I

SYSTEMATICS
This book is about a fascinating field of biology called plant systematics. The purpose of this chapter is to introduce the basics: what a plant is, what systematics is, and the reasons for studying plant systematics.

PLANTS

WHAT IS A PLANT?
This question can be answered in either of two conceptual ways. One way, the traditional way, is to define groups of organisms such as plants by the characteristics they possess. Thus, historically, “plants” included those organisms that possess photosynthesis, cell walls, spores, and a more or less sedentary behavior. This traditional grouping of plants contained a variety of microscopic organisms, all of the “algae,” and the more familiar plants that live on land. A second way to answer the question “What is a plant?” is to evaluate the evolutionary history of life and to use that history to delimit the groups of life. We now know from repeated research studies that some of the photosynthetic organisms evolved independently of one another and are not closely related.

Thus, the meaning or definition of the word plant can be ambiguous and can vary from person to person. Some still like to treat plants as a “polyphyletic” assemblage (see later discussion), defined by the common (but independently evolved) characteristic of photosynthesis. However, delimiting organismal groups based on evolutionary history has gained almost universal acceptance. This latter type of classification directly reflects the patterns of that evolutionary history and can be used to explicitly test evolutionary hypotheses (discussed later; see Chapter 2).

An understanding of what plants are requires an explanation of the evolution of life in general.

PLANTS AND THE EVOLUTION OF LIFE
Life is currently classified as three major groups (sometimes called domains) of organisms: Archaea (also called Archaeabacteria), Bacteria (also called Eubacteria), and Eukarya or eukaryotes (also spelled eucaryotes). The evolutionary relationships of these groups are summarized in the simplified evolutionary tree or cladogram of Figure 1.1. The Archaea and Bacteria consist of small, mostly unicellular organisms that possess circular DNA, replicate by fission, and lack membrane-bound organelles. The two groups differ from one another in the chemical structure of certain cellular components. Eukaryotes are unicellular or multicellular organisms that possess linear DNA (organized as histone-bound chromosomes), replicate by mitotic and often meiotic division, and possess membrane-bound organelles such as nuclei, cytoskeletal structures, and (in almost all) mitochondria (Figure 1.1).
Some of the unicellular bacteria (including, e.g., the Cyanobacteria, or blue-greens) carry on photosynthesis, a biochemical system in which light energy is used to synthesize high-energy compounds from simpler starting compounds, carbon dioxide and water. These photosynthetic bacteria have a system of internal membranes called thylakoids, within which are embedded photosynthetic pigments, compounds that convert light energy to chemical energy. Of the several groups of eukaryotes that are photosynthetic, all have specialized photosynthetic organelles called chloroplasts, which resemble photosynthetic bacteria in having pigment-containing thylakoid membranes.

How did chloroplasts evolve? It is now largely accepted that chloroplasts of eukaryotes originated by the engulfment of an ancestral photosynthetic bacterium (probably a cyanobacterium) by an ancestral eukaryotic cell, such that the photosynthetic organelles of eukaryotes originated by the engulfment of an ancestral eukaryotic cell, such that the photosynthetic bacterium continued to live and ultimately multiply inside the eukaryotic cell (Figures 1.1, 1.2). (Mitochondria also evolved by this process, from an ancestral, nonphotosynthetic bacterium; see Figure 1.1.) The evidence for this is the fact that chloroplasts,
like bacteria today, (a) have their own single-stranded, circular DNA; (b) have a smaller sized, 70S ribosome; and (c) replicate by fission. These engulfed photosynthetic bacteria provided high-energy products to the eukaryotic cell, the "host" eukaryotic cell provided a beneficial environment for the photosynthetic bacteria. The condition of two species living together in close contact is termed symbiosis, and the process in which symbiosis results by the engulfment of one cell by another is termed endosymbiosis. Over time, these endosymbiotic, photosynthetic bacteria became transformed structurally and functionally, retaining their own DNA and the ability to replicate, but losing the ability to live independently of the host cell. In fact, over time there has been a transfer of some genes from the DNA of the host cell to the DNA of the engulfed bacteria, making the two biochemically interdependent.

Although knowledge of eukaryotic relationships is still in flux, the most recent data from molecular systematic studies indicates that this so-called "primary" endosymbiosis of the chloroplast probably occurred one time, a shared evolutionary novelty of the red algae (Rhodophyta) and green plants (Viridiplantae or Chlorobionta; Figure 1.1). This early chloroplast became modified with regard to photosynthetic pigments, thylakoid structure, and storage products into forms characteristic of the red algae and green plants (see Figure 1.1). In addition, several lineages of photosynthetic organisms—including the euglenoids, dinoflagellates, and brown algae (Phaeophyta), and a few other lineages—may have acquired chloroplasts via "secondary" endosymbioses, which occurred by the engulfment of an ancestral chloroplast-containing eukaryote by another eukaryotic cell (Figure 1.1). The final story is yet to be elucidated.

LAND PLANTS

Of the major groups of photosynthetic eukaryotes, the green plants (Viridiplantae or Chlorobionta) are united primarily by distinctive characteristics of the green plant chloroplast with respect to photosynthetic pigments, thylakoid structure, and storage compounds (see Chapter 3 for details). Green plants include both the predominately aquatic "green algae" and a group known as embryophytes (formally, the Embryophyta), usually referred to as the land plants (Figure 1.3). The land plants are united by several evolutionary novelties that were adaptations to the transition from an aquatic environment to living on land. These include (1) an outer cuticle, which aids in protecting tissues from desiccation; (2) specialized gametangia (egg and sperm producing organs) that have an outer, protective layer of sterile cells; and (3) an intercalated diploid phase (sporophyte) in the life cycle, the early, immature component of which is termed the embryo (hence, "embryophytes"; see Chapter 3 for details).

Just as the green plants include the land plants, the land plants are inclusive of the vascular plants (Figure 1.3), the latter being united by the evolution of an independent sporophyte and xylem and phloem vascular conductive tissue (see Chapter 4). The vascular plants are inclusive of the seed plants (Figure 1.3), which are united by the evolution of wood and seeds (see Chapter 5). Finally, seed plants include the angiosperms (Figure 1.3), united by the evolution of the flower, including carpels and stamens, and by a number of other specialized features (see Chapters 6–8).

For the remainder of this book, the term plant is treated as equivalent to the embryophytes, the land plants. The rationale for this is partly that land plants make up a so-called monophyletic group, whereas the photosynthetic eukaryotes as a whole are not monophyletic and, as a group, do not accurately reflect evolutionary history (see later discussion, Chapter 2). And, practically, it is land plants that most people are talking about when they refer to "plants," including those in the field of plant systematics. However, as noted before, the word plant can be used by some to refer to other groupings; when in doubt, get a precise clarification.
WHY STUDY PLANTS?

The tremendous importance of plants cannot be overstated. Without them, we and most other species of animals (as well as many other groups of organisms) wouldn’t be here. Photosynthesis in plants and the other photosynthetic organisms changed the earth in two major ways. First, the fixation of carbon dioxide and the release of molecular oxygen in photosynthesis directly altered the earth’s atmosphere over billions of years. What used to be an atmosphere deficient in oxygen underwent a gradual change. As a critical mass of oxygen accumulated in the atmosphere, selection for oxygen-dependent respiration occurred (via oxidative phosphorylation in mitochondria), which may have been a necessary precursor in the evolution of many multicellular organisms, including all animals. In addition, an oxygen-rich atmosphere permitted the establishment of an upper atmosphere ozone layer, which shielded life from excess UV radiation. This allowed organisms to inhabit more exposed niches that were previously inaccessible.

Second, the compounds that photosynthetic species produce are utilized, directly or indirectly, by nonphotosynthetic, heterotrophic organisms. For virtually all land creatures and many aquatic ones as well, land plants make up the so-called primary producers in the food chain, the source of high-energy compounds such as carbohydrates, structural compounds such as certain amino acids, and other compounds essential to metabolism in some heterotrophs. Thus, most species on land today, including millions of species of animals, are absolutely dependent on plants for their survival. As primary producers, plants are the major components of many communities and ecosystems. The survival of plants is
essential to maintaining the health of those ecosystems, the severe disruption of which could bring about rampant species extirpation or extinction and disastrous changes in erosion, water flow, and ultimately climate.

To humans, plants are also monumentally important in numerous, direct ways (Figures 1.4, 1.5). Agricultural plants, most of which are flowering plants, are our major source of food. We utilize all plant parts as food products: roots (e.g., sweet potatoes and carrots; Figure 1.4A,B); stems (e.g., yams, cassava/manioc, potatoes; Figure 1.4C); leaves (e.g., cabbage, celery, lettuce; Figure 1.4D); flowers (e.g., cauliflower and broccoli; Figure 1.4E); and fruits and seeds, including grains such as rice (Figure 1.4F), wheat (Figure 1.4G), corn (Figure 1.4H), rye, barley, and oats, legumes such as beans and peas (Figure 1.4I), and a plethora of fruits such as bananas (Figure 1.4J), tomatoes, peppers, pineapples (Figure 1.4K), apples (Figure 1.4L), cherries, peaches, melons, kiwis, citrus, olives (Figure 1.4M), and others too numerous to mention. Other plants are used as flavoring agents, such as herbs (Figure 1.5A–D) and spices (Figure 1.5E), as stimulating beverages, such as chocolate, coffee, tea, and cola (Figure 1.5F), or as alcoholic drinks, such as beer, wine, distilled liquors, and sweet liqueurs. Woody trees of both conifers and flowering plants are used structurally for lumber and for pulp products such as paper (Figure 1.5G). Non-woody plants, such as bamboos, palms, and a variety of other species, serve as construction materials for a great variety of purposes. Plant fibers are used to make thread for cordage (such as sisal), for sacks (such as jute for burlap), and for textiles (most notably cotton, Figure 1.5H, but also linen and hemp, Figure 1.5I). Extracts from plants, which include essential oils, latex (for rubber or balata), vegetable oils, pectins, starches, and waxes, have a plethora of uses in industry, food, perfume, and cosmetics. In many cultures, plants or plant products are used as euphorics or hallucinogenics (whether legally or illegally), such as marijuana (Figure 1.5J), opium, cocaine, and a great variety of other species that have been used by indigenous peoples for centuries. Plants are important for their aesthetic beauty, and the cultivation of plants as ornamentals is an important industry. Finally, plants have great medicinal significance, to treat a variety of illnesses or to maintain good health. Plant products are very important in the pharmaceutical industry; their compounds are extracted, semisynthesized, or used as templates to synthesize new drugs. Many “modern” drugs, from aspirin (originally derived from the bark of willow trees) to vincristine and vinblastine (obtained from the Madagascar periwinkle, used to treat childhood leukemia; Figure 1.5J), are ultimately derived from plants. In addition, various plant parts of a great number of species are used whole or are processed as so-called herbal supplements, which have become tremendously popular of late.

The people, methods, and rationale concerned with the plant sciences (defined here as the study of land plants) are as diverse as the uses and importance of plants. Some of the fields in the plant sciences are very practically oriented. Agriculture and horticulture deal with improving the yield or disease resistance of food crops or cultivated ornamental plants, e.g., through breeding studies and identifying new cultivars. Forestry is concerned with the cultivation and harvesting of trees used for lumber and pulp. Pharmacognosy deals with crude natural drugs, often of plant origin. In contrast to these more practical fields of the plant sciences, the “pure” sciences have as their goal the advancement of scientific knowledge (understanding how nature works) through research, regardless of the practical implications. But many aspects of the pure sciences also have important practical applications, either directly by applicable discovery or indirectly by providing the foundation of knowledge used in the more practical sciences. Among these are plant anatomy, dealing with cell and tissue structure and development; plant chemistry and physiology, dealing with biochemical and biophysical processes and products; plant molecular biology, dealing with the structure and function of genetic material; plant ecology, dealing with interactions of plants with their environment; and, of course, plant systematics.

Note that a distinction should be made between “botany” and “plant sciences.” Plant sciences is the study of plants, treated as equivalent to land plants here. Botany is the study of most organisms traditionally treated as plants, including virtually all eukaryotic photosynthetic organisms (land plants and the several groups of “algae”) plus other eukaryotic organisms with cell walls and spores (true fungi and groups that were formerly treated as fungi, such as the Oomycota and slime molds). Thus, in this sense, botany is inclusive of but broader than the plant sciences. Recognition of both botany and plant sciences as fields of study can be useful, although how these fields are defined can vary and may require clarification.

**SYSTEMATICS**

**WHAT IS SYSTEMATICS?**

Systematics is defined in this book as a science that includes and encompasses traditional taxonomy, the description, identification, nomenclature, and classification of organisms, and that has as its primary goal the reconstruction of phylogeny, or evolutionary history, of life. This definition of systematics is not novel, but neither is it universal. Others in the field would treat taxonomy and systematics as separate but overlapping areas; still others argue that historical usage necessitates what is in essence a reversal of the definitions used here. But words, like organisms, evolve. The use of systematics to describe an
CHAPTER 1 PLANT SYSTEMATICS: AN OVERVIEW


I. Seeds (pulse legumes), from top, clockwise to center: Glycine max, soybean; Lens culinaris, lentil; Phaseolus aureus, mung bean; Phaseolus vulgaris, pinto bean; Phaseolus vulgaris, black bean; Cicer arietinum, chick-pea/garbanzo bean; Vigna unguiculata, black-eyed pea; Phaseolus lunatus, lima bean.

Figure 1.5  Further examples of economically important plants. A–D. Herbs. A. *Petroselinum crispum*, parsley. B. *Salvia officinalis*, sage. C. *Rosmarinus officinalis*, rosemary. D. *Thymus vulgaris*, thyme. E. Spices and herbs, from upper left: *Cinnamomum cassia/zeylanicum*, cinnamon (bark); *Vanilla planifolia*, vanilla (fruit); *Laurus nobilis*, laurel (leaf); *Syzygium aromaticum*, cloves (flower buds); *Myristica fragrans*, nutmeg (seed); *Carum carvi*, caraway (fruit); *Anethum graveolens*, dill (fruit); *Pimenta dioica*, allspice (seed); *Piper nigrum*, pepper (seed). F. Flavoring plants, from upper left, clockwise. *Theobroma cacao*, chocolate (seeds); *Coffea arabica*, coffee (seeds); *Camellia sinensis*, tea (leaves). G. Wood products: lumber (*Sequoia sempervirens*, redwood), and paper derived from wood pulp. H. Fiber plant. *Gossypium* sp., cotton (seed trichomes), one of the most important natural fibers. I. Euphoric, medicinal, and fiber plant. *Cannabis sativa*, marijuana, hemp; stem fibers used in twine, rope, and cloth; resins contain the euphoric and medicinal compound tetrahydrocannabinol. J. Medicinal plant. *Catharanthus roseus*, Madagascar periwinkle, from which is derived vincristine and vinblastine, used to treat childhood leukemia.
all-encompassing field of endeavor is both most useful and represents the consensus of how most specialists in the field use the term, an example being the journal *Systematic Botany*, which contains articles both in traditional taxonomy and phylogenetic reconstruction. Plant systematics is studied by acquiring, analyzing, and synthesizing information about plants and plant parts, the content and methodology of which is the topic for the remainder of this book. (See Stevens 1994.)

Systematics is founded in the principles of evolution, its major premise being that there is one phylogeny of life. The goal of systematists is, in part, to discover that phylogeny.

**EVOUION**

**Evolution**, in the broadest sense, means “change” and can be viewed as the cumulative changes occurring since the origin of the universe some 14 billion years ago. Biological evolution, the evolution of life, may be defined (as it was by Charles Darwin) as “descent with modification.” **Descent** is the transfer of genetic material (enclosed within a cell, the unit of life) from parent(s) to offspring over time. This is a simple concept, but one that is important to grasp and ponder thoroughly. Since the time that life first originated some 3.8 billion years ago, all life has been derived from preexisting life. Organisms come to exist by the transfer of genetic material, within a surrounding cell, from one or more parents. Descent may occur by simple clonal reproduction, such as a single bacterial cell “parent” dividing by fission to form two “offspring” cells or a land plant giving rise to a vegetative propagule. It may also occur by complex sexual reproduction (Figure 1.6A), in which each of two parents produces specialized gametes (e.g., sperm and egg cells), which contain half the complement of genetic material, the result of meiosis. Two of the gametes fuse together to form a new cell, the zygote, which may develop into a new individual (as occurs in plants; see Chapter 3) or may itself divide by meiosis to form gametes. Descent through time results in the formation of a **lineage** (Figure 1.6B), a set of organisms interconnected through time and space by the transfer of genetic material from parents to offspring. So, in a very literal sense, we and all other forms of life on earth are connected by descent, the transfer of DNA (actually the pattern of DNA) from parent to offspring (ancestor to descendant), generation after generation.

The **modification** component of evolution refers to a change in the genetic material that is transferred from parent(s) to offspring, such that the genetic material of the offspring is different from that of the parent(s). This modification may occur either by mutation, which is a direct alteration of DNA, or by genetic recombination, whereby existing genes are reshuffled in different combinations (during meiosis, by crossing over and independent assortment). Systematics is concerned with the identification of the unique modifications of evolution (see later discussion).

It should also be asked, what evolves? Although genetic modification may occur in offspring relative to their parents, individual organisms do not generally evolve. This is because a new individual begins when it receives its complement of DNA from the parent(s); that individual’s DNA does not change during its/his/her lifetime (with the exception of relatively rare, nonreproductive “somatic” mutations). The general units of evolution are populations and species. A **population** is a group of individuals of the same species that is usually geographically delimited and that typically have a significant amount of gene exchange. **Species** are groups of populations that are related to one another by various criteria and that have evolutionarily diverged from other such groups. There are a number of different species concepts or definitions, dependent on the biological system and on the criteria used to recognize them (see Chapter 19). With changes in the genetic makeup of offspring (relative to parents), the genetic makeup of populations and species changes over time.

In summary, evolution is descent with modification occurring by a change in the genetic makeup (DNA) of populations or species over time. How does evolution occur? Evolutionary change may come about by two major mechanisms: (1) **genetic drift**, in which genetic modification is random; or (2) **natural selection**, in which genetic change is directed and nonrandom. Natural selection is the differential contribution of genetic material from one generation to the next, differential in the sense that genetic components of the population or species are contributed in different amounts to the next generation; those genetic combinations resulting in increased survival or reproduction are contributed to a greater degree. (A quantitative measure of this differential contribution is known as **fitness**.) Natural selection results in an **adaptation**, a structure or feature that performs a particular function and which itself brings about increased survival or reproduction. In a consideration of the evolution of any feature in systematics, the possible adaptive significance of that feature should be explored.

Finally, an ultimate result of evolution is **speciation**, the formation of new species from preexisting species. Speciation can follow lineage divergence, the splitting of one lineage into two, separate lineages (Figure 1.6C). Lineage divergence is itself a means of increasing evolutionary diversity. If two, divergent lineages remain relatively distinct, they may change independently of one another, into what may be designated as separate species (see Chapter 19).

**TAXONOMY**

**Taxonomy** is a major part of systematics that includes four components: **Description**, **Identification**, **Nomenclature**, and **Classification**. (Remember the mnemonic device: **DINC**.) The general subjects of study are taxa (singular, **taxon**), which are defined
Figure 1.6  

A. Simplified diagram of descent in sexually reproducing land plants, in which diploid sporophytes give rise to haploid spores (through meiosis), which develop into haploid gametophytes; the latter produce egg and sperm, fusing to form a diploid zygote, which develops into a diploid sporophyte.  

B. A lineage, the result of transfer of genetic material over time and space.  

C. Divergence of one lineage into two, which may result in speciation (illustrated here).
or delimited groups of organisms. Ideally, taxa should have a property known as monophyly (discussed later; Chapter 2) and are traditionally treated at a particular rank (see later discussion). It should be pointed out that the four components of taxonomy are not limited to formal systematic studies but are the foundation of virtually all intellectual endeavors of all fields, in which conceptual entities are described, identified, named, and classified. In fact, the ability to describe, identify, name, and classify things undoubtedly has been selected for in humans and, in part, in other animals as well.

**Description** is the assignment of features or attributes to a taxon. The features are called **characters**. Two or more forms of a character are **character states**. One example of a character is “petal color,” for which two character states are “yellow” and “blue.” Another character is “leaf shape,” for which possible character states are “elliptic,” “lanceolate,” and “ovate.” Numerous character and character state terms are used in plant systematics, both for general plant morphology (see Chapter 9) and for specialized types of data (Chapters 10–14). The purpose of these descriptive character and character state terms is to use them as tools of communication, for concisely categorizing and delimiting the attributes of a taxon, an organism, or some part of the organism. An accurate and complete listing of these features is one of the major objectives and contributions of taxonomy.

**Identification** is the process of associating an unknown taxon with a known one, or recognizing that the unknown is new to science and warrants formal description and naming. One generally identifies an unknown by first noting its characteristics, that is, by describing it. Then, these features are compared with those of other taxa to see if they conform. Plant taxa can be identified in many ways (see Chapter 15). A taxonomic key is perhaps the most utilized of identification devices. Of the different types of taxonomic keys, the most common, used in virtually all floras, is a dichotomous key. A dichotomous key consists of a series of two contrasting statements. Each statement is a **lead**; the pair of leads constitutes a **couplet** (Figure 1.7). That lead which best fits the specimen to be identified is selected; then all couplets hierarchically beneath that lead (by indentation and/or numbering) are sequentially checked for agreement until an identification is reached (Figure 1.7).

**Nomenclature** is the formal naming of taxa according to some standardized system. For plants, algae, and fungi, the rules and regulations for the naming of taxa are provided by the International Code of Botanical Nomenclature (see Chapter 16). These formal names are known as **scientific names**, which by convention are translated into the Latin language. The fundamental principle of nomenclature is that all taxa may bear only one scientific name. Although they may seem difficult to learn at first, scientific names are much preferable to common (vernacular) names (Chapter 16).

The scientific name of a species traditionally consists of two parts (typically underlined or italicized): the genus name, which is always capitalized, e.g., *Quercus*, plus the specific epithet, which by general consensus is not capitalized, e.g., *aegrifolia*. Thus, the species name for what is commonly called California live oak is *Quercus agrifolia*. Species names are known as **binomials** (literally meaning “two names”) and this type of nomenclature is called binomial nomenclature, first formalized in the mid-18th century by Carolus Linnaeus.

**Classification** is the arrangement of entities (in this case, taxa) into some type of order. The purpose of classification is to provide a system for cataloguing and expressing relationships between these entities. Taxonomists have traditionally agreed upon a method for classifying organisms that utilizes categories called **ranks**. These taxonomic ranks are hierarchical, meaning that each rank is inclusive of all other ranks beneath it (Figure 1.8).

As defined earlier, a **taxon** is a group of organisms typically treated at a given rank. Thus, in the example of Figure 1.8, Magnoliophyta is a taxon placed at the rank of phylum; Liliopsida is a taxon placed at the rank of class; Arecaceae is a taxon placed at the rank of family; etc. Note that taxa of a particular rank generally end in a particular suffix (Chapter 16). There is a trend among systematic biologists to eliminate the rank system

<table>
<thead>
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<th>Couplet:</th>
<th>Lead:</th>
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| 1. Annual; leaves <=1 cm long; flowers 1–4 mm | 2. Leaves opposite, pairs fused around stem; flowers axillary; petals <2 mm | 3. Shrubs or shrub 
4. Leaves alternate, many in rosette; sepals 6–16; petals ± free |
| 2. Leaves alternate above, free; flowers in terminal cyme; petals 1.5–4.5 mm | 4. Leaves opposite, few, not ciliate; sepals 5; petals fused, tube > sepals | 3. Perennial herb (annual or biennial in Sedum radiatum) |
| 5. Inflorescence axillary; cauline leaves different from rosette leaves | 5. Inflorescence terminal; cauline leaves like rosettes, or basal leaves brown, scale-like | 6. Sedum |

of classification (see Chapter 16). In this book, ranks are used for naming groups but not emphasized as ranks.

There are two major means of arriving at a classification of life: phenetic and phylogenetic. **Phenetic** classification is that based on overall similarities. Most of our everyday classifications are phenetic. For efficiency of organization (e.g., storing and retrieving objects, like nuts and bolts in a hardware store) we group similar objects together and dissimilar objects apart. Many traditional classifications in plant systematics are phenetic, based on noted similarities between and among taxa. **Phylogenetic** classification is that which is based on evolutionary history, or pattern of descent, which may or may not correspond to overall similarity (see later discussion, Chapter 2).

**PHYLOGENY**

**Phylogeny**, the primary goal of systematics, refers to the evolutionary history of a group of organisms. Phylogeny is commonly represented in the form of a cladogram (or phylogenetic tree), a branching diagram that conceptually represents the evolutionary pattern of descent (see Figure 1.9). The lines of a cladogram represent **lineages**, which (as discussed earlier) denote descent, the sequence of ancestral-descendant populations through time (Figure 1.9A). Thus, cladograms have an implied (relative) time scale. Any branching of the cladogram represents lineage divergences, the diversification of lineages from one common ancestor.

Changes in the genetic makeup of populations, i.e., evolution, may occur in lineages over time. Evolution may be recognized as a change from a preexisting, or ancestral, character state to a new, derived character state. The derived character state is an evolutionary novelty, also called an **apomorphy** (Figure 1.9A). **Phylogenetic systematics**, or **cladistics**, is a methodology for inferring the pattern of evolutionary history of a group of organisms, utilizing these apomorphies (Chapter 2).

As cited earlier, cladograms serve as the basis for phylogenetic classification. A key component in this classification system is the recognition of what are termed monophyletic groups of taxa. A **monophyletic group**, or clade, is a group consisting of a common ancestor plus all (and only all) descendants of that common ancestor. For example, the monophyletic groups of the cladogram in Figure 1.9B are circled. A phylogenetic classification recognizes only monophyletic groups. Note that some monophyletic groups are included within others (e.g., in Figure 1.9B the group containing only taxa E and F is included within the group containing only taxa D, E, and F, which is included within the group containing only taxa B, C, D, E, and F, etc.). The sequential listing of clades can serve as a phylogenetic classification scheme (see Chapter 2).

In contrast to a monophyletic group, a **paraphyletic group** is one consisting of a common ancestor but not all descendants of that common ancestor; a **polyphyletic group** is one in which there are two or more separate groups, each with a separate common ancestor. Paraphyletic and polyphyletic groups distort the accurate portrayal of evolutionary history and should be abandoned (see Chapter 2).

Knowing the phylogeny of a group, in the form of a cladogram, can be viewed as an important end in itself. As discussed earlier, the cladogram may be used to devise a system of classification, one of the primary goals of taxonomy. The cladogram can also be used as a tool for addressing several interesting biological questions, including biogeographic or ecological history, processes of speciation, and adaptive character evolution. A thorough discussion of the principles and methodology of phylogenetic systematics is presented in Chapter 2.

**WHY STUDY SYSTEMATICS?**

The rationale and motives for engaging in a study of systematics are worth examining. For one, systematics is important in providing a foundation of information about the tremendous diversity of life. Virtually all fields of biology are dependent on the correct taxonomic determination of a given study organism, which relies on formal description, identification, naming, and classification. Systematic research is the basis for acquiring, cataloging, and retrieving information about life’s diversity. Essential to this research is documentation, through collection (Chapter 17) and storage of reference specimens, e.g., for plants in an accredited herbarium (Chapter 18). Computerized data entry of this collection information is now vital to cataloging and retrieving the vast amount of information dealing with biodiversity (Chapter 18).
Figure 1.9  Example of a cladogram or phylogenetic tree for taxa A–F.  
A. Cladogram showing lineages and apomorphies, the latter indicated by thick hash marks. 
B. Cladogram with common ancestors shown and monophyletic groups (clades) circled.
Systematics is also an integrative and unifying science. One of the “fun” aspects of systematics is that it may utilize data from all fields of biology: morphology, anatomy, embryology/development, ultrastructure, paleontology, ecology, geography, chemistry, physiology, genetics, karyology, and cell/molecular biology. The systematist has an opportunity to understand all aspects of his/her group of interest in an overall synthesis of what is known from all biological specialties, with the goal being to understand the evolutionary history and relationships of the group.

Knowing the phylogeny of life can give insight into other fields and have significant practical value. For example, when a species of Dioscorea, wild yam, was discovered to possess steroid compounds (used first in birth control pills), examination of other closely related species revealed species that contained even greater quantities of these compounds. Other examples corroborate the practical importance of knowing phylogenetic relationships among plant species. The methodology of phylogenetics is now an important part of comparative biology, used by, for example, evolutionary ecologists, functional biologists, and parasitologists, all of whom need to take history into account in formulating and testing hypotheses.

The study of systematics provides the scientific basis for defining or delimiting species and infraspecific taxa (subspecies or varieties) and for establishing that these are distinct from other, closely related and similar taxa. Such studies are especially important today in conservation biology (Chapter 19). In order to determine whether a species or infraspecific taxon of plant is rare or endangered and warrants protection, one must first know the limits of that species or infraspecific taxon. In addition, understanding the history of evolution and geography may aid in conservation and management decisions, where priorities must be set as to which regions to preserve.

Finally, perhaps the primary motivation for many, if not most, in the field of systematics has been the joy of exploring the intricate complexity and incredible diversity of life. This sense of wonder and amazement about the natural world is worth cultivating (or occasionally rekindling). Systematics can also be a challenging intellectual activity, generally requiring acute and patient skills of observation. Reconstruction of phylogenetic relationships and ascertaining the significance of those relationships can be especially challenging and rewarding. But today we also face a moral issue: the tragic and irrevocable loss of species, particularly accelerated by rampant destruction of habitat, such as deforestation in the tropics. We can all try to help, both on a personal and professional level. Systematics, which has been called simply “the study of biodiversity,” is the major tool for documenting that biodiversity and can be a major tool for helping to save it. Perhaps we can all consider reassessing our own personal priorities in order to help conserve the life that we study.

**REVIEW QUESTIONS**

**PLANTS**
1. What is a “plant”? In what two conceptual ways can the answer to this question be approached?
2. What are the three major groups of life currently accepted?
3. Name and define the mechanism for the evolution of chloroplasts.
4. Name some chlorophyllous organismal groups that have traditionally been called “plants” but that evolved or acquired chloroplasts independently.
5. Draw a simplified cladogram showing the relative relationships among the green plants (Chlorobionta/Viridiplantae), land plants (embryophytes), vascular plants (tracheophytes), seed plants (spermatophytes), gymnosperms, and angiosperms (flowering plants).
6. Why are land plants treated as equivalent to “plants” in this book?
7. List the many ways that plants are important, both in evolution of life on earth and in terms of direct benefits to humans.

**SYSTEMATICS**
8. What is systematics and what is its primary emphasis?
9. Define biological evolution, describing what is meant both by descent and by modification.
10. What is a lineage?
11. Name and define the units that undergo evolutionary change.
12. What are the two major mechanisms for evolutionary change?
13. What is a functional feature that results in increased survival or reproduction called?
14. Name and define the four components of taxonomy.
15. Define character and character state.
16. Give one example of a character and character state from morphology or from some type of specialized data.
17. What is a dichotomous key? A couplet? A lead?
18. What is a scientific name?
19. Define binomial and indicate what each part of the binomial is called.
20. What is the difference between rank and taxon?
21. What is the plural of taxon?
22. Name the two main ways to classify organisms and describe how they differ.
23. Define phylogeny and give the name of the branching diagram that represents phylogeny.
24. What does a split, from one lineage to two, represent?
25. Name the term for both a preexisting feature and a new feature.
26. What is phylogenetic systematics (cladistics)?
27. What is a monophyletic group or clade? A paraphyletic group? A polyphyletic group?
28. For what can phylogenetic methods be used?
29. How is systematics the foundation of the biological sciences?
30. How can systematics be viewed as unifying the biological sciences?
31. How is systematics of value in conservation biology?
32. Of what benefit is plant systematics to you?

EXERCISES

1. Obtain definitions of the word plant by asking various people (lay persons or biologists) or looking in reference sources, such as dictionaries or textbooks. Tabulate the various definitions into classes. What are the advantages and disadvantages of each?
2. Take a day to note and list the uses and importance of plants in your everyday life.
3. Pick a subject, such as history or astronomy, and cite how the principles of taxonomy are used in its study.
4. Do a web search for a particular plant species (try common and scientific name) and note what aspect of plant biology each site covers.
5. Peruse five articles in a systematics journal and tabulate the different types of research questions that are addressed.

REFERENCES FOR FURTHER STUDY

GENERAL

OTHER PLANT SYSTEMATICS TEXTBOOKS