CHAPTER 1

Introduction to Plants and Botany

LEARNING OBJECTIVES

After reading this chapter, students will be able to:

- Recognize the relationship between plants and climate change.
- Describe the difficulty in creating a singular definition of a plant.
- List four fundamental tenets of the scientific method.
- Give an example of an area where the scientific method is inappropriate.
- Summarize the fundamental concepts related to the study of plants.
- Order the process of evolution from early prokaryote to plant.
- Provide two examples of plant adaptations.
- Explain the difference between observation and interpretation.

OUTLINE

- Concepts
- Plants
- Scientific Method
- Areas Where the Scientific Method Is Inappropriate
- Using Concepts to Understand Plants
- Origin and Evolution of Plants
- Diversity of Plant Adaptations
- Plants Versus the Study of Plants

Box 1-1 Plants and People: Plants and People, Including Students

Box 1-2 Plants and People: The Characteristics of Life

Box 1-3 Plants and People: Algae and Global Warming

Did You Know?

- Early humans were weaving fibers of flax plants into rough clothing as early as 36,000 years ago.
- Vanilla, chocolate, coffee, tea, cinnamon, and mint are all made from plants.
- Plant products kill tens of thousands of people every year, not only through accidental poisoning but through cancer caused by smoking tobacco.
- Science and the scientific method are a simple set of accepted rules about the ways in which evidence can be gathered and processed.

Chapter Opener Image: People and animals must have oxygen to live. Without oxygen, we would die of asphyxiation. The plants here are photosynthesizing in the sunshine, producing the oxygen we need. The roots of these trees hold the soil in place, even on steep slopes. Without the trees, rain would wash all the soil away leaving just bare rock and this river would flood after every rain or be almost dry when there is a dry period. Global warming is causing less snowfall (and more snow melt) in mountains; this alters river flow and the suitability of the area for plants and animals. Worthington Glacier, Alaska.

Concepts

Earth is becoming hotter, flooding is more frequent, and weather is more violent because we burn coal, oil, and other fossil fuels, which releases carbon dioxide into the atmosphere. Carbon dioxide is one of several greenhouse gases that allow visible sunlight to pass through the atmosphere and strike Earth's surface, heating it. The warmer rocks, soil, and water give off infrared radiation back out toward space, but greenhouse gases absorb infrared light and heat the atmosphere. It is a simple relationship: The higher the concentration of greenhouse gases in the atmosphere, the hotter the climate. As Earth becomes hotter, more water evaporates out of the oceans into the air, where it then falls as heavy rains, causing flooding throughout the world. The warmer air also causes snow and ice on mountain tops to melt faster, increasing flooding. Every summer brings more mudslides in California, larger floods on the Mississippi and other rivers, and more violent tornadoes and hurricanes. This is global warming, also known as global climate change.

What does this have to do with botany? Everything. Plants in the sun photosynthesize; that is, they take carbon dioxide out of the air and use it to make the chemicals that compose their bodies. Most of the weight of leaves, stems, roots, flowers, fruits, and seeds is carbon that was carbon dioxide in the air before plants captured it. As plants photosynthesize, they remove carbon dioxide from the air and lock it into their bodies, helping to keep Earth cool and counteracting the warming we are causing. An important question now is "Can plants remove enough carbon dioxide from the air to counteract the damage we are doing?" The answer is "probably not."

The balance between the addition of atmospheric carbon dioxide by us and its removal by plants is affected by several factors that are easy to understand. All animals, fungi, bacteria, and other nonphotosynthetic organisms produce carbon dioxide just by being alive. As our bodies "burn" our food (technically, as they respire it), carbon dioxide is produced; therefore, animals (including humans) have been adding carbon dioxide to the atmosphere for billions of years. The real problem began when our ancestors discovered fire: We then began burning wood and coal and, more recently, petroleum, natural gas, and other fossil fuels, adding carbon dioxide to the air in huge quantities. Until our mastery of fire, plants were actually taking carbon dioxide out of the air faster than our respiration was adding it.

Photosynthesis originated 2.8 billion years ago, and the amount of carbon dioxide in the air has decreased and Earth has cooled, until the start of the Industrial Revolution when we began burning massive amounts of fuel. If photosynthesis has been removing carbon dioxide from the atmosphere, does that mean there was more carbon dioxide in the air in the past? And, if so, was Earth warmer in the past? The answer to both questions is yes. Earth formerly had much more carbon dioxide in its atmosphere and consequently was much hotter. Earth's climate is changing now, but it has always been changing and has never stayed the same for long periods of time.

In addition to respiration and burning, carbon dioxide is added to the air as volcanoes erupt and as magma (molten rock) comes upward at mid-ocean ridges between the giant tectonic plates that carry the continents on Earth's surface. Carbon dioxide is also removed as certain algae build shells of calcium carbonate: All limestone rock on Earth is composed of vast numbers of microscopic shells of certain algae, clams, and other marine animals. At times in the past volcanoes were very active and added carbon dioxide faster than photosynthesis could remove it, causing Earth to heat up. At other times they were inactive and photosynthesis outpaced volcanism and Earth cooled.

Neither heating nor cooling has ever been severe enough to risk killing all life on Earth. Instead, when Earth was warm, rains were also heavy (because of the warm oceans), so plants grew faster and more abundantly, absorbing more carbon dioxide. When plants take most of the carbon dioxide out of the air, Earth cools and dries, and plant growth slows.

Today, we are at an unusually cool period in Earth's history. Plants have taken so much carbon dioxide out of the air there is almost none to trap the sun's heat. We are actually in an ice age right now, known as the Pleistocene Ice Age, but we are in its warm period (called the Holocene warm period), known as an interglacial period (cold periods of ice ages are called glacials because glaciers are then common on almost all mountains). Is it bad that Earth is unusually cool? Should we be burning even more petroleum and coal to heat it up?

The current coolness is exceptional, but it is the climate in which we evolved and became distinct from the other great apes. It is also the climate in which most of our food plants evolved: Wheat, rye, barley, and corn are grasses that flourish under cool, dry conditions. Grasses grow on open, treeless plains, but when Earth is warm most of its surface is covered by forests, and grasses do not grow well in the shade below trees. You may know that a significant step in the evolution of us modern humans is that, unlike our ancestors who were adapted to living in trees, we gradually evolved to walk upright on the ground, freeing our forelimbs (our arms) such that we could use our hands for holding and manipulating tools. We did not come down out of the trees until open grasslands finally appeared on Earth, and those came about in the last 30 million years as Earth became cooler, drier, and the forests receded, all due to plant photosynthesis.

More recently, we people began to cultivate our own food. Agriculture is new, having separate, independent origins in Europe, Asia, Africa, and the Americas less than about 11,000 years ago. That is a significant number: The current interglacial period we are living in now began only 14,000 years ago. Snow and ice began to melt away, people spread across more of the land, and some humans made the journey from Asia to the Americas at that time. In the very short time of just a few thousand years between 14,000 years ago and 11,000 years ago, humans progressed from being wandering hunter-gatherers to starting the first farms, then establishing villages and towns, and then civilization began with art, writing, religion, and science.

Let's go back to our original question: "What does this have to do with botany?" Again, the answer is everything. Plants changed the climate of Earth such that we can now live on it. Plants also produce the oxygen we breathe and the food we eat. We get cloth, paper, lumber, and chemicals from plants, and plants are important to us spiritually because of their beauty.

As you study the following pages, think of the many ways in which plant biology affects our own biology. And think of other organisms; we share Earth's surface not only with plants but also with all other animals, fungi, and microbes. All our biologies affect those of all other organisms, as we are all interconnected and interdependent.

Plants

Botany is the scientific study of plants. This definition requires an understanding of the concepts "plants" and "scientific study." It may surprise you to learn that it is difficult to define precisely what a plant is. Plants have so many types and variations that a simple definition has many exceptions, and a definition that includes all plants and excludes all nonplants may be too complicated to be useful. Also, biologists do not agree about whether certain organisms—particularly algae—are indeed plants. Rather than memorizing a terse definition, more is gained by understanding what plants are, what the exceptional or exotic cases are, and why botanists disagree about certain organisms.

Your present concept of plants is probably quite accurate: Most plants have green leaves, stems, roots, and flowers (**FIGURE 1-1**), but you can think of exceptions immediately. Conifers such as pine, spruce, and fir have cones rather than flowers (**FIGURE 1-2**), and many cacti and succulents do not appear to have leaves. Both conifers and succulents, however, are obviously plants because they closely resemble organisms that unquestionably are plants. Similarly, ferns and mosses (**FIGURES 1-3** and **1-4**) are easily recognized as plants. Fungi, such as mushrooms (**FIGURE 1-5**) and puffballs, were included in the plant kingdom because they are immobile and produce

FIGURE 1-1 This evening primrose (*Oenothera*) is obviously a flowering plant. It has a short stem and numerous simple leaves; its extensive root system is not visible here.

FIGURE 1-2 Conifers, like this spruce (*Picea*), produce seeds in cones; the conifers, together with the flowering plants and a few other groups, are known as seed plants.

FIGURE 1-3 Ferns have several features in common with flowering plants; they have leaves, stems, and roots; however, they never produce seeds, and they have neither flowers nor wood.

FIGURE 1-4 Of all terrestrial plants, mosses have the least in common with flowering plants. They have structures called "leaves" and "stems," but these are not the same as in flowering plants. They have no roots at all.

(A) (B) Courtesy of C. Mims, University of Georgia

FIGURE 1-5 Fungi such as **(A)** mushrooms and **(B)** brackets are not considered to be plants. They are never green and cannot obtain their energy from sunlight. Also, their tissues and physiology are quite different from those of plants. Fungi are important to plants, however, because many fungi break down dead material in the soil such as fallen leaves and rotting tree trunks; as the fungi cause these materials to rot, they release minerals and enrich the soil.

spores, which function somewhat like seeds; however, biologists no longer consider fungi to be plants because recent observations show that fungi differ from plants in many basic biochemical and genetic respects.

Algae are more problematical. One group, the green algae (**FIGURE 1-6**), is similar to plants in biochemistry and cell structure, but it also has many significant differences. Some botanists conclude that it is more useful to include green algae with plants; others exclude them, pointing out that some green algae have more in common with the seaweeds known as red algae and brown algae (**FIGURE 1-7**). Arbitrarily declaring that green algae are or are not plants solves nothing; the important thing is to understand the concepts involved and why disagreement exists (**TABLE 1-1**).

All plants have a scientific name. Each name consists of two words: a genus (pronounced GEE nus) name and a specific epithet. For example, the genus *Prunus* has several species with edible fruits, and they are distinguished by their species epithet: Cherries are *Prunus avium*, peaches are *Prunus persica*, and apricots are *Prunus armeniaca*. The name of cherries is not just "*avium*," it is both words: *Prunus avium*. In the scientific names of plants, the genus name is always capitalized but the species epithet is not (it is not *Prunus Avium*). Both words are italicized or underlined. Closely related genera

FIGURE 1-6 These green algae do not look much like plants, but many aspects of their biochemistry and cellular organization are very similar to those of plants. Some green algae were the ancestors of land plants; although not considered to be true plants, they are obviously closely related to plants.

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FIGURE 1-7 These brown algae (*Fucus*), commonly called kelp, have very plant-like bodies as a result of convergent evolution: they are not true plants. Their biochemistry, genetics, anatomy, and reproduction differ greatly from those of plants.

TABLE 1-1 The Three Domains of Organisms

Prokaryotes
Domain Archaea
Domain Bacteria (including cyanobacteria)
Eukaryotes
Domain Eukarya
Protista: single-cell organisms (protozoans, algae); multicellular algae
Kingdom Myceteae: fungi such as mushrooms, puffballs, bread mold
Kingdom Animalia: animals
Kingdom Plantae:[1] plants
Division Bryophyta: mosses
Division Pteridophyta: ferns
Division Coniferophyta: conifers
Division Magnoliophyta:[2] flowering plants

[1]Within kingdom Plantae, many botanists recognize about 17 divisions; only the four most familiar are listed here. Many botanists conclude that algae should be included in kingdom Plantae.

[2]Some people use the term Angiospermophyta.

are grouped together into families; in botany, family names are always capitalized and always end in "-aceae" (pronounced as if you are spelling the word "ace": AY see ee). *Prunus* is in the rose family Rosaceae (pronounced rose AY see ee), along with roses (*Rosa*), apples (*Malus*), strawberries (*Fragaria*), and many others. A very few families have old, alternative endings, but those are rarely used. For example, the modern name for the mustard family is Brassicaceae (with the "-aceae" ending); the old family name, Cruciferae, is almost never encountered except in older publications. For animals, family names end in "-ae." We humans are *Homo sapiens* in the family Hominidae; other members of our family are chimpanzees (*Pan*), gorillas (*Gorilla*), and orangutans (*Pongo*).

Scientific Method

The concept of a scientific study can be understood by examining earlier approaches to studying nature. Until the 15th century, several methods for analyzing and explaining the universe and its phenomena were used, with religion and speculative philosophy being especially important. In religious methods, the universe is assumed to either be created by or contain deities. The important feature is that the actions of gods cannot be studied: They are either hidden or capricious, changing from day to day and altering natural phenomena. Agricultural studies would be useless because some years crops might flourish or fail because of weather or disease, but in other years, crop failure might be due to a god's intervention (a miracle) to reward or punish people. There would be no reason to expect consistent results from experiments. In a religious system, much of the knowledge of the world comes as a revelation from the deity rather than by observation and study of the world. A fundamental principle of all religions is faith: People must believe in the god without physical proof of its existence or actions.

Speculative philosophy reached its greatest development with the ancient Greek philosophers. Basically, their method of analyzing the world involved thinking about it logically. They sought to develop logical explanations for simple observations and then followed the logic as far as possible. An example is the philosophical postulation of atoms by Democritus around 400 BCE (before the common era). From the observation that all objects could be cut or broken into two smaller objects, it follows logically that the two pieces can each be subdivided again into two more, and so on. Finally, some size must be reached at which further subdivision is not possible; objects of that size are atoms. But there was no proof, no experiment to determine if that was actually valid. Democritus could have been wrong: For all anyone knew, it might have been possible to continue dividing pieces forever, infinitely. Speculative philosophy did not involve verification; philosophical predictions were made, but no actual experiment or observation was performed to see if they were correct. A speculation is a statement that cannot be proved or disproved (e.g., "If Elvis were still alive, he would still be performing in Las Vegas."). A problem with this method is that often several alternative conclusions are equally plausible logically; only experimentation reveals which is actually true.

Starting before the 1400s, a new method, called the **scientific method**, slowly began to develop. Several fundamental tenets were established:

1. *Source of information. All accepted information can be derived only from carefully documented and controlled observations or experiments.* Claims emanating from priests or prophets—or scientists—cannot be accepted automatically; they must be subjected to verification and proof. For example, for hundreds of years, medicine was taught using a text called *Materia Medica* written by 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 was more accurate than accepting undocumented claims, even if the claims had been made by an extremely famous, respected person.
2. *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, and no instrument has ever detected ghosts reliably: If ghosts do exist, they must be intangible and cannot be studied by the scientific method. Anything that cannot be observed cannot be studied.
3. *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 may have (1) made an innocent mistake, (2) tested the drug on people who would have gotten better anyway, or (3) been committing fraud; however, 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's outcome was altered by benevolent spirits and the second by evil spirits.

4. *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 of our research, all of 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 and then later—often years later—DNA-based evidence indicates that 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 model. If its predictions are accurate, they support the hypothesis; if its predictions are inaccurate, they prove that 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 (**FIGURE 1-8**). 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 either that the hypothesis must be altered somewhat or that the entire hypothesis has been wrong. For instance, plants such as Indian pipe or *Conopholis* (**FIGURE 1-9**) grow the same with or without light; they do not need light for growth. 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

(A) Courtesy of R. Fulginiti, University of Texas, Austin

(B) Courtesy of R. Fulginiti, University of Texas, Austin

FIGURE 1-8 **(A)** This aspen forest in Michigan does not have a dense canopy, but it intercepts so much light that few plants survive in the shade. The herb is the bracken fern *Pteridium aquilinum*. **(B)** Near the aspen forest is an open area with more light; herb growth, in this case a sedge, is much more abundant.

FIGURE 1-9 The yellowish flowers pushing out of the pine needle litter constitute almost the entire plant body of this parasitic plant, *Conopholis mexicana*. It is attached to the roots of nearby trees and draws nutrients from them. Like fungi, it cannot obtain its energy from sunlight, but so many other aspects of its anatomy and physiology are like those of ordinary plants that we have no difficulty in recognizing that this is a true plant, not a fungus.

and plant growth are tangible phenomena that 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. 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.

In former times, if a theory had sufficient support, it was referred to as a "law," such as the laws of thermodynamics or the law that for every action there is an equal and opposite reaction. Physicists occasionally still do this but biologists never use the term "law." Even though we have tens of thousands of observations that plants are composed of cells, there is no "law that all plants are composed of cells," instead we just treat this as a well-supported theory. No biologist expects that there will be a discovery that shows that plants are not actually made up of cells, but we simply do not ever use the term "law."

Many people attempt to discredit the theory of evolution by natural selection by saying that it is merely a theory of evolution, not a law of evolution; these people do not realize that their argument is nonsensical.

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 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, it is used as an answer in itself that prevents further study. Photosynthesis is certainly complex, and it may have been designed by some intelligent being; however, believing that does not help us to understand photosynthesis at all, and it does not help us to 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; however, both morality and ethics have no chemical composition, no mass, no electromagnetic spectrum—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. Science, however, cannot say whether 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 whether 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 well-developed ethical philosophy for assessing the appropriateness of various actions.

Using Concepts to Understand Plants

The growth, reproduction, and death of plants—indeed, all aspects of their lives—are governed by a small number of basic principles. Each chapter in this text opens with a section called "Concepts," which discusses the principles most relevant to the topics in that particular chapter. Here in this chapter and at the beginning of your study of botany and plants, I want to introduce you briefly to some of these principles and to encourage you to use them as you read and think about plants. These concepts will make plant biology more easily understood—the numerous facts, figures, names, and data will be less overwhelming when you realize that they all fit into the patterns governed by a few fundamental concepts.

1. *Plant metabolism is based on the principles of chemistry and physics.* Weeds may seem to appear from nothing as if by magic; however, that is never true—they grow from seeds. All the principles you learn in your chemistry or physics classes are completely valid for plants.
2. *Plants must have a means of storing and using information.* After a seed germinates, it grows and develops into a plant, becoming larger and more complex; then it reproduces. The plant is taking in energy and chemical compounds and transforming them into the organic chemical compounds it uses to build more of itself. This requires a

complex, carefully controlled metabolism, and there must be a mechanism for storing and using the information that regulates that metabolism. As you may already know, genes are the primary means of storing this information.

3. *Plants reproduce, passing their genes and information on to their descendants.* Because an individual obtains its genes from its parents, the information it uses to control its metabolism is similar to the information its parent had used; thus, offspring and parents resemble each other. For example, a bean seed contains genes whose information guides the seed's metabolism into constructing a new bean plant, but a tomato seed grows into a tomato plant because it received different genes and information from its parents (**FIGURE 1-10**).
4. *Genes, and the information they contain, change.* As plants make copies of their genes during reproduction, accidental changes (mutations) occasionally occur, and this causes the affected gene and its information to change. This is quite rare, and most genes (and information) are passed unaltered from parents to offspring; however, as mutations occur and change a gene's information, they basically generate new information such that the plant that grows and develops under the control of the mutated gene may be slightly (or significantly) different from its parents. Thus, over time, a gradual evolution occurs in the genes, information, and biology of plants. Consequently, in a large population of many individuals of a species, some variation exists; the individuals are not identical (**FIGURE 1-11**).

FIGURE 1-10 This bean seed is developing into a bean plant, guided by genetic information it inherited from its parents.

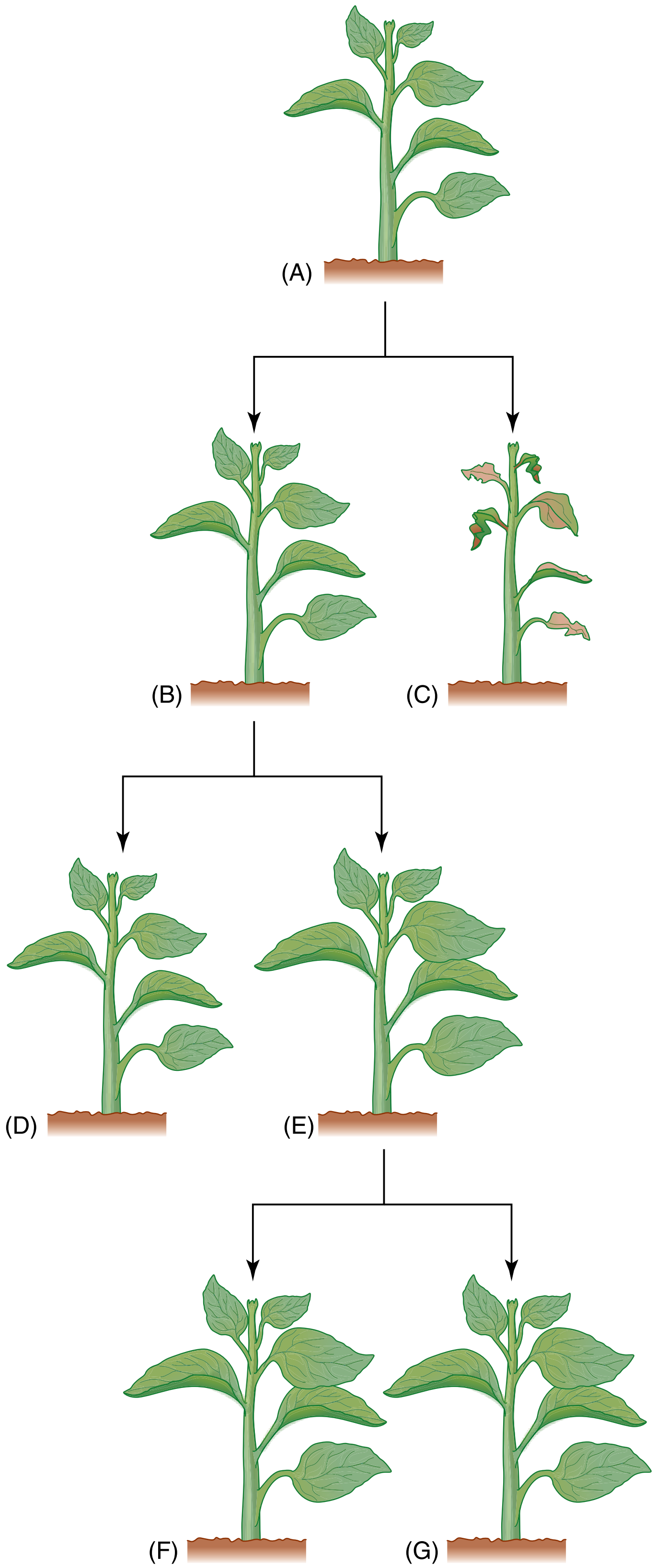

FIGURE 1-11 **(A)** A plant produces numerous offspring, many of which resemble it strongly **(B)**. Mutations may occur that cause, for instance, leaves to be malformed and poorly shaped for photosynthesis **(C)**; most or all these mutants die and do not reproduce. The normal plants continue to reproduce (B) and **(D)**, but another mutation may occur that causes the leaves to be larger and more efficient at photosynthesis **(E)**. These may grow and reproduce so well that they crowd out the original parental types, and the plant population finally contains only the type with large leaves **(F)** and **(G)** .

Plants and People

BOX 1-1 Plants and People, Including Students

Plants and people affect each other. The most obvious perhaps are the ways that people benefit from plants: They are the sources of our food, wood, paper, fibers, and medicines. It is difficult to excite students by listing the world production of wheat and lumber in metric tons, but just consider what your life would be like without chocolate, coffee, tea, sugar, vanilla, cinnamon, pepper, strawberries, mahogany, ebony, cotton, linen, roses, orchids, or the paper that examinations are written on. The oxygen we breathe comes entirely from plants. Plants affect each of us every day, not simply by keeping us alive but also by providing wonderful sights, textures, and fragrances that enrich our existence.

However, plants and people affect each other in ways that are not readily apparent in our day-to-day lives. Listed here are a few important topics you should be aware of. Think about their importance and how you—as an actual biological organism—interact with the other organisms on this planet.

Biotechnology is a set of laboratory techniques that allow us to alter plants and animals, giving them new traits and characteristics. Farmers have done this for thousands of years with controlled breeding of the best plants and animals (artificial selection), but biotechnology permits much more rapid, extensive alterations. We must now consider whether such manipulations are safe and worthwhile.

Global warming and *climate change* are caused by a buildup of carbon dioxide in our atmosphere caused by burning coal, oil, gas, and the trees of forests everywhere (not just tropical rain forests). Carbon dioxide traps heat, preventing Earth from radiating excess energy into space. Global warming is causing polar ice caps to melt, and climate change alters circulation of ocean currents and even the amount and pattern of rainfall. Preserving our forests and planting more trees might help stop and reverse global warming, but the possibility exists that global warming is preventing the occurrence of another ice age.

Desertification is the conversion of ordinary forest or grassland to desert. Accurate measurements are difficult, but it appears that deserts may be spreading as people cut shrubs and trees for firewood and allow goats to eat remaining vegetation. Once an area has been converted to desert, its soil is rapidly eroded, making recovery difficult. Something as simple as cheap solar cookers might prevent the Sahara desert from spreading farther across Africa.

Habitat loss results when an area is changed so much that a particular species can no longer survive in the area. Significant causes are the construction of highways, housing subdivisions, and shopping malls with enormous parking lots; these eliminate almost all species from an area, but habitats are also lost by logging, farming, mining, damming rivers, and spilling toxic chemicals. As habitat is lost, plants or animals must try to survive on the smaller remaining habitat. Once too little habitat is left, species usually become extinct.

Introduced exotics are organisms native to one part of the world but which have been brought to another part, where they thrive. Examples of introduced exotic animals are fire ants in the southern United States and zebra mussels in the Great Lakes region. Water hyacinth, purple loosestrife, and kudzu (a vine) were introduced to the United States and are now proliferating and reproducing so vigorously that they are crowding out many plants that normally grow here.

It is not realistic to believe that we humans will stop all activities that have negative impacts on our environment and on the other species with which we share this planet, but we can search for ways to minimize the harm we cause by recycling, conserving resources, and avoiding products that require pollution-causing manufacturing techniques.

(A) (B)

FIGURE B1-1 Habitat loss is caused by many types of human activity. **(A)** This church parking lot covers acres of land previously used for grazing. Now it is used only 2 or 3 hours 1 day a week. Other than the few trees that were spared, it has no plants or animals, it prevents rain from soaking into the ground, and the asphalt leaches harmful chemicals into nearby creeks. No other business is nearby that could use this parking lot on weekdays or at night, which would at least provide additional benefit to offset the ecological damage it causes. **(B)** Even the construction of beautiful parks is habitat destruction.

5. *Plants must survive in their own environment.* They must be adapted to the conditions in the area where they live. If they are not adapted to that area's conditions, they grow and reproduce poorly or die prematurely. Other plants whose genes result in characters that make those plants more suited to live in that area grow and reproduce more successfully and produce more offspring. Also, plants do not exist in isolation: A significant aspect of a plant's environment is the presence of other organisms. Some neighboring organisms may be helpful to the plant; others may be harmful, and most perhaps have little effect on it. This concept can be important when trying to understand a plant's structure and metabolism: One type of photosynthetic metabolism and leaf structure may function well if a particular plant always grows in the shade of taller neighbors, whereas a different type of photosynthetic metabolism and leaf structure may be necessary for a plant that grows nearby but in an unshaded area.
6. *Plants are highly integrated organisms.* The structure and metabolism of one part have some impact on the rest of the plant. When studying the biology of leaves, consider how the structure and metabolism of stems, roots, epidermis, and other parts might affect the function of those leaves. Large leaves absorb more sunlight and energy than small leaves; however, if a plant has large leaves, it may need to have a large root system to absorb water and minerals for the leaves, and it may need wide stems to conduct enough water and minerals from the roots to the leaves. Keep in mind that structure and metabolism must be integrated: The structure of a cell, tissue, or organ must be compatible with the metabolic function of that same cell, tissue, or organ. For example, if a leaf is fibrous and tough, insects may find it unpalatable and may avoid eating it; however, if the leaf is too fibrous, the fibers may block the absorption of sunlight. Such a structure would be incompatible with photosynthesis.
7. *An individual plant is the temporary result of the interaction of genes and environment.* Be careful to consider differences between an individual plant and that plant's species (the group made up of all similar plants). Consider something like a sunflower: An individual plant exists because its parents underwent reproduction and one of their seeds landed in a suitable environment, where the information in the seed's genes interacted with the environment by way of the seed's structure and metabolism. There are two concepts of "sunflower" here: (1) the actual plant that we can observe, measure, cultivate, and enjoy and that interacts with its environment, absorbs resources, responds to changes, attracts pollinators, and resists pathogens and (2) the genetic information that guides all of this and that has existed for thousands of years, evolving gradually as it has been passed down through all the ancestors of this particular individual sunflower. This information does not exist only in this one individual but rather in all of the currently living sunflower individuals. It will continue to exist in future individuals long after this generation has passed away.
8. *Plants do not have purpose or decision-making capacity.* It is easy to speak and write as if plants were capable of thinking and planning. We might say, "Plants produce roots in order to absorb water"; however, this suggests that the plants are capable of analyzing what they need and deciding what they are going to do. Assuming that plants have human characters such as thought and decision-making capacity is called **anthropomorphism**, and it should be avoided. Similarly, assuming that processes or structures have a purpose is called **teleology**, and it too is inaccurate. Consider an alternative way of phrasing the sentence: "Plant roots absorb water," leaving out the phrase "in order to." The reality of the situation is that some of the information in the plant's genes causes the plant to produce roots, which have a structure and a metabolism that result in water absorption. Plants have roots because they inherited root genes from their ancestors, not in order to absorb water. Absorbing water is a beneficial result that aids in the survival of the plant, but it is not the result of a decision (anthropomorphism) or purpose (teleology).

Origin and Evolution of Plants

Life on Earth began about 3.5 billion years ago. At first, living organisms were simple, like present-day bacteria, in both their metabolism and structure; however, over thousands of millions of years cells gradually increased in complexity through evolution by natural selection. The process is easy to understand: As organisms reproduce, their offspring differ slightly from each other in their features—they are not identical. Offspring with features that make them poorly adapted to the habitat probably do not grow well and reproduce poorly if they live long enough to become mature (Figure 1-11 and **FIGURE 1-12**). Other offspring with features that cause them to be well-adapted grow well and reproduce abundantly, passing on the beneficial features to their own offspring. This is called **natural selection**. New features come about periodically by mutations, and natural selection determines which new features are eliminated and which are passed on to future generations. Evolution by natural selection is a model consistent with observations of natural organisms, experiments, and theoretical considerations.

As early organisms became more complex, major advances occurred. One was the evolution of the type of photosynthesis that produces oxygen and carbohydrates. This photosynthesis is present in all green plants, but it first arose about 2.8 billion years ago in a bacterium-like organism called a cyanobacterium. Later, cell structure became more efficient as subcellular components evolved. These components, called organelles, each provide a unique structure and chemistry specialized to a specific function. Division of labor and specialization had come about.

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FIGURE 1-12 Mutations that produce disadvantageous features usually contribute to the death, sooner or later, of an organism. If the individual cannot undergo reproduction (because it is dead), it cannot pass the mutation on to offspring and the deleterious mutation is eliminated.

A particularly significant evolutionary step occurred when DNA, the molecule that stores hereditary information, became located in its own organelle—the cell nucleus. Because this step was so important and occurred with so many other fundamental changes in cell metabolism, we classify all cells as prokaryotes if they do not have nuclei (bacteria, cyanobacteria, and archaeans) or as eukaryotes if they do have nuclei (all plants, animals, fungi, and algae) (Table 1-1).

By the time nuclei became established, evolution had produced thousands of species of prokaryotes. The newly evolved eukaryotes also diversified. Some acquired an energy-transforming organelle, the mitochondrion, and some acquired chloroplasts, which carry out photosynthesis and convert the energy in sunlight to the chemical energy of carbohydrates. Those with chloroplasts evolved into algae and plants; those without evolved into protozoans, fungi, and animals (**FIGURE 1-13**).

All organisms are classified into three large groups called **domains**: domain Bacteria, domain Archaea, and domain Eukarya; within Eukarya are kingdom Plantae, kingdom Animalia, kingdom Myceteae (fungi), and protists (eukaryotes that do not fit easily into the other three eukaryotic kingdoms). Some protists are closely related to Plantae because some green algae became adapted to living on land and gradually evolved into true plants. As a consequence, early plants resembled those green algae, but as

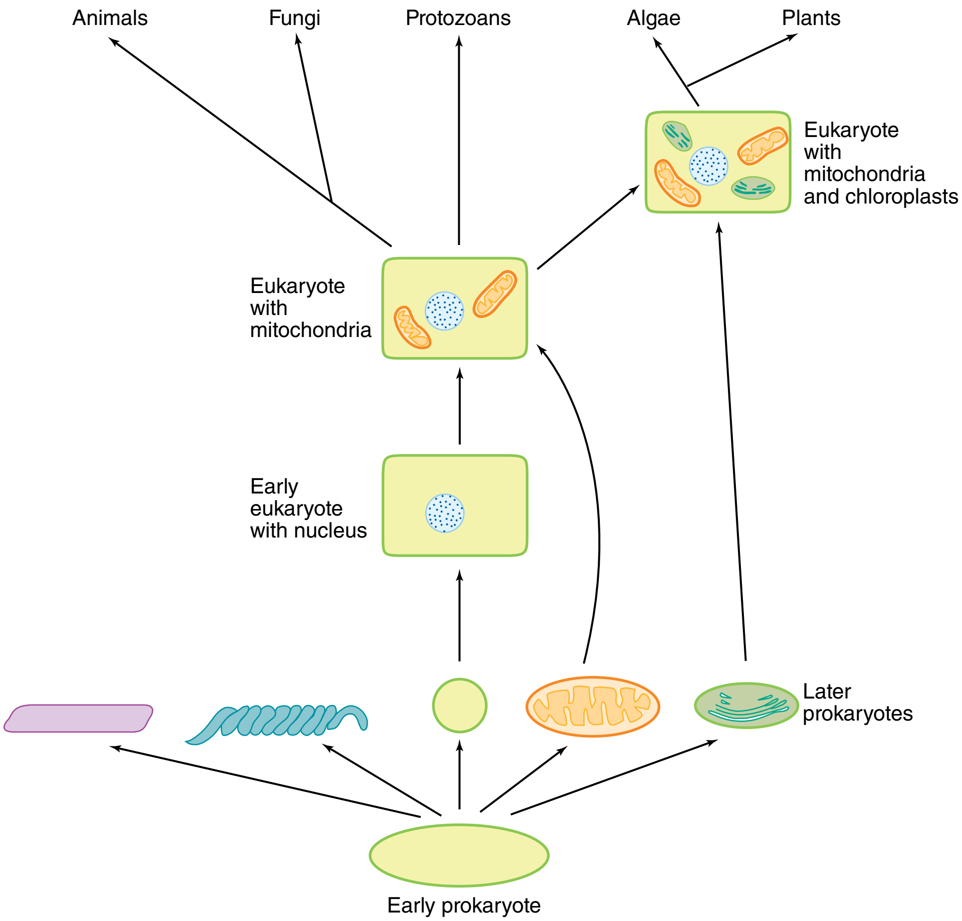

FIGURE 1-13 The earliest cells were simple, but over hundreds of millions of years they became more complex metabolically. Later, some evolved into simple eukaryotic cells with a true nucleus, which later developed mitochondria. Some of these evolved into protozoans, animals, and fungi. Others developed chloroplasts and evolved into plants. Protozoans and algae are protists.

more mutations occurred and natural selection eliminated less adaptive ones, plants lost algal characteristics and gained more features suited to surviving on land. Thousands of species arose, but most became extinct, as those that were more fit grew more rapidly, survived longer, and produced more offspring. Species that did not become extinct evolved into more species and so on. The living plants that surround us are the current result of the continuous process of evolution.

Not all organisms evolve at the same rate; some early species were actually so well adapted that they competed successfully against newer species. Algae are so well suited to life in oceans, lakes, and streams that they still thrive even though most features present in modern, living algae must be more or less identical to those present in the ancestral algae that lived more than 1 billion years ago. Features that seem relatively unchanged are **relictual features** (technically known as **plesiomorphic features**; formerly called primitive features). Like the algae, ferns are well-adapted to certain habitats and have not changed much in 250 million years; they too have many relictual features. Modern conifers are similar to early ones that arose about 320 million years ago. The most recently evolved group consists of the flowering plants, which originated about 100 to 120 million years ago with the evolution of several features: flowers; broad, flat, simple leaves; and wood that conducts water with little friction. The members of the aster family (sunflowers, daisies, and dandelions) (**FIGURE 1-14**) have many features that evolved recently from features present in ancestral flowering plants. These are **derived features** (technically known as **apomorphic features**; formerly called advanced features) (i.e., they have been derived evolutionarily from ancestral features). One recent (highly derived) feature in the asters is a group of chemical compounds that discourage herbivores from eating the plants. The terms "primitive" and "advanced" are avoided in that they imply inferior and superior.

FIGURE 1-14 This is *Gazania splendens* in the aster family. It has many derived features, especially the bitter, toxic chemicals (iridoid compounds) in its leaves; lettuce is in the same family, but plant geneticists have eliminated the genes that produce the antiherbivore features. As a result, lettuce is sweet both to us and to insects, rabbits, and deer.

In the same way that different groups evolve at different rates, various features also evolve at different rates. For instance, the asters are a mixture of the recently derived antiherbivore compounds, less recently derived flowers, and still less recently derived wood. In addition, their bodies are covered with a waxy waterproof layer, the cuticle, that has not changed much since land plants first evolved about 420 million years ago, and their leaves contain chloroplasts and nuclei that are much like those of green algae and are extremely relictual.

Diversity of Plant Adaptations

More than 297,000 species of plants exist today. An unknown number of species, perhaps also several hundred thousand, existed at one time but have become extinct. Virtually all of this diversity came about through evolution by natural selection—survival of the fittest; however, the existence of 297,000 types of living plants means that there must be at least 297,000 ways of being fit on today's Earth. For any particular aspect of the environment, many types of adaptation are possible. There is not one single, exclusive, perfect adaptation. Consider plants growing in a climate with freezing winters. Frozen soil is physiologically dry because roots cannot extract water from it. If the winter air is dry and windy, shoots lose water, and plants are in danger of dying from dehydration. How can plants adapt to this? Mutations that cause leaves to fall off in autumn and mutations that cause bark to develop on all exposed parts of the stem reduce the surface area through which water is lost; such mutations are advantageous in this environment, and many species have these adaptations. In other species, the entire shoot system above ground dies, but subterranean bulbs, corms, or tubers persist and produce a new shoot the next spring. Another adaptation is for the plant itself to die but its seeds to live through the harsh conditions. Finally, evergreen species retain both stem and leaves, but the leaves have extra thick cuticles and other modifications that minimize water loss.

This diversity is extremely important, and you must be careful to think in terms of alternative adaptations, alternative methods of coping with the environment. The physical and biological world is made up of gradients: It is not simply either hot or cold but rather ranges continuously from hot in some areas at some times to warm, cool, and cold in the same or other areas at other times. Roots face a range of water availability from flooded, waterlogged soil to moist, somewhat dry, and even arid soil (**FIGURE 1-15**). Studying and understanding plants and their survival require that we place the plant in the context of its habitat: What are the significant environmental factors? What predators and pathogens must it protect itself from? What physical stresses must it survive? What are the advantageous, helpful aspects of its habitat? When you think in terms of gradients and ranges of habitat factors, you appreciate the range of responses and adaptations that exists.

FIGURE 1-15 A mountain provides many types of environments. Higher altitudes are always covered with snow and ice; no plants can survive there. In the lower, warmer altitudes, the steep slopes allow rain to run off rapidly, so the soil is dry. Conifers are well-adapted to these conditions. In the flat valley bottoms, water accumulates as marshes; the roots of sedges and rushes can tolerate the constant moisture, but the roots of conifers would drown. Each type of plant is adapted to specific conditions, even though they grow almost side by side.

Plants Versus the Study of Plants

Mathematicians, physicists, and chemists study the world and derive interpretations that are considered universally valid. The relationships of numbers to each other are the same everywhere in the Universe; if intelligent beings exist elsewhere, their mathematicians will discover exactly the same mathematical relationships. The same is true for physics and chemistry.

Some aspects of biological knowledge also are universally valid: All metabolic processes, either on Earth or elsewhere in the Universe, can be predicted by mathematics, physics, and chemistry. Organisms everywhere must take in energy and matter and convert it metabolically into the substance of their own bodies. This cannot be done with perfect efficiency, and thus, all organisms produce waste heat and waste matter. Furthermore, all organisms must be capable of reproduction and must have a system of heredity.

However, biologists study organisms that exist only on Earth, and we are reasonably certain that if life exists on some other planet, it is not exactly like life here (**BOX 1-2**). Much of what we study does not have universal truth; therefore, knowing about certain plants in certain habitats does not let us predict precisely the nature of other plants in other habitats. Much of our knowledge is applicable only to a particular set of plants or a certain metabolism. In the biological sciences, the fundamental principles have universal validity, but many details are peculiar to the organisms being studied.

As biologists study organisms, we attempt to create a model of an unknown world. Plants are part of reality, and the study of plants attempts to create a model of that reality and build a vocabulary to exchange ideas about the reality. Our observations and interpretations constitute a body of knowledge that is both incomplete and inaccurate. Because we do not know everything about all organisms, our knowledge is an incomplete reflection of reality, and at least some of our hypotheses are wrong. In college courses, even introductory botany, you study areas where we are still gathering information and our knowledge is incomplete. Often, not enough data are present to form coherent hypotheses in which we can have great confidence. You must think carefully about the things you read and hear and analyze whether they seem reasonable and logical and have been verified.

As you read, you will deal with two types of information: observations and interpretations. Most **observations** are reasonably accurate and trustworthy; we usually have to consider only whether the botanist was careful, observed correctly and without error, and reported truthfully. **Interpretations** are more difficult; they are entirely human constructs based on observations, intuition, previous experience, calculations, and expectations. How can we judge whether an interpretation has any relation to reality? A correct scientific interpretation must make an accurate prediction about the outcome of a future observation or experiment.

Your study of the material in this book, as well as your studies of plants themselves, will be easier if you keep in mind two questions that can be asked about any biological phenomenon:

1. *Are there alternatives to this phenomenon?* Do other structures exist that could perform that same function? Could a different metabolic pathway also occur? If no alternative is possible, why not? If alternatives are possible, do they exist? Did they evolve and then become extinct?

   For example, consider photosynthesis: Do plants have alternative sources of energy other than sunlight? We concluded earlier in the chapter that parasitic plants do not need sunlight; they can grow in dark areas. Also, most seeds germinate underground, in complete darkness. Therefore, it seems at first glance that there are alternatives to photosynthesis; however, parasitic plants depend on host plants that do carry out photosynthesis, and germinating seeds rely on stored nutrients they obtained from their parent plant. All plants must, therefore, receive adequate sunlight, at least indirectly. On a theoretical basis, it seems possible that an insect-trapping plant like a Venus flytrap might become so efficient that it could live solely by catching animals, but none is known to be that efficient: They catch only enough insects to provide a little extra nitrogen, not enough to provide the plant with all of the energy it needs.
2. *What are the consequences?* What are the consequences of a particular feature as opposed to an alternative feature or the absence of the feature? Every feature, structure, or metabolism has consequences for the plant, making it either better or less well adapted. Some may have dramatic, highly significant consequences; others may be close to neutral. When you consider the consequences of a particular feature, you must consider the biology of the plant in its natural habitat as it faces competition, predators, pathogens, and stresses.

Plants and People

BOX 1-2 The Characteristics of Life

Botany is a subdivision of biology, the study of life. Despite the importance to biology of defining life, no satisfactory definition exists. As we study metabolism, structure, and ecology more closely, we understand many life processes in chemical/physical terms. It is difficult to distinguish between biology and chemistry or between living and nonliving, but the lack of a definition for life does not bother biologists; very few short definitions are accurate, and life is such a complex and important subject that a full understanding gained through extensive experience is more useful than a definition.

Although we cannot define life, it is critically important for us to recognize it and to know when it is absent. Many hospitals use artificial ventilators, blood pumps, and drugs to maintain the bodies of victims of accidents or illness. The person's cells are alive, but is the person alive? On a less dramatic scale, how does one recognize whether seeds are alive or dead? A farmer about to spend $100,000 on seed corn wants to be certain that the seed is alive. How do we recognize that coral is alive? It looks like rock but grows slowly—but stalactites are rock and they also grow.

The ability to recognize life or its absence is important in space exploration also. The surface of Mars is dry, but water may exist within the soil; many bacteria on Earth live below ground, obtaining energy from chemicals in rock. Europa, a moon of Jupiter, has an ocean below a layer of permanent ice; on Earth, worms, clams, and bacteria live in complete, icy darkness near vents on the ocean floor, obtaining enough energy from volcanic gases to thrive, not just survive. When we explore Mars, Europa, and other parts of the solar system, how will we search for life? How will we know whether we have found it?

All living beings have all of the following characteristics; if even one is missing, the material is not alive:

1. *Metabolism involving the exchange of energy and matter with the environment.* Organisms absorb energy and matter, convert some of it into their own bodies, and excrete the rest. Many nonliving systems also do this: Rivers absorb water from creeks, mix it with mud and boulders, and then "excrete" it into oceans.
2. *Nonrandom organization.* All organisms are highly structured, and decay is the process of its molecules returning to a random arrangement; however, many nonliving systems also have this feature: Crystals have an orderly arrangement as do many cloud patterns, weather patterns, and ripple patterns in flowing streams.
3. *Growth.* All organisms increase in size from the time they are formed: Fertilized eggs grow into seeds or embryos, and each in turn grows into an adult. At some point, growth may cease—we stop getting taller at about 25 years of age. This too is not sufficient to distinguish living from nonliving: Mountains and crystals also grow.
4. *A system of heredity and reproduction.* An organism must produce offspring very similar to itself such that when the individual dies life persists within its progeny. Fires reproduce but are not alive.
5. *A capacity to respond to the environment such that metabolism is not adversely affected.* When conditions become dry, an organism can respond by becoming dormant, conserving water, or obtaining water more effectively. Mountains also respond to the environment by growing as geological forces push them upward and by becoming smaller as erosion wears them away.

In addition to these absolute requirements of life, two features are almost certainly associated with all forms of life: (1) Organisms develop, such that young individuals and old ones have distinctive features, and (2) organisms evolve, changing with time as the environment changes.

Although these various features are always present in living creatures, no one characteristic is sufficient to be certain that something is living versus inanimate. We have no difficulty being certain that rivers, fire, and crystals are not living, but when we search for life on other planets or even in some exotic habitats here on Earth, deciding whether we have actually discovered life might be quite problematical.

FIGURE B1-2A Lichens grow extremely slowly and remain dormant for months; almost no sign of life can be detected during their dormant period.

FIGURE B1-2B These seeds of corn (*Zea mays*) are alive and healthy, but inactive metabolically. They will germinate and become obviously alive, but only if given the proper conditions.

Plants and People

BOX 1-3 Algae and Global Warming

Photosynthesis removes carbon dioxide from the atmosphere and helps keep Earth cool enough for us to live. Various organisms other than plants are photosynthetic and help reduce the amount of carbon dioxide in our air. Two types of bacteria, called "purple bacteria" and "green bacteria," have an unusual type of photosynthesis that differs from that of plants but allows those bacteria to absorb carbon dioxide from the environment and keep it out of the air. Purple bacteria and green bacteria are both rather rare, so they do not remove very much carbon dioxide. Other bacteria, called "cyanobacteria," are extremely common and carry out a type of photosynthesis that is very similar to that of plants. Cyanobacteria grow in many types of soil as well, in ponds and streams, and especially abundantly in sewage. The total amount of cyanobacteria in the world is great enough that they remove significant amounts of carbon dioxide from the air. Unfortunately, all bacteria are tiny and their bodies are rather delicate, so they break down quickly after they die and the carbon atoms in their bodies are converted back into carbon dioxide. But if the bacteria are eaten by an animal, then the carbon-containing molecules in their bodies become part of the bodies of the animals, and if those animals are then eaten by others, the carbon continues to be locked up in a body rather than going back into the air. However, this only keeps carbon dioxide out of the atmosphere for just a few years at most, because no animal lives for more than a few decades. Even long-lived animals shed hair, skin, and other parts and defecate: All these decompose, and their carbon is converted to carbon dioxide.

Algae, the close relatives of plants, are a group of organisms that are important allies in our attempts to combat global warming. There are many types of algae (most are named by the color of their pigments, such as red algae, green algae, brown algae, and so on), and all carry out photosynthesis that is almost identical to that of plants. Furthermore, algae are abundant in oceans, lakes, and rivers as well as in moist soils, rocks, and even tree bark. Just like plants, algae absorb carbon dioxide as they photosynthesize and lock it into the molecules of their bodies. Like bacteria, many algae are so delicate they decompose quickly after they die, so they do not keep carbon dioxide out of the air for long.

However, microscopic algae, called coccolithophorids (or just coccoliths), make a shell of calcium carbonate (**FIGURE B1-3**). This shell is so dense that as soon as the coccoliths die, their bodies sink to the bottom of the oceans. The cold temperatures there slow decay to such a degree that the shells do not break down for thousands, even millions of years. Consequently, as these microscopic algae grow and then die, carbon dioxide is removed from the atmosphere for very long times. One of the possibilities for combating global warming is to make these algae grow faster and more abundantly by fertilizing the oceans in areas where coccoliths already live. The hypothesis is that by adding just enough of the right kinds of nutrients, coccoliths will grow rapidly enough to start removing large amounts of carbon dioxide that will offset much of the damage we do by burning petroleum and coal. So far, experimental trials have been encouraging.

FIGURE B1-3 Limestone is calcium carbonate, composed of the shells of sea animals such as clams, mollusks, and certain algae. As these creatures formed their shells, they removed carbon dioxide from the atmosphere, causing the climate to become cooler. All the rock in this area along the Pecos River is part of a gigantic region of limestone that extends for hundreds of square miles.

Consider photosynthesis again. A consequence of depending on photosynthesis is that plants with many large leaves can harvest more light than plants with few, small leaves; however, a consequence of having large leaves is that they lose more water, they are more easily seen by hungry leaf-eating animals, they are good landing sites for disease-causing fungal spores, and so on. A further consequence of obtaining energy from sunlight is that the light does not need to be hunted the way that animals must hunt for their food. Because the sun rises every morning, plants can just sit in one spot and spread their leaves (**FIGURE 1-16**). They do not need eyes, brains, muscles, or digestive systems to locate, catch, and consume their source of energy. Plants can be very simple and survive, whereas most animals must be complex.

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FIGURE 1-16 This tree obtains its energy from sunlight, which is always located in the sky; the plant does not have to hunt for it. Sophisticated sense organs and the power of movement are completely unnecessary; having them would not make the plant more adapted.

Finally, no matter where you are, plants are readily available for direct observation. You can figure out a great deal by observing a plant and thinking about it (as opposed to just observing it). You will be surprised at how much you already know about plants. As you read, think about how the principles discussed apply to plants you are familiar with. It can be boring to memorize names and terms, but if you think about the material, analyze it, understand it, and see where it is not valid for all plants or all situations, you will find both botany and plants to be enjoyable.

At the Next Level

1. *Independent, advanced study.* The purpose of these *At the Next Level* boxes is to suggest to you information that would be relevant to a more advanced understanding of the topics of the current chapter. Because Chapter 1 is an introductory chapter, most of its topics will be developed later in this book, and if you would like to read ahead now, just check the table of contents and find topics that appeal to you. Also, leaf through the book and read various boxes or figure legends: these are short enough that you can easily read through those you find interesting and skip the others.
2. *The development of our current concepts.* We are familiar with concepts of cells, plants, life, gravity, energy, motion, and many other phenomena. But our present understanding is the result of thousands of years of trying to understand the world. I recommend reading a bit of the history of science, especially the history of biology. You will be amazed to learn that concepts we assume have always been known had to be discovered; other concepts that most of us have never heard of had been widely accepted but had to be disproven and discarded. I recommend three books. Two, *The Epic History of Biology* by Anthony Serafini (1993, Perseus Publishing) and *History of Botanical Science: An Account of the Development of Botany from Ancient Times to the Present Day* by A. Morton (1982, Academic Press), are shorter, more direct, and easy to follow. The third book, *The Growth of Biological Thought: Diversity, Evolution, and Inheritance* by Ernst Meyer (1985, Belknap Press), is more detailed and parts will be difficult for a freshman or sophomore, but it is a book that any biologist should read; it is a book you will want to have for the rest of your life.
3. *Science and ethics.* The scientific method cannot deal with things that are not tangible or physical, and certainly plants never face ethical or moral dilemmas, but we humans do. Ethics and morality are not my specialty and I will not recommend any particular book or article, but I do strongly suggest that you think about ethics and search out information on your own. An Internet search is a good place to start, and book reviews on Amazon.com are excellent guides as to which books might be of value to you.

SUMMARY

1. It is difficult to define a plant. It is more important to develop a familiarity with plants and understand how they differ from animals, fungi, protists, and prokaryotes. The differences are presented in later chapters.
2. The scientific method requires that all information be gathered through documented, repeatable observations and experiments. It rejects any concept that can never be examined, and it requires that all hypotheses be tested and be consistent with all relevant observations. It is based on skepticism.
3. Science and religion address completely different kinds of problems. Science cannot solve moral problems; religion cannot explain physical processes.
4. Living organisms have evolved by natural selection. As organisms reproduce, mutations cause some offspring to be less fit, some to be more fit. Those whose features are best suited for the environment grow and reproduce best and leave more offspring than do those that are poorly adapted.
5. For any particular environment, several types of adaptation can be successful.
6. Our knowledge of the world is incomplete and inaccurate; as scientific studies continue, incompleteness diminishes and inaccuracies are corrected.
7. Two simple questions are powerful analytical tools: (1) What are the alternatives, and (2) what are the consequences?

IMPORTANT TERMS

anthropomorphism
apomorphic features
botany
derived features
domains
hypothesis
interpretations
natural selection
observations
plesiomorphic features
relictual features
scientific method
teleology
theory

REVIEW QUESTIONS

1. Your present concept of plants is probably quite accurate. Most have roots, stems, leaves, and flowers. Can you name two plants that have cones rather than flowers? Can you name a plant that appears to not have leaves?
2. Name two types of fungi. Why were fungi originally included in the plant kingdom? Biologists no longer consider fungi to be plants because they differ in many basic ______________ and _______________ aspects.
3. How would you distinguish between plants and animals? What characters are important? Be careful to consider unusual plants and animals. Can all animals move? Do they all eat?
4. What are three methods for analyzing nature? Name some advantages and disadvantages of each.
5. Is it always easy to recognize that something is a living being rather than an inanimate object? Europa is a moon of Jupiter (see Box 1-2), and it is so far from the sun that there is not enough light for photosynthesis. The bottom of its ocean must be completely dark and icy cold. Are there locations like this on Earth that support life and that therefore let us hypothesize that life might also exist on Europa?
6. In the scientific method, all accepted information can be derived only from documented and controlled ________ _____________ or ________________________. If someone claimed to have a new treatment of a disease or a new type of eye surgery, would you want some sort of documentation and proof before you let them give you drugs or operate on you?
7. The scientific method deals only with __________ ________ phenomena and objects.
8. Physical forces that control the world are ____________ through time and are the ________ everywhere.
9. The fundamental basis of the scientific method is ________. Describe this concept.
10. What is a hypothesis? A theory? Why is it important that each be able to predict the outcome of a future experiment? How do these differ from a speculation?
11. If a hypothesis makes predictions that are not accurate and do not help explain future observations, do those inaccurate predictions prove the hypothesis is not a good model of reality? On the other hand, if the hypothesis does make accurate predictions, does that accuracy prove the hypothesis is correct?
12. Do any concepts exist for which the scientific method is inappropriate? Some people suffer terribly from certain incurable diseases. Can scientific methods be used to develop drugs that could end a person's life? Can scientific methods be used to decide whether it is right or wrong to use such drugs? Do you think the concept of right and wrong actually exists? Can you prove it with scientific methods? Are right and wrong concepts that can be measured, weighed, dissected? Do they have a chemical composition?
13. List the eight concepts that can be used to understand plants.
14. The first concept used to understand plants is that plant metabolism is based on the principles of________________

and ______________. If this is true, do you think that praying for good harvests or for rain is effective?

15. The fifth concept used to understand plants is that plants must survive in their own ______________________. Imagine a plant adapted to a desert and one adapted to a rain forest. Do you think that the leaves of one might be different from the leaves of the other? That one might have enlarged roots that can store water and the other would not need these? Would it be easier to understand a plant's anatomy and physiology, all its biology, if we also know the type of habitat to which it is adapted?
16. What is the eighth concept used for studying plants? It is difficult to avoid using the phrase "in order to" when referring to plants. Change the following sentences to be more accurate. The first one is done as an example:
    a. Plants have leaves in order to photosynthesize. "Plants have leaves that photosynthesize," or "photosynthesis in plants occurs in leaves."
    b. Plants have flowers in order to reproduce.
    c. Plant cells divide in order to make more cells.
    d. Wind-pollinated plants have their flowers located high above the ground in order to be exposed to stronger wind.
    e. Some plants have red flowers to attract hummingbirds.
    f. After I eat dinner, my stomach secretes acid in order to help digest the food.
17. Life on Earth began about ________ ________________ years ago. At first, organisms were simple, like present-day ____________________.
18. When organisms reproduce, some of their offspring are poorly adapted, and they do not grow and reproduce as well as the offspring that are well adapted. This is called ___________________ ____________________.
19. Look at Figure 1-12. What is the fifth concept used for understanding plants (in the section Using Concepts to Understand Plants)? We do not know for certain what the environment of this deer is, but would you guess that the deer is well adapted or poorly adapted? Is it likely to survive long enough to pass on its genes for this particular skin pattern? Now imagine that the deer's environment changes. All hunting is outlawed. There are not even any poachers—no hunters at all try to kill deer. In this new environment, does this skin pattern matter any more? Is the deer still poorly adapted?
20. Name the three domains, and describe the types of organisms in each. Which are prokaryotes? Which are eukaryotes?
21. What are relictual (plesiomorphic) features? Derived (apomorphic) features? Which organisms seem to have a larger percentage of relictual features—prokaryotes or eukaryotes? Algae or flowering plants? Amoebas or humans?
22. It is important to distinguish between plants and the study of plants—that is, the reality of the plant world and the model of it presented in this book and in lecture. Do we already know everything there is to be known about plants? Have we discovered every plant species that exists? Are all of our hypotheses about plants correct?
23. Plants are part of________________. The study of plants attempts to create a ____________________ of that and build a vocabulary to exchange _______________ about the reality. Can our model ever be incorrect? Can reality be incorrect? If our model—our hypotheses and theories—does not predict accurately, which is wrong—reality or the model?
24. As you read, you will deal with two types of information: _________________ and _________ ________________. Which of these are reasonably accurate and trustworthy? The other is more difficult. Why? If the second type does not make any kind of prediction about the outcome of a future observation or experiment, would there be any way to determine whether it is accurate?
25. This chapter closes by suggesting that you keep in mind two questions as you study this book and plants themselves. What are the two questions?