Plants supply all the fruits shown here, as well as the wood for the table, the paper in the sketchbook, and the handle for the knife. Bacteria and fungi convert milk to cheese. Of the fruits here, some come from trees, some from herbs, some come from plants that live for years, others that live for only a few months. This lunch will provide necessary carbohydrates, proteins, vitamins, and so on, but just as importantly, it will be delicious and enjoyable. (Courtesy of Chris McCoy.)

1 Introduction

Plants Are Important to People

Plants Provide Our Oxygen, Energy, and the Atoms of Our Bodies

Could you live without plants? There is an easy way to find out: hold your breath. As we take in a lungful of air, our bodies absorb the oxygen, a chemical that is essential to our life. Without oxygen we simply cannot live. And all the oxygen we breathe, all the oxygen that sustains our lives was produced by plants. The green parts of plants contain a pigment called chlorophyll, which captures sunlight and makes its energy available for photosynthesis (**FIGURE 1.1**). During photosynthesis, plants force carbon dioxide and water to react with each other, converting them into sugar and oxygen. The oxygen is released into the air, where it sustains our life. Without the oxygen produced by plants and photosynthesis, we could not live more than a few minutes. No animal or fungus can perform photosynthesis.

FIGURE 1.1. The green parts of plants carry out photosynthesis, which captures energy, creates organic compounds, and releases oxygen. The cyclists are breathing the oxygen, and their food is based on plants, whether they eat the plants as salad, pasta, vegetables, or as milk or meat.

The sugar produced by photosynthesis also is critically important to our lives. First, plants use it to build all parts of their bodies; plant metabolism combines simple sugar with various minerals from the soil and constructs all the chemicals found in the plant body. All the proteins, starches, oils, flavors, aromas, and other chemicals begin as sugar produced by photosynthesis. If we tried a similar feat—eating nothing but sugar and mineral supplements—we would die quickly. We must eat more complex foods, foods that are parts of a plant body or that come from animals or fungi that have themselves consumed plants. Our digestive systems break these complex chemicals down into simpler forms such as amino acids, fatty acids, and so on, and then we absorb them through our small intestine and use them to build our own bodies. The chemicals that make up our bodies all started out as parts of the bodies of many plants. Even if you mostly eat meat and never eat fruit and vegetables except as a last resort, the meat you consume came from an animal that ate plants. Look at your hands, arms, any part of your body you can see: all of it started off as sugar produced by photosynthesis in a plant. Without plants, our very bodies would not exist.

Photosynthesis captures the energy of sunlight and is the source of our own energy. When we eat food, part of it is used to construct our bodies, to make more skin (we shed skin cells constantly, which is especially noticeable in dry weather or after a sunburn), more hair, more muscle, and more fat. But most of our food is "burned," or more accurately, it is combined with oxygen in a process called respiration that gives us the energy we need to move, to be warm, to pump our blood: all the energy we need just to stay alive comes from the energy that plants captured during photosynthesis. We may sit in the sun to warm ourselves, but that warmth cannot be used to make our muscles move or to drive our metabolism.

It is a profound thought: all the material of our bodies, all the energy we use, all the oxygen that keeps us alive, all of this comes from plants. And it is not just we people; all other animals are just as dependent on plants as we are.

Plants Protect Us

We use plants to protect us from the environment. Think of yourself at this very moment, while you are reading this. If you are indoors in a building, imagine what would happen if all the wood—wood comes from plants—suddenly disappeared: many buildings would either collapse or vanish except for the nails. Sitting in a concrete building? Wood forms were used to hold the concrete as it hardened. There is a good chance your chair and table would vanish if wood suddenly ceased to exist. Now think of your clothing: without plants, your cotton shirts, pants, dresses, coats, socks, sneakers, and underwear would all vanish—most of us would be naked without plant products. To get a feeling for how much we rely on plants to protect us from the environment, imagine yourself somewhere with no plants—the Sahara Desert, for example, or the North Pole—and imagine you are naked.

Plants protect us in other ways. We get warmth from firewood, coal, and charcoal. In many parts of the world all heating and cooking are done with fires fueled by hand-gathered twigs, sticks, and dry grass that people collect themselves. Since ancient times, people have obtained medicines from plants, and even today some of our drugs are extracted directly from plants, while others are produced from starting materials obtained from plants.

Plants protect us on a much larger scale and in ways we rarely think about. They alter many factors in our environment such that our lives are possible. For example, plants stabilize soil. It is easy to assume that this has little to do with the lives of most people, but remember that all parts of Earth's surface are exposed to winds and rains that can move soil (**FIGURE 1.2**). Without a stabilizing layer of vegetation, soil would erode away until all of it had been blown or washed into one of the oceans and the land's surface was just barren, uninhabitable rock. Any bare patch of soil will produce a dust cloud as wind blows over it, and this has many consequences: blinding dust storms cause traffic accidents that kill people; the dust chokes people and animals, making breathing difficult; it covers the leaves of downwind plants, inhibiting their growth; and so on. The soil carried off by a dust storm is the uppermost, richest topsoil, and without it, the remaining soil is less fertile and more rocky, less capable of sustaining revegetation. Rain and melting snow also erode soil, washing it lower on hillsides and carrying it into streams, lakes, and rivers, making them muddy, damaging the gills of fish and invertebrates, and polluting the water we drink. Almost all of us drink water pumped out of rivers. Along coastlines, plants stabilize sand dunes, preventing them from blowing away. Such dunes lessen the impact of storm surges and high water that accompany hurricanes and tropical storms. Without coastal dunes, inland flooding would be much worse. Coastal wetlands and marshes offer similar protection, as well as being a habitat for millions of fish, birds, crustaceans, and other animals (**FIGURE 1.3**). Trees and shrubs that grow along rivers hold their banks in place, reducing erosion and flooding and helping to keep mud and silt out of the water. Without vegetation covering its surface, soil would be in constant motion, mostly moving downslope and downstream, and land would be mostly bare rock.

FIGURE 1.2. The vegetation at the top of the hill was disrupted by farming, and now without roots to stabilize the soil, erosion occurs with every rain, washing soil particles down into a river below.

FIGURE 1.3. These dune and marsh plants along the Texas Gulf coast stabilize sandy soil and help hold it in place when hurricanes and tropical storms come through this area. In the years between storms, habitats like this support a large diversity of plants (palms, grasses, and sedges are visible), as well as many sorts of animals. Without these plants, the dunes would erode and salt water would be pushed inland during storms, damaging large areas of habitat.

Plants Affect Us Psychologically

Plants affect our mood and emotions. Just think of these foods, all of which come from plants: chocolate, sugar, cinnamon, mint, peppermint, and other spices; cakes, pies, pastries, doughnuts made from wheat flour; fresh apples, peaches, cherries, oranges, walnuts, pecans, almonds, cashews; tortillas (both corn and flour), pasta. If your tastes are focused more on fast-food hamburgers, then probably at least the catsup, mustard, tomatoes, lettuce, pickles, french fries, and onion rings are things you like. It is probably safe to say that everybody has some plant-based food they really enjoy.

Other foods are more calming. It is hard to imagine relaxing without a cup of tea or coffee, or perhaps a glass of wine or beer. If we extend the list to hard liquors (ones that have been distilled to increase their alcohol content), the flavors and aromas are derived from the plants that were used in the fermentation mix. Marijuana and tobacco are other plant products that calm us, but tobacco also appears below under the heading Plants Can Kill Us.

Even plants we don't eat affect us emotionally. Think of flowers given as gifts: roses on Valentine's Day, flowers children give to their parents, the flowers we give to friends who are ill, or just a simple bouquet or potted plant from one friend to another. We use flowers to express our emotions and feelings, in celebrations and in mourning: weddings always involve flowers, as do funerals. Gardening is a hobby that gives pleasure to many people, whether they have an extensive garden or just a plant on a windowsill. Perfumes and fragrances, which are so important on many social occasions, are extracted from flowers, fruits, or other plant parts. Many religious services are still accompanied by the burning of incense, especially frankincense and myrrh, just as they have been for thousands of years.

Plants Can Kill Us

Plants are rooted to the soil, unable to move but surrounded by animals that, given the chance, will eat them, lay eggs in them, break them apart to use as nesting material, or maybe just trample them without notice. Numerous defense mechanisms have evolved in plants; most plants are far from helpless. Many plants are so toxic that eating just a few leaves or seeds will kill an adult within a day or two. And the poisons are diverse, some affecting our nervous system, others our heart, and others our general metabolism. Probably the plant poison most familiar to people is that in poison ivy, and stinging nettles are painfully familiar to many people. The sap of many spurges (the genus *Euphorbia*) is not only poisonous if eaten, just touching the sap can cause blisters on the skin. An especially insidious plant poison is nicotine: it is slow acting, but smoking tobacco usually results in cancer of the lungs, throat, or mouth. Worldwide, more than 1.3 million people die from lung cancer each year.

Some plants might not kill us, but they have spines that make our lives miserable. Sharp stickers have evolved numerous times in many different groups of plants and can be found on leaves, stems, and even fruits. Most likely everyone has been cut by a rose thorn at least once in their life, and most people in arid areas have first-hand experience with the spines of cacti, agaves, yuccas, and other desert plants. Spiny vegetation occurs in all kinds of habitats, not just deserts; many palms and bamboos of wet areas are spiny, as are prairie plants such as prickly poppies and thistles. Although spines are usually merely painful for us, they can be deadly to animals, either injuring them badly and leading to infection or blinding them. On a small scale, many tiny plants that are preyed upon by tiny insects also have spines, too small for us to notice, but effective against the insects.

And just as we occasionally trample and harm plants without intending to hurt them, plants may do the same to us. Wind-pollinated plants such as ragweed, cedars, oaks, and others release copious amounts of pollen into the air, causing misery for millions of people who suffer from hay fever, allergies, and asthma. The irritation these plants cause is entirely incidental; it is not a defense mechanism, it does not protect the plants, and they derive no benefit from our suffering. It is simply that our immune systems are unnecessarily sensitive to chemicals on the pollen grains.

People Are Important to Plants

We Cultivate and Protect Plants

At present, people are important to plants, both helping and harming them. We help certain plants by cultivating them as crops for food, lumber, cloth, oils, and ornamentals. Wheat, rice, corn, potatoes, cotton, and soybeans dominate vast areas of Earth's land area, but they could not do this without human help (**FIGURE 1.4**). If we became extinct, these crop plants would soon disappear, unable to compete against wild plants without our help. We plow ground for them, sow their seeds, water and weed them. Afterward, we harvest them but save some of their seed to propagate them the next year. For some crops, we provide them with pollinators by keeping hives of honeybees close to the fields. For vanilla, people actually pollinate each flower by hand. This leads us to wonder whether we have domesticated plants or if they have domesticated us.

FIGURE 1.4. These oats are thriving under artificial conditions created by a farmer: the soil was plowed to make it soft, seeds were sown, weeds have been eliminated, fertilizers supplied, and insect pests have been eliminated. Without all this care, weeds would quickly take over this field, and animals, insects, and fungi would attack the oats.

We realize now that natural areas on Earth are not unlimited and they cannot restore themselves if damaged too badly. Conserving natural habitats has become a goal that many people have accepted, and large areas of land have been protected in the form of national and state parks, nature preserves, and wildlife refuges owned and controlled by government agencies. In addition, a great deal of habitat is protected by nongovernmental organizations such as The Nature Conservancy, World Wildlife Fund, Natural Resources Defense Council, Sierra Club, and many others. In some cases, conservation is brought about by arranging conservation easements with landowners: the land remains in private hands but the owners agree to restrict hunting, grazing, farming, construction, and other practices that would damage the plants and animals. Conservation easements are a relatively new method in conservation biology, and they have shown that many landowners are eager to be involved in protecting the natural aspects of the land.

As the concept of conservation biology has developed, we realize it is important to preserve tracts of land that are large enough to include self-sustaining populations of plants and animals. If our goal is to protect an endangered plant species, then it is best to have a preserve that supports the animals that pollinate those plants, as well as any other animals such plants depend on. Many plants are adapted to natural cycles of flooding or fires; those too should be included in conservation efforts.

Many habitats were already severely damaged before people developed the concept of conservation ethics. For example, much of the midwestern region of the United States was tall grass prairie before it was cleared for farming; virtually no natural patches of tall grass prairie have survived. However, numerous efforts are underway to restore some of these areas, and an entire field of science—restoration ecology—is developing.

Fortunately, it is possible for each of us to protect plants and animals in our own daily lives. We can consume less and make thoughtful choices about what we do.

FIGURE 1.5. Urban sprawl causes large amounts of habitat destruction. When people live widely separated from each other, more freeways are needed, but if more people would live in high-density housing, cities could be more compact and fewer highways and parking lots would be needed.

We can use less food, paper, chemicals; walk or bicycle more and drive less; keep our homes and classrooms less heated in winter and less air-conditioned in summer. Rather than use either paper or plastic bags at stores, carry a reusable cloth bag. If each of us consumes less, there will be less pollution, less natural land converted to shopping malls, parking lots, and farmland; less overfishing of oceans. Each of us can make a difference every day.

We Damage the Habitats of Plants

People harm plants in many ways, both intentionally and inadvertently. Probably the greatest damage is **habitat destruction** caused by clearing land for construction projects, cutting forests for lumber, draining wetlands for farming, and flooding valleys behind dams (**FIGURE 1.5**). Smog and air pollution damage plants downwind, and dumping wastes into rivers harms aquatic life. Oil spills from drilling platforms and oil tankers has damaged thousands of miles of coastal habitats.

What Are Plants?

Being a book about plants and people, we should consider just what plants and people are. Technical details are a bit complicated, but almost certainly you already have an accurate idea of which organisms are plants and which are not.

How Plants Are Related to All Other Organisms

There are three basic types of organisms, called **Bacteria**, **Archaea**, and **Eukarya**. Bacteria are probably already familiar to you: they are microscopic, usually have a body consisting of just a single simple cell shaped like a rod, a spiral, or a sphere. Bacteria occur in almost every conceivable place, such as soil, water, air; in forests, grasslands, deserts, and snow-covered areas; on and in our bodies, on plant surfaces, and in our food unless it has been sterilized. Some bacteria cause the diseases that are treated with antibiotics. One group of bacteria is the Cyanobacteria, which are green and able to photosynthesize.

Archaeans are less familiar to most people, but they are also microscopic and unicellular. They are not as widespread as bacteria, mostly being located in habitats that are extremely acidic or hot, such as the geysers and thermal pools of Yellowstone National Park. Cells of both bacteria and archaeans have no nucleus, and thus the two groups are known as **prokaryotes** (this means "before nuclei").

The third group, Eukarya, consists of all plants, algae, animals, fungi, and many microscopic organisms. This diverse group has an important unifying feature: their cells each contain a nucleus ("eukarya" means "true nucleus"). In addition, the cells of **eukaryotes** are much more complex than those of prokaryotes, as described in Chapter 9. When eukaryotes first originated billions of years ago, perhaps by the modification of some archaeans, they were all organisms whose bodies consisted of just a single microscopic cell. At this early stage, some evolved to be capable of photosynthesis, and these then became more numerous. Many variations evolved and some gradually evolved into algae and plants. Meanwhile, some of the other early eukaryotes evolved into animals and fungi (such as mushrooms, puffballs, and yeast). Until recently, most biologists assumed that fungi and plants were closely related because both groups reproduce by spores, neither moves, and neither has any of the internal organs that typify most animals. But many key aspects of the metabolism of fungi resemble those of animals and differ from those of plants.

In the photosynthetic line of evolution, **algae** diversified into several types. At present, there are green algae, red algae, brown algae, and several other types, each characterized by their pigments and other features (**FIGURE 1.6**). About 420 million years ago, one group of green algae evolved to have features that allowed them to live on land rather than in water. Members of this group are the **true plants** (see Chapter 9 for more about the differences between algae and plants). The first true plants were small and simple, but as time passed, several new features evolved in some of them, and gradually they diversified into the plant groups that exist today. Following are brief descriptions of the major groups of plants, most of which are probably familiar to you (**TABLE 1.1**).

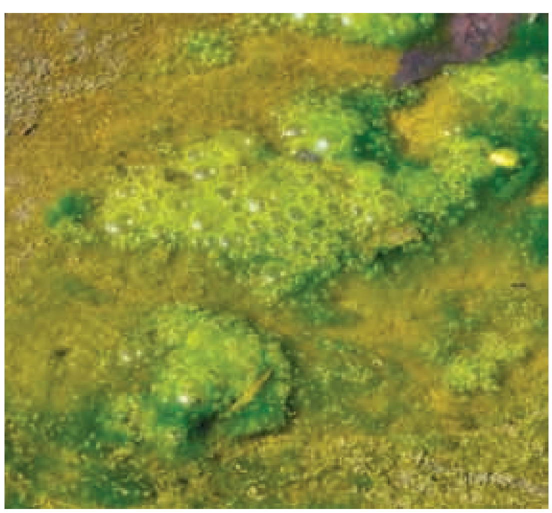

FIGURE 1.6. Slow-moving streams are good habitats for many green algae, such as these. They are green because they contain chlorophyll and other pigments like true plants, and they carry out photosynthesis. The bubbles are oxygen liberated by photosynthesis.

TABLE 1.1. The Major Types of Plants and Their Relatives

I. **Green algae**, in particular a group called Charophyta, are the group of organisms most closely related to plants.

II. **Bryophytes** are plants that have no vascular tissue and no seeds. Members are mosses, liverworts, and hornworts.

III. **Vascular plants** are plants that have vascular tissues, tissues that conduct water and nutrients from one part of a plant to another.

A. **Ferns and fern-allies** are plants that have vascular tissue but do not make seeds during sexual reproduction.

B. **Seed plants** are vascular plants that produce seeds during sexual reproduction.

1. **Cycads** are the "sago palms" and their relatives.
2. **Conifers** are the pines and their relatives.
3. **Angiosperms** are the flowering plants. Angiosperms are the most abundant of all types of plants. There are more types (species) of angiosperms than all other plants combined, and they occur in more habitats and cover more of the Earth's surface than all other plants. Almost all our food, spice, medicinal, crop, and ornamental plants are angiosperms.

The Major Groups of Plants

1. Flowering plants are technically known as **angiosperms**. Flowers are reproductive structures; some parts produce pollen grains, which carry sperm cells, other parts have egg cells. During reproduction, new embryos form as part of a seed, and all seeds occur inside fruits. Plants with obvious flowers, such as roses, petunias, snapdragons, and lilies are flowering plants (**FIGURE 1.7**). But in many other angiosperms, the flowers are tiny and inconspicuous; for example, the flowers of grasses are so small and pale you might never notice them, and the same is true for those of oaks, elms, cattails, and palms (**FIGURE 1.8**). Other angiosperms have large, obvious flowers, but they bloom so rarely—at least in cultivation—that many people mistakenly assume that they never flower. Cacti are a good example of this: when kept on a windowsill, potted cacti may survive and grow without being healthy enough to flower, but in nature they produce spectacular flowers that no one could miss. All angiosperms have **vascular tissues**, that is, tissues that conduct water and nutrients from one part of the plant to another. Plants with vascular tissues are **vascular plants**.

FIGURE 1.7. The name "flowering plant" sometimes confuses people. It is meant to indicate plants that reproduce with flowers rather than cones or some other means. In the winter, when this rose bush has no flowers on it, it will still be a flowering plant. The more proper term "angiosperm" is less confusing but is not used as often except in technical writing. (Courtesy of Chris McCoy.)

2. Conifers are the pines, spruces, firs, and their relatives (**FIGURE 1.9**). They produce cones rather than flowers, and are always trees that live for years; they are never small herbs or plants that live for less than a year. Their leaves are needles or scales, they are never broad and flat like those of most flowering plants (never like a geranium or maple leaf). Like angiosperms, all conifers are vascular plants and all produce seeds.

3. Cycads might not be familiar to many of you because they only survive where winters are mild; even a brief, light frost kills most species of them (**FIGURE 1.10**). Cycads are vascular plants that produce seeds in structures that superficially resemble the cones

FIGURE 1.8. The flowers of some flowering plants are so small or inconspicuous it is easy to be familiar with the plant but not realize that it ever makes flowers. Sandburs (several species of the genus *Cenchrus*) are familiar to all of us: the burs that hurt our feet are flowers with stickers on them. Later the flowers develop into fruits that are larger and even more painful.

of conifers. But they differ from conifers in significant details (particularly their very soft wood) and are considered to be only distantly related to conifers.

4. Ferns are probably very familiar plants. They tend to have large leaves subdivided into many parts with complex shapes (**FIGURE 1.11**). They have vascular tissue but never produce seeds during their sexual reproduction. All plants produce spores, even

FIGURE 1.9. This cedar (*Cedrus*) is a conifer and is related to pines, firs, and other plants that reproduce with cones instead of flowers. Cedars grow to be large trees with short needle-like leaves that occur in clusters. Their cones produce resins (often called "pitch"), some of which have oozed out and are visible as white patches.

FIGURE 1.10. Cycads (also called "sago palms") often look like small palm trees with large, leathery leaves. They produce seeds in very large cones, each with many large seeds.

FIGURE 1.11. Many ferns grow best in low, filtered light in the shade of large trees although some are adapted to the intense sunlight of deserts. Here, we see only leaves of bracken fern (*Pteridium*), their shoots grow entirely underground, spreading widely; it is possible that there is only a single fern plant in this image. Ferns never produce flowers or cones, instead some of their leaves produce spores that blow away and later grow into new plants (see Chapter 7 for more details).

the seed plants, but spores are especially easy to see on the underside of many fern leaves. Several groups of plants are so similar to ferns—and so unfamiliar to most people—that they are just called **fern allies** in most wildflower guides and other non-technical books. Fern allies include horsetails (also called scouring rushes; **FIGURE 1.12**), spike-mosses, and club-mosses (neither is a true moss; **FIGURE 1.13**). Like ferns, these are vascular plants that never make seeds.

5. Mosses, liverworts, and **hornworts** are often grouped together and informally called **bryophytes** (**FIGURE 1.14**). Bryophytes are tiny plants, and their bodies have fewer tissues and organs than do the bodies of all other plants: they have none of the vascular tissues that all other plants have, and they never make seeds, cones, or flowers. Many do not have anything equivalent to leaves, roots, or stems; the bodies of many liverworts are just flat sheets of green cells.

It is easy to think of some plants as "advanced" and others as "primitive," but we must be careful when we think about this. Mosses and liverworts do have simple bodies and they lack many features present in angiosperms, but that is not the same as being primitive or poorly adapted. All plants that are alive today must be reasonably well-adapted to their habitats, otherwise they would have been crowded out by other plants, they would have become

FIGURE 1.12. Horsetails (also called scouring rushes; *Equisetum*) are usually small plants but these, *Equisetum giganteum*, are the largest ones known. Horsetails are rather common in moist areas, especially along railroad tracks. Equisetums have hollow jointed stems (they can be pulled apart easily), and their surface contains silica and is very rough. (Courtesy of Chad Husby.)

FIGURE 1.13. Club mosses (*Lycopodium*) prefer shady, moist habitats such as this forest in North Carolina. Although they have vascular tissues, club-mosses never become very large, rarely more than a meter tall.

FIGURE 1.14. Mosses and liverworts often grow together, as shown here. The larger, ribbon-like plants with a netted pattern on their surface are liverworts in the genus *Conocephalum*. The smaller, leafy plants are mosses. Unlike the other plants illustrated in this chapter, these do not have vascular tissue and never grow to be very large. Being so small, mosses and liverworts often live in small cracks in rock where seed plants could not fit.

extinct. The tiny simple body of a moss or liverwort requires only a few resources to build, and just a short period of photosynthesis will make enough sugar to synthesize all the chemicals needed to build their small bodies, whereas weeks of photosynthesis are necessary before a flowering plant has enough energy and chemicals to bloom. Each plant is well-adapted to its own particular habitat. Many people like to think of ourselves, human beings, as being the pinnacle of evolution, the most advanced animal to ever exist, but there are millions more worms than there are people, living in a greater number of places, even inside some of us. Rather than thinking about which is more or less advanced, it is more productive to think about how each is adapted to its environment, and how the lives of various organisms impact those of others.

An Individual Plant

It is important to distinguish the individual from the group. Think about "people"—we are the species ***Homo sapiens***—and think about yourself. Much of your biology is like mine or that of anyone else, but there are aspects of your life that differ from those of all other people. Each of us is unique in some way. Each of us may have a particular strength—some are smarter, stronger, more dexterous, more talented, more artistic, more resistant to disease—and each of us has a particular weakness, but our entire species, all of us together, have all the strengths and all the weaknesses. Whereas each individual has a set of characteristics, the whole species is more varied because it has all the characteristics of all the individuals. At some point, an individual person must die, but our species does not have to. If at least some of us are reproducing and some are adapted to conditions somewhere on Earth, *Homo sapiens* should be able to persist as a species for millions of years.

The same is true of plants. Individual plants of a particular species have certain characteristics, but the entire species has all the characteristics of all its members. The species is variable, and with enough variability, it may be able to evolve rapidly enough that it can survive even if its habitat changes. A critical point here is that larger populations tend to have more genetic diversity and thus are more likely to survive changes in the environment. When we impact plants, usually by reducing their populations by damaging their habitats, we reduce the number of individuals and the variability of the species. If we cause plant populations to be too small, we put the entire species at risk of extinction.

Things that Are Not Plants

Many creatures resemble plants in being fixed to the soil and unable to move from place to place. Don't be embarrassed if they have fooled you into thinking they are plants; all of the following have been mistakenly classified as plants at some point in the past. **Lichens** are not plants, they are not even individual organisms (**FIGURE 1.15**). Each consists of a network of fungal cells associated with hundreds of cells of algae, the two growing together. Some lichens grow as a simple crust on the surface of rocks or wood, but others have what appear to be stems and leaf-like structures. But despite the similarity, lichens are not plants. The corals that grow in tropical oceans are stationary, unable to move from place to place, and some have a fan-like shape that resembles a leaf. But corals are entire colonies made up of thousands or millions of tiny animals; they are not plants. Fungi have many plant-like characters, but they are their own group, the Kingdom Fungi. Examples are mushrooms (often called toadstools), puffballs, bracket fungi, morels, and chanterelles (**FIGURE 1.16**).

FIGURE 1.15. This rock in Zion National Park is covered with several lichens, each with different pigments: one is orange, others are dark gray, light gray and chartreuse. None is an actual plant; instead, each is a set of fungus cells and algal cells growing together, and each helping each other (this is a mutualistic relationship). The algae could not live on bare rock in full sunlight like this without the fungi, and similarly the fungi must have the algae to grow here.

FIGURE 1.16. This mushroom is the deadly fly agaric (*Amanita muscaria*). Many people mistakenly assume that fungi are plants but actually they are more closely related to animals. Mushrooms are often called toadstools.

BOX 1.1. The Scientific Method

Background

People have always tried to understand the world and how it works. At first, people believed that the world was filled with many spirits—some good, some malicious—that control weather, crops, floods, diseases (and recovery from disease), plagues of grasshoppers, and so on. Gradually, these were replaced by a multitude of gods and goddesses, and then later, the concept developed that there was a single god controlling all aspects of the world. Starting just before the 1400s, a new method, called the **scientific method**, slowly began to develop, a method that could help us understand details of how the world functions. Several fundamental principles were established as follows.

Principles of the Scientific Method

Source of information. *All accepted information can be derived only from carefully documented and controlled observations or experiments*. Explanations made by priests, prophets, scientists, or anyone else cannot be accepted automatically; they must be subjected to verification and proof. For example, for hundreds of years, medicine was taught using texts based on the work of Galen, a Roman physician who lived in the second century CE (common era = AD). In the early 1500s, Andreas Vesalius began dissecting human corpses and noticed that in many cases, Galen had been mistaken. Vesalius promoted the idea that observation of the world itself (in this case, human bodies) was more accurate than accepting undocumented claims, even if the claims had been made by an extremely famous, respected person and were preserved in ancient, highly revered books.

Examples from our own modern times are important. Various drugs and herbal supplements are advertised as curing illnesses or improving health. Under the scientific method, such claims themselves, even if made by famous and respected drug companies, are not sufficient. The actual data must be made available and the research must be described so carefully that other, independent scientists can repeat the studies so as to determine whether the drugs or supplements are indeed effective or whether these are cases of false advertising.

Phenomena that can be studied. *Only tangible phenomena and objects are studied*, such as heat, plants, minerals, and weather. We cannot see or feel magnetism or neutrons but we can construct instruments that detect them reliably. In contrast, we do not see or feel ghosts, leprechauns, elves, trolls, or unicorns, and no instrument has ever detected any of these reliably: if such things do exist, they must be intangible and cannot be studied by the scientific method. Anything that cannot be observed cannot be studied.

Constancy and universality. *Physical forces that control the world are constant through time and are the same everywhere*. Water has always been and always will be composed of hydrogen and oxygen; gravity is the same now as it has been in the past. The world itself changes—mountains erode, rivers change course, plants evolve—but the forces remain the same. Experiments done at one time and place should give the same results if they are carefully repeated at a different time and place. Constancy and universality allow us to plan future experiments and predict what the outcome should be: if we do the experiment and do not get the predicted outcome, it must be that our theory was incorrect, not that the fundamental forces of the world have suddenly changed. This prevents people from explaining things as miracles or the intervention of evil spirits. For example, if someone claims that a new drug cures a particular disease, we can check that by testing the same drug against that disease. If it does not work, the first person (1) may have made an innocent mistake, (2) may have tested the drug on people who would have gotten better anyway, (3) may have been committing fraud. But we do not have to worry that the difference in the two experiments is due to the fundamental laws of chemistry and physics having changed, or that the first experiment outcome was altered by benevolent spirits, the second by evil spirits.

Basis. *The fundamental basis of the scientific method is skepticism*, the principle of never being certain of a conclusion, of always being willing to consider new evidence. No matter how much evidence there is for or against a theory, it does no harm to keep a bit of doubt in our minds and to be willing to consider more evidence. For example, there is a tremendous amount of evidence supporting the theory that all plants are composed of cells, and there is no known evidence against it. All our research, all our teaching assumes that plants indeed are composed of cells, but the concept of skepticism requires that if new, contrary evidence is presented, we must be willing to change our minds. As a further example, consider people who have been convicted of crimes, then later—often years later—DNA-based evidence indicates they are innocent: skepticism is the willingness to consider new evidence.

Scientific studies take many forms, but basically they begin with a series of observations, followed by a period of experimentation mixed with further observation and analysis. At some point, a hypothesis, or model, is constructed to account for the observations: a **hypothesis** (unlike a speculation) must make predictions that can be tested. For example, scientists in the Middle Ages observed that plants never occur in dark caves and grow poorly indoors where light is dim. They hypothesized that plants need light to grow. This can be formally stated as a pair of simple alternative hypotheses: (1) plants need light to grow, and (2) plants do not need light to grow. The experimental testing may involve the comparison of several plants outdoors, some in light and others heavily shaded, or it may involve several plants indoors, some in the normal gloom and others illuminated by a window or a skylight. Such experiments give results consistent with hypothesis 1; hypothesis 2 would be rejected.

A hypothesis must be tested in various ways. It must be consistent with further observations and experiments, and it must be able to predict the results of future experiments: one of the greatest values of a hypothesis or theory is its power as a predictive tool. If its predictions are accurate, they support the hypothesis; if its predictions are inaccurate, they prove the hypothesis is incorrect. In this case, the hypothesis predicts that environments with little or no light will have few or no plants. Observations are consistent with these predictions. In a heavy forest, shade is dense at ground level and few plants grow there. Similarly, as light penetrates the ocean, it is absorbed by water until at great depth all light has been absorbed; no plants or algae grow below that depth.

If a hypothesis continues to match observations, we have greater confidence that it is correct, and it may come to be called a **theory**. Occasionally, a hypothesis does not match an observation; that may mean that the observation is wrong (we scientists do make mistakes), or that the hypothesis must be altered somewhat, or that the whole hypothesis has been wrong. For instance, plants such as Indian pipe or *Boschniakia* grow the same with or without light; they do not need light for growth (**FIGURE B1.1**). These are parasitic plants that obtain their energy by drawing nutrients from host plants. Thus our hypothesis needs only minor modification: all plants except parasitic ones need sunlight for growth. It remains a reasonably accurate predictive model.

Note the four principles of the scientific method here. First, the hypothesis is based on observations and can be tested with experiments; we do not accept it simply because some famous scientist declared it to be true. Second, sunlight and plant growth are tangible phenomena we can either see directly or measure with instruments. Third, if we repeat the experiment anytime or anywhere we expect to get the same results. And fourth, we interpret the evidence as supporting the hypothesis but we keep an open mind and are willing to consider new data or a new hypothesis.

FIGURE B1.1. This *Boschniakia* is a parasitic plant; it has a modified root system that attaches to surrounding plants and obtains nutrients from them. It does not have chlorophyll, and it cannot perform photosynthesis itself, but it relies on the photosynthesis occurring in its host plants. Mistletoes are partially parasitic, but unlike *Boschniakia*, they carry out their own photosynthesis and just obtain water and mineral from the host.

Before the 1900s, theories that had overwhelming support were called “laws.” These were statements considered to be universally true and proven for all time. But biologists do not use the concept of “law” any longer; instead, we realize that some of what we know is incomplete and some is wrong. So we keep an open mind and continue making observations and experiments. Occasionally people will try to discredit evolution because it is only a theory and not a law; what they do not realize is that there are no laws in biology.

The concept of intelligent design has recently been proposed to explain many complex phenomena. Its fundamental concept is that many structures and metabolisms are too complicated to have resulted from evolution and natural selection. Instead they must have been created

(continued)

by some sort of intelligent force or being. This may or may not be true, but this does not help us to analyze and understand the world; instead, the concept of intelligent design is an answer in itself, an answer that discourages further study. Photosynthesis is certainly complex, and it may have been designed by some intelligent being, but believing that does not help us to understand it at all, it does not help us plan future experiments. In contrast, the scientific method is a means through which we are discovering even the most subtle details of photosynthesis.

Areas Where the Scientific Method Is Inappropriate

Certain concepts exist for which the scientific method is inappropriate. We all believe that it is not right to wantonly kill each other, that racism and sexism are bad, and that things such as morality and ethics exist. But both morality and ethics have no chemical composition, no physical structure, no temperature; they are not tangible and thus cannot be studied by the scientific method. Science can study, measure, analyze, and describe the factors that cause people to kill each other or to be racist or sexist, and it can predict the outcome of these actions. But science cannot say if such actions are right or wrong, moral or immoral. Consider euthanasia: many types of incurable cancer cause terrible pain and suffering in their final stages, which may last for months. We have drugs that can arrest breathing so that a person dies painlessly and peacefully. Science developed the drugs and can tell us the metabolic effects of using them, but it cannot tell us if it is right to use them to help a person die and avoid pain. Biological advances have made us capable of surrogate motherhood, of detecting fetal birth defects early enough to allow a medically safe abortion, and of producing insecticides that protect crops but pollute the environment. These advances have made it more important than ever for us to have a well-developed ethical philosophy for assessing the appropriateness of various actions.

Types of Interactions Between Organisms

All organisms live close to other organisms, interacting with multiple other creatures throughout their lives. Any place on Earth that has life will have several types, not just one. If you see plants, then there almost certainly are fungi present as well, along with bacteria, soil algae, and numerous animals, perhaps most of them microscopic. And of course, if you are seeing the plants, that means that at least one person is there, interacting with the other organisms.

Most interactions between organisms can be classified as one of four basic types:

1. Both members benefit. A relationship is **mutualistic** if both organisms benefit from the relationship, if both organisms grow and develop better together than if one of the partners were missing (Figure 1.15). Many plant and people relationships are mutualistic, for example when we cultivate crops or establish and maintain a garden. Placing hives of honeybees near crops is beneficial to the crop, the bees, and to us. Establishing national and state parks as places of both wildlife preservation as well as recreation is beneficial to ourselves and the organisms in the parks.

2. One member is unaffected, the other is helped. In a **commensal** relationship one partner is unaffected and the other benefits. As we build towns, cities, and farms, we also build vacant lots and small pieces of land that are no longer natural but neither are they cultivated. These are ideal for plants such as dandelions, chickweed, plantago, tumbleweeds, and other weeds that we often just ignore. These plants benefit from the disturbances that we create, but their presence has almost no impact on us at all. When we build artificial lakes, reservoirs, and canals, many water plants benefit but we are not affected. Have you ever gone hiking then pulled sticky seeds out of your socks and shoes? You have helped distribute the seeds of some plants (so the plants benefit), but you probably didn't even notice the seeds. Unfortunately, this happens on a larger and more serious scale: seeds and animals are unintentionally moved long distances, even from one continent to another as materials are shipped around the world. This usually has no direct impact on us, but it introduces the organisms into new habitats, habitats where they may have never before existed. If they survive (or even worse, if they thrive), they become introduced invasive weeds that benefit from an expansion of their range, but which harm the native plants and animals.

3. Both members are harmed. A relationship is a **competition** when two or more species compete for the same resource. For example, roots of separate plants compete for water in the soil, leaves compete for light, and plants compete just to have enough space for their bodies. A competition tends to harm both members because neither one grows as well as it could if it had the entire resource all to itself. People compete with plants and other organisms for space and water, and people usually win. We eliminate all vegetation and animals from huge areas of land so that we can build towns, factories, farms, ranches, ski areas, marinas, airports, highways, sport facilities with huge parking lots, and so on. We dam rivers and divert water to our needs, leaving downstream ecosystems deprived of water. We even compete with plants for their pollinators and seed dispersers when we spray insecticides to kill insects and when hunters kill birds and animals.

There are not many examples of competitions in which plants win against people, but there are a few. Certain weeds, for example witchweed (*Striga*), are so invasive and difficult to control that they have forced farmers to abandon cropland. If ranchers allow pastures to be overgrazed in drier areas, prickly pear cactus (*Opuntia*) can invade and spread so aggressively that the pasture becomes useless.

4. One member is harmed, the other benefits. In a **predatory** relationship, one member is harmed and the other benefits, and usually this term is reserved for specific pairs of organisms in which the actions occur repeatedly. For examples, lions prey on zebras, and parasitic plants such as mistletoe prey on their host plants. Animals such as buffalo that graze on grasses and others, like deer that browse on leaves and twigs, are described as predators. In this respect, we prey on plants when we pick the flowers or fruits of wild plants: we take something from them but we are not cultivating them, we are not helping them. Similarly, we prey on rare orchids, bromeliads, parrots, and tropical fish when we collect them from their natural habitats rather than cultivating them. I know of no examples in which plants prey on people.

Important Terms

algae	eukaryote	moss
angiosperm	fern	mutualism
Archaea	fern ally	predation
Bacteria	flowering plant	prokaryote
bryophyte	habitat destruction	scientific method
commensal	*Homo sapiens*	theory
competition	hornwort	true plant
conifer	hypothesis	vascular plant
cycad	lichen	vascular tissue
Eukarya	liverwort	

Concepts

- All the material of our bodies, all our energy, and all the oxygen we breathe are produced by plants.
- Plants provide us with necessities such as clothing, housing, heat, medicine, and other essentials.
- Plants provide us with nonessential foods, flavors, drinks, aromas, and beauty that add richness to our lives.
- The natural areas of Earth are not unlimited and we must preserve wilderness areas, species and their habitats; in some cases the habitats have been damaged and must be restored.
- Many activities by all sorts of people destroy or damage habitats, endangering plants, animals, and other species.
- All plants are eukaryotes (their cells have true nuclei); most plants are vascular plants (they have vascular tissues); most plants we use are seed plants, either conifers or angiosperms (flowering plants).
- Relationships between organisms can be mutualistic, commensal, competitive, or predatory.
- The scientific method is a set of standards for the type of information and logic that can be used when trying to understand material aspects of the world. One principle is skepticism, that we must keep our minds open to new possibilities.