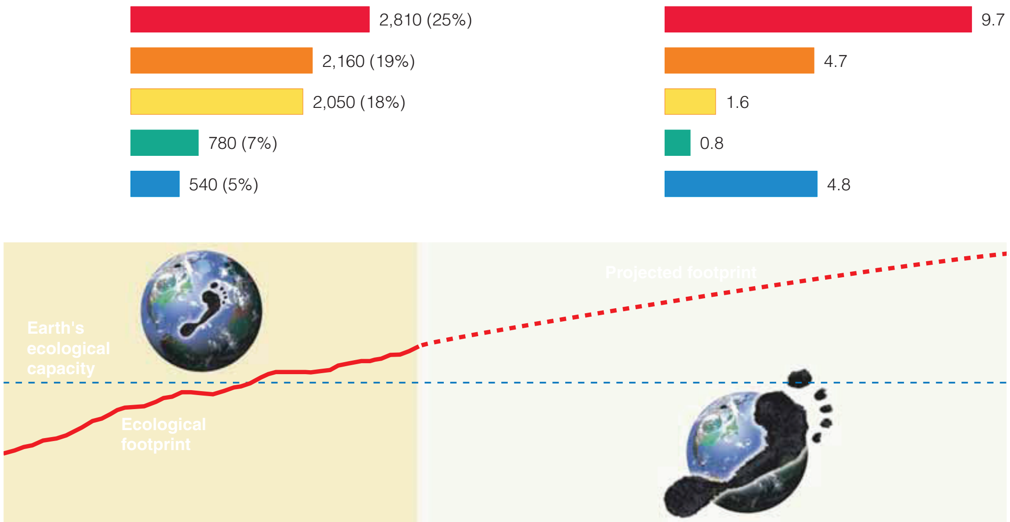


Figure 1-10 **Natural capital use and degradation:** total and per capita ecological footprints of selected countries (top). In 2003, humanity's total or global ecological footprint was about 25% higher than the earth's ecological capacity (bottom) and is projected to be twice the planet's ecological capacity by 2050. **Question:** If we are living beyond the earth's biological capacity, why do you think the human population and per capita resource consumption are still growing exponentially? (Data from Worldwide Fund for Nature, Global Footprint Network)

today's 6.7 billion. In other words, we are living unsustainably by depleting and degrading some of the earth's irreplaceable natural capital and the natural renewable income it provides as our ecological footprints grow and spread across the earth's surface (**Concept 1-3**). For more on this subject, see the Guest Essay by Michael Cain at CengageNOW™. See the Case Study that follows about the growing ecological footprint of China.

THINKING ABOUT
Your Ecological Footprint

Estimate your own ecological footprint by visiting the website **www.myfootprint.org/**. What are three things you could do to reduce your ecological footprint?

■ CASE STUDY
China's New Affluent Consumers

More than a billion super-affluent consumers in developed countries are putting immense pressure on the earth's natural capital. Another billion consumers are attaining middle-class, affluent lifestyles in rapidly developing countries such as China, India, Brazil, South Korea, and Mexico. The 700 million middle-class consumers in China and India number more than twice the size of the entire U.S. population, and the number is growing rapidly. In 2006, the World Bank projected that by 2030 the number of middle-class consumers living in today's developing nations will reach 1.2 billion—about four times the current U.S. population.

China is now the world's leading consumer of wheat, rice, meat, coal, fertilizers, steel, and cement, and it is the second largest consumer of oil after the United States. China leads the world in consumption of goods such as television sets, cell phones, refrigerators, and soon, personal computers. On the other hand, after 20 years of industrialization, two-thirds of the world's most polluted cities are in China; this pollution threatens the health of urban dwellers. By 2020, China is projected to be the world's largest producer and consumer of cars and to have the world's leading economy in terms of GDP PPP.

Suppose that China's economy continues growing exponentially at a rapid rate and its projected population size reaches 1.5 billion by 2033. Then China will need two-thirds of the world's current grain harvest, twice the world's current paper consumption, and more than the current global production of oil.

According to environmental policy expert Lester R. Brown:

> *The western economic model—the fossil fuel–based, automobile-centered, throwaway economy—is not going to work for China. Nor will it work for India, which by 2033 is projected to have a population even larger than China's, or for the other 3 billion people in developing countries who are also dreaming the "American dream."*

For more details on the growing ecological footprint of China, see the Guest Essay by Norman Myers for this chapter at CengageNOW.

THINKING ABOUT
China and Sustainability

What are three things China could do to shift toward more sustainable consumption? What are three things the United States, Japan, and the European Union could do to shift toward more sustainable consumption?

Cultural Changes Have Increased Our Ecological Footprints

Culture is the whole of a society's knowledge, beliefs, technology, and practices, and human cultural changes have had profound effects on the earth.

Evidence of organisms from the past and studies of ancient cultures suggest that the current form of our species, *Homo sapiens sapiens,* has walked the earth for perhaps 90,000–195,000 years—less than an eye-blink in the 3.56 billion years of life on the earth. Until about 12,000 years ago, we were mostly *hunter–gatherers* who obtained food by hunting wild animals or scavenging their remains and gathering wild plants. Early hunter–gathers lived in small groups and moved as needed to find enough food for survival.

Since then, three major cultural changes have occurred. *First* was the *agricultural revolution,* which began 10,000–12,000 years ago when humans learned how to grow and breed plants and animals for food, clothing, and other purposes. *Second* was the *industrial–medical revolution,* beginning about 275 years ago when people invented machines for the large-scale production of goods in factories. This involved learning how to get energy from fossil fuels, such as coal and oil, and how to grow large quantities of food in an efficient manner. *Finally,* the *information–globalization revolution* began about 50 years ago, when we developed new technologies for gaining rapid access to much more information and resources on a global scale.

Each of these cultural changes gave us more energy and new technologies with which to alter and control more of the planet to meet our basic needs and increasing wants. They also allowed expansion of the human population, mostly because of increased food supplies and longer life spans. In addition, they each resulted in greater resource use, pollution, and environmental degradation as our ecological footprints expanded (Figure 1-10) and allowed us to dominate the planet.

Many environmental scientists and other analysts call for us to bring about a new **environmental,** or **sustainability, revolution** during this century. It would involve learning how to reduce our ecological footprints and live more sustainability.

For more background and details on environmental history, see Supplement 5 (p. S31).

1-4 What Is Pollution and What Can We Do about It?

CONCEPT 1-4 Preventing pollution is more effective and less costly than cleaning up pollution.

Pollution Comes from a Number of Sources

Pollution is any in the environment that is harmful to the health, survival, or activities of humans or other organisms. Pollutants can enter the environment naturally, such as from volcanic eruptions, or through human activities, such as burning coal and gasoline and discharging chemicals into rivers and the ocean.

The pollutants we produce come from two types of sources. **Point sources** are single, identifiable sources. Examples are the smokestack of a coal-burning power or industrial plant (Figure 1-11), the drainpipe of a factory, and the exhaust pipe of an automobile. **Nonpoint sources** are dispersed and often difficult to identify. Examples are pesticides blown from the land into the air and the runoff of fertilizers and pesticides from farmlands, lawns, gardens, and golf courses into streams and lakes. It is much easier and cheaper to identify and control or prevent pollution from point sources than from widely dispersed nonpoint sources.

There are two main types of pollutants. **Biodegradable pollutants** are harmful materials that can be broken down by natural processes. Examples are human sewage and newspapers. **Nondegradable pollutants** are harmful materials that natural processes cannot break down. Examples are toxic chemical elements such as lead, mercury, and arsenic (see Supplement 6, p. S39, for an introduction to basic chemistry).

Pollutants can have three types of unwanted effects. *First,* they can disrupt or degrade life-support systems for humans and other species. *Second,* they can damage wildlife, human health, and property. *Third,* they can create nuisances such as noise and unpleasant smells, tastes, and sights.

We Can Clean Up Pollution or Prevent It

Consider the smoke produced by a steel mill. We can try to deal with this problem by asking two entirely different questions. One question is "how can we clean up the smoke?" The other is "how can we avoid producing the smoke in the first place?"

The answers to these questions involve two different ways of dealing with pollution. One is **pollution cleanup,** or **output pollution control,** which involves cleaning up or diluting pollutants after they have been produced. The other is **pollution prevention,** or **input pollution control,** which reduces or eliminates the production of pollutants.

Environmental scientists have identified three problems with relying primarily on pollution cleanup. *First,* it is only a temporary bandage as long as population and consumption levels grow without corresponding improvements in pollution control technology. For example, adding catalytic converters to car exhaust systems has reduced some forms of air pollution. At the same time, increases in the number of cars and the total distance each car travels have reduced the effectiveness of this cleanup approach.

Second, cleanup often removes a pollutant from one part of the environment only to cause pollution in another. For example, we can collect garbage, but the garbage is then *burned* (perhaps causing air pollution and leaving toxic ash that must be put somewhere), *dumped* on the land (perhaps causing water pollution through runoff or seepage into groundwater), or *buried* (perhaps causing soil and groundwater pollution).

Ray Pfortner/Peter Arnold, Inc.

Figure 1-11 *Point-source air pollution* from a pulp mill in New York State (USA).

Third, once pollutants become dispersed into the environment at harmful levels, it usually costs too much or is impossible to reduce them to acceptable levels.

Pollution prevention (front-of-the-pipe) and pollution cleanup (end-of-the-pipe) solutions are both needed. But environmental scientists, some economists, and some major companies urge us to put more emphasis on prevention because it works better and in the long run is cheaper than cleanup (**Concept 1-4**).

1-5 Why Do We Have Environmental Problems?

▶ **CONCEPT 1-5A Major causes of environmental problems are population growth, wasteful and unsustainable resource use, poverty, exclusion of environmental costs of resource use from the market prices of goods and services, and attempts to manage nature with insufficient knowledge.**

▶ **CONCEPT 1-5B People with different environmental worldviews often disagree about the seriousness of environmental problems and what we should do about them.**

Experts Have Identified Five Basic Causes of Environmental Problems

As we run more and more of the earth's natural resources through the global economy, in many parts of the world, forests are shrinking, deserts are expanding, soils are eroding, and agricultural lands are deteriorating. In addition, the lower atmosphere is warming, glaciers are melting, sea levels are rising, and storms are becoming more destructive. And in many areas, water tables are falling, rivers are running dry, fisheries are collapsing, coral reefs are disappearing, and various species are becoming extinct.

According to a number of environmental and social scientists, the major causes of these and other

Figure 1-12 Environmental and social scientists have identified five basic causes of the environmental problems we face (**Concept 1-5A**). **Question:** What are three ways in which your lifestyle contributes to these causes?

environmental problems are population growth, wasteful and unsustainable resource use, poverty, failure to include the harmful environmental costs of goods and services in their market prices, and insufficient knowledge of how nature works (Figure 1-12 and **Concept 1-5A**).

We have discussed the exponential growth of the human population (**Core Case Study**), and here we will examine other major causes of environmental problems in more detail.

Poverty Has Harmful Environmental and Health Effects

Poverty occurs when people are unable to meet their basic needs for adequate food, water, shelter, health, and education. Poverty has a number of harmful environmental and health effects (Figure 1-13). The daily lives of half of the world's people, who are trying to live on the equivalent of less than $2 a day, are focused on getting enough food, water, and cooking and heating fuel to survive. Desperate for short-term survival, some of these people deplete and degrade forests, soil, grasslands, fisheries, and wildlife, at an ever-increasing rate. They do not have the luxury of worrying about long-term environmental quality or sustainability.

Poverty affects population growth. To many poor people, having more children is a matter of survival. Their children help them gather fuel (mostly wood and animal dung), haul drinking water, and tend crops and livestock. Their children also help to care for them in their old age (which is their 40s or 50s in the poorest countries) because they do not have social security, health care, and retirement funds.

While poverty can increase some types of environmental degradation, the reverse is also true. Pollution and environmental degradation have a severe impact on the poor and can increase poverty. Consequently, many of the world's desperately poor people die prematurely from several preventable health problems.

One such problem is *malnutrition* from a lack of protein and other nutrients needed for good health (Figure 1-14). The resulting weakened condition can increase the chances of death from normally nonfatal illnesses, such as diarrhea and measles. A second problem is limited access to adequate sanitation facilities and clean drinking water. More than 2.6 billion people (38% of the world's population) have no decent bathroom facilities. They are forced to use fields, backyards, ditches, and streams. As a result, more than 1 billion people—one of every seven—get water for drinking, washing, and cooking from sources polluted by human and animal feces. A third problem is severe respiratory disease and premature death from inhaling indoor air pollutants produced by burning wood or coal in open fires or in poorly vented stoves for heat and cooking.

According to the World Health Organization, these factors cause premature death for at least 7 million people each year. *This amounts to about 19,200 premature deaths per day, equivalent to 96 fully loaded 200-passenger airliners crashing every day with no survivors!* Two-thirds of those dying are children younger than age 5. The news media rarely cover this ongoing human tragedy.

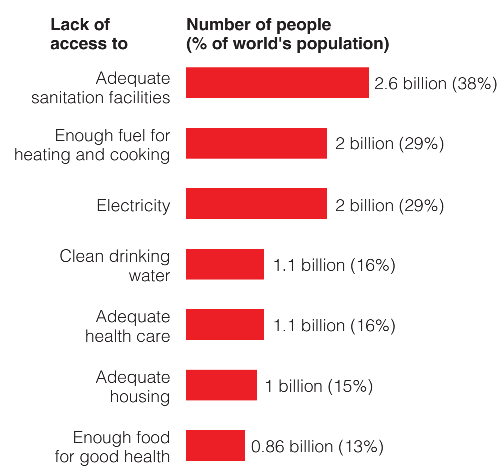


Figure 1-13 Some harmful results of poverty. **Question:** Which two of these effects do you think are the most harmful? Why? (Data from United Nations, World Bank, and World Health Organization)

Tom Koene/Peter Arnold, Inc.

Figure 1-14 *Global Outlook:* in developing countries, one of every three children under age 5, such as this child in Lunda, Angola, suffers from severe malnutrition caused by a lack of calories and protein. According to the World Health Organization, each day at least 13,700 children under age 5 die prematurely from malnutrition and infectious diseases, most from drinking contaminated water and being weakened by malnutrition.

The *great news* is that we have the means to solve the environmental, health, and social problems resulting from poverty within 20–30 years if we can find the political and ethical will to act.

Affluence Has Harmful and Beneficial Environmental Effects

The harmful environmental effects of poverty are serious, but those of affluence are much worse (Figure 1-10, top). The lifestyles of many affluent consumers in developed countries and in rapidly developing countries such as India and China (p. 15) are built upon high levels of consumption and unnecessary waste of resources. Such affluence is based mostly on the assumption—fueled by mass advertising—that buying more and more things will bring happiness.

This type of affluence has an enormous harmful environmental impact. It takes about 27 tractor-trailer loads of resources per year to support one American, or 7.9 billion truckloads per year to support the entire U.S. population. Stretched end-to-end, each year these trucks would reach beyond the sun!

While the United States has far fewer people than India, the average American consumes about 30 times as much as the average citizen of India and 100 times as much as the average person in the world's poorest countries. As a result, the average environmental impact, or ecological footprint per person, in the United States is much larger than the average impact per person in developing countries (Figure 1-10, top).

On the other hand, affluence can lead people to become more concerned about environmental quality. It also provides money for developing technologies to reduce pollution, environmental degradation, and resource waste.

In the United States and most other affluent countries, the air is cleaner, drinking water is purer, and most rivers and lakes are cleaner than they were in the 1970s. In addition, the food supply is more abundant and safer, the incidence of life-threatening infectious diseases has been greatly reduced, lifespans are longer, and some endangered species are being rescued from premature extinction.

Affluence financed these improvements in environmental quality, based on greatly increased scientific research and technological advances. And education spurred citizens insist that businesses and elected officials improve environmental quality. Affluence and education have also helped to reduce population growth in most developed countries. However, a downside to wealth is that it allows the affluent to obtain the resources they need from almost anywhere in the world without seeing the harmful environmental impacts of their high-consumption life styles.

THINKING ABOUT

The Poor, the Affluent, and Exponentially Increasing Population Growth

CORE CASE STUDY

Some see rapid population growth of the poor in developing countries as the primary cause of our environmental problems. Others say that the much higher resource use per person in developed countries is a more important factor. Which factor do you think is more important? Why?

Prices Do Not Include the Value of Natural Capital

When companies use resources to create goods and services for consumers, they are generally not required to pay the environmental costs of such resource use. For example, fishing companies pay the costs of catching fish but do not pay for the depletion of fish stocks. Timber companies pay for clear-cutting forests but not for the resulting environmental degradation and loss of wildlife habitat. The primary goal of these companies is to maximize their profits, so they do not voluntarily pay these harmful environmental costs or even try to assess them, unless required to do so by government laws or regulations.

As a result, the prices of goods and services do not include their harmful environmental costs. Thus, consumers are generally not aware of them and have no effective way to evaluate the resulting harmful effects on the earth's life-support systems and on their own health.

Another problem is that governments give companies tax breaks and payments called *subsidies* to assist them in using resources to run their businesses. This helps to create jobs and stimulate economies, but it can also result in degradation of natural capital, again because the value of the natural capital is not included in the market prices of goods and services. We explore this problem and some possible solutions in later chapters.

People Have Different Views about Environmental Problems and Their Solutions

Differing views about the seriousness of our environmental problems and what we should do about them arise mostly out of differing environmental worldviews. Your **environmental worldview** is a set of assumptions and values reflecting how you think the world works and what you think your role in the world should be. This involves **environmental ethics,** which are our beliefs about what is right and wrong with how we treat the environment. Here are some important *ethical questions* relating to the environment:

- Why should we care about the environment?
- Are we the most important beings on the planet or are we just one of the earth's millions of different forms of life?
- Do we have an obligation to see that our activities do not cause the premature extinction of other species? Should we try to protect all species or only some? How do we decide which species to protect?
- Do we have an ethical obligation to pass on to future generations the extraordinary natural world in a condition at least as good as what we inherited?
- Should every person be entitled to equal protection from environmental hazards regardless of race, gender, age, national origin, income, social class, or any other factor?

THINKING ABOUT
Our Responsibilities

How would you answer each of the questions above? Compare your answers with those of your classmates. Record your answers and, at the end of this course, return to these questions to see if your answers have changed.

People with widely differing environmental worldviews can take the same data, be logically consistent, and arrive at quite different conclusions because they start with different assumptions and moral, ethical, or religious beliefs (**Concept 1-5B**). Environmental worldviews are discussed in detail in Chapter 25, but here is a brief introduction.

The **planetary management worldview** holds that we are separate from nature, that nature exists mainly to meet our needs and increasing wants, and that we can use our ingenuity and technology to manage the earth's life-support systems, mostly for our benefit, indefinitely.

The **stewardship worldview** holds that we can and should manage the earth for our benefit, but that we have an ethical responsibility to be caring and responsible managers, or *stewards,* of the earth. It says we should encourage environmentally beneficial forms of economic growth and development and discourage environmentally harmful forms.

The **environmental wisdom worldview** holds that we are part of, and totally dependent on, nature and that nature exists for all species, not just for us. It also calls for encouraging earth-sustaining forms of economic growth and development and discouraging earth-degrading forms. According to this view, our success depends on learning how life on earth sustains itself and integrating such *environmental wisdom* into the ways we think and act.

Many of the ideas for the stewardship and environmental wisdom worldviews are derived from the writings of Aldo Leopold (Individuals Matter, p. 22).

We Can Learn to Make Informed Environmental Decisions

The first step for dealing with an environmental problem is to carry out scientific research on the nature of the problem and to evaluate possible solutions to the problem. Once this is done, other factors involving the social sciences and the humanities (Table 1-1) must be used to evaluate each proposed solution. This involves considering various *human values.* What are its projected short-term and long-term beneficial and harmful environmental, economic, and health effects? How much will it cost? Is it ethical? Figure 1-15 shows the major steps involved in making an environmental decision.

We Can Work Together to Solve Environmental Problems

Making the shift to more sustainable societies and economies involves building what sociologists call **social capital.** This involves getting people with different views and values to talk and listen to one another, find common ground based on understanding and trust, and work together to solve environmental and other problems. This means nurturing openness, communication, cooperation, and hope and discouraging close-mindedness, polarization, confrontation, and fear.

Solutions to environmental problems are not black and white, but rather all shades of gray because proponents of all sides of these issues have some legitimate and useful insights. In addition, any proposed solution has short- and long-term advantages and disadvantages that must be evaluated (Figure 1-15). This means that citizens who strive to build social capital also search for *trade-off solutions* to environmental problems—an important theme of this book. They can also try to agree on shared visions of the future and work together to develop strategies for implementing such visions beginning at the local level, as citizens of Chattanooga, Tennessee (USA), have done.

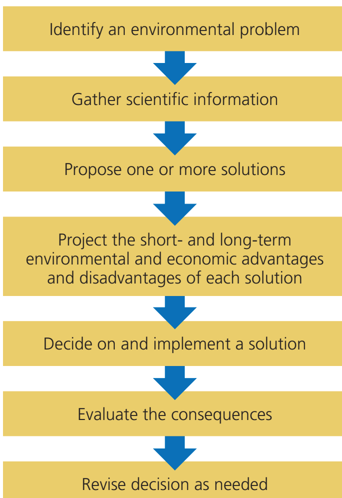


Figure 1-15 Steps involved in making an environmental decision.

■ **CASE STUDY**

The Environmental Transformation of Chattanooga, Tennessee

Local officials, business leaders, and citizens have worked together to transform Chattanooga, Tennessee (USA), from a highly polluted city to one of the most sustainable and livable cities in the United States (Figure 1-16).

During the 1960s, U.S. government officials rated Chattanooga as having the dirtiest air in the United States. Its air was so polluted by smoke from its coke ovens and steel mills that people sometimes had to turn on their vehicle headlights in the middle of the day. The Tennessee River, flowing through the city's industrial center, bubbled with toxic waste. People and industries fled the downtown area and left a wasteland of abandoned and polluting factories, boarded-up buildings, high unemployment, and crime.

In 1984, the city decided to get serious about improving its environmental quality. Civic leaders started a *Vision 2000* process with a 20-week series of community meetings in which more than 1,700 citizens from all walks of life gathered to build a consensus about what the city could be at the turn of the century. Citizens identified the city's main problems, set goals, and brainstormed thousands of ideas for solutions.

Chattanooga Area Convention and Visitors Bureau

Figure 1-16 Since 1984, citizens have worked together to make the city of Chattanooga, Tennessee, one of the most sustainable and best places to live in the United States.

INDIVIDUALS MATTER

Aldo Leopold's Environmental Ethics

According to *Aldo Leopold* (Figure 1-A), the role of the human species should be to protect nature, not conquer it.

In 1933, Leopold became a professor at the University of Wisconsin and in 1935, he was one of the founders of the U.S. Wilderness Society. Through his writings and teachings, he became one of the leaders of the *conservation* and *environmental movements* of the 20th century. In doing this, he laid important groundwork for the field of environmental ethics.

Leopold's weekends of planting, hiking, and observing nature at his farm in Wisconsin provided material for his most famous book, *A Sand County Almanac,* published after his death in 1949. Since then, more than 2 million copies of this environmental classic have been sold.

The following quotations from his writings reflect Leopold's *land ethic,* and they form the basis for many of the beliefs of the modern stewardship and environmental wisdom worldviews:

- *All ethics so far evolved rest upon a single premise: that the individual is a member of a community of interdependent parts.*
- *To keep every cog and wheel is the first precaution of intelligent tinkering.*
- *That land is a community is the basic concept of ecology, but that land is to be loved and respected is an extension of ethics.*
- *The land ethic changes the role of Homo sapiens from conqueror of the land-community to plain member and citizen of it.*
- *We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect.*
- *Anything is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise.*

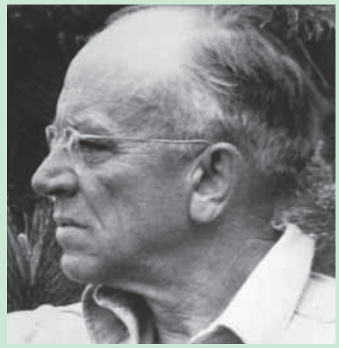

Courtesy of the University of Wisconsin—Madison Archives

Figure 1-A Individuals Matter: *Aldo Leopold* (1887–1948) was a forester, writer, and conservationist. His book *A Sand County Almanac* (published after his death) is considered an environmental classic that inspired the modern environmental and conservation movement.

By 1995, Chattanooga had met most of its original goals. The city had encouraged zero-emission industries to locate there and replaced its diesel buses with a fleet of quiet, zero-emission electric buses, made by a new local firm.

The city also launched an innovative recycling program after environmentally concerned citizens blocked construction of a garbage incinerator that would have emitted harmful air pollutants. These efforts paid off. Since 1989, the levels of the seven major air pollutants in Chattanooga have been lower than those required by federal standards.

Another project involved renovating much of the city's low-income housing and building new low-income rental units. Chattanooga also built the nation's largest freshwater aquarium, which became the centerpiece for downtown renewal. The city developed a riverfront park along both banks of the Tennessee River running through downtown. The park draws more than 1 million visitors per year. As property values and living conditions have improved, people and businesses have moved back downtown.

In 1993, the community began the process again in *Revision 2000.* Goals included transforming an abandoned and blighted area in South Chattanooga into a mixed community of residences, retail stores, and zero-emission industries where employees can live near their workplaces. Most of these goals have been implemented.

Chattanooga's environmental success story, enacted by people working together to produce a more livable and sustainable city, is a shining example of what other cities can do by building their social capital.

Individuals Matter

Chattanooga's story shows that a key to finding solutions to environmental problems is to recognize that most social change results from individual actions and individuals acting together (using *social capital*) to bring about change through *bottom-up* grassroots action. In other words, *individuals matter*—another important theme of this book. Here are two pieces of good news. First, research by social scientists suggests that it takes only 5–10% of the population of a community, a country, or the world to bring about major social change. Second, such research also shows that significant social change can occur much more quickly than most people think.

Anthropologist Margaret Mead summarized our potential for social change: "Never doubt that a small group of thoughtful, committed citizens can change the world. Indeed, it is the only thing that ever has."

1-6 What Are Four Scientific Principles of Sustainability?

▶ **CONCEPT 1-6 Nature has sustained itself for billions of years by using solar energy, biodiversity, population control, and nutrient cycling—lessons from nature that we can apply to our lifestyles and economies.**

Studying Nature Reveals Four Scientific Principles of Sustainability

How can we live more sustainably? According to environmental scientists, we should study how life on the earth has survived and adapted to major changes in environmental conditions for billions of years. We could make the transition to more sustainable societies by applying these *lessons from nature* to our lifestyles and economies, as summarized below and in Figure 1-17 (**Concept 1-6**).

- *Reliance on Solar Energy:* the sun (solar capital) warms the planet and supports photosynthesis used by plants to provide food for themselves and for us and most other animals.

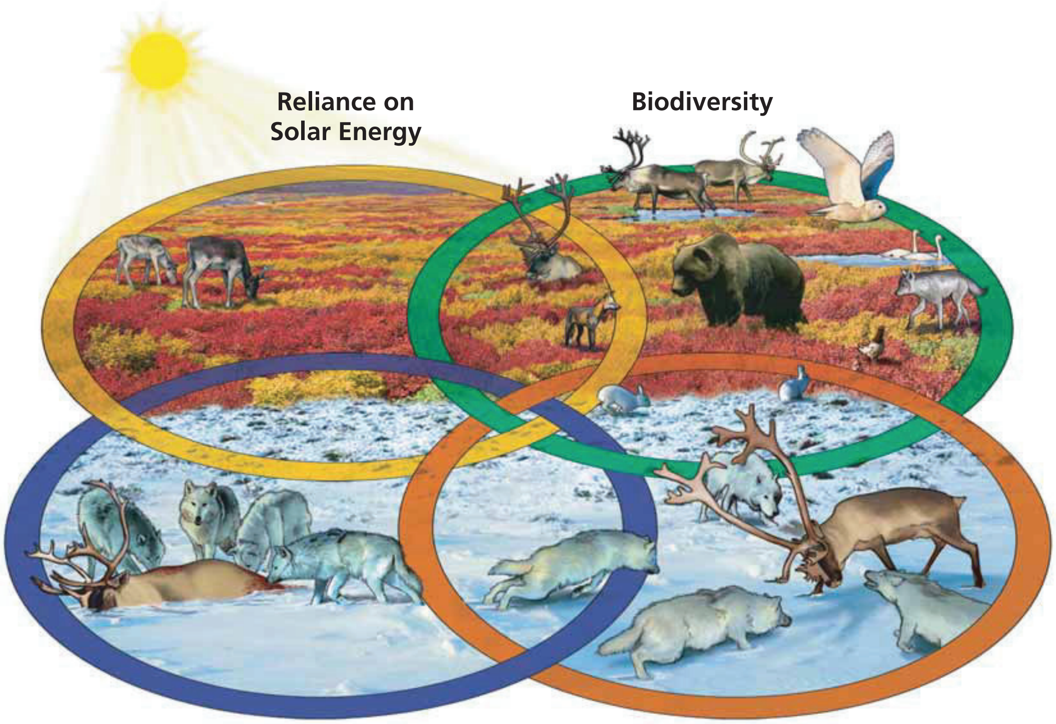


Figure 1-17 **Four scientific principles of sustainability:** These four interconnected principles of sustainability are derived from learning how nature has sustained a variety of life forms on the earth for about 3.56 billion years. The top left oval shows sunlight stimulating the production of vegetation in the arctic tundra during its brief summer (*solar energy*) and the top right oval shows some of the diversity of species found there during the summer (*biodiversity*). The bottom right oval shows arctic gray wolves stalking a caribou during the long cold winter (*population control*). The bottom left oval shows arctic gray wolves feeding on their kill. This, plus huge numbers of tiny decomposers that convert dead matter to soil nutrients, recycle all materials needed to support the plant growth shown in the top left and right ovals (*nutrient cycling*).

Figure 1-18 **Solutions:** some shifts involved in bringing about the *environmental* or *sustainability revolution*. **Question:** Which three of these shifts do you think are most important? Why?

- *Biodiversity* (short for *biological diversity*): the astounding variety of different organisms, the genes they contain, the ecosystems in which they exist, and the natural services they provide have yielded countless ways for life to adapt to changing environmental conditions throughout the earth's history.
- *Population Control:* competition for limited resources among different species places a limit on how much their populations can grow.
- *Nutrient Cycling:* natural processes recycle chemicals that plants and animals need to stay alive and reproduce (Figure 1-4). There is little or no waste in natural systems.

Using the four **scientific principles of sustainability** to guide our lifestyles and economies could help us bring about an *environmental* or *sustainability revolution* during your lifetime (see the Guest Essay by Lester R. Brown at CengageNOW). Figure 1-18 lists some of the shifts involved in bringing about this new cultural change by learning how to live more sustainably.

Scientific evidence indicates that we have perhaps 50 years and no more than 100 years to make such crucial cultural changes. If this is correct, sometime during this century we could come to a critical fork in the road, at which point we will choose a path toward sustainability or continue on our current unsustainable course. Everything you do, or do not do, will play a role in our collective choice of which path we will take. One of the goals of this book is to provide a realistic environmental vision of the future that, instead of immobilizing you with fear, gloom, and doom, will energize you by inspiring realistic hope.

REVISITING Exponential Growth and Sustainability

We face an array of serious environmental problems. This book is about *solutions* to these problems. Making the transition to more sustainable societies and economies challenges us to devise ways to slow down the harmful effects of exponential growth (**Core Case Study**) and to use the same power of exponential growth to implement more sustainable lifestyles and economies.

The key is to apply the four **scientific principles of sustainability** (Figure 1-17 and **Concept 1-6**) to the design of our economic and social systems and to our individual lifestyles. We can use such information to help slow human population growth, sharply reduce poverty, curb the unsustainable forms of resource use that are eating away at the earth's natural capital, build social capital, and create a better world for ourselves, our children, and future generations.

Exponential growth is a double-edged sword. It can cause environmental harm. But we can also use it positively to amplify beneficial changes in our lifestyles and economies by applying the four **scientific principles of sustainability**. Through our individual and collective actions or inactions, we choose which side of that sword to use.

We are rapidly altering the planet that is our only home. If we make the right choices during this century, we can create an extraordinary and sustainable future on our planetary home. If we get it wrong, we face irreversible ecological disruption that could set humanity back for centuries and wipe out as many as half of the world's species.

You have the good fortune to be a member of the 21st century *transition generation,* which will decide what path humanity takes. What a challenging and exciting time to be alive!

What's the use of a house
if you don't have a decent planet to put it on?

HENRY DAVID THOREAU

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 6. What is **exponential growth?** Why is living in an exponential age a cause for concern for everyone living on the planet?

2. Define **environment.** Distinguish among **environmental science, ecology,** and **environmentalism.** Distinguish between an **organism** and a **species.** What is an **ecosystem?** What is **sustainability?** Explain the terms **natural capital, natural resources, natural services, solar capital,** and **natural capital degradation.** What is **nutrient cycling** and why is it important? Describe the ultimate goal of an **environmentally sustainable society.** What is **natural income?**

3. What is the difference between **economic growth** and **economic development?** Distinguish among **gross domestic product (GDP), per capita GDP,** and **per capita GDP PPP.** Distinguish between **developed countries** and **developing countries** and describe their key characteristics. What is **environmentally sustainable economic development?**

4. What is a **resource?** What is **conservation?** Distinguish among a **renewable resource, nonrenewable resource,** and **perpetual resource** and give an example of each. What is **sustainable yield?** Define and give three examples of **environmental degradation.** What is the tragedy of the commons? Distinguish between **recycling** and **reuse** and give an example of each. What is an **ecological footprint?** What is a **per capita ecological footprint?** Compare the total and per capita ecological footprints of the United States and China.

5. What is **culture?** Describe three major cultural changes that have occurred since humans arrived on the earth. Why has each change led to more environmental degradation? What is the **environmental** or **sustainability revolution?**

6. Define **pollution.** Distinguish between **point sources** and **nonpoint sources** of pollution. Distinguish between **biodegradable pollutants** and **nondegradable pollutants** and give an example of each. Distinguish between **pollution cleanup** and **pollution prevention** and give an example of each. Describe three problems with solutions that rely mostly on pollution cleanup.

7. Identify five basic causes of the environmental problems that we face today. What is **poverty?** In what ways do poverty and affluence affect the environment? Explain the problems we face by not including the harmful environmental costs in the prices of goods and services.

8. What is an **environmental worldview?** What is **environmental ethics?** Distinguish among the **planetary management, stewardship,** and **environmental wisdom worldviews.** Describe Aldo Leopold's environmental ethics. What major steps are involved in making an environmental decision? What is **social capital?**

9. Discuss the lessons we can learn from the environmental transformation of Chattanooga, Tennessee (USA). Explain why individuals matter in dealing with the environmental problems we face.

10. What are four **scientific principles of sustainability**? Explain how exponential growth (**Core Case Study**) affects them. CORE CASE STUDY SUSTAINABILITY

Note: Key Terms are in **bold** type.

CRITICAL THINKING

1. List three ways in which you could apply **Concepts 1-5A** and **1-6** to making your lifestyle more environmentally sustainable.

2. Describe two environmentally beneficial forms of exponential growth (**Core Case Study**). CORE CASE STUDY

3. Explain why you agree or disagree with the following propositions:
   - **a.** Stabilizing population is not desirable because, without more consumers, economic growth would stop.
   - **b.** The world will never run out of resources because we can use technology to find substitutes and to help us reduce resource waste.

4. Suppose the world's population stopped growing today. What environmental problems might this help solve? What environmental problems would remain? What economic problems might population stabilization make worse?

5. When you read that at least 19,200 people die prematurely each day (13 per minute) from preventable malnutrition and infectious disease, do you **(a)** doubt that it is true, **(b)** not want to think about it, **(c)** feel hopeless, **(d)** feel sad, **(e)** feel guilty, or **(f)** want to do something about this problem?

6. What do you think when you read that **(a)** the average American consumes 30 times more resources than

the average citizen of India, and **(b)** human activities are projected to make the earth's climate warmer? Are you skeptical, indifferent, sad, helpless, guilty, concerned, or outraged? Which of these feelings help perpetuate such problems, and which can help solve them?

7. For each of the following actions, state one or more of the four **scientific principles of sustainability** (Figure 1-17) that are involved: **(a)** recycling soda cans; **(b)** using a rake instead of leaf blower; **(c)** choosing to have no more than one child; **(d)** walking to class instead of driving; **(e)** taking your own reusable bags to the grocery store to carry things home in; **(f)** volunteering to help restore a prairie ; and **(g)** lobbying elected officials to require that 20% of your country's electricity be produced by renewable wind power by 2020.

8. Explain why you agree or disagree with each of the following statements: **(a)** humans are superior to other forms of life, **(b)** humans are in charge of the earth, **(c)** all economic growth is good, **(d)** the value of other forms of life depends only on whether they are useful to us, **(e)** because all forms of life eventually become extinct we should not worry about whether our activities cause their premature extinction, **(f)** all forms of life have an inherent right to exist, **(g)** nature has an almost unlimited storehouse of resources for human use, **(h)** technology can solve our environmental problems, **(i)** I do not believe I have any obligation to future generations, and **(j)** I do not believe I have any obligation to other forms of life.

9. What are the basic beliefs of your environmental worldview (p. 20)? Record your answer. Then at the end of this course, return to your answer to see if your environmental worldview has changed. Are the beliefs included in your environmental worldview consistent with your answers to question 8? Are your environmental actions consistent with your environmental worldview?

10. List two questions that you would like to have answered as a result of reading this chapter.

Note: See Supplement 13 (p. S78) for a list of Projects related to this chapter.

ECOLOGICAL FOOTPRINT ANALYSIS

If a country's or the world's *ecological footprint per person* (Figure 1-10, p. 15) is larger than its *biological capacity per person* to replenish its renewable resources and to absorb the resulting waste products and pollution, it is said to have an *ecological deficit*. If the reverse is true, it has an *ecological credit* or *reserve*. Use the data below to calculate the ecological deficit or credit for various countries. (For a map of ecological creditors and debtors, see Figure 4 on p. S26 in Supplement 4.)

Place	Per Capita Ecological Footprint (hectares per person)*	Per Capita Biocapacity (hectares per person)	Ecological Credit (+) or Debit (−) (hectares per person)
World	2.2	1.8	− 0.4
United States	9.8	4.7	
China	1.6	0.8	
India	0.8	0.4	
Russia	4.4	0.9	
Japan	4.4	0.7	
Brazil	2.1	9.9	
Germany	4.5	1.7	
United Kingdom	5.6	1.6	
Mexico	2.6	1.7	
Canada	7.6	14.5	

Source: Date from WWF, *Living Planet Report 2006*.
*1 hectare = 2.47 acres

1. Which two countries have the largest ecological deficits?

2. Which two countries have an ecological credit?

3. Rank the countries in order from the largest to the smallest per capita footprint.

LEARNING ONLINE

Log on to the Student Companion Site for this book at **academic.cengage.com/biology/miller**, and choose Chapter 1 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

2 Science, Matter, Energy, and Systems

CORE CASE STUDY Carrying Out a Controlled Scientific Experiment

One way in which scientists learn about how nature works is to conduct a *controlled experiment.* To begin, scientists isolate *variables,* or factors that can change within a system or situation being studied. An experiment involving *single-variable analysis* is designed to isolate and study the effects of one variable at a time.

To do such an experiment, scientists set up two groups. One is the *experimental group* in which a chosen variable is changed in a known way, and the other is the *control group* in which the chosen variable is not changed. If the experiment is designed and run properly, differences between the two groups should result from the variable that was changed in the experimental group.

In 1963, botanist F. Herbert Bormann, forest ecologist Gene Likens, and their colleagues began carrying out a classic controlled experiment. The goal was to compare the loss of water and nutrients from an uncut forest ecosystem (the *control site*) with one that was stripped of its trees (the *experimental site*).

They built V-shaped concrete dams across the creeks at the bottoms of several forested valleys in the Hubbard Brook Experimental Forest in New Hampshire (Figure 2-1). The dams were anchored on impenetrable bedrock, so that all surface water leaving each forested valley had to flow across a dam where scientists could measure its volume and dissolved nutrient content.

In the first experiment, the investigators measured the amounts of water and dissolved plant nutrients that entered and left an undisturbed forested area (the control site) (Figure 2-1, left). These measurements showed that an undisturbed mature forest is very efficient at storing water and retaining chemical nutrients in its soils.

The next experiment involved setting up an experimental forested area. One winter, the investigators cut down all trees and shrubs in one valley (the experimental site), left them where they fell, and sprayed the area with herbicides to prevent the regrowth of vegetation. Then they compared the inflow and outflow of water and nutrients in this experimental site (Figure 2-1, right) with those in the control site (Figure 2-1, left) for 3 years.

With no plants to help absorb and retain water, the amount of water flowing out of the deforested valley increased by 30–40%. As this excess water ran rapidly over the ground, it eroded soil and carried dissolved nutrients out of the deforested site. Overall, the loss of key nutrients from the experimental forest was six to eight times that in the nearby control forest.

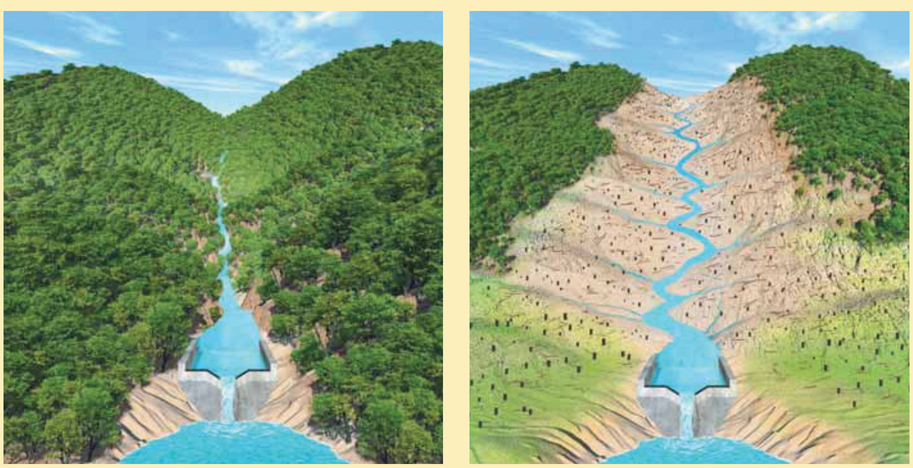


Figure 2-1 Controlled field experiment to measure the effects of deforestation on the loss of water and soil nutrients from a forest. V–notched dams were built into the impenetrable bedrock at the bottoms of several forested valleys (left) so that all water and nutrients flowing from each valley could be collected and measured for volume and mineral content. These measurements were recorded for the forested valley (left), which acted as the control site. Then all the trees in another valley (the experimental site) were cut (right) and the flows of water and soil nutrients from this experimental valley were measured for 3 years.

Key Questions and Concepts

2-1 What is science?

CONCEPT 2-1 Scientists collect data and develop theories, models, and laws about how nature works.

2-2 What is matter?

CONCEPT 2-2 Matter consists of elements and compounds, which are in turn made up of atoms, ions, or molecules.

2-3 How can matter change?

CONCEPT 2-3 When matter undergoes a physical or chemical change, no atoms are created or destroyed (the law of conservation of matter).

2-4 What is energy and how can it be changed?

CONCEPT 2-4A When energy is converted from one form to another in a physical or chemical change, no energy is created or destroyed (first law of thermodynamics).

CONCEPT 2-4B Whenever energy is changed from one form to another, we end up with lower-quality or less usable energy than we started with (second law of thermodynamics).

2-5 What are systems and how do they respond to change?

CONCEPT 2-5A Systems have inputs, flows, and outputs of matter and energy, and their behavior can be affected by feedback.

CONCEPT 2-5B Life, human systems, and the earth's life-support systems must conform to the law of conservation of matter and the two laws of thermodynamics.

Note: Supplements 1 (p. S2), 2 (p. S4), 5 (p. S31), and 6 (p. S39) can be used with this chapter.

Science is an adventure of the human spirit.
It is essentially an artistic enterprise, stimulated largely by curiosity,
served largely by disciplined imagination,
and based largely on faith in the reasonableness, order,
and beauty of the universe.

WARREN WEAVER

2-1 What Is Science?

▶ **CONCEPT 2-1 Scientists collect data and develop theories, models, and laws about how nature works.**

Science Is a Search for Order in Nature

Have you ever seen an area in a forest where all the trees were cut down? If so, you might wonder about the effects of cutting down all those trees. You might wonder how it affected the animals and people living in that area and how it affected the land itself. That is what scientists Bormann and Likens (**Core Case Study**) thought about when they designed their experiment. CORE CASE STUDY

Such curiosity is what motivates scientists. **Science** is an endeavor to discover how nature works and to use that knowledge to make predictions about what is likely to happen in nature. It is based on the assumption that events in the natural world follow orderly cause-and-effect patterns that can be understood through careful observation, measurements, experimentation, and modeling. Figure 2-2 (p. 30) summarizes the scientific process.

There is nothing mysterious about this process. You use it all the time in making decisions. Here is an example of applying the scientific process to an everyday situation:

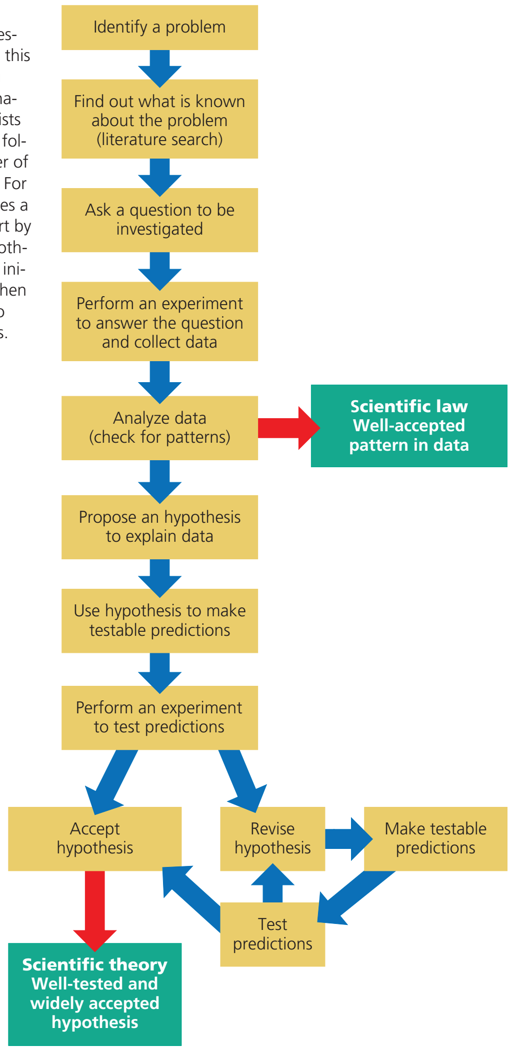
Observation: You try to switch on your flashlight and nothing happens.

Question: Why didn't the light come on?

Hypothesis: Maybe the batteries are dead.

Test the hypothesis: Put in new batteries and try to switch on the flashlight.

Figure 2-2 *What scientists do.* The essence of science is this process for testing ideas about how nature works. Scientists do not necessarily follow the exact order of steps shown here. For example, sometimes a scientist might start by formulating a hypothesis to answer the initial question and then run experiments to test the hypothesis.



Result: Flashlight still does not work.

New hypothesis: Maybe the bulb is burned out.

Experiment: Replace bulb with a new bulb.

Result: Flashlight works when switched on.

Conclusion: Second hypothesis is verified.

Here is a more formal outline of steps scientists often take in trying to understand nature, although not always in the order listed:

- *Identify a problem.* Bormann and Likens (**Core Case Study**) identified the loss of water and soil nutrients from cutover forests as a problem worth studying.
- *Find out what is known about the problem.* Bormann and Likens searched the scientific literature to find out what was known about retention and loss of water and soil nutrients in forests.
- *Ask a question to be investigated.* The scientists asked: "How does clearing forested land affect its ability to store water and retain soil nutrients?
- *Collect data to answer the question.* To collect **data**—information needed to answer their questions—scientists make observations of the subject area they are studying. Scientific observations involve gathering information by using human senses of sight, smell, hearing, and touch and extending those senses by using tools such as rulers, microscopes, and satellites. Often scientists conduct **experiments,** or procedures carried out under controlled conditions to gather information and test ideas. Bormann and Likens collected and analyzed data on the water and soil nutrients flowing from a patch of an undisturbed forest (Figure 2-1, left) and from a nearby patch of forest where they had cleared the trees for their experiment (Figure 2-1, right).
- *Propose a hypothesis to explain the data.* Scientists suggest a **scientific hypothesis,** a possible and testable explanation of what they observe in nature or in the results of their experiments. The data collected by Bormann and Likens show a decrease in the ability of a cleared forest to store water and retain soil nutrients such as nitrogen. They came up with the following hypothesis to explain their data: When a forest is cleared, it retains less water and loses large quantities of its soil nutrients when water from rain and melting snow flows across its exposed soil.
- *Make testable predictions.* Scientists use a hypothesis to make testable or logical predictions about what should happen if the hypothesis is valid. They often do this by making "If . . . then" predictions. Bormann and Likens predicted that *if* their original hypothesis was valid for nitrogen, *then* a cleared forest should also lose other soil nutrients such as phosphorus.
- *Test the predictions with further experiments, models, or observations.* To test their prediction, Bormann and Likens repeated their controlled experiment and measured the phosphorus content of the soil. Another way to test predictions is to develop a **model,** an approximate representation or simulation of a system being studied. Since Bormann and Likens performed their experiments, scientists have developed increasingly sophisticated mathematical and computer models of how forest systems work. Data from Bormann and Likens's research and that of other scientists can be fed into such models and

used to predict the loss of phosphorus and other types of soil nutrients. These predictions can be compared with the actual measured losses to test the validity of the models.

- *Accept or reject the hypothesis.* If their new data do not support their hypotheses, scientists come up with other testable explanations. This process continues until there is general agreement among scientists in the field being studied that a particular hypothesis is the best explanation of the data. After Bormann and Likens confirmed that the soil in a cleared forest also loses phosphorus, they measured losses of other soil nutrients, which also supported their hypothesis. A well-tested and widely accepted scientific hypothesis or a group of related hypotheses is called a **scientific theory.** Thus, Bormann and Likens and their colleagues developed a theory that trees and other plants hold soil in place and help it to retain water and nutrients needed by the plants for their growth.

Important features of the scientific process are *curiosity, skepticism, peer review, reproducibility,* and *openness to new ideas.* Good scientists are extremely curious about how nature works. But they tend to be highly skeptical of new data, hypotheses, and models until they can be tested and verified. **Peer review** happens when scientists report details of the methods and models they used, the results of their experiments, and the reasoning behind their hypotheses for other scientists working in the same field (their peers) to examine and criticize. Ideally, other scientists repeat and analyze the work to see if the data can be reproduced and whether the proposed hypothesis is reasonable and useful (Science Focus, below).

For example, Bormann and Likens (**Core Case Study**) submitted the results of their for-

CORE CASE STUDY

SCIENCE FOCUS

Easter Island: Some Revisions to a Popular Environmental Story

For years, the story of Easter Island has been used in textbooks as an example of how humans can seriously degrade their own life-support system. It concerns a civilization that once thrived and then largely disappeared from a small, isolated island in the great expanse of the South Pacific, located about 3,600 kilometers (2,200 miles) off the coast of Chile.

Scientists used anthropological evidence and scientific measurements to estimate the ages of certain artifacts found on Easter Island (also called Rapa Nui). They hypothesized that about 2,900 years ago, Polynesians used double-hulled, seagoing canoes to colonize the island. The settlers probably found a paradise with fertile soil that supported dense and diverse forests and lush grasses. According to this hypothesis, the islanders thrived, and their population increased to as many as 15,000 people.

Measurements made by scientists seemed to indicate that over time, the Polynesians began living unsustainably by using the island's forest and soil resources faster than they could be renewed. When they used up the large trees, the islanders could no longer build their traditional seagoing canoes for fishing in deeper offshore waters, and no one could escape the island by boat.

Without the once-great forests to absorb and slowly release water, springs and streams dried up, exposed soils were eroded, crop yields plummeted, and famine struck. There was no firewood for cooking or keeping warm. According to the original hypothesis, the population and the civilization collapsed as rival clans fought one another for dwindling food supplies, and the island's population dropped sharply. By the late 1870s, only about 100 native islanders were left.

In 2006, anthropologist Terry L. Hunt, Director of the University of Hawaii Rapa Nui Archeological Field School, evaluated the accuracy of past measurements and other evidence and carried out new measurements to estimate the ages of various artifacts. He used these data to formulate an alternative hypothesis describing the human tragedy on Easter Island.

Hunt came to several new conclusions. *First,* the Polynesians arrived on the island about 800 years ago, not 2,900 years ago. *Second,* their population size probably never exceeded 3,000, contrary to the earlier estimate of up to 15,000. *Third,* the Polynesians did use the island's trees and other vegetation in an unsustainable manner, and by 1722, visitors reported that most of the island's trees were gone.

But one question not answered by the earlier hypothesis was, why did the trees never grow back? Recent evidence and Hunt's new hypothesis suggest that rats (which either came along with the original settlers as stowaways or were brought along as a source of protein for the long voyage) played a key role in the island's permanent deforestation. Over the years, the rats multiplied rapidly into the millions and devoured the seeds that would have regenerated the forests.

Another of Hunt's conclusions was that after 1722, the population of Polynesians on the island dropped to about 100, mostly from contact with European visitors and invaders. Hunt hypothesized that these newcomers introduced fatal diseases, killed off some of the islanders, and took large numbers of them away to be sold as slaves.

This story is an excellent example of how science works. The gathering of new scientific data and reevaluation of older data led to a revised hypothesis that challenges our thinking about the decline of civilization on Easter Island. As a result, the tragedy may not be as clear an example of human-caused ecological collapse as was once thought. However, there is evidence that other earlier civilizations did suffer ecological collapse largely from unsustainable use of soil, water, and other resources, as described in Supplement 5 on p. S31.

Critical Thinking

Does the new doubt about the original Easter Island hypothesis mean that we should not be concerned about using resources unsustainably on the island in space we call Earth? Explain.

est experiments to a respected scientific journal. Before publishing this report, the journal editors had it reviewed by other soil and forest experts. Other scientists have repeated the measurements of soil content in undisturbed and cleared forests of the same type and also in different types of forests. Their results have also been subjected to peer review. In addition, computer models of forest systems have been used to evaluate this problem, with the results subjected to peer review.

Scientific knowledge advances in this way, with scientists continually questioning measurements, making new measurements, and sometimes coming up with new and better hypotheses (Science Focus, p. 31). As a result, good scientists are *open to new ideas* that have survived the rigors of the scientific process.

Scientists Use Reasoning, Imagination, and Creativity to Learn How Nature Works

Scientists arrive at conclusions, with varying degrees of certainty, by using two major types of reasoning. **Inductive reasoning** involves using specific observations and measurements to arrive at a general conclusion or hypothesis. It is a form of "bottom-up" reasoning that goes from the specific to the general. For example, suppose we observe that a variety of different objects fall to the ground when we drop them from various heights. We can then use inductive reasoning to propose that *all objects fall to the earth's surface when dropped.*

Depending on the number of observations made, there may be a high degree of certainty in this conclusion. However, what we are really saying is "All objects that we or other observers have dropped from various heights have fallen to the earth's surface." Although it is extremely unlikely, we cannot be *absolutely sure* that no one will ever drop an object that does not fall to the earth's surface.

Deductive reasoning involves using logic to arrive at a specific conclusion based on a generalization or premise. It is a form of "top-down" reasoning that goes from the general to the specific. For example,

Generalization or premise: All birds have feathers.

Example: Eagles are birds.

Deductive conclusion: Eagles have feathers.

THINKING ABOUT

The Hubbard Brook Experiment and Scientific Reasoning

CORE CASE STUDY

In carrying out and interpreting their experiment, did Bormann and Likens rely primarily on inductive or deductive reasoning?

Deductive and inductive reasoning and critical thinking skills (pp. 2–3) are important scientific tools. But scientists also use intuition, imagination, and creativity to explain some of their observations in nature. Often such ideas defy conventional logic and current scientific knowledge. According to physicist Albert Einstein, "There is no completely logical way to a new scientific idea." Intuition, imagination, and creativity are as important in science as they are in poetry, art, music, and other great adventures of the human spirit, as reflected by scientist Warren Weaver's quotation found at the opening of this chapter.

Scientific Theories and Laws Are the Most Important Results of Science

If an overwhelming body of observations and measurements supports a scientific hypothesis, it becomes a scientific theory. *Scientific theories are not to be taken lightly.* They have been tested widely, are supported by extensive evidence, and are accepted by most scientists in a particular field or related fields of study.

Nonscientists often use the word *theory* incorrectly when they actually mean *scientific hypothesis,* a tentative explanation that needs further evaluation. The statement, "Oh, that's just a theory," made in everyday conversation, implies that the theory was stated without proper investigation and careful testing—the opposite of the scientific meaning of the word.

Another important and reliable outcome of science is a **scientific law,** or **law of nature:** a well-tested and widely accepted description of what we find happening over and over again in the same way in nature. An example is the *law of gravity,* based on countless observations and measurements of objects falling from different heights. According to this law, all objects fall to the earth's surface at predictable speeds.

A scientific law is no better than the accuracy of the observations or measurements upon which it is based (see Figure 1 in Supplement 1 on p. S3). But if the data are accurate, a scientific law cannot be broken, unless and until we get contradictory new data.

Scientific theories and laws have a high probability of being valid, but they are not infallible. Occasionally, new discoveries and new ideas can overthrow a well-accepted scientific theory or law in what is called a **paradigm shift.** It occurs when the majority of scientists in a field or related fields accept a new *paradigm,* or framework for theories and laws in a particular field.

A good way to summarize the most important outcomes of science is to say that scientists collect data and develop theories, models, and laws that describe and explain how nature works (**Concept 2-1**). Scientists use reasoning and critical thinking skills. But the best scientists also use intuition, imagination, and creativity in asking important questions, developing hypotheses, and designing ways to test them.

For a superb look at how science works and what scientists do, see the Annenberg video series, *The Habitable Planet: A Systems Approach to Environmental Science* (see the website at **www.learner.org/resources/series209.html**). Each of the 13 videos describes how scientists working on two different problems related to a certain subject are learning about how nature works. Also see Video 2, *Thinking Like Scientists,* in another Annenberg series, *Teaching High School Science* (see the website at **www.learner.org/resources/series126.html**).

The Results of Science Can Be Tentative, Reliable, or Unreliable

A fundamental part of science is *testing.* Scientists insist on testing their hypotheses, models, methods, and results over and over again to establish the reliability of these scientific tools and the resulting conclusions.

Media news reports often focus on disputes among scientists over the validity of data, hypotheses, models, methods, or results (see Science Focus, below). This helps to reveal differences in the reliability of various scientific tools and results. Simply put, some science is more reliable than other science, depending on how carefully it has been done and on how thoroughly the hypotheses, models, methods, and results have been tested.

Sometimes, preliminary results that capture news headlines are controversial because they have not been widely tested and accepted by peer review. They are not yet considered reliable, and can be thought of as **tentative science** or **frontier science.** Some of these results will be validated and classified as reliable and some will be discredited and classified as unreliable. At the frontier stage, it is normal for scientists to disagree about the meaning and accuracy of data and the validity of hypotheses and results. This is how scientific knowledge advances.

By contrast, **reliable science** consists of data, hypotheses, theories, and laws that are widely accepted by scientists who are considered experts in the field under study. The results of reliable science are based on

SCIENCE FOCUS

The Scientific Consensus over Global Warming

Based on measurements and models, it is clear that carbon dioxide and other gases in the atmosphere play a major role in determining the temperature of the atmosphere through a natural warming process called the *natural greenhouse effect.* Without the presence of these *greenhouse gases* in the atmosphere, the earth would be too cold for most life as we know it to exist, and you would not be reading these words. The earth's natural greenhouse effect is one of the most widely accepted theories in the atmospheric sciences and is an example of *reliable science.*

Since 1980, many climate scientists have been focusing their studies on three major questions:

- How much has the earth's atmosphere warmed during the past 50 years?
- How much of the warming is the result of human activities such as burning oil, gas, and coal and clearing forests, which add carbon dioxide and other greenhouse gases to the atmosphere?
- How much is the atmosphere likely to warm in the future and how might this affect the climate of different parts of the world?

To help clarify these issues, in 1988, the United Nations and the World Meteorological Organization established the Intergovernmental Panel on Climate Change (IPCC) to study how the climate system works, document past climate changes, and project future climate changes. The IPCC network includes more than 2,500 climate experts from 70 nations.

Since 1990, the IPCC has published four major reports summarizing the scientific consensus among these climate experts. In its 2007 report, the IPCC came to three major conclusions:

- It is *very likely* (a 90–99% probability) that the lower atmosphere is getting warmer and has warmed by about 0.74 C° (1.3 F°) between 1906 and 2005.
- Based on analysis of past climate data and use of 19 climate models, it is *very likely* (a 90–99% probability) that human activities, led by emissions of carbon dioxide from burning fossil fuels, have been the main cause of the observed atmospheric warming during the past 50 years.
- It is *very likely* that the earth's mean surface temperature will increase by about 3 C° (5.4 F°) between 2005 and 2100, unless we make drastic cuts in greenhouse gas emissions from power plants, factories, and cars that burn fossil fuels.

This scientific consensus among most of the world's climate experts is currently considered the most *reliable science* we have on this subject.

As always, there are individual scientists who disagree with the scientific consensus view. Typically, they question the reliability of certain data, say we don't have enough data to come to reliable conclusions, or question some of the hypotheses or models involved. However, in the case of global warming, they are in a distinct and declining minority.

Media reports are sometimes confusing or misleading because they present reliable science along with a quote from a scientist in the field who disagrees with the consensus view, or from someone who is not an expert in the field. This can cause public distrust of well-established reliable science, such as that reported by the IPCC, and may sometimes lead to a belief in ideas that are not widely accepted by the scientific community. (See the Guest Essay on environmental reporting by Andrew C. Revkin at CengageNOW.)

Critical Thinking

Find a newspaper article or other media report that presents the scientific consensus view on global warming and then attempts to balance it with a quote from a scientist who disagrees with the consensus view. Try to determine: **(a)** whether the dissenting scientist is considered an expert in climate science, **(b)** whether the scientist has published any peer reviewed papers on the subject, and **(c)** what organizations or industries are supporting the dissenting scientist.

the self-correcting process of testing, open peer review, reproducibility, and debate. New evidence and better hypotheses (Science Focus, p. 31) may discredit or alter tried and accepted views and even result in paradigm shifts. But unless that happens, those views are considered to be the results of reliable science.

Scientific hypotheses and results that are presented as reliable without having undergone the rigors of peer review, or that have been discarded as a result of peer review, are considered to be **unreliable science.** Here are some critical thinking questions you can use to uncover unreliable science:

- Was the experiment well designed? Did it involve enough testing? Did it involve a control group? (**Core Case Study**) CORE CASE STUDY
- Have the data supporting the proposed hypotheses been verified? Have the results been reproduced by other scientists?
- Do the conclusions and hypotheses follow logically from the data?
- Are the investigators unbiased in their interpretations of the results? Are they free of a hidden agenda? Were they funded by an unbiased source?
- Have the conclusions been verified by impartial peer review?
- Are the conclusions of the research widely accepted by other experts in this field?

If the answer to each of these questions is "yes," then the results can be classified as reliable science. Otherwise, the results may represent tentative science that needs further testing and evaluation, or they can be classified as unreliable science.

Environmental Science Has Some Limitations

Before continuing our study of environmental science, we need to recognize some of its limitations, as well as those of science in general. *First,* scientists can disprove things but they cannot prove anything absolutely, because there is always some degree of uncertainty in scientific measurements, observations, and models.

SCIENCE FOCUS

Statistics and Probability

Statistics consists of mathematical tools used to collect, organize, and interpret numerical data. For example, suppose we weigh each individual in a population of 15 rabbits. We can use statistics to calculate the *average* weight of the population. To do this, we add up the weights of the 15 rabbits and divide the total by 15. Similarly, Bormann and Likens (**Core Case Study**) made many measurements of nitrate levels in the water flowing from their undisturbed and cut patches of forests (Figure 2-1) and then averaged the results to get the most reliable value. CORE CASE STUDY

Scientists also use the statistical concept of probability to evaluate their results. **Probability** is the chance that something will happen. For example, if you toss a nickel, what is the probability or chance that it will come up heads? If your answer is 50%, you are correct. The chance of the nickel coming up heads is ½, which can also be expressed as 50% or 0.5. Probability is often expressed as a number between 0 and 1 written as a decimal (such as 0.5).

Now suppose you toss the coin 10 times and it comes up heads 6 times. Does this mean that the probability of it coming up heads is 0.6 or 60%? The answer is no because the *sample size*—the number of objects or events studied—was too small to yield a statistically accurate result. If you increase your sample size to 1,000 by tossing the coin 1,000 times, you are almost certain to get heads 50% of the time and tails 50% of the time.

It is important when doing scientific research to take samples in different places, in order to get a comprehensive evaluation of the variable being studied. It is also critical to have a large enough sample size to give an accurate estimate of the overall probability of an event happening.

For example, if you wanted to study the effects of a certain air pollutant on the needles of pine trees, you would need to locate different stands of the same type of pine tree that are all exposed to the pollutant over a certain period of time. At each location, you would need to measure the levels of the pollutant in the atmosphere at different times and average the results. You would also need to make measurements of the damage (such as needle loss) to a large enough sample of trees in each location over a certain time period. Then you would average the results in each location and compare the results from all locations.

If the average results were consistent in different locations, you could then say that there is a certain probability, say 60% (or 0.6), that this type of pine tree suffered a certain percentage loss of its needles when exposed to a specified average level of the pollutant over a given time. You would also need to run other experiments to determine that natural needle loss, extreme temperatures, insects, plant diseases, drought, or other factors did not cause the needle losses you observed. As you can see, getting reliable scientific results is not a simple process.

Critical Thinking

What does it mean when an international body of the world's climate experts says that there is a 90–99% chance (probability of 0.9–0.99) that human activities, led by emissions of carbon dioxide from burning fossil fuels, have been the main cause of the observed atmospheric warming during the past 50 years? Why would the probability never be 100%?

Instead scientists try to establish that a particular hypothesis, theory, or law has a very high *probability* (90–99%) of being true and thus is classified as reliable science. Most scientists rarely say something like, "Cigarettes cause lung cancer." Rather, they might say, "Overwhelming evidence from thousands of studies indicates that people who smoke have an increased risk of developing lung cancer."

THINKING ABOUT
Scientific Proof

Does the fact that science can never prove anything absolutely mean that its results are not valid or useful? Explain.

Second, scientists are human and cannot be expected to be totally free of bias about their results and hypotheses. However, bias can be minimized and often uncovered by the high standards of evidence required through peer review, although some scientists are bypassing traditional peer review by publishing their results online.

A *third* limitation involves use of statistical tools. There is no way to measure accurately how much soil is eroded annually worldwide, for example. Instead, scientists use statistical sampling and methods to estimate such numbers (Science Focus, at left). Such results should not be dismissed as "only estimates" because they can indicate important trends.

A *fourth* problem is that many environmental phenomena involve a huge number of interacting variables and complex interactions, which makes it too costly to test one variable at a time in controlled experiments such as the one described in the **Core Case Study** that opens this chapter. To help deal with this problem, scientists develop mathematical models that include the interactions of many variables. Running such models on computers can sometimes overcome this limitation and save both time and money. In addition, computer models can be used to simulate global experiments on phenomena like climate change, which are impossible to do in a controlled physical experiment.

CORE CASE STUDY

Finally, the scientific process is limited to understanding the natural world. It cannot be applied to moral or ethical questions, because such questions are about matters for which we cannot collect data from the natural world. For example, we can use the scientific process to understand the effects of removing trees from an ecosystem, but this process does not tell us whether it is right or wrong to remove the trees.

Much progress has been made, but we still know too little about how the earth works, its current state of environmental health, and the environmental impacts of our activities. These knowledge gaps point to important *research frontiers,* several of which are highlighted throughout this text.

2-2 What Is Matter?

CONCEPT 2-2 Matter consists of elements and compounds, which are in turn made up of atoms, ions, or molecules.

Matter Consists of Elements and Compounds

To begin our study of environmental science, we start at the most basic level, looking at matter—the stuff that makes up life and its environment. **Matter** is anything that has mass and takes up space. It is made up of **elements,** each of which is a fundamental substance that has a unique set of properties and cannot be broken down into simpler substances by chemical means. For example, gold is an element; it cannot be broken down chemically into any other substance.

Some matter is composed of one element, such as gold or silver, but most matter consists of **compounds:** combinations of two or more different elements held together in fixed proportions. For example, water is a compound made of the elements hydrogen and oxygen, which have chemically combined with one another. (See Supplement 6 on p. S39 for an expanded discussion of basic chemistry.)

To simplify things, chemists represent each element by a one- or two-letter symbol. Table 2-1 (p. 36), lists the elements and their symbols that you need to know to understand the material in this book. Just four elements—oxygen, carbon, hydrogen, and nitrogen—make up about 96% of your body weight and that of most other living things.

Atoms, Ions, and Molecules Are the Building Blocks of Matter

The most basic building block of matter is an **atom:** the smallest unit of matter into which an element can be divided and still retain its chemical properties. The idea that all elements are made up of atoms is called the **atomic theory** and is the most widely accepted scientific theory in chemistry.

Table 2-1

Elements Important to the Study of Environmental Science

Element	Symbol	Element	Symbol
Hydrogen	H	Bromine	Br
Carbon	C	Sodium	Na
Oxygen	O	Calcium	Ca
Nitrogen	N	Lead	Pb
Phosphorus	P	Mercury	Hg
Sulfur	S	Arsenic	As
Chlorine	Cl	Uranium	U
Fluorine	F		

Atoms are incredibly small. In fact, more than 3 million hydrogen atoms could sit side by side on the period at the end of this sentence. If you could view them with a supermicroscope, you would find that each different type of atom contains a certain number of three different types of *subatomic particles:* positively charged **protons (p), neutrons (n)** with no electrical charge, and negatively charged **electrons (e).**

Each atom consists of an extremely small and dense center called its **nucleus**—which contains one or more protons and, in most cases, one or more neutrons—and one or more electrons moving rapidly somewhere around the nucleus in what is called an *electron probability cloud* (Figure 2-3). Each atom (except for *ions,* expained at right) has equal numbers of positively charged protons and negatively charged electrons. Because these electrical charges cancel one another, *atoms as a whole have no net electrical charge.*

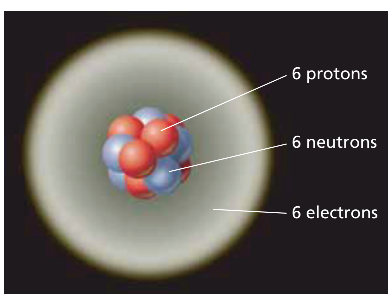


Figure 2-3 Greatly simplified model of a carbon-12 atom. It consists of a nucleus containing six positively charge protons and six neutral neutrons. There are six negatively charged electrons found outside its nucleus. We cannot determine the exact locations of the electrons. Instead, we can estimate the *probability* that they will be found at various locations outside the nucleus—sometimes called an *electron probability cloud.* This is somewhat like saying that there are six airplanes flying around inside a cloud. We don't know their exact location, but the cloud represents an area where we can probably find them.

Each element has a unique **atomic number,** equal to the number of protons in the nucleus of its atom. Carbon (C), with 6 protons in its nucleus (Figure 2-3), has an atomic number of 6, whereas uranium (U), a much larger atom, has 92 protons in its nucleus and an atomic number of 92.

Because electrons have so little mass compared to protons and neutrons, *most of an atom's mass is concentrated in its nucleus.* The mass of an atom is described by its **mass number:** the total number of neutrons and protons in its nucleus. For example, a carbon atom with 6 protons and 6 neutrons in its nucleus has a mass number of 12, and a uranium atom with 92 protons and 143 neutrons in its nucleus has a mass number of 235 ($92 + 143 = 235$).

Each atom of a particular element has the same number of protons in its nucleus. But the nuclei of atoms of a particular element can vary in the number of neutrons they contain, and therefore, in their mass numbers. Forms of an element having the same atomic number but different mass numbers are called **isotopes** of that element. Scientists identify isotopes by attaching their mass numbers to the name or symbol of the element. For example, the three most common isotopes of carbon are carbon-12 (Figure 2-3, with six protons and six neutrons), carbon-13 (with six protons and seven neutrons), and carbon-14 (with six protons and eight neutrons). Carbon-12 makes up about 98.9% of all naturally occurring carbon.

A second building block of matter is an **ion**—an atom or groups of atoms with one or more net positive or negative electrical charges. An ion forms when an atom gains or loses one or more electrons. An atom that loses one or more of its electrons becomes an ion with one or more positive electrical charges, because the number of positively charged protons in its nucleus is now greater than the number of negatively charged electrons outside its nucleus. Similarly, when an atom gains one or more electrons, it becomes an ion with one or more negative electrical charges, because the number of negatively charged electrons is greater than the number of positively charged protons in its nucleus.

Ions containing atoms of more than one element are the basic units found in some compounds (called *ionic compounds*). For more details on how ions form see p. S39 in Supplement 6.

The number of positive or negative charges carried by an ion is shown as a superscript after the symbol for an atom or a group of atoms. Examples encountered in this book include a *positive* hydrogen ion (H^+), with one positive charge, an aluminum ion (Al^{3+}) with three positive charges, and a *negative* chloride ion (Cl^-) with one negative charge. These and other ions listed in Table 2-2 are used in other chapters in this book.

One example of the importance of ions in our study of environmental science is the nitrate ion (NO_3^-), a nutrient essential for plant growth. Figure 2-4 shows measurements of the loss of nitrate ions from the deforested area (Figure 2-1, right) in the controlled experiment run by Bormann and Likens (**Core Case Study**). Numerous chemical analyses of the water flowing through the dams of the cleared forest area showed an average 60-fold rise in the concentration of NO_3^- compared to water running off of the uncleared forest area. The stream below this valley became covered with algae whose populations soared as a result of an excess of nitrate plant nutrients. After a few years, however, vegetation began growing back on the cleared valley and nitrate levels in its runoff returned to normal levels.

Ions are also important for measuring a substance's **acidity** in a water solution, a chemical characteristic that helps determine how a substance dissolved in water will interact with and affect its environment. Scientists use **pH** as a measure of acidity, based on the amount of hydrogen ions (H^+) and hydroxide ions (OH^-) contained in a particular volume of a solution. Pure water (not tap water or rainwater) has an equal number of H^+ and OH^- ions. It is called a *neutral solution* and has a pH of 7. An *acidic solution* has more hydrogen ions than hydroxide ions and has a pH less than 7. A *basic solution* has more hydroxide ions than hydrogen ions and has a pH greater than 7. (See Figure 5 on p. S41 in Supplement 6 for more details.)

The third building block of matter is a **molecule:** a combination of two or more atoms of the same or different elements held together by forces called *chemical bonds*. Molecules are the basic units of some compounds

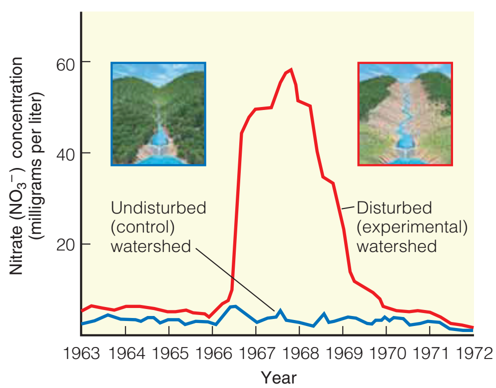


Figure 2-4 Loss of nitrate ions (NO_3^-) from a deforested watershed in the Hubbard Brook Experimental Forest in New Hampshire (Figure 2-1, right). The average concentration of nitrate ions in runoff from the deforested experimental watershed was 60 times greater than in a nearby unlogged watershed used as a control (Figure 2-1, left). (Data from F. H. Bormann and Gene Likens)

Table 2-2

Ions Important to the Study of Environmental Science

Positive Ion	Symbol	Negative Ion	Symbol
hydrogen ion	H^+	chloride ion	Cl^-
sodium ion	Na^+	hydroxide ion	OH^-
calcium ion	Ca^{2+}	nitrate ion	NO_3^-
aluminum ion	Al^{3+}	sulfate ion	SO_4^{2-}
ammonium ion	NH_4^+	phosphate ion	PO_4^{3-}

Table 2-3

Compounds Important to the Study of Environmental Science

Compound	Formula	Compound	Formula
sodium chloride	NaCl	methane	CH_4
carbon monoxide	CO	glucose	$C_6H_{12}O_6$
carbon dioxide	CO_2	water	H_2O
nitric oxide	NO	hydrogen sulfide	H_2S
nitrogen dioxide	NO_2	sulfur dioxide	SO_2
nitrous oxide	N_2O	sulfuric acid	H_2SO_4
nitric acid	HNO_3	ammonia	NH_3

(called *molecular compounds*). Examples are shown in Figure 4 on p. S41 in Supplement 6.

Chemists use a **chemical formula** to show the number of each type of atom or ion in a compound. This shorthand contains the symbol for each element present and uses subscripts to represent the number of atoms or ions of each element in the compound's basic structural unit. Examples of compounds and their formulas encountered in this book are sodium chloride (NaCl) and water (H_2O, read as "H-two-O"). These and other compounds important to our study of environmental science are listed in Table 2-3.

You may wish to mark the pages containing Tables 2-1 through 2-3, as they could be useful references for understanding material in other chapters.

CENGAGENOW™ Examine atoms—their parts, how they work, and how they bond together to form molecules—at CengageNOW™.

Organic Compounds Are the Chemicals of Life

Table sugar, vitamins, plastics, aspirin, penicillin, and most of the chemicals in your body are **organic compounds,** which contain at least two carbon atoms combined with atoms of one or more other elements. All other compounds are called **inorganic compounds.** One exception, methane (CH_4), has only one carbon atom but is considered an organic compound.

The millions of known organic (carbon-based) compounds include the following:

- *Hydrocarbons:* compounds of carbon and hydrogen atoms. One example is methane (CH_4), the main component of natural gas, and the simplest organic compound. Another is octane (C_8H_{18}), a major component of gasoline.
- *Chlorinated hydrocarbons:* compounds of carbon, hydrogen, and chlorine atoms. An example is the insecticide DDT ($C_{14}H_9Cl_5$).
- *Simple carbohydrates* (simple sugars): certain types of compounds of carbon, hydrogen, and oxygen atoms. An example is glucose ($C_6H_{12}O_6$), which most plants and animals break down in their cells to obtain energy. (For more details see Figure 8 on p. S42 in Supplement 6.)

Larger and more complex organic compounds, essential to life, are composed of *macromolecules.* Some of these molecules, called *polymers,* are formed when a number of simple organic molecules (*monomers*) are linked together by chemical bonds, somewhat like rail cars linked in a freight train. The three major types of organic polymers are

- *complex carbohydrates* such as cellulose and starch, which consist of two or more monomers of simple sugars such as glucose (see Figure 8 on p. S42 in Supplement 6),
- *proteins* formed by monomers called *amino acids* (see Figure 9 on p. S42 in Supplement 6), and
- *nucleic acids* (DNA and RNA) formed by monomers called *nucleotides* (see Figures 10 and 11 on p. S43 in Supplement 6).

Lipids, which include fats and waxes, are a fourth type of macromolecule essential for life (see Figure 12 on p. S43 in Supplement 6).

Matter Comes to Life through Genes, Chromosomes, and Cells

The story of matter, starting with the hydrogen atom, becomes more complex as molecules grow in complexity. This is no less true when we examine the fundamental components of life. The bridge between nonliving and living matter lies somewhere between macromolecules and **cells**—the fundamental structural units of life, which we explore in more detail in the next chapter.

Above, we mentioned nucleotides in DNA (see Figures 10 and 11 on p. S43 in Supplement 6). Within some DNA molecules are certain sequences of nucleotides called **genes.** Each of these distinct pieces of DNA contains instructions, called *genetic information,* for making specific proteins. Each of these coded units of genetic information concerns a specific **trait,** or characteristic passed on from parents to offspring during reproduction in an animal or plant.

Thousands of genes, in turn, make up a single **chromosome,** a special DNA molecule together with a number of proteins. Genetic information coded in your chromosomal DNA is what makes you different from an oak leaf, an alligator, or a flea, and from your parents. In other words, it makes you human, but it also makes you unique. The relationships of genetic material to cells are depicted in Figure 2-5.

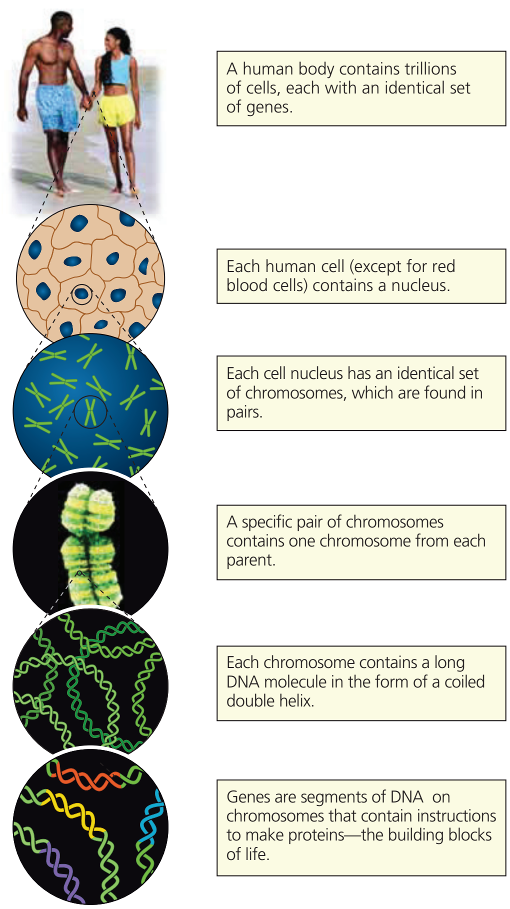


Figure 2-5 Relationships among cells, nuclei, chromosomes, DNA, and genes.

Matter Occurs in Various Physical Forms

The atoms, ions, and molecules that make up matter are found in three *physical states:* solid, liquid, and gas. For example, water exists as ice, liquid water, or water vapor depending on its temperature and the surrounding air pressure. The three physical states of any sample of matter differ in the spacing and orderliness of its atoms, ions, or molecules. A solid has the most compact and orderly arrangement, and a gas the least compact and orderly arrangement. Liquids are somewhere in between.

Some Forms of Matter Are More Useful than Others

Matter quality is a measure of how useful a form of matter is to humans as a resource, based on its availability and *concentration,* or amount of it that is contained in a given area or volume. **High-quality matter** is highly concentrated, is typically found near the earth's surface, and has great potential for use as a resource. Low-quality matter is not highly concentrated, is often located deep underground or dispersed in the ocean or atmosphere, and usually has little potential for use as a resource. See Figure 2-6 for examples illustrating differences in matter quality.

Figure 2-6 Examples of differences in matter quality. *High-quality matter* (left column) is fairly easy to extract and is highly concentrated; *low-quality matter* (right column) is not highly concentrated and is more difficult to extract than high-quality matter.

2-3 How Can Matter Change?

▶ **CONCEPT 2-3 When matter undergoes a physical or chemical change, no atoms are created or destroyed (the law of conservation of matter).**

Matter Undergoes Physical, Chemical, and Nuclear Changes

When a sample of matter undergoes a **physical change,** its *chemical composition,* or the arrangement of its atoms or ions within molecules does not change. A piece of aluminum foil cut into small pieces is still aluminum foil. When solid water (ice) melts or liquid water boils, none of the H_2O molecules are changed. The molecules are simply arranged in different spatial (physical) patterns.

THINKING ABOUT
Controlled Experiments and Physical Changes (CORE CASE STUDY)

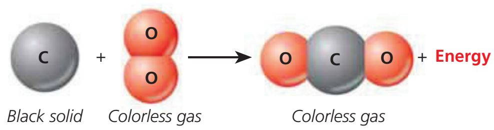
How would you set up a controlled experiment (**Core Case Study**) to verify that when water changes from one physical state to another, its chemical composition does not change?

In a **chemical change,** or **chemical reaction,** there is a change in the arrangement of atoms or ions within molecules of the substances involved. Chemists use *chemical equations* to represent what happens in a chemical reaction. For example, when coal burns completely, the solid carbon (C) in the coal combines with oxygen gas (O_2) from the atmosphere to form the gaseous compound carbon dioxide (CO_2).

Reactant(s) ⟶ **Product(s)**

Carbon + Oxygen ⟶ Carbon dioxide + **Energy**

$C + O_2 \longrightarrow CO_2 +$ **Energy**



In addition to physical and chemical changes, matter can undergo three types of **nuclear changes,** or changes in the nuclei of its atoms (Figure 2-7). In the first type, called **natural radioactive decay,** isotopes spontaneously emit fast-moving subatomic particles, high-energy radiation such as gamma rays, or both (Figure 2-7, top). The unstable isotopes are called **radioactive isotopes** or **radioisotopes.**

Nuclear fission is a nuclear change in which the nuclei of certain isotopes with large mass numbers (such as uranium-235) are split apart into lighter nuclei when struck by neutrons; each fission releases two or three neutrons plus energy (Figure 2-7, middle). Each of these neutrons, in turn, can trigger an additional fission reaction. Multiple fissions within a certain amount of mass produce a **chain reaction,** which releases an enormous amount of energy.

Nuclear fusion is a nuclear change in which two isotopes of light elements, such as hydrogen, are forced together at extremely high temperatures until they fuse to form a heavier nucleus (Figure 2-7, bottom). A tremendous amount of energy is released in this process. Fusion of hydrogen nuclei to form helium nuclei is the source of energy in the sun and other stars.

We Cannot Create or Destroy Matter

We can change elements and compounds from one physical, chemical, or nuclear form to another, but we can never create or destroy any of the atoms involved in any physical or chemical change. All we can do is rearrange the atoms, ions, or molecules into different spatial patterns (physical changes) or combinations (chemical changes). These statements, based on many thousands of measurements, describe a scientific law known as the **law of conservation of matter:** when a physical or chemical change occurs, no atoms are created or destroyed (**Concept 2-3**).

This law means there is no "away" as in "to throw away." *Everything we think we have thrown away remains here with us in some form.* We can reuse or recycle some materials and chemicals, but the law of conservation of matter means we will always face the problem of what to do with some quantity of the wastes and pollutants we produce.

We talk about consuming matter as if matter is being used up or destroyed, but the law of conservation of matter says that this is impossible. What is meant by *matter consumption,* is not destruction of matter, but rather conversion of matter from one form to another.

2-4 What Is Energy and How Can It Be Changed?

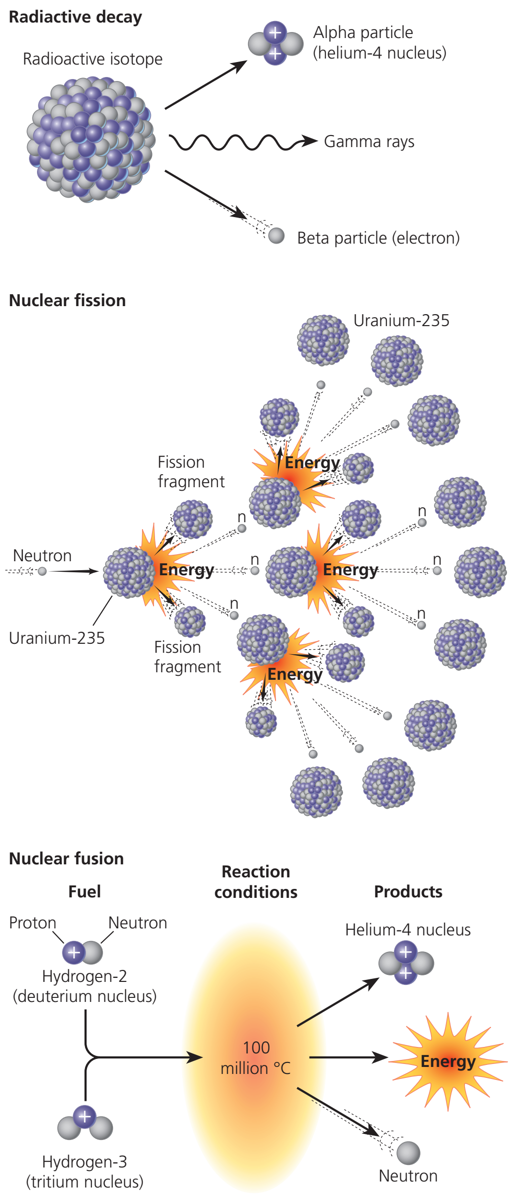
▶ **CONCEPT 2-4A When energy is converted from one form to another in a physical or chemical change, no energy is created or destroyed (first law of thermodynamics).**

▶ **CONCEPT 2-4B Whenever energy is changed from one form to another, we end up with lower-quality or less usable energy than we started with (second law of thermodynamics).**

Energy Comes in Many Forms

Energy is the capacity to do work or transfer heat. Work is done when something is moved. The amount of work done is the product of the force applied to an object to move it a certain distance (work = force × distance). For example, it takes a certain amount of muscular force to lift this book to a certain height.

There are two major types of energy: *moving energy* (called *kinetic energy*) and *stored energy* (called *potential energy*). Moving matter has **kinetic energy** because it has mass and velocity. Examples are wind (a mov-



Radioactive decay occurs when nuclei of unstable isotopes spontaneously emit fast-moving chunks of matter (alpha particles or beta particles), high-energy radiation (gamma rays), or both at a fixed rate. A particular radioactive isotope may emit any one or a combination of the three items shown in the diagram.

Nuclear fission occurs when the nuclei of certain isotopes with large mass numbers (such as uranium-235) are split apart into lighter nuclei when struck by a neutron and release energy plus two or three more neutrons. Each neutron can trigger an additional fission reaction and lead to a *chain reaction*, which releases an enormous amount of energy.

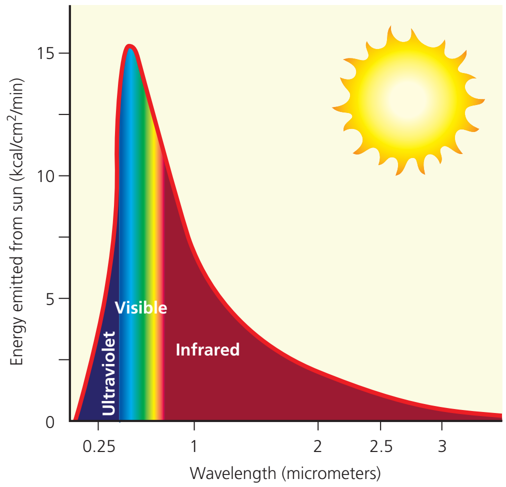
Nuclear fusion occurs when two isotopes of light elements, such as hydrogen, are forced together at extremely high temperatures until they fuse to form a heavier nucleus and release a tremendous amount of energy.

Figure 2-7 Types of nuclear changes: natural radioactive decay (top), nuclear fission (middle), and nuclear fusion (bottom).

ing mass of air), flowing water, and electricity (flowing electrons).

Another form of kinetic energy is **heat:** the total kinetic energy of all moving atoms, ions, or molecules within a given substance. When two objects at different temperatures contact one another, heat flows from the warmer object to the cooler object.

Heat can be transferred from one place to another by three different methods: *radiation* (the emission of electromagnetic energy), *conduction* (the transfer of



CENGAGENOW™ **Active Figure 2-8** *Solar capital:* the spectrum of electromagnetic radiation released by the sun consists mostly of visible light. *See an animation based on this figure at* CengageNOW.

kinetic energy between substances in contact with one another), and *convection* (the movement of heat within liquids and gases from warmer to cooler portions).

In **electromagnetic radiation,** another form of kinetic energy, energy travels in the form of a *wave* as a result of changes in electric and magnetic fields. There are many different forms of electromagnetic radiation, each having a different *wavelength* (distance between successive peaks or troughs in the wave) and *energy content.* Forms of electromagnetic radiation with short wavelengths, such as gamma rays, X rays, and ultraviolet (UV) radiation, have a higher energy content than do forms with longer wavelengths, such as visible light and infrared (IR) radiation (Figure 2-8). Visible light makes up most of the spectrum of electromagnetic radiation emitted by the sun (Figure 2-8).

CENGAGENOW™ Find out how color, wavelengths, and energy intensities of visible light are related at CengageNOW.

The other major type of energy is **potential energy,** which is stored and potentially available for use. Examples of potential energy include a rock held in your hand, an unlit match, the chemical energy stored in gasoline molecules, and the nuclear energy stored in the nuclei of atoms.

Potential energy can be changed to kinetic energy. Hold this book up, and it has potential energy; drop it on your foot, and its potential energy changes to kinetic energy. When a car engine burns gasoline, the potential energy stored in the chemical bonds of gasoline molecules changes into mechanical (kinetic) energy, which propels the car, and heat. Potential energy stored in the molecules of carbohydrates you eat becomes kinetic energy when your body uses it to move and do other forms of work.

CENGAGENOW™ Witness how a Martian might use kinetic and potential energy at CengageNOW.

Some Types of Energy Are More Useful Than Others

Energy quality is a measure of an energy source's capacity to do useful work. **High-quality energy** is concentrated and has a high capacity to do useful work. Examples are very high-temperature heat, nuclear fission, concentrated sunlight, high-velocity wind, and energy released by burning natural gas, gasoline, or coal.

By contrast, **low-quality energy** is dispersed and has little capacity to do useful work. An example is heat dispersed in the moving molecules of a large amount of matter (such as the atmosphere or an ocean) so that its temperature is low. The total amount of heat stored in the Atlantic Ocean is greater than the amount of high-quality chemical energy stored in all the oil deposits of Saudi Arabia. Yet because the ocean's heat is so widely dispersed, it cannot be used to move things or to heat things to high temperatures.

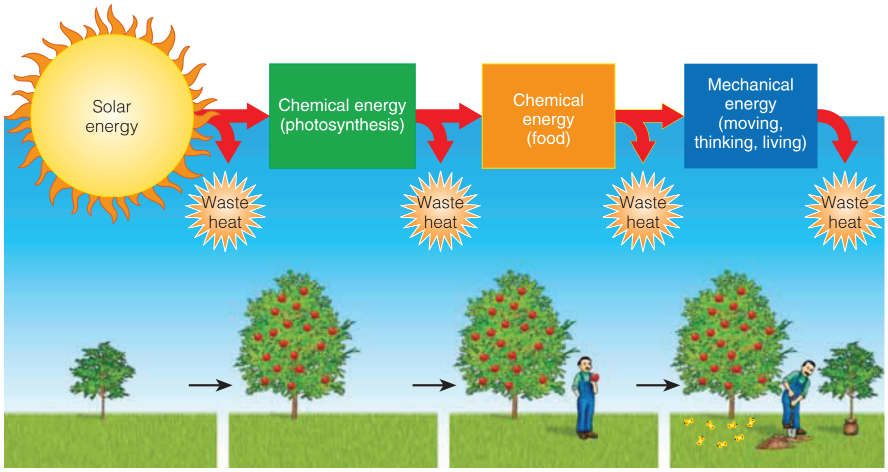
Energy Changes Are Governed by Two Scientific Laws

Thermodynamics is the study of energy transformations. Scientists have observed energy being changed from one form to another in millions of physical and chemical changes. But they have never been able to detect the creation or destruction of any energy in such changes. The results of these experiments have been summarized in the **law of conservation of energy,** also known as the **first law of thermodynamics:** When energy is converted from one form to another in a physical or chemical change, no energy is created or destroyed (**Concept 2-4A**).

This scientific law tells us that when one form of energy is converted to another form in any physical or chemical change, *energy input always equals energy output.* No matter how hard we try or how clever we are, we cannot get more energy out of a system than we put in. This is one of nature's basic rules.

People talk about consuming energy but the first law says that it is impossible to use up energy. *Energy consumption,* then, means converting energy from one form to another with no energy being destroyed or created in the process.

Because the first law of thermodynamics states that energy cannot be created or destroyed, only converted from one form to another, you may be tempted to think



CENGAGENOW™ **Active Figure 2-9** The second law of thermodynamics in action in living systems. Each time energy changes from one form to another, some of the initial input of high-quality energy is degraded, usually to low-quality heat that is dispersed into the environment. *See an animation based on this figure at* CengageNOW. **Question:** What are three things that you did during the past hour that degraded high-quality energy?

there will always be enough energy. Yet if you fill a car's tank with gasoline and drive around or use a flashlight battery until it is dead, something has been lost. But what is it? The answer is *energy quality,* the amount of energy available that can perform useful work.

Countless experiments have shown that whenever energy changes from one form to another, we always end up with less usable energy than we started with. These results have been summarized in the **second law of thermodynamics:** When energy changes from one form to another, we always end up with lower-quality or less usable energy than we started with (**Concept 2-4B**). This lower-quality energy usually takes the form of heat given off at a low temperature to the environment. There it is dispersed by the random motion of air or water molecules and becomes even less useful as a resource.

In other words, *energy always goes from a more useful to a less useful form when it is changed from one form to another.* No one has ever found a violation of this fundamental scientific law. It is another one of nature's basic rules.

Consider three examples of the second law of thermodynamics in action. *First,* when you drive a car, only about 6% of the high-quality energy available in its gasoline fuel actually moves the car, according to energy expert Amory Lovins. (See his Guest Essay at CengageNOW.) The remaining 94% is degraded to low-quality heat that is released into the environment. Thus, 94% of the money you spend for gasoline is not used to transport you anywhere.

Second, when electrical energy in the form of moving electrons flows through filament wires in an incandescent lightbulb, about 5% of it changes into useful light, and 95% flows into the environment as low-quality heat. In other words, the *incandescent lightbulb* is really an energy-wasting *heat bulb.*

Third, in living systems, solar energy is converted into chemical energy (food molecules) and then into mechanical energy (used for moving, thinking, and living). During each conversion, high-quality energy is degraded and flows into the environment as low-quality heat. Trace the flows and energy conversions in Figure 2-9 to see how this happens.

The second law of thermodynamics also means *we can never recycle or reuse high-quality energy to perform useful work.* Once the concentrated energy in a serving of food, a liter of gasoline, or a chunk of uranium is released, it is degraded to low-quality heat that is dispersed into the environment.

Energy efficiency, or **energy productivity,** is a measure of how much useful work is accomplished by a particular input of energy into a system. There is plenty of room for improving energy efficiency. Scientists estimate that only 16% of the energy used in the United States ends up performing useful work. The remaining 84% is either unavoidably wasted because of the second law of thermodynamics (41%) or unnecessarily wasted (43%). Thus, thermodynamics teaches us an important lesson: the cheapest and quickest way to get more energy is to stop wasting almost half the energy we use. We explore energy waste and energy efficiency in depth in Chapters 15 and 16.

CENGAGENOW™ See examples of how the first and second laws of thermodynamics apply in our world at CengageNOW.

2-5 What Are Systems and How Do They Respond to Change?

CONCEPT 2-5A **Systems have inputs, flows, and outputs of matter and energy, and their behavior can be affected by feedback.**

CONCEPT 2-5B **Life, human systems, and the earth's life-support systems must conform to the law of conservation of matter and the two laws of thermodynamics.**

Systems Have Inputs, Flows, and Outputs

A **system** is a set of components that function and interact in some regular way. The human body, a river, an economy, and the earth are all systems.

Most systems have the following key components: **inputs** from the environment, **flows** or **throughputs** of matter and energy within the system at certain rates, and **outputs** to the environment (Figure 2-10) (**Concept 2-5A**). One of the most powerful tools used by environmental scientists to study how these components of systems interact is computer modeling. (Science Focus, below)

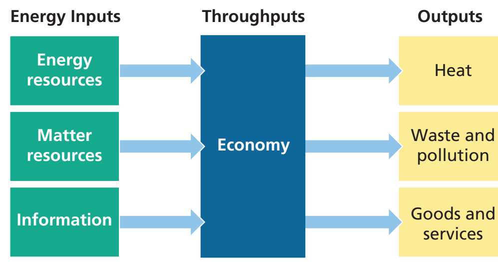


Figure 2-10 Inputs, throughput, and outputs of an economic system. Such systems depend on inputs of matter and energy resources and outputs of waste and heat to the environment. Such a system can become unsustainable if the throughput of matter and energy resources exceeds the ability of the earth's natural capital to provide the required resource inputs or the ability of the environment to assimilate or dilute the resulting heat, pollution, and environmental degradation.

Systems Respond to Change through Feedback Loops

When people ask you for feedback, they are usually seeking your response to something they said or did. They might feed this information back into their mental processes to help them decide whether and how to change what they are saying or doing.

Similarly, most systems are affected one way or another by **feedback,** any process that increases (positive feedback) or decreases (negative feedback) a change to a system (**Concept 2-5A**). Such a process, called a **feedback loop,** occurs when an output of matter, energy,

SCIENCE FOCUS

The Usefulness of Models

Scientists use *models,* or simulations, to learn how systems work. Some of our most powerful and useful technologies are mathematical and computer models.

Making a mathematical model usually requires going through three steps many times. *First,* scientists make guesses about systems they are modeling and write down equations to express these estimates. *Second,* they compute the likely behavior of a system implied by such equations. *Third,* they compare the system's projected behavior with observations of its actual behavior, also considering existing experimental data.

Mathematical models are particularly useful when there are many interacting variables, when the time frame of events being modeled is long, and when controlled experiments are impossible or too expensive to conduct.

After building and testing a mathematical model, scientists use it to predict what is *likely* to happen under a variety of conditions. In effect, they use mathematical models to answer *if–then* questions: "*If* we do such and such, *then* what is likely to happen now and in the future?" This process can give us a variety of projections or scenarios of possible futures or outcomes based on different assumptions. Mathematical models (like all other models) are no better than the assumptions on which they are built and the data fed into them.

Using data collected by Bormann and Likens in their Hubbard Brook experiment (**Core Case Study**), scientists created mathematical models to describe a forest and evaluate what happens to soil nutrients or other variables if the forest is disturbed or cut down.

Other areas of environmental science where computer modeling is becoming increasingly important include the studies of climate change, deforestation, biodiversity loss, and ocean systems.

Critical Thinking

What are two limitations of computer models? Do their limitations mean that we should not rely on such models? Explain.

or information is fed back into the system as an input and leads to changes in that system.

A **positive feedback loop** causes a system to change further in the same direction (Figure 2-11). In the Hubbard Brook experiments, for example (**Core Case Study**), researchers found that when vegetation was removed from a stream valley, flowing water from precipitation caused erosion and loss of nutrients, which caused more vegetation to die. With even less vegetation to hold soil in place, flowing water caused even more erosion and nutrient loss, which caused even more plants to die.

CORE CASE STUDY

Such accelerating positive feedback loops are of great concern in several areas of environmental science. One of the most alarming is the melting of polar ice, which has occurred as the temperature of the atmosphere has risen during the past few decades. As that ice melts, there is less of it to reflect sunlight, and more water is exposed to sunlight. Because water is darker, it absorbs more solar energy, making the area warmer and causing the ice to melt faster, thus exposing more water. The melting of polar ice thus accelerates, causing a number of serious problems that we explore further in Chapter 19.

A **negative,** or **corrective, feedback loop** causes a system to change in the opposite direction from which is it moving. A simple example is a thermostat, a device that controls how often, and how long a heating or cooling system runs (Figure 2-12). When the furnace in a house is turned on and begins heating the house, the thermostat can be set to turn the furnace off when the temperature in the house reaches the set number. The house then stops getting warmer and starts to cool.

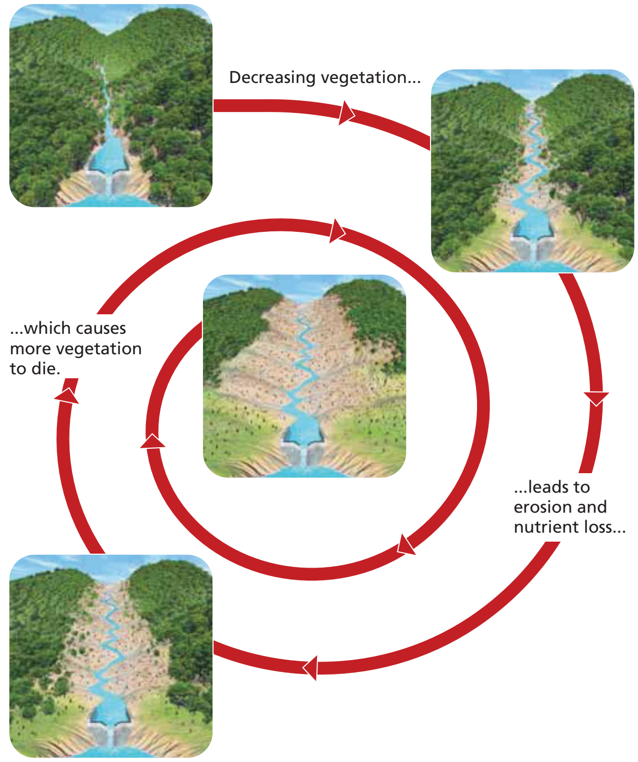


Figure 2-11 *Positive feedback loop.* Decreasing vegetation in a valley causes increasing erosion and nutrient losses, which in turn causes more vegetation to die, which allows for more erosion and nutrient losses. The system receives feedback that continues the process of deforestation.

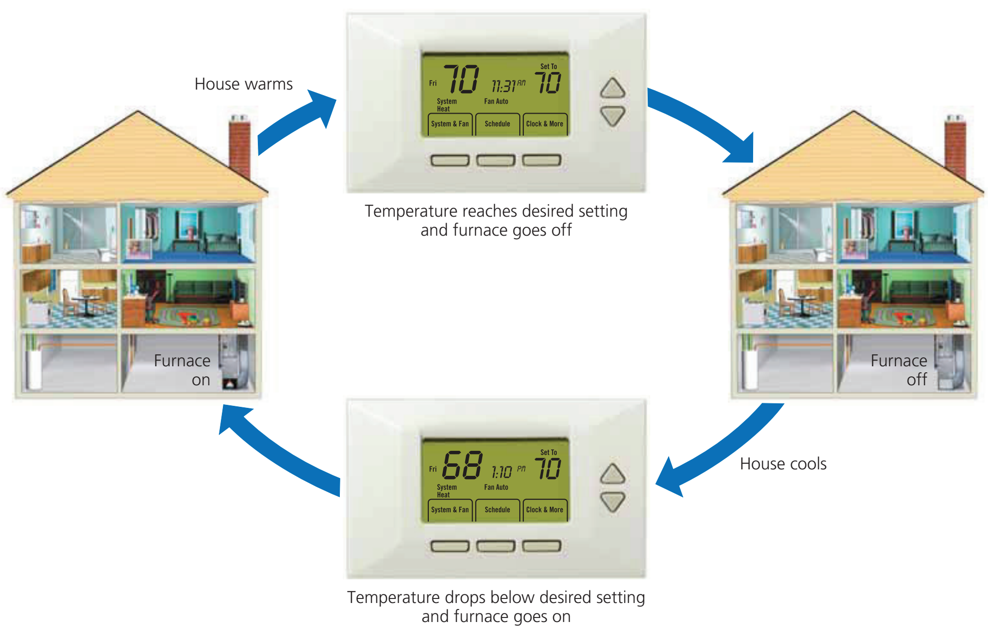


Figure 2-12 *Negative feedback loop.* When a house being heated by a furnace gets to a certain temperature, its thermostat is set to turn off the furnace, and the house begins to cool instead of continuing to get warmer. When the house temperature drops below the set point, this information is fed back, and the furnace is turned on and runs until the desired temperature is reached. The system receives feedback that reverses the process of heating or cooling.

THINKING ABOUT
Hubbard Brook and Feedback Loops

CORE CASE STUDY

How might experimenters have employed a negative feedback loop to stop, or correct, the positive feedback loop that resulted in increasing erosion and nutrient losses in the Hubbard Brook experimental forest?

An important case of a negative feedback loop is the recycling and reuse of some resources such as aluminum, copper, and glass. For example, an aluminum can is one output of a mining and manufacturing system. When that output becomes an input, as the can is recycled and used in place of raw aluminum to make a new product, that much less aluminum is mined and the environmental impact of the mining-manufacturing system is lessened. Such a negative feedback loop therefore can promote sustainability and reduce the environmental impact of human activities by reducing the use of matter and energy resources and the amount of pollution and solid waste produced by use of such material.

Time Delays Can Allow a System to Reach a Tipping Point

Complex systems often show **time delays** between the input of a feedback stimulus and the response to it. For example, scientists could plant trees in a degraded area such as the Hubbard Brook experimental forest to slow erosion and nutrient losses (**Core Case Study**), but it would take years for the trees and other vegetation to grow enough to accomplish this purpose.

CORE CASE STUDY

Time delays can also allow an environmental problem to build slowly until it reaches a *threshold level,* or **tipping point,** causing a fundamental shift in the behavior of a system. Prolonged delays dampen the negative feedback mechanisms that might slow, prevent, or halt environmental problems. In the Hubbard Brook example, if erosion and nutrient losses reached a certain point where the land could not support vegetation, then an irreversible tipping point would have been reached, and it would be futile to plant trees to try to restore the system. Other environmental problems that can reach tipping point levels are population growth, leaks from toxic waste dumps, global climate change, and degradation of forests from prolonged exposure to air pollutants.

System Effects Can Be Amplified through Synergy

A **synergistic interaction,** or **synergy,** occurs when two or more processes interact so that the combined effect is greater than the sum of their separate effects. Scientific studies reveal such an interaction between smoking and inhaling asbestos particles. Lifetime smokers have ten times the risk that nonsmokers have of getting lung cancer. And individuals exposed to asbestos particles for long periods increase their risk of getting lung cancer fivefold. But people who smoke and are exposed to asbestos have 50 times the risk that nonsmokers have of getting lung cancer.

Similar dangers can result from combinations of certain air pollutants that, when combined, are more hazardous to human health than they would be acting independently. We examine such hazards further in Chapter 17.

On the other hand, synergy can be helpful. Suppose we want to persuade an elected official to vote for a certain environmental law. You could write, e-mail, or visit the official. But you may have more success if you can get a group of potential voters to do such things. In other words, the combined or synergistic efforts of people working together can be more effective than the efforts of each person acting alone.

RESEARCH FRONTIER

Identifying environmentally harmful and beneficial synergistic interactions. See **academic.cengage.com/biology/miller**.

Human Activities Can Have Unintended Harmful Results

SUSTAINABILITY

One of the lessons we can derive from the four **scientific principles of sustainability** (see back cover) is that *everything we do affects someone or something in the environment in some way.* In other words, any action in a complex system has multiple and often unintended, unpredictable effects. As a result, most of the environmental problems we face today are unintended results of activities designed to increase the quality of human life.

For example, clearing trees from the land to plant crops can increase food production and feed more people. But it can also lead to soil erosion, flooding, and a loss of biodiversity, as Easter Islanders and other civilizations learned the hard way (Science Focus, p. 31, and Supplement 5 on p. S31).

One factor that can lead to an environmental surprise is a *discontinuity* or abrupt change in a previously stable system when some *environmental threshold* or *tipping point* is crossed. Scientific evidence indicates that we are now reaching an increasing number of such tipping points. For example, we have depleted fish stocks in some parts of the world to the point where it is not profitable to harvest them. Other examples, such as deforested areas turning to desert, coral reefs dying, species disappearing, glaciers melting, and sea levels rising, will be discussed in later chapters.

RESEARCH FRONTIER

Tipping points for various environmental systems such as fisheries, forests coral reefs, and the earth's climate system. See **academic.cengage.com/biology/miller**.

Life, economic and other human systems, and the earth's life support systems depend on matter and energy, and therefore they must obey the law of conservation of matter and the two laws of thermodynamics (**Concept 2-5B**). Without these laws, economic growth based on using matter and energy resources to produce goods and services (Figure 2-10) could be expanded indefinitely and cause even more serious environmental problems. But these scientific laws place limits on what we can do with matter and energy resources.

A Look Ahead

In the next six chapters, we apply the three basic laws of matter and thermodynamics and the four **scientific principles of sustainability** (see back cover) to living systems. Chapter 3 shows how the sustainability principles related to solar energy and nutrient cycling apply in ecosystems. Chapter 4 focuses on using the biodiversity principle to understand the relationships between species diversity and evolution. Chapter 5 examines how the biodiversity and population control principles relate to interactions among species and how such interactions regulate population size. In Chapter 6, we apply the principles of biodiversity and population control to the growth of the human population. In Chapter 7, we look more closely at terrestrial biodiversity in different types of deserts, grasslands, and forests. Chapter 8 examines aquatic biodiversity in aquatic systems such as oceans, lakes, wetlands, and rivers.

REVISITING The Hubbard Brook Experimental Forest and Sustainability

CORE CASE STUDY

The controlled experiment discussed in the **Core Case Study** that opened this chapter revealed that clearing a mature forest degrades some of its natural capital (Figure 1-7, p. 12). Specifically, the loss of trees and vegetation altered the ability of the forest to retain and recycle water and other critical plant nutrients—a crucial ecological function based on one of the four **scientific principles of sustainability** (see back cover). In other words, the uncleared forest was a more sustainable system than a similar area of cleared forest (Figures 2-1 and 2-4).

This loss of vegetation also violated the other three scientific principles of sustainability. For example, the cleared forest had fewer plants that could use solar energy to produce food for animals. And the loss of plants and animals reduced the life-sustaining biodiversity of the cleared forest. This in turn reduced some of the interactions between different types of plants and animals that help control their populations.

Humans clear forests to grow food and build cities. The key question is, how far can we go in expanding our ecological footprints (Figure 1-10, p. 15) without threatening the quality of life for our own species and the other species that keep us alive and support our economies? To live sustainably, we need to find and maintain a balance between preserving undisturbed natural systems and modifying other natural systems for our use.

The second law of thermodynamics holds, I think, the supreme position among laws of nature. . . . If your theory is found to be against the second law of thermodynamics, I can give you no hope.

ARTHUR S. EDDINGTON

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 29. Describe the controlled scientific experiment carried out at the Hubbard Brook Experimental Forest. What is **science?** Describe the steps involved in the scientific process. What is **data?** What is an **experiment?** What is a **model?** Distinguish among a **scientific hypothesis, scientific theory,** and **scientific law** (**law of nature**). What is **peer review** and why is it important? Explain why scientific theories are not to be taken lightly and why people often use the term "theory" incorrectly.
2. Distinguish between **inductive reasoning** and **deductive reasoning** and give an example of each. Explain why scientific theories and laws are the most important results of science.
3. What is a **paradigm shift?** Distinguish among **tentative science** (**frontier science**), **reliable science,** and **unreliable science.** Describe the scientific consensus concerning global warming. What is **statistics?** What is **probability** and what is its role in scientific conclusions? What are five limitations of science and environmental science?
4. What is **matter?** Distinguish between an **element** and a **compound** and give an example of each. Distinguish among **atoms, ions,** and **molecules** and give an

example of each. What is the **atomic theory?** Distinguish among **protons, neutrons,** and **electrons.** What is the **nucleus** of an atom? Distinguish between the **atomic number** and the **mass number** of an element. What is an **isotope?** What is **acidity?** What is **pH?**

5. What is a **chemical formula?** Distinguish between **organic compounds** and **inorganic compounds** and give an example of each. Distinguish among complex carbohydrates, proteins, nucleic acids, and lipids. What is a **cell?** Distinguish among **genes, traits,** and **chromosomes.** What is **matter quality?** Distinguish between **high-quality matter** and **low-quality matter** and give an example of each.

6. Distinguish between a **physical change** and a **chemical change (chemical reaction)** and give an example of each. What is a **nuclear change?** Explain the differences among **natural radioactive decay, nuclear fission,** and **nuclear fusion.** What is a **radioactive isotope (radioisotope)?** What is a **chain reaction?** What is the **law of conservation of matter** and why is it important?

7. What is **energy?** Distinguish between **kinetic energy** and **potential energy** and give an example of each. What is **heat?** Define and give two examples of **electromagnetic radiation.** What is **energy quality?** Distinguish between **high-quality energy** and **low-quality energy** and give an example of each.

8. What is the **law of conservation of energy (first law of thermodynamics)** and why is it important? What is the **second law of thermodynamics** and why is it important? Explain why this law means that we can never recycle or reuse high-quality energy. What is **energy efficiency (energy productivity)** and why is it important?

9. Define and give an example of a **system?** Distinguish among the **input, flow (throughput),** and **output** of a system. Why are scientific models useful? What is **feedback?** What is a **feedback loop?** Distinguish between a **positive feedback loop** and a **negative (corrective) feedback loop** in a system, and give an example of each. Distinguish between a **time delay** and a **synergistic interaction (synergy)** in a system and give an example of each. What is a **tipping point?**

10. Explain how human activities can have unintended harmful environmental results. Relate the four **scientific principles of sustainability** to the Hubbard Brook Experimental Forest controlled experiment (**Core Case Study**). CORE CASE STUDY SUSTAINABILITY

Note: Key Terms are in **bold** type.

CRITICAL THINKING

1. What ecological lesson can we learn from the controlled experiment on the clearing of forests described in the **Core Case Study** that opened this chapter? CORE CASE STUDY

2. Think of an area you have seen where some significant change has occurred to a natural system. What is a question you might ask in order to start a scientific process to evaluate the effects of this change, similar to the process described in the **Core Case Study**? CORE CASE STUDY

3. Describe a way in which you have applied the scientific process described in this chapter (Figure 2-2) in your own life, and state the conclusion you drew from this process. Describe a new problem that you would like to solve using this process.

4. Respond to the following statements:
   a. Scientists have not absolutely proven that anyone has ever died from smoking cigarettes.
   b. The natural greenhouse theory—that certain gases (such as water vapor and carbon dioxide) warm the lower atmosphere—is not a reliable idea because it is just a scientific theory.

5. A tree grows and increases its mass. Explain why this phenomenon is not a violation of the law of conservation of matter.

6. If there is no "away" where organisms can get rid of their wastes, why is the world not filled with waste matter?

7. Someone wants you to invest money in an automobile engine, claiming that it will produce more energy than the energy in the fuel used to run it. What is your response? Explain.

8. Use the second law of thermodynamics to explain why a barrel of oil can be used only once as a fuel, or in other words, why we cannot recycle high-quality energy.

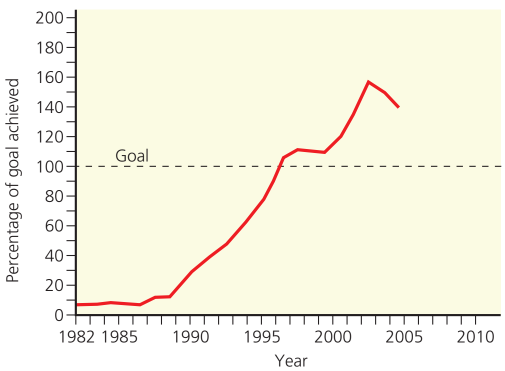
9. **a.** Imagine you have the power to revoke the law of conservation of matter for one day. What are three things you would do with this power?
   b. Imagine you have the power to violate the first law of thermodynamics for one day. What are three things you would do with this power?

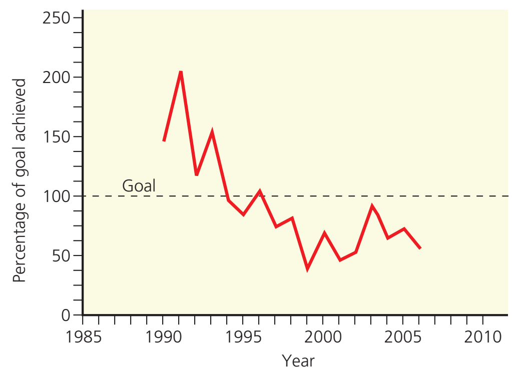
10. List two questions that you would like to have answered as a result of reading this chapter.

Note: See Supplement 13 (p. S78) for a list of Projects related to this chapter.

DATA ANALYSIS

Marine scientists from the U.S. state of Maryland have produced the following two graphs as part of a report on the current health of the Chesapeake Bay. They are pleased with the recovery of the striped bass population but are concerned about the decline of the blue crab population, because blue crabs are consumed by mature striped bass. Their hypothesis is that as the population of striped bass increases, the population of blue crab decreases.





Using the data in the above graphs, answer the following questions:

1. Which years confirm their hypothesis?

2. Which years do not support their hypothesis?

3. If the crab population reaches 100% of the goal figure, what would you predict the striped bass goal figure would be?

LEARNING ONLINE

Log on to the Student Companion Site for this book at **academic.cengage.com/biology/miller**, and choose Chapter 2 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.