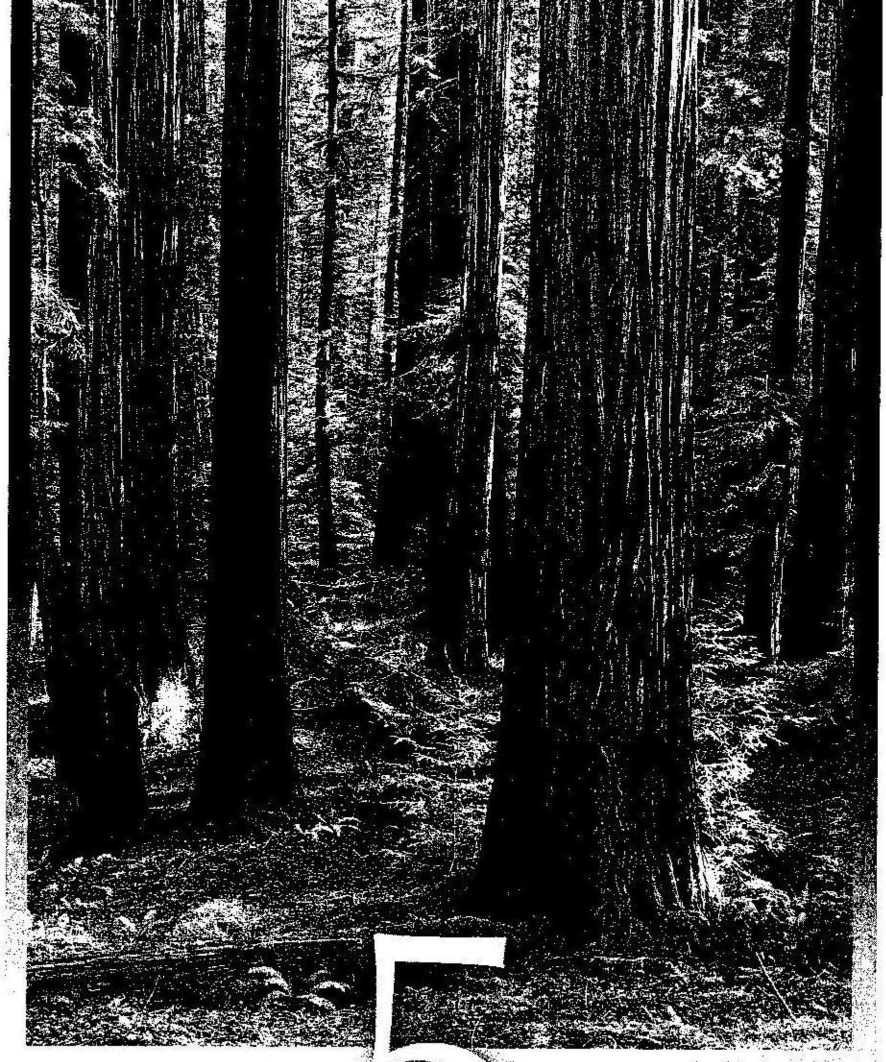


5

"Just think how much deeper the ocean would be if sponges didn't live there."

"After eating, do amphibians need to wait an hour before getting OUT of the water?"

"Do fish get cramps after eating?"

"If a tree falls in the forest and no one is around to see it,
do the other trees make fun of it?"

Steve Wright, comedian

Diversity of Life

outline

INTRODUCTION

Life is built upon a deep, underlying molecular plan—DNA. A nucleotide backbone makes up this fundamental, common molecular motif throughout all life. The same four nitrogen-containing bases are paired into a long and spiraled double helix, a universal standard in all living organisms. Yet life is also complex and varied (figure 5.1). Life is diversity on a theme. The bases of this diversity include fundamental changes in molecular metabolism, in the cellular unit itself, in the assembly of single-celled into multicellular organisms, and in differences in basic lifestyle. Some of these changes are summarized in figure 5.2, which represents major transitions in the history of life. Notice that multicellularity in plants, fungi, and animals accompanies three different, respective lifestyles. Plants incorporate *photosynthesis* into their biology, fungi *absorb* environmental nutrients, and animals *ingest* energy—three different survival strategies.

PROKARYOTES

Prokaryotes are *bacteria*, which in human terms is a nasty word. Bacteria are associated with disease, and in many cases they certainly deserve our contempt. But not all bacteria are harmful to humans. Some actually provide benefits. Let's look at the groups.

At one time, most microorganisms were lumped together into just "bacteria," which included prokaryotic microbes, mostly single-celled. However, newer techniques of analysis reveal that there are really two major groups of microbes. One is the "true" bacteria, sometimes called eubacteria or now more commonly just *Bacteria*; the other is the *Archaea* (*Archaebacteria*), or "ancient" bacteria (figure 5.1). Members of both groups are prokaryotes. The groups differ primarily in their chemical composition and the structure of their cell walls.

Bacteria (Eubacteria)

The bacteria include the *cyanobacteria*, sometimes called "blue-green algae." Cyanobacteria are photosynthetic; their chlorophyll is

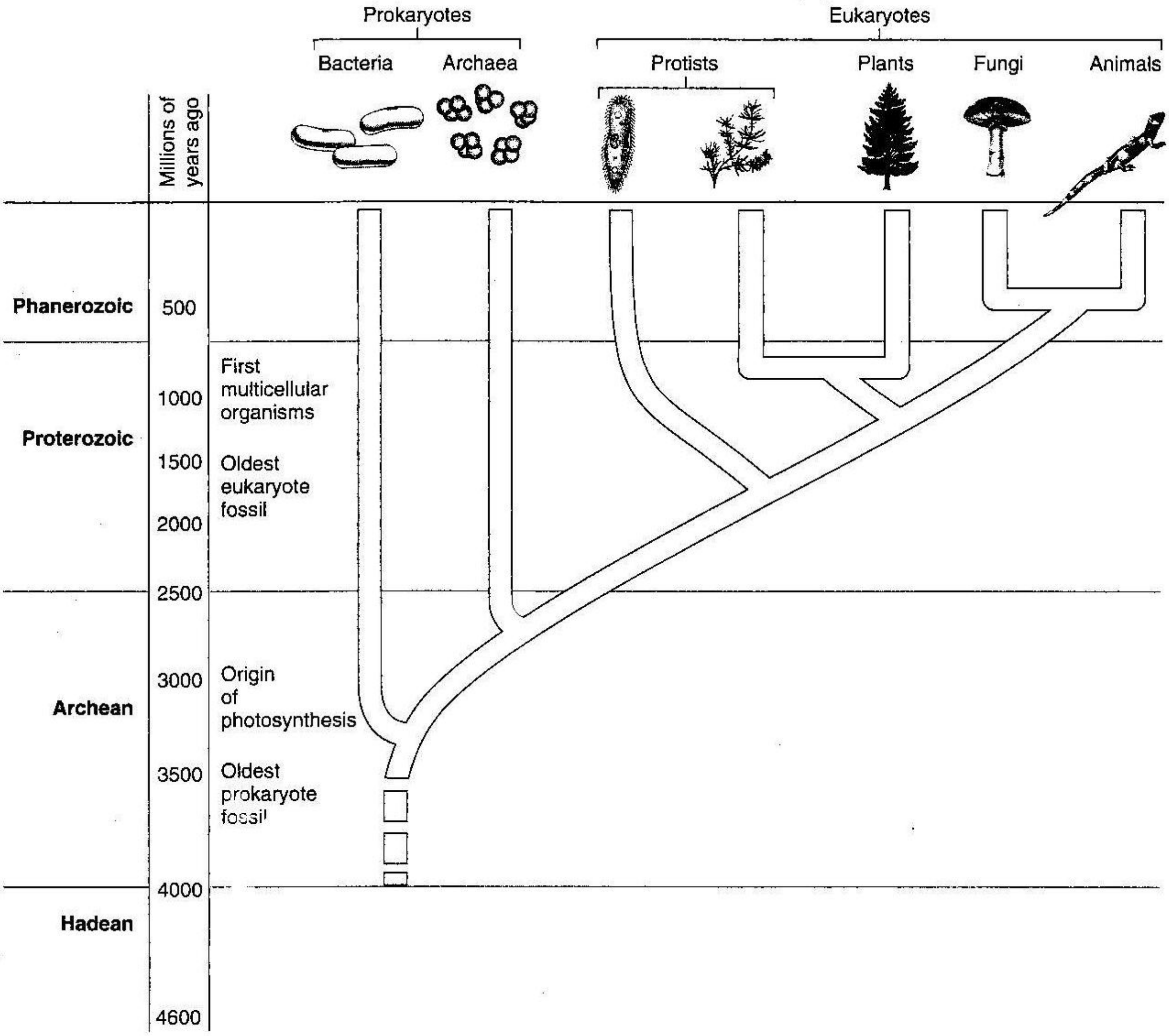


FIGURE 5.1 Major Groups of Organisms The phylogenetic tree represents the approximate time of appearance and relationships of these groups.

similar to that in plants and algae today, and they similarly produce free oxygen as a by-product. Cyanobacteria are *photoautotrophs*—they carry out photosynthesis using solar energy (*photo-*) to build directly for their own use (*autotrophs*) organic molecules from carbon dioxide. Their appearance about 3.5 billion years ago coincided with the onset of free oxygen buildup in the Earth's atmosphere, which changed the environment in which subsequent life evolved.

Some nasty bacteria are found amongst the eubacteria. Pathogenic forms include bacteria responsible for the plague, cholera, lyme disease, dental caries (tooth decay), anthrax, and the sexually transmitted disease chlamydia. But also included are the usually harmless *Escherichia coli*, or *E. coli* for short. Some eubacteria are *chemoautotrophs*—they obtain their energy not from sunlight but instead from the chemical bonds (hence, "chemo-") of inorganic molecules. Some of the most important chemoautotrophs convert nitrogen (N_2) to ammonia (NH_3), a process termed **nitrogen fixation**. Through several sequential steps, nitrate (NO_3^-) is produced, which is then taken up by plants. This is critical because nitrogen is an important component of proteins and nucleic acids, yet only these eubacteria—and no other organisms—have

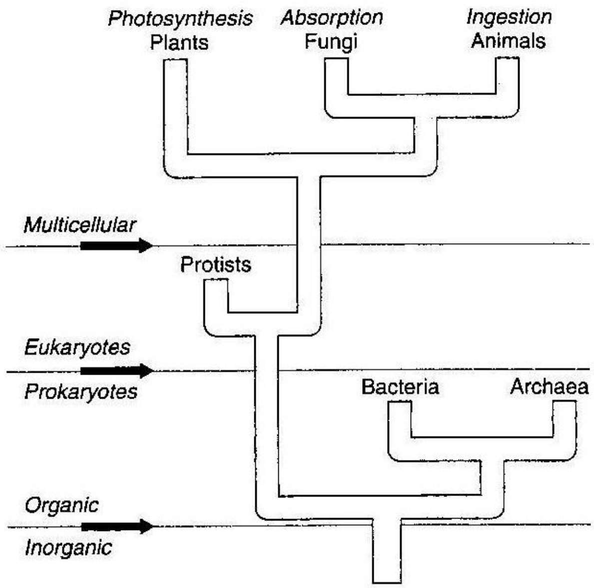


FIGURE 5.2 Major Evolutionary Transitions and Lifestyles The basic domains of life represent major changes in structure, function, and basic strategies of existence. The first major transition was from inorganic to organic existence, followed by the prokaryotic cell as heterotroph and autotroph, and prokaryote to eukaryote. Although clumps of cells occurred earlier, plants, fungi, and animals represent specialists that build on multicellular organization, respectively, in photosynthesis, absorption, ingestion.

the ability to take nitrogen and fix it in usable compounds. In so doing, these single-celled prokaryotes make nitrogen available to other organisms, mostly plants.

Archaea (Archaebacteria)

Archaea are the extremists of the bacterial world, perhaps evolutionary products of the harsh environmental conditions under which they emerged on the young, inhospitable Earth more than 3 billion years ago. They grow only in oxygen-free (anaerobic) environments like the atmosphere of the young Earth. Today, they have withdrawn into the remnants of such sheltered anaerobic environments. Some archaea are *thermophiles* (heat-loving); these thrive in hot springs in Yellowstone National Park (United States) at 70–75°C (160°F) or next to deep-ocean hydrothermal rift vents at temperatures above 100°C (212°F). Others such as *Halophilic* (salt-loving) archaea prosper in water with extremely high salt concentrations such as occur in the Great Salt Lake or the Dead Sea. The *methanogens* produce methane gas. Some methanogens are denizens of swamps and marshes, where the methane they produce bubbles out as "marsh gas"; others live in the guts of animals such as ruminants (e.g., cattle, bison, wildebeests), where they break down cellulose but produce methane as a by-product.

EUKARYOTES

Eukaryotes have nucleated cells filled with organelles. Many (e.g., plants, fungi, animals) are multicellular, but not all. Perhaps the most diverse of the eukaryotes are the protists.

Protists

The protists are a motley lot, an artificial assemblage, but one of useful convenience. Some are unicellular, others colonial, and some even multicellular. In early classifications, photosynthetic protists were placed with plants; those that ingested food, with animals;

Consider This—

E. coli—Friend and Foe

The human gut holds about 2 pounds of bacteria of various kinds. A small proportion of these are *E. coli*. Like different breeds of dogs, different strains of *E. coli* may be docile or fierce. Most *E. coli* synthesize vitamin K and B-complex vitamins, which are then beneficially absorbed by the body. However, some strains of *E. coli* can become pathogenic, producing urinary tract infections, diarrhea, and even life-threatening blood infections. Why different strains should switch from friend to foe is not known. But the outbreak of such rogue bacteria seems to result from opportunity (contaminated food, poorly cooked food) and from some genetic mutations that promote the release of virulent toxins.

others stood alone. Most likely, protists will eventually be split into smaller, natural taxonomic units. For now, let's just look at the diversity. You may know of some of them already.

Algae. Algae are one of the photosynthetic groups of protists, including red, brown, and green algae. Some red algae live in fresh water, but most are marine protists. The long, leafy "kelp" along shallow ocean shores is a brown alga that can form massive underwater groves. In green algae, the close chemical similarities of their chlorophylls betray their close relationship to plants. Along with cyanobacteria, the green algae make up the community of aquatic organisms known as **phytoplankton**. The phytoplankton are at the base of most marine and freshwater food webs, as well as being responsible for much of the world's O_2 production.

Sarcodina. Amongst the Sarcodina are the amoebas, which move by means of fluid cell extensions, the pseudopods. Most are harmless, but one species causes amoebic dysentery. Foraminifera, or just "forams," are part of this protist group. Each unicellular foram secretes a shell, usually of calcium, in which it lives.

Flagellates. The flagellates include protists with a whiplike *flagellum* that, like a cellular tail, beats to move the microorganism along. Sudden, explosive population buildup can produce "red tides," a bloom of flagellates toxic to many marine organisms. The flagellate *Trypanosoma*, the vector carried by the tsetse fly, is responsible for sleeping sickness common in tropical regions. Another flagellate, *Giardia*, present in clear waters of mountains streams, causes the hiker's diarrhea.

Plants

Plants are denizens of the land. They arose from aquatic seaweeds—specifically from green algae, perhaps leafy or filamentous in shape—and colonized terrestrial environments. Some, such as water lilies and cattails, have returned to a watery environment. But plants are designed for life on land and carry adaptations to serve them there.

Terrestrial Adaptations

Life on land poses special problems and opportunities, compared to life in water. On land, sunlight is unfiltered by sea or fresh water, and its full energy can be tapped through photosynthesis. On the other hand, the buoyancy of surrounding water that floats aquatic algae is gone in thin air. Remaining upright, alone against gravity, is a major problem. So is the threat of desiccation—dehydration from exposure to the hot sun and drying wind. For most plants, these problems are addressed with *root* and *shoot systems* (figure 5.3). The root system taps into one environment, the soil, where it anchors the plant and finds water and minerals to support the plant. The shoot system takes advantage of another environment, the air, where it gathers carbon dioxide and spreads its leaves out into solar collectors, taking full advantage of photosynthesis.

The leaves and other parts of the shoot are coated with a waxy layer, the *cuticle*. You may have noticed this shiny cuticle on the surface of polished apples. This watertight sealant on the aerial parts of the plant reduces water loss from interior tissue. Gas exchange between the atmosphere and interior tissues of the leaf, a necessary part of photosynthesis, occurs through numerous tiny pores, the *stomata* (sing., *stoma*), passing through the cuticle. Stomata open and close to permit entry of

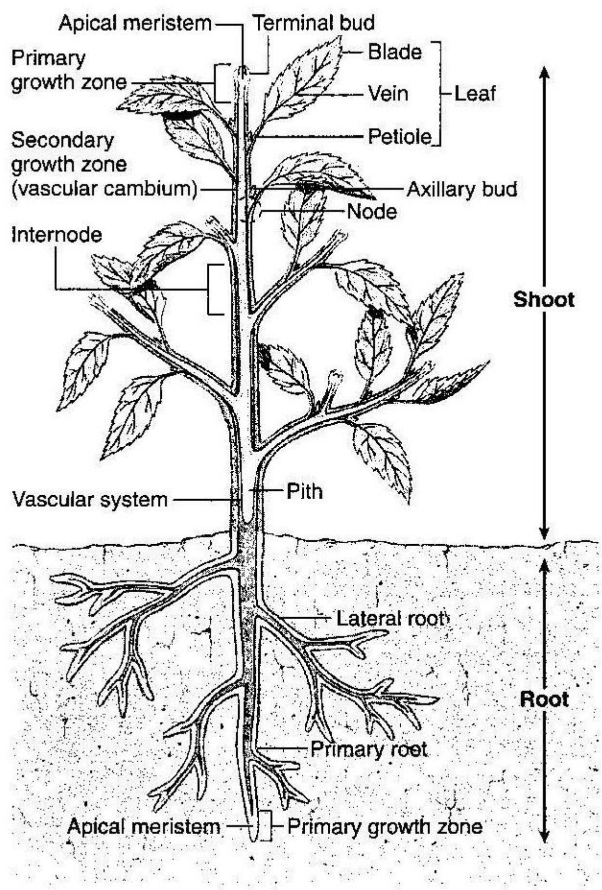


FIGURE 5.3 Plant Body, Shoot and Root
Primary growth in length is within apical meristems at the tips of stems and tips of roots.

carbon dioxide and exit of oxygen. Walls of cells supporting the plant are often reinforced with *lignin*, a chemical that hardens to strengthen the shoot projecting above the ground and help hold it erect. Most plants also have a plumbing system made up of **vascular tissue**, which is composed of tubular cells running throughout the plant. Some of the vascular tissue conducts water and minerals from roots to shoots; other tubes conduct sugars from shoots to roots. Bundles of vascular tissue also form pillars that help support the plant. The vascular system is easily seen as *veins* that spread along the undersides of leaves.

Growth

A plant's growth in height occurs at the shoot tip, not by elongation within its stem or trunk. However, increase in girth—widening of woody plants—occurs throughout the shoot and root systems by adding material laterally, along the plant's length. Some plants are **annual plants** that live only one year and then die. Others are **perennial plants**, those that live for more than a year. In trees, which are perennial plants, much of the growth in girth occurs in an active ring of cells just beneath the bark, the *vascular cambium*. In environments imposing stressful dry (tropical) or cold (temperate) seasons, the vascular cambium ceases growth during these stressful seasons and enters *dormancy*. When rains return or spring brings warm temperatures, growth resumes, producing a new layer of large, water-swollen cells. As the tree approaches the next dormant phase, growth slows, cells in the vascular cambium are small, as the tree enters dormancy once again. Each annual pulse of growth plus dormancy therefore produces one **growth ring**—an annual episode of growth marked by a ring of large and compact cells. Preserved in the trunk of the tree from year to year, the age of the tree is represented in these yearly growth rings. Foresters and others use core-sampling tools on living trees to take a small plug of the tree and count the rings on the extracted sample to determine the age of the tree.

Whether slow or swift, plants grow continuously by simple cell proliferation, termed **vegetative growth**. If a plant part is nibbled or broken off, new shoots grow out; parts or "runners" also may extend out from the main plant, take root, and give rise to whole new plants. Some animals are capable of similar growth via part replacement and can produce a new organism from body fragments or by budding. But in plants, vegetative growth is highly accommodating, so much so that gardeners can clip off "cuttings," bits of plant shoots, to start new growth or even new plants. Some plants propagate by such vegetative means. In fact, this natural method of proliferation, released from natural controls, can become an ecological problem. The watermilfoil is a freshwater plant introduced into North America from Eurasia. Largely through vegetative growth, it has spread to lakes, rivers, and ponds in most states and provinces, where it forms dense floating mats that choke off light to native plants below.

Reproduction

Plants reproduce by both mitosis and meiosis. But unlike animals, plants have a life cycle that includes an **alternation of generations**, wherein diploid ($2n$) individuals and haploid (n) individuals successively alternate with each other. Recall that during meiosis, the pairs of chromosomes in a cell divide—each half of the pair moving into one of the gametes (eggs or sperm) produced (see chapter 3 and Appendix 1). Just before meiosis, the cell holds a full complement of paired chromosomes and is *diploid* ($2n$); after meiosis, the chromosome number is halved in the gametes, which are consequently *haploid* (n). Within plants, the life cycle alternates between **sporophyte individuals** ($2n$; produce spores) and **gametophyte individuals** (n; produce gametes) (figure 5.4).

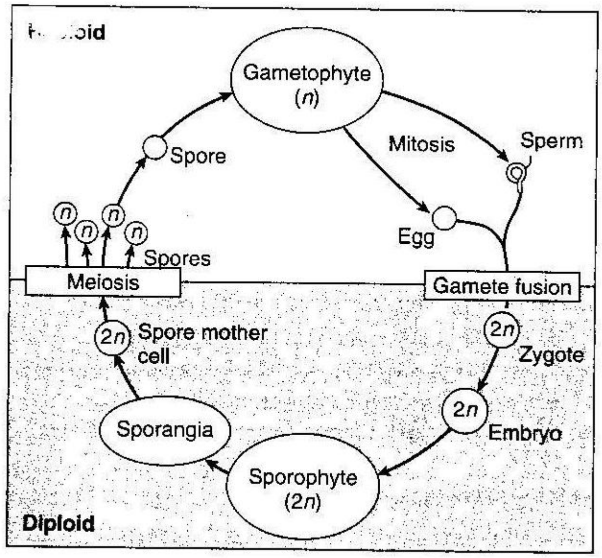


FIGURE 5.4 Alternation of Generations, Plants The life cycles of plants are different from ours and those of all animals. Animals are diploid ($2n$) and the only haploid (n) stage is found in their eggs and sperm. In plants, diploid individuals (sporophytes) alternate with haploid individuals (gametophytes), although the prominence of each might be quite different in different groups of plants.

Plant Diversity

The transition from green algae to plants—from water to land—may have been an easy one. Even today, many green algae live in shallow water around the edges of lakes and ponds, areas subjected to occasional drying. If plants adapted to such drying, then the colonization of land required only an extension of the time exposed to air until the transition became permanent.

Estimates of the time of this transition recently were pushed back. Fossils speak to the presence of plants at about 450 million years ago. However, extrapolating back from molecular changes in current plants, the much deeper date of 700 million years ago is now tentatively proposed for the transition to land plants (see figure 5.1).

Bryophytes (mosses). Some of the earliest land plants were the *bryophytes*, mosses being the most common example (figure 5.5). Mosses mostly lack both vascular tissue and true roots for water and nutrient transport. They thrive in damp, shady places, although they can withstand prolonged periods of drought. They also lack lignin to strengthen their cell walls, keeping them short and low to the ground. Mosses are common in near-polar regions, forming great ground-covering mats.

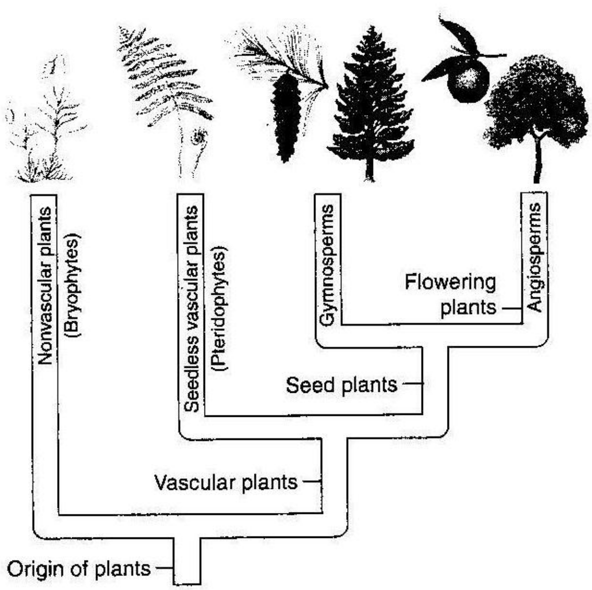


FIGURE 5.5 Plant Evolution The major groups of plants are shown. Note that adaptive transitions evolved at different points: water to land from ancestral green algae (not shown); nonvascular to vascular; seedless to seed; flowers.

Pteridophytes (ferns). Ferns are the most abundant member of the *pteridophytes* (ter.rid.o-fites), which also include the horsetails and the much lesser known club "mosses," not to be confused with true mosses, which are properly members of the bryophytes (figure 5.5). Fossils mark the presence of ferns at 350 million years ago (Devonian period). Ferns are characterized by an underground specialized stem, the *rhizome*, which is equipped with short roots. The leaves are aerial *fronds* that unfurl from coiled-up, young leaves ("fiddleheads") at the tip of the rhizome. No seeds are produced, but ferns show alternation of generations. Spores are produced in clusters on the underside of the mature frond (sporophyte individual). After meiosis, the shed spores (now haploid) produce a small, heart-shaped form (gametophyte individual) that produces eggs and sperm, which, following fertilization, grow directly into the rhizome and fronds of the young fern.

Pteridophytes are vascular plants. During the mid to late Paleozoic, they became predominant, forming great forests in tropical regions. With lignin-reinforced cell walls and added support from the vascular tissue, some reached great heights. Distant relatives of the club mosses produced giant woody trees more than 120 feet (40 m) tall. One period of the Paleozoic era was especially favorable to coal formation and was named, in recognition of this, the Carboniferous. In this period, the dead plants did not completely decay in waters of tropical swamps. Instead, their organic debris accumulated, forming peat, as occurs today in peat bogs. Later, when the peat was inundated and covered by overriding marine seas and sediments, the heat and pressure converted the peat into coal. These great coal deposits literally fueled the Industrial Revolution of the nineteenth and twentieth centuries.

The *seed plants* are vascular plants that include the gymnosperms (e.g., conifers) and angiosperms (flowering plants). They introduce new innovations especially suited to address the problems of terrestrial life. One innovation is the seed, a protective case for the young plant embryo; the other innovation is pollen, a hardy transport package for sperm. Specifically, a **seed** is a small capsule composed of a protective *seed coat*, the *plant embryo*, and a supply of *nutrients* to support the young plant up until it germinates. Seedless plants, such as mosses and ferns, produce resistant spores that can develop into new organisms. Spores survive extremes of temperature and moisture to which mosses and fern plants themselves might succumb. The seed represents a different solution to environmental challenges. The seed is a protective package in which the tiny plant embryo develops and is sheltered.

The other innovation of seed plants is **pollen**. A pollen grain is a much-reduced male gametophyte, composed of just a few cells. Transported to the female, some of these cells develop into sperm, which eventually reach eggs of the female plant, resulting in fertilization. Pollen grains are resistant to extremes of temperature and moisture, a further adaptation to reproduction in a terrestrial environment.

Gymnosperms (Conifers, allies). The earliest of the seed plants to evolve are the *gymnosperms*. They are present in the Carboniferous along with the then more abundant seedless plants. By the end of the Carboniferous, the climate began to dry, most swamps disappeared, and the gymnosperms began a rise to prominence. The most common among them today are the *conifers*—cone-bearing trees—including pine, fir, redwood, spruce, cedar, and juniper. The conifer tree is a sporophyte with the tiny, much-reduced gametophyte living in the cones. The cones are made up of specialized, compacted leaves called *scales*. In female cones, the scales protect the **ovule**, in which the tiny female gametophyte develops forming eggs. In male cones, the male gametophyte produces pollen grains that hold sperm. Pollen grains are usually carried on the wind to the ovule. The successful trip from male to female is termed **pollination**. When the pollen enters the ovule, the pollen discharges sperm that fertilize the eggs.

Following fertilization, the ovule develops into the seed, including the protective coats, food supply, and young plant embryo within. Released from the cone, the seed, often attached to a propeller-like extension, may be carried by the wind a long distance and survive for months or years until favorable conditions promote germination. The food supply enclosed in the seed sustains the young sprout until it can set roots and begin photosynthesis.

Angiosperms (Flowering plants). The **angiosperms** are also vascular seed plants. They debuted after gymnosperms during the mid Mesozoic, but came into prominence during the late part of the Mesozoic. Today, the gymnosperms supply us with lumber and paper; the angiosperms supply us with most of our plant foods—cereal grains (wheat, barley, oats, corn) and fruits (apples, berries, oranges, and the like). Flowers distinguish angiosperms from all other plants and advertise their sex organs for all to see. The flower is derived, in part, from modified leaves (figure 5.6). During the reproductive season, flowers open to surround and protect

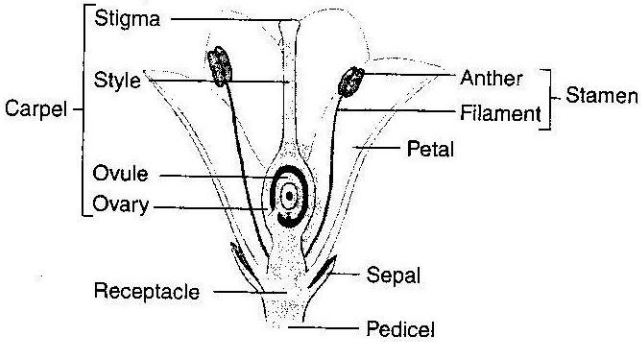


FIGURE 5.6 Flower Structure The female structures (carpel) and male structures (stamen) are shown. Note the ovule within the ovary of the female.

the reproductive organs of the plant—stamen and carpel (pistil)—and often to catch the attention of animals, the **pollinators** (sometimes called animal vectors) that are attracted to these plant parts. Pollen is produced in the anther, the male part of the flower that is perched atop the thin filament (figures 5.6 and 5.7). Pollen grains (male gametophyte) are carried or transported by pollinators, by wind, or sometimes by water and gravity, to other flowers where they settle on the sticky tip of the female stigma; sperm travel down the style into the ovule, which holds the female gametophyte, and fertilize the eggs within (figure 5.7). Oddly, a second fertilization occurs, a feature unique to angiosperms. A second sperm fertilizes another female cell, which develops not into an embryo, like the first, but into the *endosperm*—the nutrient tissue that provides food for the young embryo. Some plants may *self-fertilize* (fertilization of one plant by its own pollen); others *cross-fertilize* (fertilization of one plant by pollen from a different plant).

The swollen base of the carpel is the **ovary**, a protective chamber that may hold one to hundreds of ovules. Following fertilization, the ovary ripens into a *fruit*, enclosing the seeds derived from the ovule or ovules. The fruit surface often develops structures that help the seeds disperse. The fluffy parachute of dandelion seeds helps in their wind-borne journeys; the burrs or prickly processes of some seeds help them catch on the fur or feathers of passing animals. The fruit may be fleshy, as in apples, peaches, and cherries, or dry, as is the pod of a soybean. A single flower with multiple carpels produces an aggregate fruit, such as a blackberry. A pineapple, like some other angiosperms, forms from an *inflorescence*, a tightly packed group of multiple flowers that fuse together to form the single fruit.

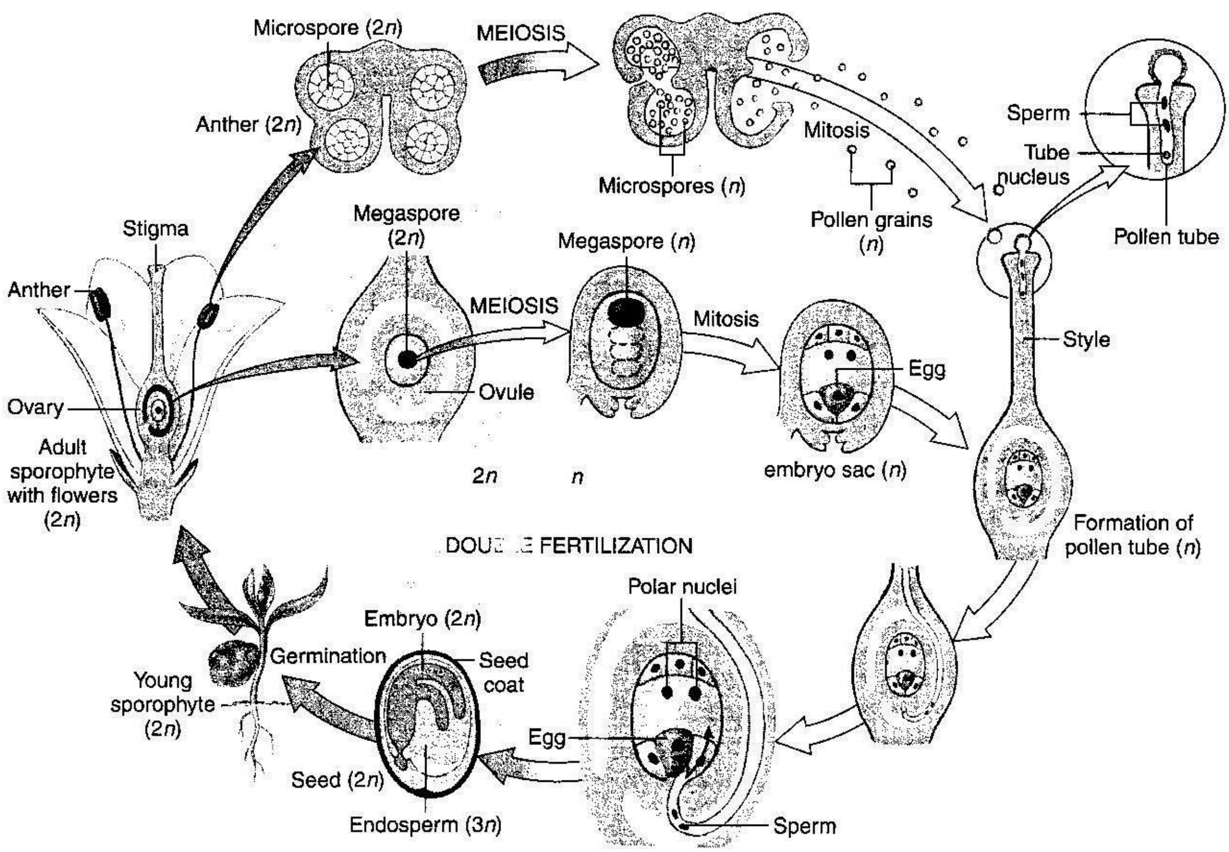


FIGURE 5.7 Angiosperm Life Cycle Animal vectors often carry pollen to the carpel. The pollen grains contain generative cells that produce the sperm and, after alighting on the stigma, travel down and within the growing pollen tube to reach the ovule and its eggs. There, sperm fertilize the egg, producing an embryo, and fertilize other cells, producing endosperm. Specifically, in the male anther, diploid spores develop (microspores, 2*n*), which after meiosis develop into pollen grains (*n*) that reach the female part of a flower and grow down to and into the ovule in a pollen tube. In the female, diploid spores develop (megaspore, 2*n*), which after meiosis develop into an egg within the embryo sac. An arriving sperm fertilizes the egg, which develops into the plant embryo (2*n*); other sperm join with the polar nuclei to produce the nutritive endosperm (3*n*).

Fungi

The fungi are not plants. In place of cellulose, the cell walls of fungi are built of chitin, a tough, nitrogen-containing polysaccharide (chain of sugars). Fungi have no chlorophyll and do not photosynthesize. Instead, fungi absorb nutrients from the substrate to which they are attached—old logs, moist ground, damp bark. They secrete digestive enzymes into the substrate, then soak up the organic molecules released. This makes fungi, along with various bacteria, the principal decomposers in forests. As decomposers, fungi feed on the dead bodies of other organisms, breaking them down and eventually returning nitrogen, carbon, and other elements to the soil where they become available for recycling to plants and animals.

Truffles, morels, and yeasts are fungi. Mushrooms, with their familiar umbrella-like tops, are the temporary reproductive structures. Fungi are made up of thin, long filaments called **hyphae** (figure 5.8). The tubular walls of the hyphae are composed of chitin and other polysaccharides, which enclose the fungal cells. Within these walls, the cytoplasm flows freely, carrying along nutrients to the far-flung parts of the fungus. Bundles of hyphae form the body of the fungus and expand into the specialized reproductive structure, the *fruiting body*. The mass of hyphae permeating the soil, wood, or other substrate is the *mycelium* (figure 5.8), which is the feeding network of a fungus.

Consider This—

Fungus among Us

The state of Oregon currently holds the record for the world's largest single organism. It is a fungus. The interwoven mycelium of this fungus spreads over 2,200 acres (about 1,660 football fields), is 3.4 miles in diameter, and weighs collectively several tons. It is pathogenic, infecting primarily coniferous forests, where it has been lodged and growing for an estimated 2,400 years. Similar, but smaller, great disks of this fungus are known from other forested regions as well. The girth and heft of this fungus qualify it as the Earth's largest known organism.

Fungi can be parasitic and destructive. The American elm tree has been almost eliminated by fungus infections across North America. Agricultural products are susceptible to rusts, fungi that attack seeds of rye, wheat, and oats. The skin disease ringworm is caused not by an animal worm, but by a fungus, as is itching athlete's foot. Fungi (and some bacteria) produce what we call "rot." A wood-digesting fungus does not distinguish between blown-down oak tree trunks and oak tree planks in a wooden ship. Fungal rot was often more of a problem to wooden warships than enemy cannon fire. Molds are odd types of fungi that appear on unattended bread, fruits, and other foods. In moist regions, canvas tents, clothing, leather boots, and even shower curtains support growths of molds.

Some fungi form cooperative associations with green algae, producing **lichens**. The fungal hyphae embrace and supply the algae with a favorable surrounding of moisture and nutrients; the photosynthetic algae return organic compounds to the fungi. Fungi also form beneficial associations with the roots of plants. Such root-fungus combinations are *mycorrhizae*. The root supplies sugars to the fungi; the fungi facilitate transfer of essential minerals from the soil to the roots.

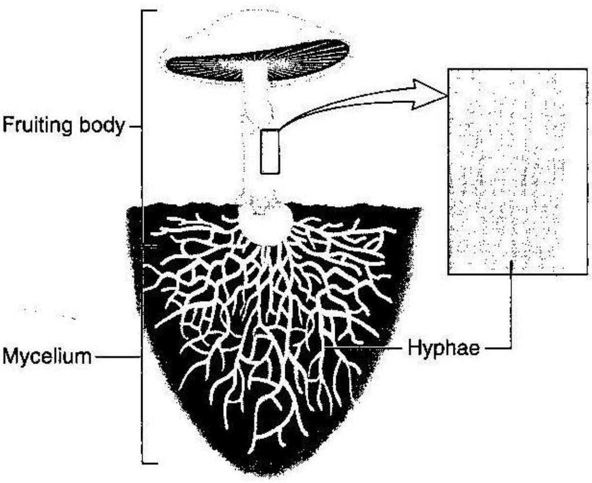


FIGURE 5.8 Fungus Filamentous hyphae produce a feeding mat, the mycelium, that permeates the food source. The hyphae typically continue aboveground as a reproductive structure, the fruiting body.

Animals

Animals meet their metabolic needs by eating other organisms. If they eat plants, they are **herbivores** or **phytophages** (*phyto-*, plant; *-phage*, eat); if they eat each other, they are **carnivores**. This survival strategy—ingestion—sets animals apart from plants, which photosynthesize, and from fungi, which absorb. The cells of animals lack the supportive cellulose cell walls of plants, so animals depend for support upon the buoyancy of water or upon specialized skeletons. Animals also move under their own power, not just when buffeted about by a breeze.

Animals arose from protists, although the specifics still elude us. The likely ancestor of animals was a single-celled *choanoflagellate* that lived in clumps or colonies. These microscopic cells came equipped with flagella, long whiplike processes that can whirl about, imparting motion to the cell, or draw in currents of food-bearing water. These animal ancestors were heterotrophs, a fundamental characteristic upon which animal descendants are based. As in most other organisms, both sexual and asexual reproduction are found in animals. *Sexual reproduction* is based on the fusion of gametes, wherein haploid egg and sperm unite; *asexual reproduction* involves budding where diploid cells proliferate (see Appendix 1). Animals that reproduce sexually pass through a **life cycle**, typically beginning with fertilized *eggs*, which grow into *larvae* or *juveniles* (sexually immature stage), which become *adults* (sexually mature stage).

Sponges (parazoa)

The simplest of the animals are the sponges. Connected needlelike spicules provide support to the body, which is **sessile**— attached to a secure aquatic substrate. Like most marine animals, sponges pass through a larval stage that is **planktonic**, free and unattached, carried about by tides and currents. A few sponges live in fresh water; most are marine. The bodies surround an internal cavity lined by flagellated cells, reminiscent of their protist ancestry. Some have tubular bodies, but most sponges are *asymmetrical*, lacking defined shape and instead conforming to rock shape or local space. This lack of symmetry sets them apart from all other animals, providing them with their alternative name, **parazoa** (beside animals). All other animals make up the **eumetazoa** ("true" animals), exhibiting well-defined body symmetry (figure 5.9).

Eumetazoa

Radiata. Jellyfishes, corals, and sea anemones are the most common examples of cnidarians, an almost exclusively marine group. The name *cnidaria* means "nettles," a reference to the *stinging cells* (cnidocytes) that cover their bodies and are especially abundant on feeding tentacles. When making contact with food or foe, these cells discharge, lashing through the victim's skin with threads laced with toxins. An unwary swimmer brushing against a jellyfish receives the same treatment, coming away with a "burning" sensation—a reaction to these toxins. Corals are important reef animals, as they secrete a calcium base on which they reside. Found in tropical waters, these are the protective coral reefs that encircle small islands, raise physical barriers that buffer strong wave action, and create a complex environment upon which other reef animals and plants depend.

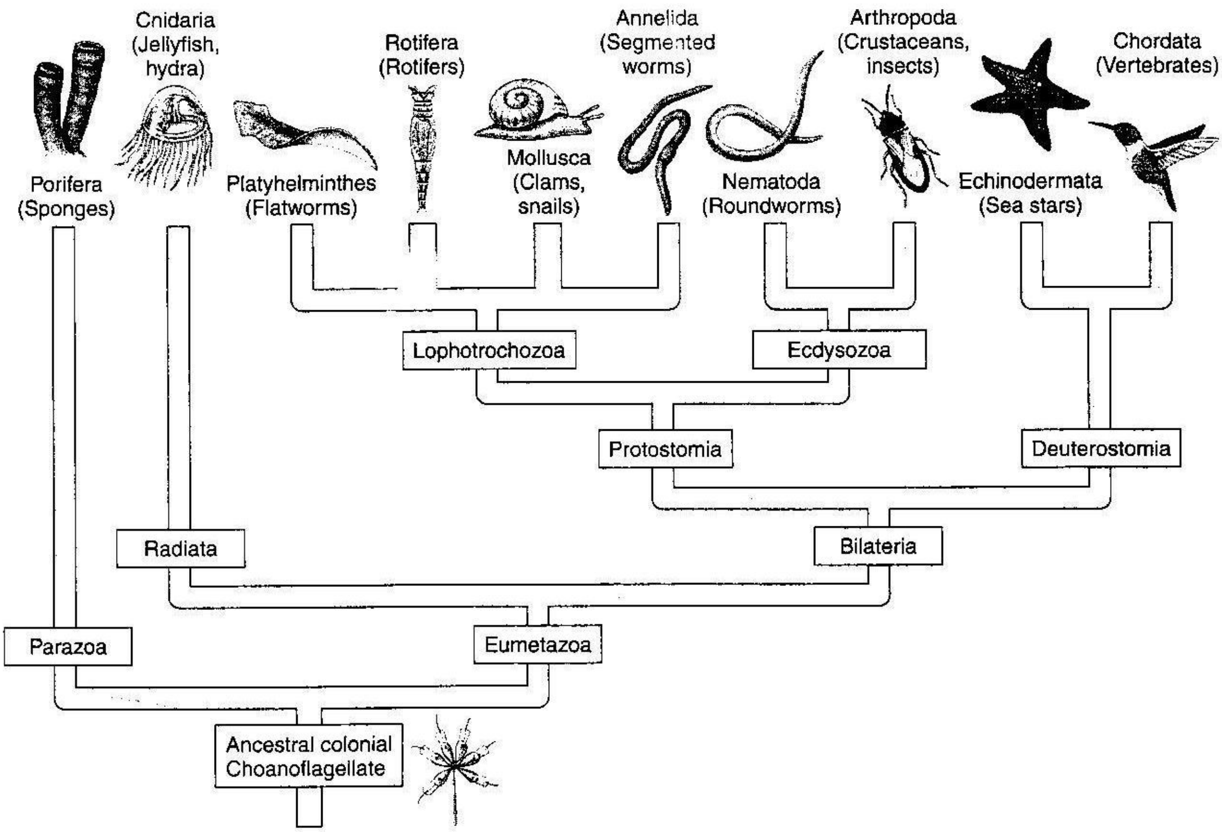


FIGURE 5.9 Animal Evolution The major groups are shown. After sponges (Parazoa) diverge, leaving all other animals (Eumetazoa), differences in symmetry reveal two groups (Radiata, Bilateria). Embryonic differences within the Bilateria are diagnostic for the Protostomia and Deuterostomia. The subgroups of protostomes are the Ecdysozoa and Lophotrochozoa. Within the deuterostomes occur the chordates, where we as vertebrates are placed. These divisions are based on molecular similarities with anatomical correlations.

Bilateria. Cnidarian body symmetry is *radial*, meaning that a central axis can be found around which all the rest of the body is equally arranged. All other eumetazoans are characterized by a body symmetry that is *bilateral*, meaning that they can be divided into left and right halves—mirror images. Most bilateral animals also have a definite front end (anterior), back end (posterior), top (dorsal), and bottom (ventral) (figure 5.10a,b). The bilateral animals divide into two major groups, originally defined by two distinctive types of embryonic development (figure 5.10 c,d). One group is the **protostomia** and the other, which evolved late in the Precambrian, is the **deuterostomia.**

The protostomia are made up of two sublineages: the lophotrochozoa and the ecdysozoa (see figure 5.9).

Protostomia—Lophotrochozoa. The **lophotrchozoa** take their name from a lophophore, a specialized crown of feeding tentacles, characteristic of many. Some of the most important amongst them are the following:

Flatworms (platyhelminthes). The flatworm body is compressed and ribbonlike. Some are **free-living**, moving about in the environment; others are **parasitic**, living within an animal host. Planarians are free-living forms that glide about on cilia that cover their ventral surfaces. Parasitic forms include liver flukes and tapeworms. Tapeworms are *segmented*, wherein body sections are repeated to produce the long adult.

Roundworms (nematodes). Roundworms are unsegmented and their bodies are round in cross section.

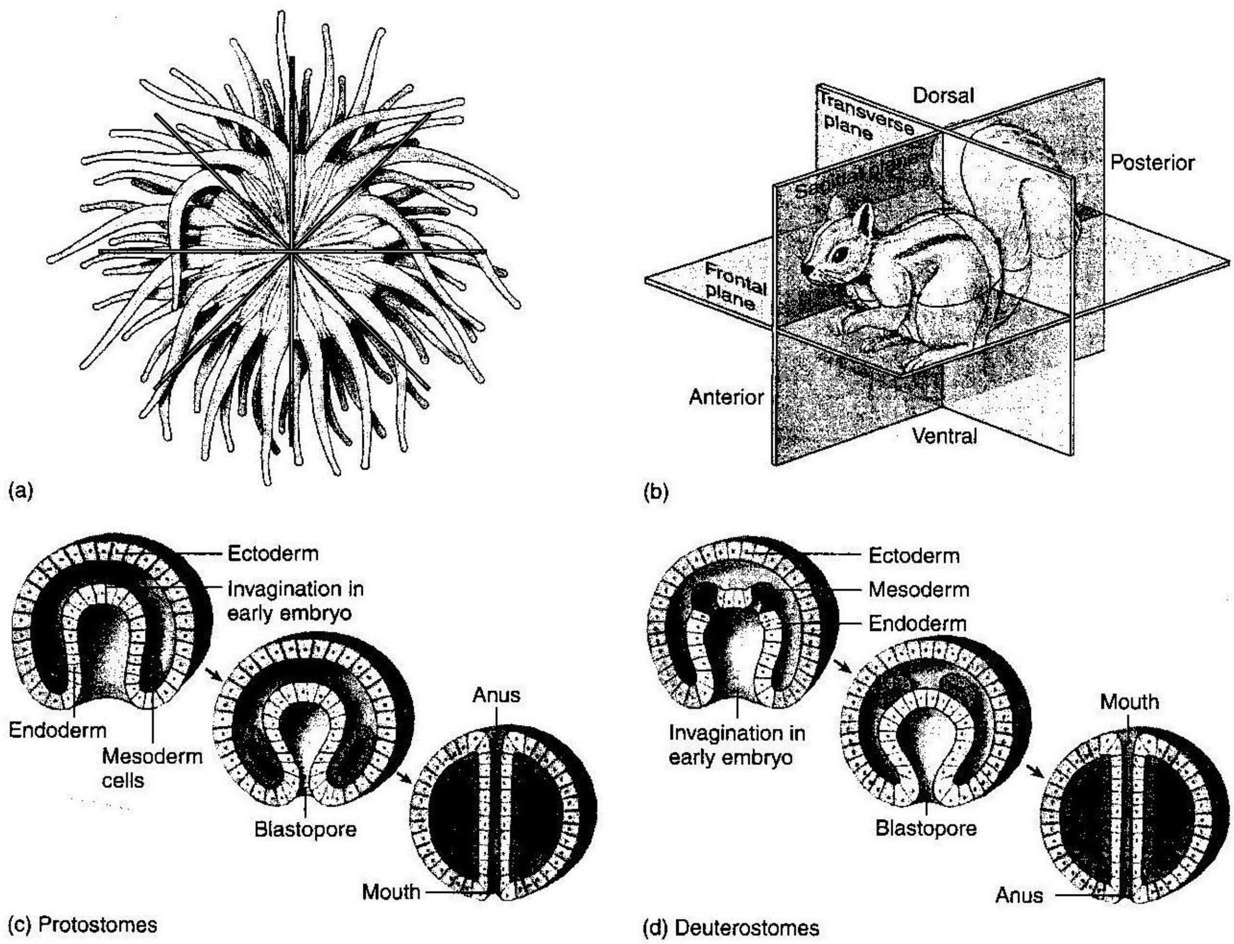


FIGURE 5.10 Animal Themes and Designs *Symmetry.* (a) Radial symmetry, illustrated by a sea anemone. (b) Bilateral symmetry, illustrated by a squirrel. Other planes of symmetry are also recognized. *Embryonic development.* (c) Embryonic development of protostomes, wherein the embryonic blastopore becomes the mouth of the adult. (d) In deuterostomes, the opposite occurs, and the blastopore becomes the anus. In both patterns, the basic embryonic body layers—ectoderm, mesoderm, and endoderm—are laid down as well. These generally give rise primarily to the adult skin, muscles and blood vessels, and gut, respectively.

They are one of the most abundant animal groups, occupying land and water in tropical to subarctic habitats. Some are parasitic, such as pinworms, hookworms, and *Ascaris*, which is especially common in farm animals.

Annelids. The common earthworm is an annelid, exhibiting the basic segmental body plan of the group. As they burrow, earthworms feed on and pass soil through their bodies, digesting the organic material it contains and leaving the indigestible material in castings (feces). Leeches are also annelids, feeding on aquatic insects or more often attaching to a passing animal and dining on its blood.

Mollusks. Many soft-bodied mollusks possess a shell or hard case into which they can withdraw. Some burrowing forms, such as clams, have a pair of closing shells. Others, such as snails, carry about a single shell for easy retreat. Others are active predators, with a reduced shell, tentacles with suckers that reach out to grasp prey, and a pair of large, keen eyes; these include the squid and octopus.

Protostomia—Ecdysozoa. The **ecdysozoa** take their name from the characteristic **molting** *(ecdysis)* wherein the growing animal sheds its external skeleton and grows a new one. The most important amongst them are the following:

Arthropods. By far, arthropods (*arthro-*, jointed; *pods*, legged) are the largest group of animals, an estimated 10 million species and still counting. They are segmental animals, with an **exoskeleton**—an external skeleton made of a tough, nitrogen-containing sugar, *chitin*. The exoskeleton is jointed, making movement possible. The exoskeleton also serves as protective armor against assaults by predators and abrasion from the environment. One of the oldest arthropods, the *trilobites*, arose in the late Precambrian. They occupied shallow marine seas, lasted throughout the subsequent almost 300 million years, and then perished, along with many other groups, during the mysterious mass extinctions at the end of the Paleozoic. The *arachnids* include the daddy longlegs, mites, ticks, scorpions, and spiders. The *crustaceans* are the crabs, lobsters, and shrimps.

By far, the largest group of arthropods is the *insects* (uniramians), most of which are winged arthropods. Half of all named animal species are insects. Their varied and diverse lifestyles place them on almost every continent, moving through complex life cycles. Generally, the larva is a feeding stage, the adult a dispersal stage. Aphids to zygoptera (damselflies), butterflies to beetles are included.

Deuterostomia. The deuterostomia include the echinoderms and chordates (figure 5.9). The echinoderms include starfishes and allies; the chordates include several small groups and one very central group, the vertebrates—which includes us, human beings.

Echinoderms. Besides starfish (sea stars), echinoderms include the sea urchins, sand dollars, brittle stars, sea cucumbers, and ancient crinoids. As larvae, echinoderms are bilateral in symmetry. As adults, they are five-armed or some derivative thereof and move along with sweeps of their arms or on the synchronized motion of tube feet (tiny suction cups on extending processes). At face value, echinoderms are unlikely taxonomic companions to the chordates. But their similar embryology and chemical structure make the connection undeniable.

Chordates. Included in the chordates are several unfamiliar groups such as sea squirts and amphioxus, but also a group central to our story, the **vertebrates**. The vertebrates include various groups of fishes, plus amphibians, reptiles, birds, and mammals. Bone tends to replace soft supportive tissues, and it leaves traces in the fossil record. A stiffening rod, the *notochord*, runs down the long axis of the body of chordates. Against its action, segmental blocks of muscle act to impart side-to-side swimming motions. Within many vertebrates, the notochord is replaced by a chain of bony or cartilage blocks, the *vertebrae*, collectively the vertebral column or "backbone." This vertebral column, from which the group takes its name, functionally forms part of an **endoskeleton**, an internal skeleton.

Upon the vertebrate body plan, a great many and diverse groups evolved (figure 5.11). The earliest vertebrates were the *jawless fishes*, including the now extinct *ostracoderms*, which were encased in protective bony armor, and their modern descendants such as *lampreys*, which lack bone and today are restricted to specialized, scavenging or parasitic lifestyles (figure 5.12). Jaws are the bony or cartilaginous supports that rim the mouth. Two early groups first to possess jaws were the *placoderms* and the *acanthodians*. Both groups are extinct, but in their time they commanded a formidable oceanic, predaceous lifestyle, guided by simple forms of paired fins. Major fish groups followed, such as the *cartilaginous fishes* (chondrichthyes) and *bony fishes* (osteichthyes). The skeleton of cartilaginous fishes is just that, cartilage, the same material that gives your ear and nose tip flexibility. Sharks and their allies have skeletons made of such material. The bony fish have extensive skeletons of bone. Today, this is the largest single group of verte-

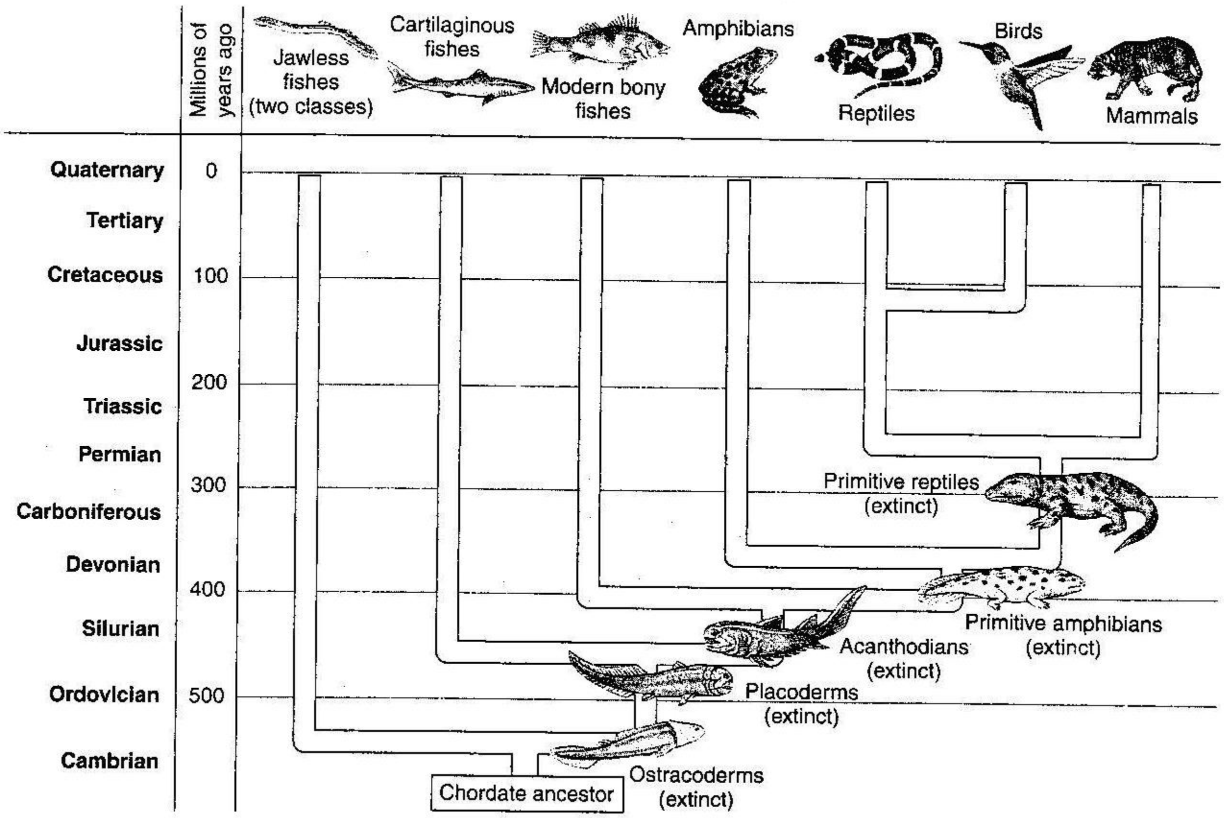


FIGURE 5.11 Vertebrate Evolution Within the chordates (see figure 5.9), the vertebrates arise from a primitive chordate ancestor. Notice the sequence of appearance; first, various fishes; then amphibians, reptiles, and mammals. Birds evolve within the reptile radiation.

brates and includes most fishes, from those seen in pet shops to tuna, trout, and many others. The *amphibians* were the first vertebrates to employ limbs, and therefore the first **tetrapods**. Arising later within the tetrapods were the reptiles, birds, and mammals. *Tetrapod* means literally "four" *(tetra-)* "footed" *(pod)*, but is understood to be a taxonomic term, not an anatomical descriptor—legless forms, such as snakes (reptile), and finned forms, such as whales (mammal), are included.

Today the amphibians include salamanders and frogs as well as a legless, burrowing group, the caecilians. Adult amphibians often venture onto land, although a moist location, a stream or pond, is usually close by. To breed, most amphibians return to water, where eggs are laid, fertilization occurs, and embryos then typically develop into small aquatic larvae or tadpoles. These larvae feed and mature, eventually undergoing a rapid and radical anatomical change—**metamorphosis**—turning them from larvae into juveniles. In most adult amphibians the gills of their fish ancestors are lost, but they still gather oxygen from the air in lungs or oxygen diffuses directly across the moist skin and is picked up by surface blood vessels. Evolving from amphibians were the **amniotes**, including reptiles, birds, and mammals (figure 5.13). Vertebrates that came before—amphibians and all fishes—are **anamniotes** (*an-*, without; -*amnion*, an amnion) because their embryos are not wrapped in the specialized embryonic amnion.

The collective name *amniotes* is taken from an embryonic innovation. The eggs of anamniotes are typically laid in water and hatched there. The invention of the shelled (cleidoic) egg emancipated the embryos from bodies of water. The amniote embryo is wrapped immediately in a thin membrane—the **amnion**—which floats the young animal in a protective jacket of water. In a sense, amniote embryos carry the water environment with them onto land. The embryo and its enveloping amnion,

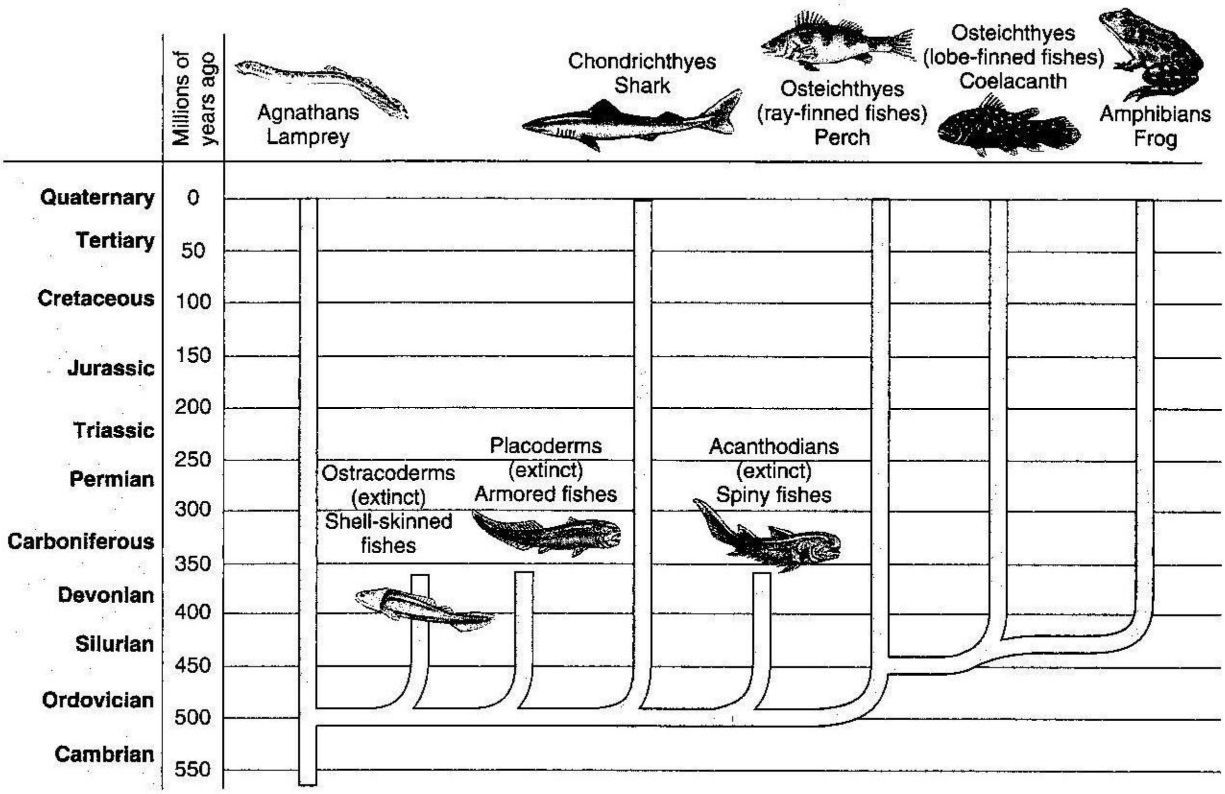


FIGURE 5.12 Evolution of Fishes Many early fish groups are now extinct, such as the ostracoderms, placoderms, and acanthodians. Amphibians, represented by the specialized frog, arose during the Devonian from a special group of bony fishes, the lobe-finned fishes, illustrated by the coelacanth.

plus any food reserves, are packaged in a leathery shell (reptiles, monotremes) or in a brittle shell (birds), altogether called the **cleidoic egg** (figure 5.14).

Radiation of the amniotes produced some of the best known and most dramatic of all the vertebrates (see figure 5.13). One lineage, *sauropsids*, produced the familiar *reptiles*—snakes, lizards, turtles, crocodiles—but also the extinct plesiosaurs, ichthyosaurs, flying pterosaurs, and, of course, the "dinosaurs." All have scaly skin and a suite of common anatomical features. Most lay eggs, but some are live-bearing. Notice that appearing within this sauropsid lineage are the *birds* (Aves), part of this radiation (see figure 5.13). Strictly speaking, birds are a specialized type of reptile, "reptiles with feathers." All birds lay eggs and are covered with feathers, used also for flight. The other great lineage of amniotes is the *synapsids*. The *mammals* evolved within this lineage. Mammals share unique anatomical similarities of internal structure, but they are characterized by a coat of hair, not scales or feathers, and females nurse their young from milk glands—mammary glands. Today, there are three living groups of mammals (figure 5.15). The smallest group is the *monotremes*, the duckbilled platypus being an example. Representatives are found today in Australia, Tasmania, and limited parts of New Guinea. Monotremes are mammals (hair, lactation), but they lay eggs incubated and hatched outside the body of the female. The *marsupials* are the pouched mammals—kangaroos, koalas, opossums, and their allies. Young are born at a very early age (no cleidoic egg) and then migrate into the female's pouch, where they find and nurse from mammary glands until they grow to a large size. Most marsupials live today in Australia, but some biologists place their center of origin in North or South America from whence they spread to current locations. The *placental mammals* are the largest group of mammals, worldwide in distribution. Neither eggs nor early birth characterized their reproduction. Instead, tissues of the fetus (young embryo) cooperate with specialized tissues along the inside wall of the female uterus ("womb"). These specialized fetal-maternal tissues

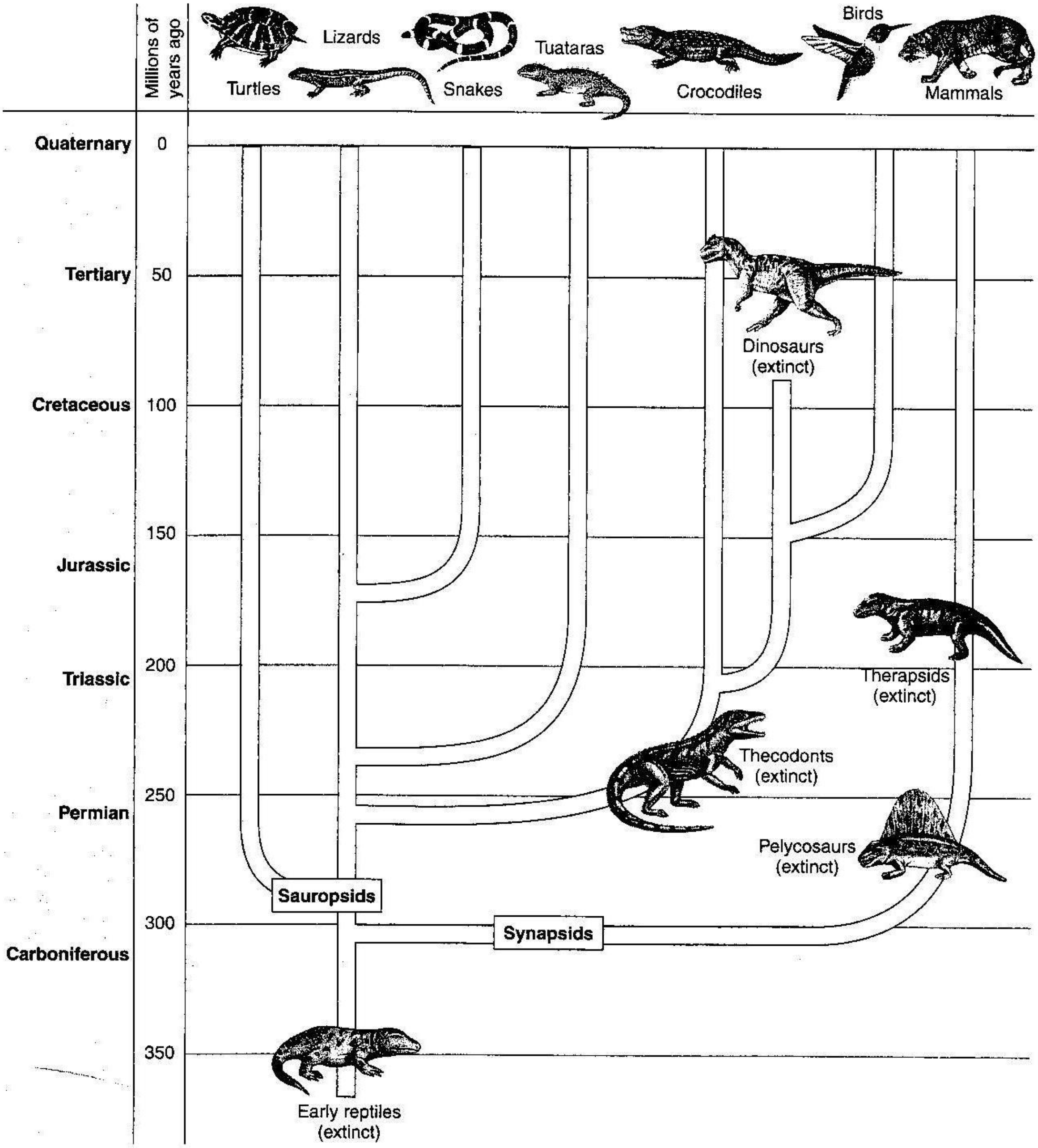
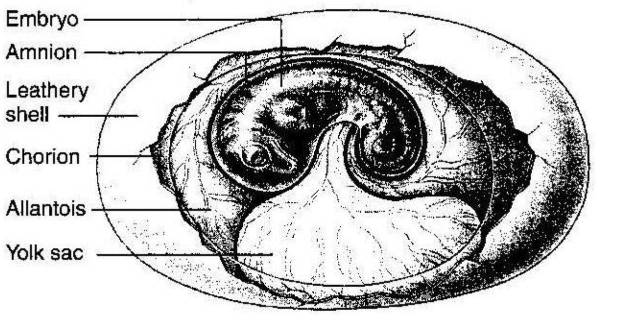


FIGURE 5.13 Evolution of Amniotes Primitive reptiles were the first amniotes arising from amphibian ancestors (not shown). From these early reptiles arose all later groups, the sauropsids and synapsids. Within the synapsid lineage, mammals arose. Within the sauropsid lineage, great diversity occurred, including modern groups of reptiles and birds, as well as the extinct dinosaurs.

form a **placenta**, connected by major blood vessels traveling to and from the fetus as the *umbilical cord.* The placenta passes oxygen and nutrients from the mother's blood to the fetus and fetal CO_2 to the mother for elimination. At birth, the placenta detaches and, along with its umbilical cord, is passed out along with

FIGURE 5.14 Cleidoic Egg Sometimes called an "amniotic egg," the cleidoic egg includes the embryo floated in a water jacket formed from a thin membrane, the amnion, and several other embryonic membranes. One is the chorion, just under the outer shell, which serves respiration. The other, the yolk sac, contains energy-rich yolk upon which the embryo draws to meet its nutritional and growth needs. All is wrapped in a leathery (reptiles, monotremes) or hard (birds) shell.



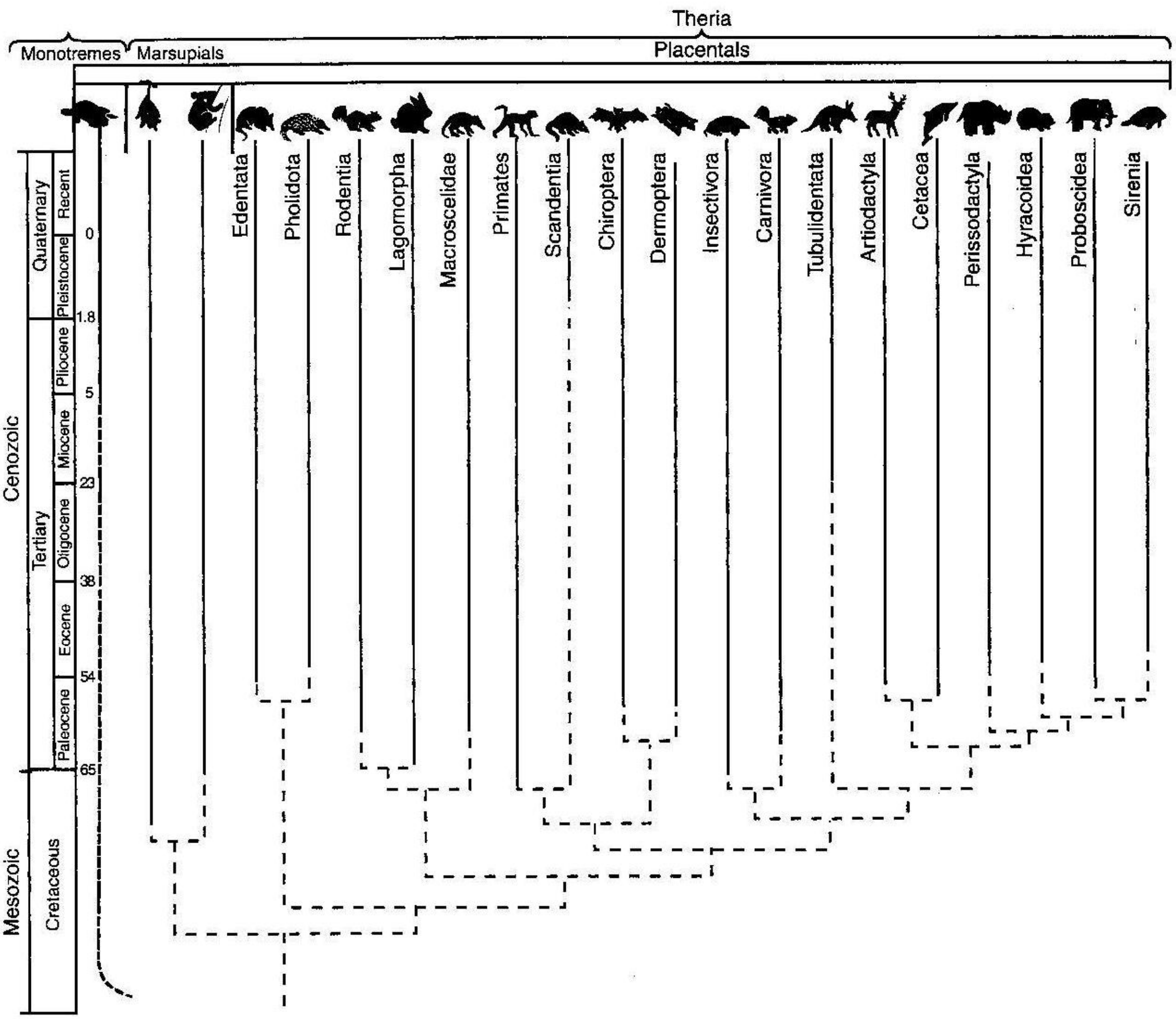


FIGURE 5.15 Living Mammals Today, mammals form three groups: monotremes, marsupials, and the largest, the placentals. The marsupials and placental mammals are sometimes placed together in the Theria, and living monotremes plus allied fossil forms in the Prototheria (not indicated).

the newborn infant mammal. All placental mammals support their growing fetus by means of a placenta, but this reproductive device is not unique to them. Placentas have been independently invented in other groups such as some lizards, some snakes, and even in a few amphibians and fishes.

ENVIRONMENT

All organisms live in an **environment**—the external world where they reside, find food, contend with foes, attract mates, elude predators, and deal with harsh climates. Here they will survive or not; here they will breed or not. It is not their characters standing in splendid isolation that determine their success, but their characters measured against the challenges of the environment. Interaction is the word—interaction between an organism and its immediate environment. The future success of an organism cannot be determined in isolation. Adaptations are not independent features living alone. All must serve, and serve well, within the environment where the organism lives. Yet environments are different, so organisms are different.

Globally, organisms live in warm *tropical* regions; adjacent *subtropical* regions; *temperate* regions; and, at the poles, extreme *polar* regions. These regions lie, generally, from the equator (tropical) to the poles (polar). The position within latitude, equator to poles, affects the character of the environment, determining the seasons and thus day length, heat/cold, and weather. In temperate regions, the year passes between warm summers and cold winters. Tropical regions lack such extreme swings in temperature but often experience extremes of moisture alternating between wet and dry seasons. Local conditions of geography, such as mountain ranges, lakes, and nearby bodies of water, affect these latitudinal caprices of climate, producing *biomes*—distinctive *ecosystems* with distinct local communities of plants and animals adapted to the particular climatic conditions. A desert ecosystem would be one example; African savannas would be another. Where oceans wash up against the land, they support *intertidal communities.* The pull of the moon's gravity sloshes the marine waters about within their large oceanic basins. Their characteristic maximum flooding up the beach during the day marks the *high tide* level; their maximum retreat the *low tide* level. Tidal patterns depend upon the size of the ocean basin and shape of the continental coastline, so tidal ebb and flow varies around the world. The consequence for marine animals living within an intertidal zone is that they are successively exposed to drying air and direct exposure to the sun as water retreats, and re-immersed when the tide returns. Dense water filters the penetrating light. The level penetrated, and thus made available for photosynthesis, is the **photic zone**; below that, where significant light does not reach, is the **aphotic zone**.

All life on Earth depends eventually on the sun. The *producers* (cyanobacteria, algae, and plants) harvest light energy in photosynthesis. Producers use this energy, along with carbon dioxide and water, to grow and proliferate. Producers are consumed by *herbivores*, which are in turn eaten by *carnivores*. The *decomposers* (bacteria, fungi) break down dead organisms, thereby returning nutrients to the soil or water, where they are again gathered up by producers and reincorporated into the tissues of living organisms.

As once succinctly put by the ecologist Eugene Odum, an organism's **habitat** is its ecological address; its **niche** is its ecological profession. The habitat is where it lives; the niche is how it lives. The habitat is an organism's specific site of residence within the environment. The niche includes the organism's sum total of immediate available resources within the environment—food, predators, mates, temperature, humidity, living space, sunlight, wind chill, soil properties, and other factors. How it utilizes these resources defines its profession, its niche. The full range of available resources that could be used describes the **fundamental niche**; what the organism actually uses is its **realized niche**. Both concepts—habitat and niche—are useful when we think about the diversity, abundance, and distribution of species. Habitat loss or habitat recovery helps us understand species loss or return; if resources are available, but no species is present, we can speak of an "empty niche" and look for the reasons why it is empty.

When two organisms attempt to use the same limited resource, they enter into **competition**—specifically, *inter*specific competition if the organisms belong to different species, *intra*specific competition if to the same species. During the fall rutting season, persons venturing into the northern woods may hear male moose trumpeting with other male moose; racks of antlers may lock in combat. But more often, a trip into the wild is not attended by the sounds of conflict and competition. You don't usually hear the sounds of beasts going at it red in tooth and claw. You don't hear the rending of tissue, gnashing of teeth, or the sound of limbs being torn from sockets. Competition can occur quietly.

For example, two species of intertidal barnacles, if occurring separately, reach their fundamental niches (figure 5.16). The high tidal areas are the first areas exposed as the tide retreats and the last areas covered when it returns. Consequently, the high tidal area is especially dry (exposed to air) and hot (exposed directly to sunlight). The barnacle *Semibalanus* is susceptible to heat and desiccation, so it reaches no higher than mid-tide; *Chthamalus*, tolerant of drying,

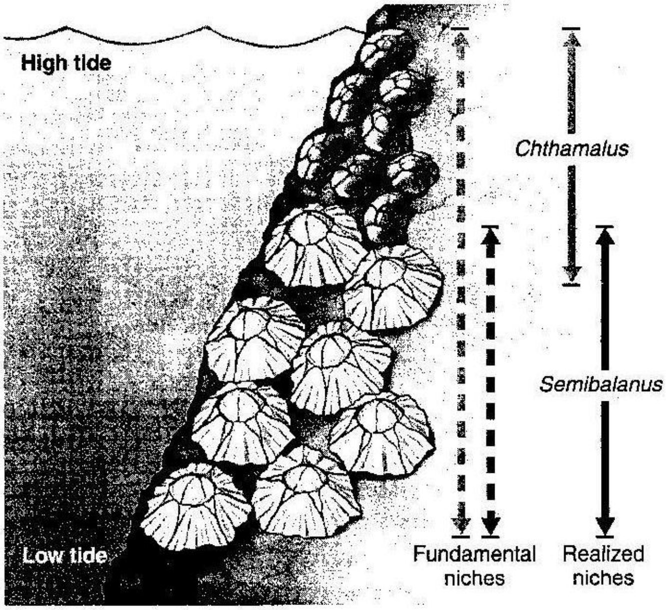


FIGURE 5.16 Competition Among Barnacles In the absence of competition, *Chthamalus* lives in low- to high-tide regions. *Semibalanus* lives in low- to mid-tide regions. These are their fundamental niches. But, together and in competition, *Semibalanus* overrides and excludes *Chthamalus* from their areas of overlap, reducing it to a smaller realized niche.

reaches all the way from low to high tide. However, when both occur together, *Semibalanus* more successfully competes for space, excluding *Chthamalus*, whose realized niche becomes restricted.

Warblers are a group of brightly decorated birds, sporting various combinations amongst the species of yellow, red, and white with black accents.

In northeastern parts of North America, five species were closely observed as they foraged in and around trees in search of insects. So closely related, competition could have been intense. But each of the species frequents different parts of the tree where it searches for food (figure 5.17). Ecologically, the species are separated, thus reducing any challenges from direct competition.

Forest plants compete for nutrients in the soil, a space in the stand of trees, and for access to sunlight. In temperate and tropical forests, major trees grow to great heights, spread their branches into a broad canopy, and intercept the sunlight for photosynthesis. Young, small tree seedlings and ground-hugging plants are in a shaded world, choked off from sunlight. Shade-tolerant plants grow slowly; others perish, outcompeted for the resource of sunlight.

OVERVIEW

The diversity of life on Earth has passed through major transitions, producing changes in complexity and major new organization of parts that function to ensure survival and reproduction of the whole organism. There is nothing inevitable about such changes, nor are they necessarily progressive. Bacteria today are probably no more complex than were their ancestors of 2 billion years ago. And bacteria today have just as tight a hold on their place in nature as more complex organisms that came later. These major transitions produced changes in complexity that afforded different ways of finding successful strategies of survival. The first of these transitions was the origin of life itself. Prokaryotes represent a stage wherein the DNA and the machinery of life it directs were housed within the walls of a protective cell. The ancestors of mitochondria and chloroplasts were once free-living prokaryotes, but they became incorporated into a host cell, thus producing eukaryotes. With eukaryotes also comes the origin of sex. Experiments with a multicellular organization occur in protists, but multicellularity is the foundation for plants, fungi, and animals, where, respectively, photosynthesis, absorption, and ingestion are characteristic lifestyle strategies.

Each organism within an ecosystem confronts survival challenges from the physical environment and from competitors of its own species and from other species.

Competition may be seldom observed directly because it can be nonviolent, as with plants vying for sunlight; or competition may be seasonal, or occur only in infrequent years of harsh weather.

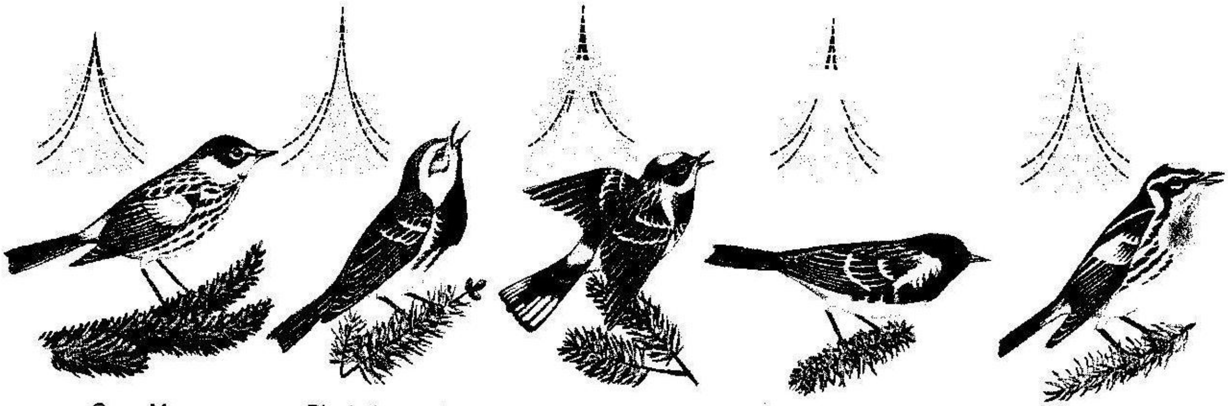


FIGURE 5.17 Wood Warblers Five species of wood warblers occur in spruce forests of the northeastern United States. Their foraging efforts are localized in different parts of the tree, represented by the shading.

And what of humans? What is our contribution to this evolution and diversification of life? Stasis and stagnation are not part of this history. The history of life on Earth is summarized in one word—*change*. We emerged from this history, as did the other organisms with which we share this planet. Stamped on our character are the consequences of that history. If we are to understand our contribution and ourselves, then it is that history we need to understand. We'll consider the evidence for evolution in chapter 6.

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