Chapter 1

About Plant Biology

KEY CONCEPTS

1. Plants include nearly half a million species of mosses, ferns, conifers, and flowering plants. In addition, plant-like relatives--certain bacteria, fungi and algae, which also are included in this book--total another million species. **Plant Biology** is the study of organisms classified either as plants or their (sometimes distant) plant like relatives.

2. Plants and their plant-like relatives are of vital importance to all life on Earth, including humans. Economic wealth is largely dependent on plant products. A major challenge of the 21st century is to attain sustainable use of our plant resources, which means no loss in the carrying capacity of the earth and no loss in the diversity of organisms that coexist on our planet.

3. The **scientific method** is a process of formulating predictions (hypotheses) about the world and then testing those hypotheses. Although it is a powerful and currently widely accepted method used for explaining our environment, the scientific method has some limitations, and it was historically used to justify actions that had negative social and ecological consequences.

4. The phylogenetic (evolutionary) relationships among plants, plant-like relatives, bacteria, and animals have become better understood but also more complex in the last decade, largely because of new techniques that analyze the sequence of base-pairs in the DNA of cell nuclei and of cell organelles such as chloroplasts. The division of life into a handful of kingdoms, a commonly accepted starting point for classification--and one used in the previous editions of this book--no longer appears possible. Many familiar names for groups of plants and the familiar hierarchies for placing these names are now known to be inappropriate.

1.1 THE IMPORTANCE OF BOTANICAL KNOWLEDGE

For most of you, this textbook and the class it accompanies represent the only formal education in organismal plant biology you will acquire in college. You are heading toward careers that seem to have little to do with plants, such as engineering, aerospace, medicine, chemistry, climatology, marine science, history, or political sciences. Our goal was to write a book that would efficiently and interestingly present a modern survey of plant biology. We also wanted to present the many interrelationships between plants and your central field of interest--connections that are important but probably would remain unknown to you without this textbook.

For those of you who are going on to a career in plant biology, such as field botanist, ethnobotanist/ethnoecologist, science writer/editor, laboratory researcher, agricultural economist, teacher, or greenhouse conservator (Fig. 1.1), we wanted to write a textbook that give you enough depth in the field to prepare you well for upper division courses. In your future, work you will be called on to show nonbotanists the relevance of plant biology to their own areas of expertise.

The linkages among different fields of knowledge may be as important as the narrower information within each field. As each area of expertise expands in its own direction, the gulf between areas widens and the importance of those who can see connections is strengthened.

Figure 1.1. Examples of botanical careers. (a) Field botanists document the locations of rare plants; they also quantify/classify vegetation as habitat types for other organisms. (b) Ethnobotanists interview indigenous people about the uses of native plants and the impact of their management techniques on the landscape. (c) Laboratory technicians or researchers explore the genetics, metabolism, morphologic development, and ecological tolerances of selected plant species. (d) Science teachers "translate" knowledge about plants to students. (e) Conservators collect, propagate, and classify plants--studying and preserving plant diversity and communicating their values to members of the community.

1.2 THE IMPORTANCE OF PLANTS

Seen from the perspective of the moon, 385,000 km away, Earth has a blue color (Fig. 1.2a). Blue oceans cover more than two thirds of the planet's surface, and a blue atmosphere extends away from the entire globe, a fuzzy halo dimming into black space. Seen from the perspective of 10 km above the surface, however, the earth looks green (Fig. 1.2b). The green color is caused by an enormous number of plants that carpet the ground, extend into the air, occupy the soil, and float below the surface of lakes and oceans. This tangle of plant tissue selectively absorbs red and blue wavelengths of sunlight, and either reflects green wavelengths or allows them to pass through. Consequently, sunlight reflected from a forest, a meadow, or a field of corn is green, as is the dappled shade beneath a tree.

The red and blue wavelengths of light are transformed by plant tissue into chemical energy in a process called **photosynthesis**. Technically, a **plant** is an organism that is green and photosynthetic (producing organic sugar from inorganic carbon dioxide, water vapor, and light). In addition, plant cells (the basic units of which all organisms are composed) are surrounded by a rigid wall made of cellulose, a molecule rarely found in other organisms. Plants have multicellular bodies usually well suited to life on land because they can control water loss, they have strengthening tissue that keeps them upright, they can somewhat regulate their temperature, and they can reproduce with microscopic drought-tolerant cells called **spores**.

Figure 1.2. (a) Earth from space. The globe is blue, as seen from the distance of its moon. (b) At closer range, Earth is predominantly green because of the prevalence of plants.

This technical definition of a plant applies to approximately 300,000 species of trees, shrubs, herbs, grasses, ferns, mosses, and algae. These different types of plants exhibit an incredible diversity of habitat, shape, life history, evolutionary history, ecology, and human use. Most of this textbook is about them. They are formally classified as belonging to the plant kingdom (Fig. 1.3).

There are another million species of plantlike organisms that are not classified as belonging to the plant kingdom, which this textbook also addresses. They are certain bacteria, fungi, and algae. Although some are green and photosynthetic, others engulf living food or feed on dead organic remains. They cannot regulate water loss and they do not possess strengthening tissue (Fig. 1.4). Many of them grow in aquatic habitats rather than on land. They exhibit enormous morphologic and habitat diversity and have great economic and ecological importance to humans. They are part of the science of botany, or plant biology, which is the study of plants and plant-like organisms. Plants and plant-like organisms provide many ecological services. That is, by merely living they serve the needs of other organisms, including humans. For example, they are sources of food, fabric, shelter, and medicine. They produce atmospheric oxygen and organic nitrogen. They build new land and inhibit its loss by erosion. They control atmospheric temperature. They decompose and cycle essential mineral nutrients.

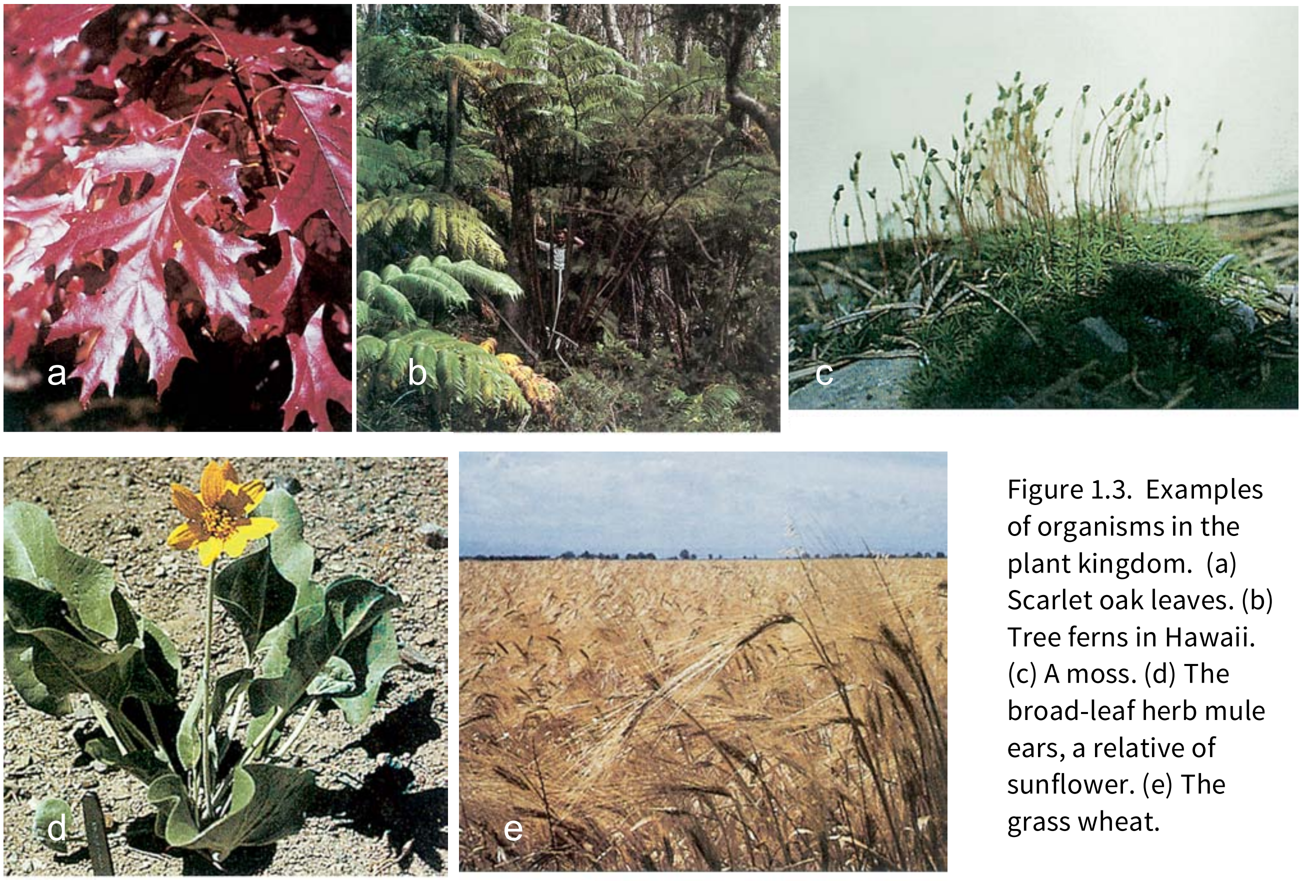

Figure 1.3. Examples of organisms in the plant kingdom. (a) Scarlet oak leaves. (b) Tree ferns in Hawaii. (c) A moss. (d) The broad-leaf herb mule ears, a relative of sunflower. (e) The grass wheat.

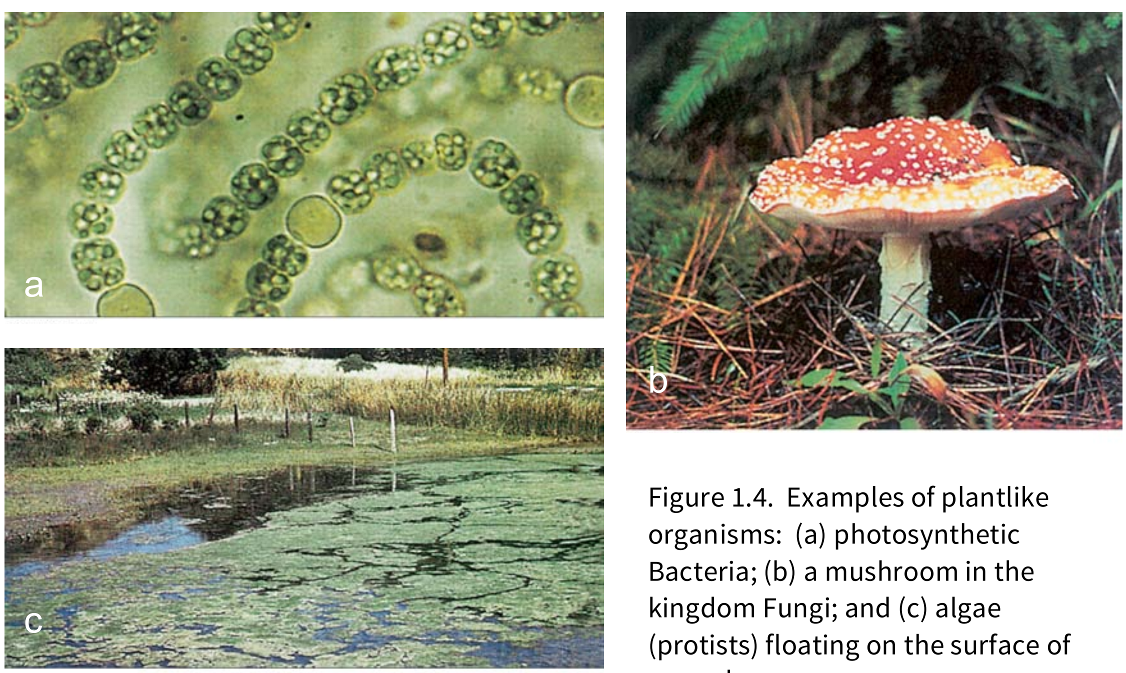

Figure 1.4. Examples of plantlike organisms: (a) photosynthetic Bacteria; (b) a mushroom in the kingdom Fungi; and (c) algae (protists) floating on the surface of a pond.

Civilizations have risen and fallen throughout recorded time depending on their access to and control of plants--especially of trees for lumber to make warships; as fuel to smelt metals, cure pottery, and generate power and heat; and as sources of wealth in the form of spices and industrial products such as rubber and oil. Anthropologists often describe human cultures and history in such terms as Stone Age, Bronze Age, and Iron Age, but truly humans have always lived in a **Wood Age**, because wood has been the ultimate measure and creator of wealth (Fig. 1.5).

Figure 1.5. Conifer forests such as this coast redwood forest have enormous economic value. The wood from a single old-growth redwood tree has a retail value of more than $50,000.

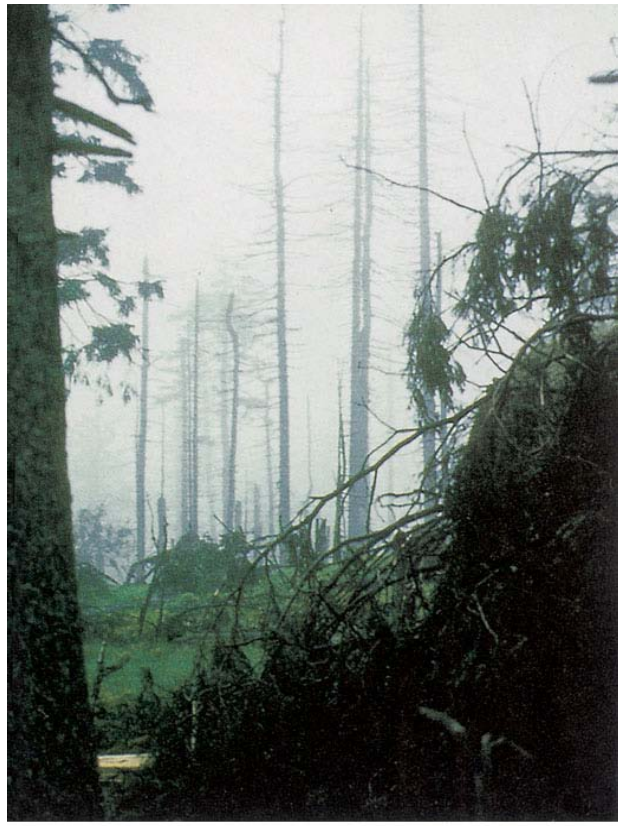

Figure 1.6. Forest decline in central Europe. Beginning in the late 1970s, many square kilometers of forest died because of a complex of factors including ozone from automobile exhaust and acids from coal burning.

Our earliest written myths and legends feature plants. The *Epic of Gilgamesh*, dated to 4,700 years ago and created by storytellers in ancient Mesopotamia (now Iraq), highlights the importance of forests and conveys an understanding of the ecological consequences of logging. Gilgamesh was ruler of Uruk and wanted to make a name for himself by building a great city. Building required lumber, but the vast cedar forest that covered mountain slopes to the east had never been entered by humans. A demigod named Humbaba protected the forest for nature and the gods. Nevertheless, Gilgamesh and his companions traveled to the forest with adzes and axes. They briefly lost themselves in their initial contemplation of the forest's beauty and holiness, but soon set to work felling trees. When Humbaba challenged them, they killed him. Then the cedars filled the air with a sad song, and the gods cast curses and promises of fire, flood, and drought on Gilgamesh and on generations of humans to come. These promises later came true when Mesopotamia's growth stripped it of natural resources , degraded the environment, and contributed to its loss of regional power.

Ironically, just as we have come to recognize the critical, pervasive importance of plants, we also recognize that we are losing natural plant cover to agriculture, urbanization, overgrazing, pollution, and extinction at a faster rate than ever before. We are finding the truth behind four "environmental laws" described in 1961 by plant biologist Barry Commoner: (1) Everything is connected to everything else; (2) everything must go somewhere; (3) nature knows best; and (4) there is no such thing as a free lunch.

In Chapter 27, we write that the term conservation once meant the "wise use" consumption of a natural resource at a rate that would result in its sustained, continued existence far into the future. However, the history of our farms, forests, pastures, and fisheries suggests that technological, growth-oriented human cultures have not been able to determine what that ideal level of resource use is. We have consistently overexploited resources beyond the balance point, thus degrading the landscape. In addition, human activities interact with soil, water, and air in unexpected ways, resulting in such potential global catastrophes as acid rain, ozone depletion (see endnote PLANTS, PEOPLE AND THE ENVIRONMENT: *Unexpected Links among Chlorofluorocarbons, Climate, and Plants*), climate change, and forest decline (Fig. 1.6).

1.3 THE SCIENTIFIC METHOD

Scientists in every field have a set of methods in common. They observe, ask questions, make educated guesses about possible answers, base predictions on those guesses, and then devise ways to test their predictions. If a predicted result actually occurs, that is evidence that the possible answer could be correct. More formally, the guesses are called **hypotheses**, and the tests and interpretations are called the **scientific method**. The scientific method was codified and encouraged in the 17th century by Rene Descartes and Sir Francis Bacon, among others. It has proven to be a very powerful method for advancing human understanding.

In science, a well-supported hypothesis, perhaps codified as a theory, is never seen as absolute truth. It is merely the best approximate explanation, and we can expect it to be modified in the future as evidence from new predictions and tests becomes available. The test-evaluate-refine-retest cycle has been entered hundreds of times for some hypotheses that are currently accepted, but hypotheses about subjects at the very edge of our current understanding may have passed through very few cycles. Sometimes, the new information calls for a complete rejection of the original hypothesis and the creation of a new one, providing the scientific equivalent of a political revolution (Fig. 1.7).

The external world, not internal convictions, should be the testing ground for hypotheses, according to the scientific method. That means that those who use the scientific method should be objective and unbiased. In fact, however, personal bias is difficult to remove completely. The questions asked, the range of expected answers, and the tests used to check predictions are all products of the culture that surrounds the scientist. In addition, one's beliefs may subconsciously influence one's science. For example, historian Greg Mitmann studied a group of biologists at the University of Chicago whose ideas about ecology were dominant during the mid-20th century. In essence, their research showed that nature was organized around cooperative behavior and community. Mitmann pointed out that these scientists were socialists and pacifists in their private lives. Did their personal beliefs lead them in interpret their scientific finding in a certain light? (Currently, by contrast, the Chicago School's ideas have been turned upside down; most biologists now hypothesize that nature is organized around competition and individuality.)

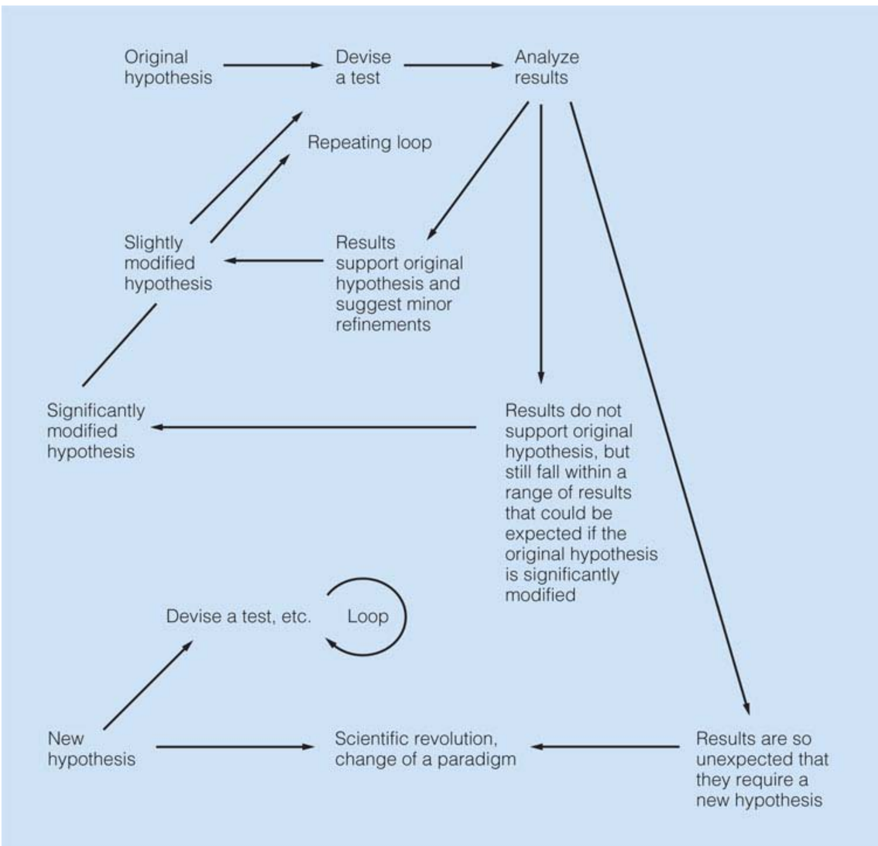

Figure 1.7. Diagram of the sequence of activities in the scientific method. Occasionally, the results of one or more tests are so different from expectations that the underlying assumptions and theories must be radically changed, resulting in a "revolution" or "paradigm shift."

Carolyn Merchant, a professor at the University of California, Berkeley, has argued that the scientific method is a peculiarly masculine invention that has fostered exploitation of natural resources. The scientific method, she claims, invites us to become isolated observers who impersonally manipulate nature to test assumptions. The ever-giving Earth Mother image of pre-science cultures has been replaced with an inanimate globe whose treasures must be forcibly extracted. Merchant writes that our scientific subjugation of nature has paralleled a time of subjugation of women, and she implies that one has caused the other.

Technology is the application of information to industrial or commercial objectives. It does not require an understanding of how or why a given process functions. Science and technology are ultimately linked but they are not the same thing and each can progress at independent rates. For example, consider the development of antibiotics, the "wonder drugs" of the mid-20th century. Penicillin, the first antibiotic, was widely and effectively prescribed by doctors for the cure of many bacterial infections beginning in the 1940s. A scientific understanding of how the drug actually worked, however, was not attained for another 20 years. Only then did researchers discover that penicillin interferes with how a bacterial cell builds a wall around itself, and that if the wall is absent, the cell contents burst open and cell dies. Another example of technology leading science was the development of plant-killing auxins (herbicides) in the 1940s. To this day, plant biologists do not have a complete understanding of how auxins derange plant growth and lead to death, yet the pragmatic, wide use of auxin-based herbicides continues. Throughout this textbook, and especially in the sidebars, we will try to link the science of plant biology with important technological application, attempting to do justice to both areas.

1.4 STUDYING PLANTS FROM DIFFERENT PERSPECTIVES

Every plant is a product of two interacting components: the genetic (inherited) material, which every cell in that plant carries, plus the environment in which that plant grew. If the genetic potential of the plant is to reach a height of 2 m, it will attain that height only if the environment permits. If certain nutrients are lacking, or if shade is too deep, or if night temperatures are too cold, or if too many animals graze the plant, then it will not reach 2 m in height, no matter how much time goes by.

Two major disciplines within plant biology deal with these two components: **Plant genetics** is the study of plant heredity, and plant ecology is the study of how the environment affects plant organisms (Fig. 1.8). Knowledge of genetics is a prerequisite for the study of plant **evolution** and classification (plant **systematics**). Similarly, knowledge of ecology is essential for reconstructing past climates and landscapes and for understanding how plants have come to be distributed around the world as they are (the disciplines of **paleoecology** and **biogeography**).

One of the many ways genes and environment become integrated is through plant metabolism. **Metabolism** is the process by which plants perform photosynthesis, transport materials internally, construct unique molecules, and use hormones to affect their behavior. The study of metabolism includes the disciplines of **plant physiology** and **plant molecular biology**.

The combination of genes, environment, and metabolism works together to produce an individual plant. The plant can then be studied in several basic ways. The study of how a plant develops from a single cell into diverse tissues and organs and an array of outer surfaces and shapes is the discipline of **plant morphology**. The study of a plant's internal structure, its tissues and cell types, is called **plant anatomy**. Plants also can be studied according to their taxonomic classification: Microbiology is the study of bacteria, mycology is the study of fungi, phycology is the study of algae, bryology is the study of mosses, and so on (Fig. 1.8).

We have chosen to write about each of these disciplines in a certain order. We begin in Chapters 2 through 15 with a multiple focus on physiology, morphology, and anatomy. In these chapters, you will find answers to the following questions:

- How do the billions of cells, dozens of tissues, and several major plant parts cooperate to achieve a complex, functioning organism?
- Why do roots grow downward but stems upward?
- How is it possible for leaves and flowers to track the sun's path during the day and thus maximize the amount of light they receive?
- How can a species regulate where and when its seeds germinate, thus increasing the chances of survival of offspring?
- How does a plant repair injuries?
- How does a plant tell time and season so that its many life cycle events occur at the appropriate times?
- How do plants acquire and transport energy, carbohydrates, water, and nutrients?

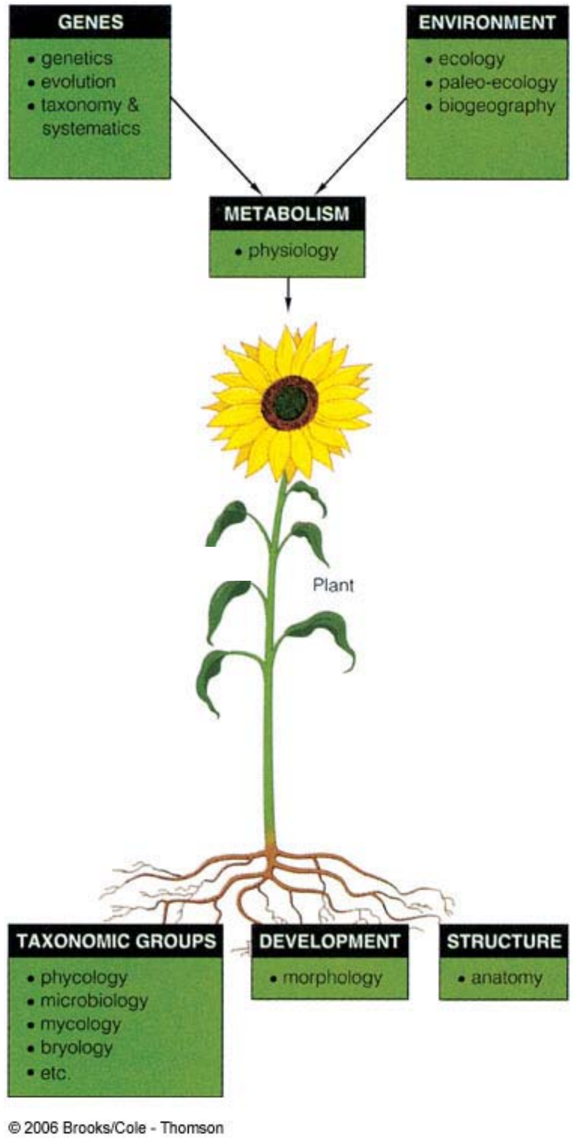

Figure 1.8. Interrelationships among several plant biology disciplines.

- How do plants solve the problems of reproduction, drought, competition, and a changing environment, while being rooted to a single location?

In Chapters 16 and 17, we describe the rapidly growing science of plant genetics and its technological implications for breeding new crops with increased yields and tolerances to diseases and weeds. These chapters answer the following questions:

- Can our understanding of genetics reach a point where we are capable of designing and engineering new species by moving bits of genetic material around or by creating the genetic material ourselves?

- ♦ Can we create genetic bank accounts for all rare and endangered species, as insurance against extinction?

In Chapters 18 through 25 we focus on the taxonomic diversity of plant and plantlike organisms, highlighting the unique way each group's morphology, anatomy, physiology, and reproduction are suited to its particular range of habitats. We also try to reconstruct the evolutionary history of each group. These chapters address the following questions:

- ♦ To which existing or extinct group is a plant most closely related?
- ♦ When did a group begin to evolve in a separate line?
- ♦ Is the group still actively evolving, or has it stagnated in some way?
- ♦ How has the group adapted to its range of habitats?

1.5 A BRIEF SURVEY OF PLANT CLASSIFICATION

Kingdoms, Domains, Divisions or Phyla, and Clades

As recently as 20 years ago, most biologists accepted a five-kingdom classification first developed in detail by the plant ecologist Robert Whittaker in 1969. The names of the five kingdoms were Monera, Fungi, Protista, Plantae, and Animalia. Each kingdom was presumed to be a monophyletic group of species; that is, all species in a kingdom were related to a single common ancestral species. The kingdom Monera included bacteria; Fungi included molds, mildews, and mushrooms; Protista included a great variety of simple organisms, some of which were photosynthetic, and largely aquatic organisms informally called algae; Plantae included more complex photosynthetic organisms that typically grew on land; and Animalia included typically motile, multicellular, non-photosynthetic organisms distributed in habitats throughout the world.

The recent use of molecular biology techniques, and a process called **cladistics**, has largely shown that the five-kingdom approach did not recognize natural (evolutionarily related) groups. By comparing the sequence of base pairs in the genetic material from one group of organisms with that from another, the overlap (the percent similarity of two strands of DNA) can be quantified. It no longer is possible to claim that the five kingdoms are monophyletic. For example, the Monera must be split into two groups, each of which does appear to be monophyletic: The domain Bacteria (which contains most of the familiar bacteria) and the domain Archaea (which superficially resemble bacteria but differ in habitat, metabolism, and cell structure). *Domain* is a neutral term, which is generally applied to groups of organisms as large or larger than a kingdom that are monophyletic.

Domain **Eukarya** includes what we commonly recognize as the plant, animal, and fungal kingdoms and the Protista. The Protista is not a monophyletic group, but there is no agreement as to where to place the various groups of organisms within it. At the moment, *protist* is an informal name that can be applied to the species of algae, slime molds, and protozoans that were formerly in the kingdom.

Each kingdom can be divided into divisions or phyla, the members of each having originated from a common ancestor. In the kingdom Plantae, for example, the division (phylum) Tracheophyta includes all plants with vascular tissue. Division names end in -

phyta. Below divisions are classes (ending in *-opsida*), orders (ending in *-ales*), families (ending in *-aceae*), genera, and species (Fig. 1.9). This hierarchy is part of the Linnaean system of taxonomy.

Taxonomy is the science of naming and categorizing organisms. Most taxonomists believe that a classification system should be both maximally useful to people and accurately reflective of what we know about the relationships among the organisms. Although the Linnaean system is easy to use, it has been found that evolutionary groups do not always correspond exactly with Linnaean categories. More importantly, the Linnaean system promotes the false idea that two groups of equal rank are biologically and evolutionarily equivalent units. Those who attempt to compare two equivalent Linnaean groups often are misled.

This textbook handles taxonomy in a new and exciting way. We have downplayed the traditional Linnaean system, and instead we emphasize evolutionary groups. These groups, known to biologists as **clades**, are uncovered by methods explained in later chapters. Clades are assembled in a branching diagram of relationships that is called a **cladogram** or a **phylogenetic tree**. Relationships in a cladogram emphasize shared features inherited from a common ancestor.

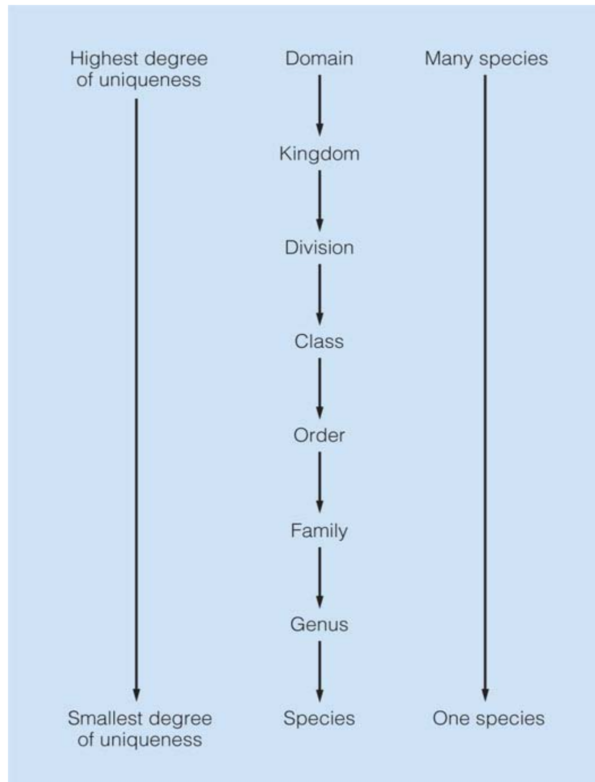

Figure 1.9. Relationships among domains, kingdoms, divisions, and smaller classification units.

Linnaeus, in contrast, based his system on the notion that all species were created as they are now and never changed. He grouped organisms on the basis of arbitrary similarities and attempted to make his system as easy to use as possible. Because we know now that many of the similarities he identified are coincidental and do not represent features shared because of inheritance from a common ancestor, it is not surprising that his taxonomic system fails to meet the needs of modern biologists.

A taxonomy based on evolutionary groups does not use hierarchical, nested categories that denote rank. Rather, it relies on one overriding principle: only evolutionary groups (clades) should be named. The evolutionary groups consist of a common ancestor and all the descendants of that ancestor. The relationship of one clade to any other clade is determined by looking at a phylogenetic tree, and not by comparing arbitrary ranks.

Although phylogenetic trees may bring new names and ideas about plant groups, we believe that all readers will soon discover their benefits. Cladograms contain much more information than the rigid categories of the old system; they promote a different way of thinking about biological diversity; they move the focus from correctly naming to understanding the evolution of the organisms under study; and, as Dobzhansky famously said about evolution in general, they provide "a framework in which everything else begins to make sense."

Plants have the best-supported and most thoroughly detailed phylogenies of all organisms. There are several areas of uncertainty (noted in the text), but also many areas where we have great confidence. Undoubtedly, future discoveries will require that some cladograms be modified. We believe that thinking phylogenetically is more useful than taxonomic "pigeon-holing," even if particular trees are someday amended.

The Domains Bacteria and Archaea Include Photosynthetic Bacteria

Organisms in the domain **Bacteria** have **prokaryotic** cells. Such cells lack an organized nucleus with a bounding membrane. They have no specialized compartments (**organelles**) within the cell sap (**cytoplasm**), their cell volume is very small, and the genetic material (DNA) in their chromosomes is organized into closed circles rather than straight lines. Sexual reproduction is unknown, although these organisms do exchange bits of genetic material across cellular bridges.

The domain **Archaea** also is composed of prokaryotic organisms, but they occupy very different habitats and have cell structure and chemistry different from those of Bacteria. The differences are so profound that one can conclude Archaeal organisms are as different from Bacteria as prokaryotes are from members of the domain Eukarya. The Archaea are divided into three groups on the basis of habitat: inhabitants of sulfur-rich anaerobic hot springs and deep ocean hydrothermal vents; inhabitants of anaerobic swamps and the guts of termites; and inhabitants of extremely saline waters. In this last group, the extreme halophiles, are photosynthetic organisms that harvest light with a unique pigment called bacteriorhodopsin.

Bacteria is also the informal name given to species in the two domains. Bacteria exist as single cells or as filaments of cells. The earliest forms of life, as revealed by fossils 3 to 4 billion years old, apparently were bacteria. Bacteria are microscopic, but their numbers and weight (biomass), collectively for the earth, are very large. Bacteria occur in virtually every habitat on Earth, including the atmosphere, soil, water, and stressful places that are hot, cold, oxygen-deficient, and even within the surface layer of rocks in Antarctica.

Bacteria are enormously beneficial as decomposer organisms, which are able to break down complex organic materials into simpler nutrient molecules that can then be taken up by other organisms. Bacteria also have detrimental effects as **pathogens** (disease-causing agents). Human diseases caused by bacteria include botulism, leprosy, meningitis, syphilis, tetanus, tuberculosis, and typhoid fever. Other bacteria cause diseases of plants.

One group of Bacteria, the **Cyanobacteria** or **blue-green algae**, has the pigment chlorophyll in its cells. These bacteria are green and are capable of conducting photosynthesis. Another characteristic that they share with algae and species in the kingdom Plantae is that their cells are surrounded by a rigid wall. Some bacteria, including many Cyanobacterial species, also have the unique capacity for nitrogen fixation--that is, to incorporate inorganic nitrogen gas from the atmosphere into ammonium, which then can be used to form organic molecules such as amino acids.

The Kingdom Fungi Contains Decomposers and Pathogens

Fungi are non-photosynthetic organisms with **eukaryotic** cells--that is, their cells have a membrane-bounded nucleus, special organelles within the cytoplasm, linear DNA, and much larger cell volumes than prokaryotes. Fungi include molds, mildews, mushrooms, rusts, and smuts. They are typically microscopic and filamentous, and their cells are surrounded by a rigid wall made of chitin, a substance more commonly found in some species of the kingdom Animalia than in algae and members of the kingdom Plantae. They reproduce sexually in a variety of complex life cycles and by asexual spores. Fungi are widely distributed throughout the world, but they are mainly terrestrial.

Fungi are ecologically important because many of them are decomposers, similar to bacteria. Others form intimate associations with the roots of plants, improving the absorbing capacity of the plant's root system. Some fungi, such as mushrooms and morels, are important foods for humans and other animals. The decomposing action of yeast fungi creates flavored cheeses, leavened bread, and alcoholic drinks. Fungi such as *Penicillium* have been used commercially to produce antibiotic drugs. Other fungi are pathogens, invading the tissue of animals or plants, causing illness, and reducing crop yields by billions of dollars annually.

The Plant Kingdom Contains Complex Plants Adapted to Life on Land

The **plant kingdom** contains mosses, ferns, pine trees, oak trees, shrubs, vines, grasses, and broad-leaved herbs--the organisms we informally call plants. Organisms in this kingdom are adapted to life on land, and some of them are among the more recent forms of life to evolve and appear in the fossil record. Plants that produce seeds, cones, and flowers are relatively large and abundant and give the landscapes of the planet their characteristic appearance, making up most of the biomass of forests, meadows, shrub lands, deserts, marshes, woodlands, and grasslands.

Members of the kingdom **Plantae** share certain unique biochemical traits. They have eukaryotic cells with walls made of cellulose, they accumulate starch as a carbohydrate storage product, and they have special types of chlorophylls and other pigments. Only green algae have these same traits, which is why they are also part of the plant kingdom.

Plants have more complex bodies than bacteria, fungi, or protists. The complexity is visible from cell to cell and from region to region within the plant's body. Some cells and tissue are specialized to transport fluids, to store reserves, to perform photosynthesis, or to add strength. Different parts or regions of the plant form such unlike structures as leaves, stems, roots, flowers, and seeds.

Plants have major ecological and economic importance. They form the base of terrestrial food chains, they are the principal human crops, and they provide building materials, clothing, cordage, medicines, and beverages. Our terrestrial ecosystems are dependent on organisms in the kingdom Plantae.

1.6 A CHALLENGE FOR THE 21ST CENTURY

Chapters 26 and 27, the final chapters of this textbook, focus on the discipline of ecology. They take us through past and present landscapes, describing the distribution of plants and their elegant solutions to environmental stresses. How do plants meet the challenges of a changing environment for continued existence? They must partition time and energy, within an individual life span, in such a way that their kind continues for another generation.

What can plants tell us by their presence, vigor, or abundance about the past, present, and future of their habitat? If, as Barry Commoner says, "Nature knows best," can we ever understand the environment well enough to permit us to restore endangered vegetation and degraded landscapes? Can we continue to increase our human population while retaining natural biological diversity and developing a sustainable use of the world's forests, grasslands, and cropland? As a species, we have not yet been successful in achieving this objective. It will remain a major challenge well into the 21st century, a century in which we expect readers such as you to contribute new insights for books yet to be written and wise actions yet to be taken. We wish you every success.

KEY TERMS

algae
Animalia
Archaea
Bacteria
biogeography
blue-green algae
botany
cellulose
clade
cladistics
cladogram
conservation
Cyanobacteria
cytoplasm
ecological services
Eukarya
eukaryotic
evolution
extreme halophiles
food chain
Fungi
hypothesis
kingdom
metabolism
monophyletic
organelle
paleoecology
pathogens
photosynthesis
phylogenetic tree
plant
plant anatomy
plant biology
plant ecology
plant genetics
plant molecular biology
plant morphology
plant physiology
plant systematics
Plantae
prokaryotic
Protista
scientific method
spore
theory

SUMMARY

1. Plant biology is the study of plants, of organisms formally classified in the kingdom Plantae, and of an equal number of plantlike organisms formally classified in the domain Bacteria, the kingdom Fungi, and protists.

2. These half-million organisms share at least some of the following traits: They are photosynthetic, nonmotile, and have cells surrounded by a rigid wall; they reproduce by spores; and they have relatively simple unicellular or multicellular bodies lacking obvious digestive, nervous, and muscular systems.

3. Plants and plantlike organisms not only pervade nearly every habitat on Earth, they are also of central importance to every ecosystem and to the human population. They are at the base of natural food chains. They produce oxygen, incorporate nitrogen, and stabilize land surfaces. They provide food, fabric, pharmaceuticals, and structural products for humans.

4. Plant biologists use the scientific method to test hypotheses about plant behavior. The scientific method involves formulating a hypothesis developing a test of that hypothesis, and then incorporating the results to formulate a modified, new, more accurate hypothesis. The method is an endless loop, because hypotheses can only be disproved, not proved. Each resulting theory can only be considered as an approximation of the truth, not a complete explanation. Technology is based on scientific study, but it can proceed, to a certain degree, independently of science.

5. Botanists study plant form and development (morphology), plant metabolism (physiology), plant genetics and evolution, plant structure (anatomy), and plant ecology.

6. Plantlike organisms include Cyanobacteria in the domain Bacteria. These organisms are prokaryotic (lack a cell nucleus). Other plantlike organisms are molds in the kingdom Fungi. Although the latter do possess rigid cell walls and reproduce with spores (as do plants), they are nonphotosynthetic. Bacteria and molds are ecologically important as decomposers. Some also are important pathogens (disease-causing agents).

7. Algae are simple, photosynthetic, and generally aquatic protists. Some algae share important biochemical traits with plants and are in the plant kingdom, but their bodies lack the complex adaptation to life on land exhibited by other members of the plant kingdom.

8. A major challenge of the 21st century is to achieve sustainable use of plant natural resources in the face of an increasing human population and increasing pollution from human technology.

Questions

1. Why does the color green in nature typically signify the presence of plants?

2. List any three ecological services provided by plant and plantlike organisms. List any three ways in which they are economically important to humans. Why can it be said that humans have lived in a "Wood Age" through most of their history?

3. What is the difference between science and technology? How does the story of our use of chlorofluorocarbons illustrate the difference?

4. What are the subject matters of the disciplines of genetics, ecology, physiology, morphology, and anatomy?

5. In what way are organisms in the domain Bacteria different from protists, animals, fungi, and plants? How are fungi and algae different from organisms in the plant kingdom?

6. Give some examples of organisms in the plant kingdom and of plantlike organisms in the Bacteria, protists, and fungi. Is there any single trait that all half-million species share?

7. Why is sustainable use of natural resources an important challenge for humans in the 21st century?

PLANTS, PEOPLE, AND THE ENVIRONMENT*: Unexpected Links among Chlorofluorocarbons, Climate, and Plants*

In the 1930s, refrigeration became widespread in homes, trains, trucks, and agriculture. The basic component in refrigerators is a gas that contains chlorine or bromine, fluorine, and carbon. The gas absorbs heat when it is allowed to expand. Freon was an early trade name for such gases, but they are more technically called chlorofluorocarbons (CFCs). They are very efficient, nontoxic, and generally nonreactive. They are also used as foam-blowing agents and as cleansers in computer industries. A related compound, methyl bromide, has commonly been used to sterilize soils.

Four decades later, however, scientists began to realize that when CFCs leaked from refrigerators or were emitted into the atmosphere from other industrial sources, they rose high into the stratosphere (25-50 km above the earth's surface) and destroyed ozone there. Ozone is an oxygen molecule that is made up of three atoms instead of the usual two. It is a natural component of the stratosphere, and it is ecologically important because it absorbs ultraviolet radiation from the sun. Chlorine atoms act as catalysts in this destruction of ozone. Because a catalyst is a molecule that enhances a chemical reaction without being used up itself, this means that a single chlorine atom can destroy thousands of molecules of ozone. The concentration of CFCs has reached a point where there is as large as a 20% loss of ozone, depending on the latitude and the season.

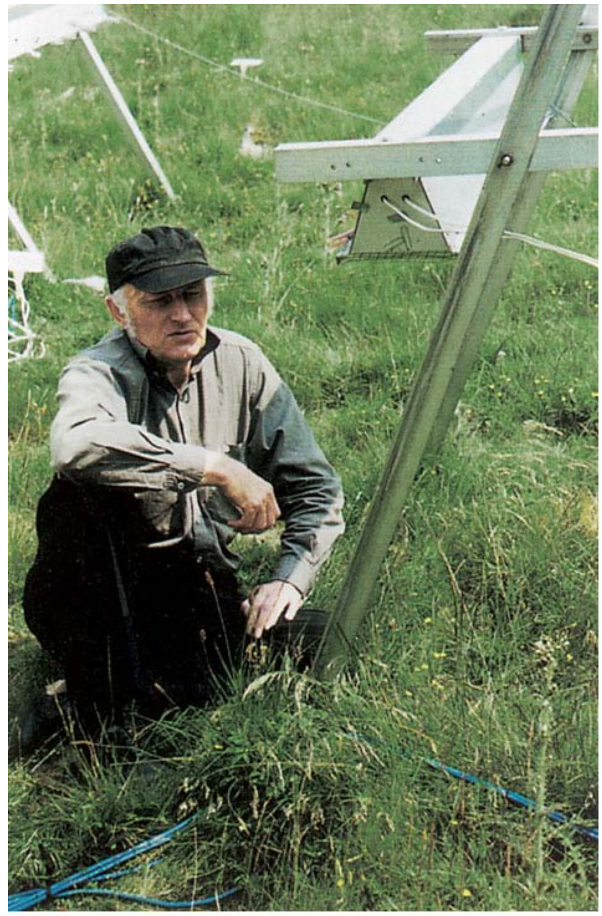

Figure 1. Researchers directed by Philip Grime (pictured), University of Sheffield, are investigating the ecological impact of 5% to 20% more ultraviolet B, greater concentrations of carbon dioxide in the atmosphere, higher soil temperatures, and decreased rainfall on U.K. grasslands.

Ozone depletion has several serious consequences. One is the likely increase of skin cancers, cataracts, and immune deficiency diseases among humans. Cancer is expected to increase by 15% during the next few decades in the heavily populated north-temperate zones of the world. Ultraviolet radiation, in particular ultraviolet B (UVB), is known to derange plant metabolism. We may expect yields of such sensitive crops as soybeans to be depressed by 25%. The impact on natural vegetation is unknown, but teams of scientists who have erected UVB lamps over grassland and tundra vegetation are studying the long-term effects of UVB.

The danger of ozone depletion was convincing enough to have led to the most comprehensive international agreement ever established: a protocol signed in Copenhagen in 1992 by nearly all the countries of the world, who agreed to dramatically reduce further production of CFCs and to eliminate all production by 2030. The catalytic nature of CFCs, however, means that their impact on the global environment will linger far into the future, well beyond the year 2030.

The elimination of CFCs will have some negative effects on agriculture because agribusiness has come to depend on industrial chillers and the use of methyl bromide to sterilize soils and to eliminate plant pathogens. Methyl bromide is used extensively in fruit, vegetable, cotton, cocoa, coffee, and grain production. Imaginative and possibly costly substitutes will be needed to replace the CFC-based technology.

One psychological consequence of the CFC situation is a realization that the impacts of technology's byproducts have become global, extending far from their point of creation into what had been considered to be pristine wilderness. Human influence has become so pervasive that no place on the globe is unaffected. As one environmentalist concluded, this is surely the signal of the death of wild nature. We are learning that the first two laws of ecology formulated by Barry Commoner are true: Everything is connected to everything else, and everything must go somewhere.