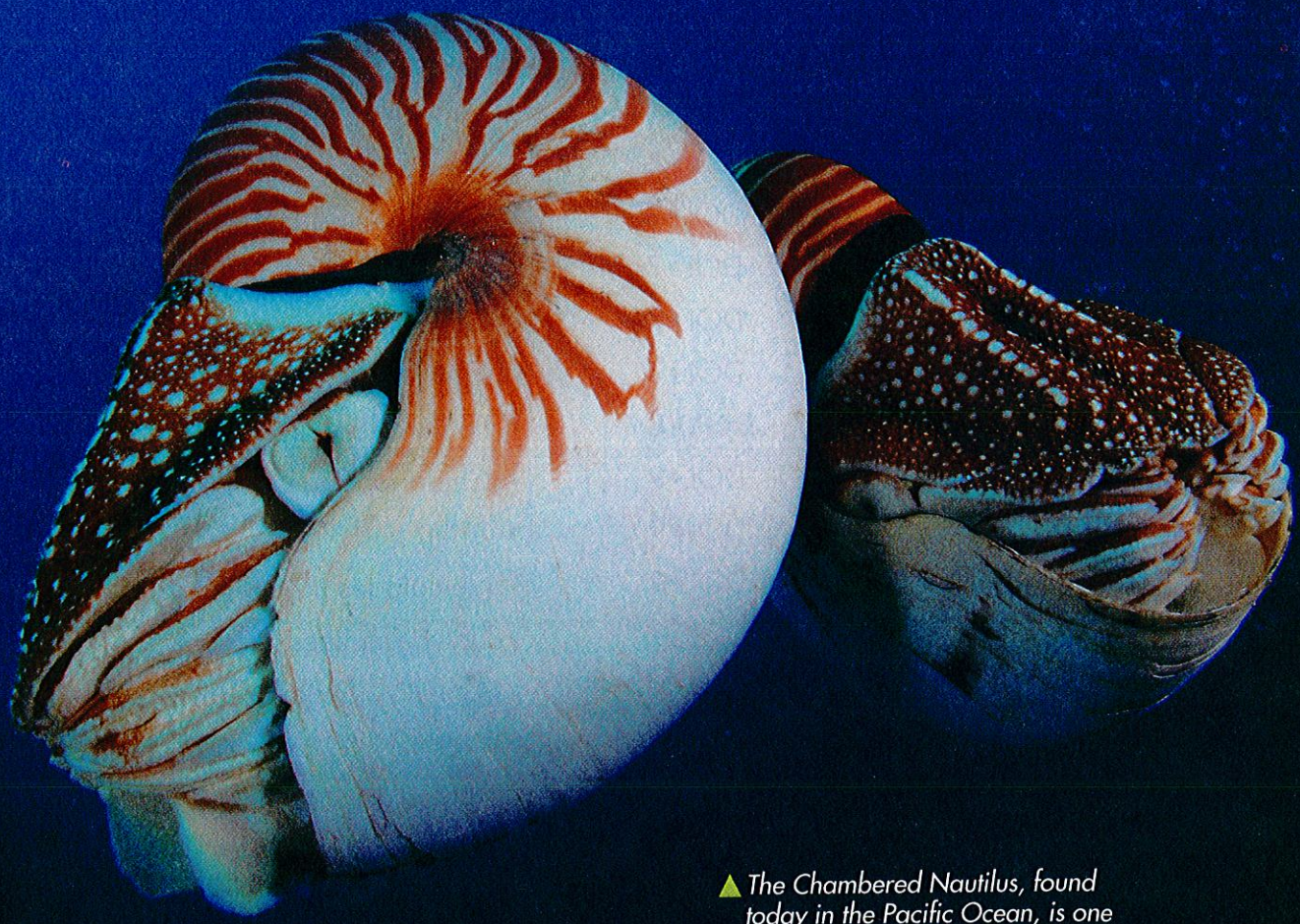
A Visual Guide to
The Diversity of Life



▲ *The Chambered Nautilus, found today in the Pacific Ocean, is one of the few living representatives of a group that once flourished in ancient seas 265 million years before the dinosaurs evolved. This Visual Guide will give you a glimpse of life's great variety and evolutionary history.*

A Visual Guide to
The Diversity of Life

CONTENTS

HOW TO USE THIS GUIDE

Use this visual reference tool to explore the classification and characteristics of organisms, including their habitats, ecology, behavior, and other important facts. This guide reflects the latest understandings about phylogenetic relationships within the three domains of life. Divided into six color-coded sections, the Visual Guide begins with a brief survey through the Bacteria and Archaea domains. It next discusses the major groups of protists, fungi, and plants. The final section provides information on nine animal phyla.

1 See how the group of organisms relates to others on the tree of life.

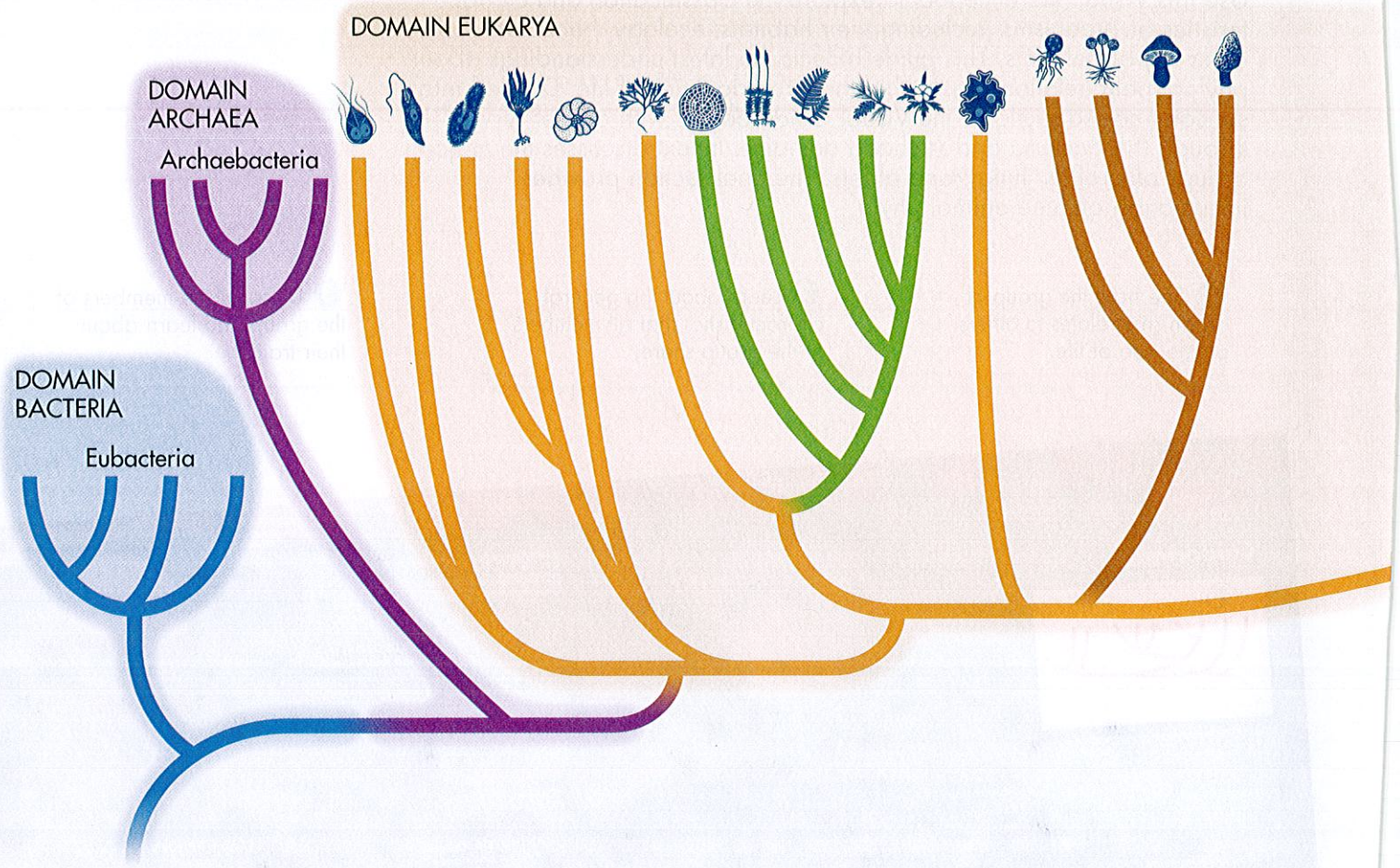
2 Learn about the general characteristics that all members of the group share.

3 Discover the members of the group and learn about their traits.

4 Investigate current news and interesting facts about the group.

5 See photographs of representative animals within each group.

THE TREE OF LIFE



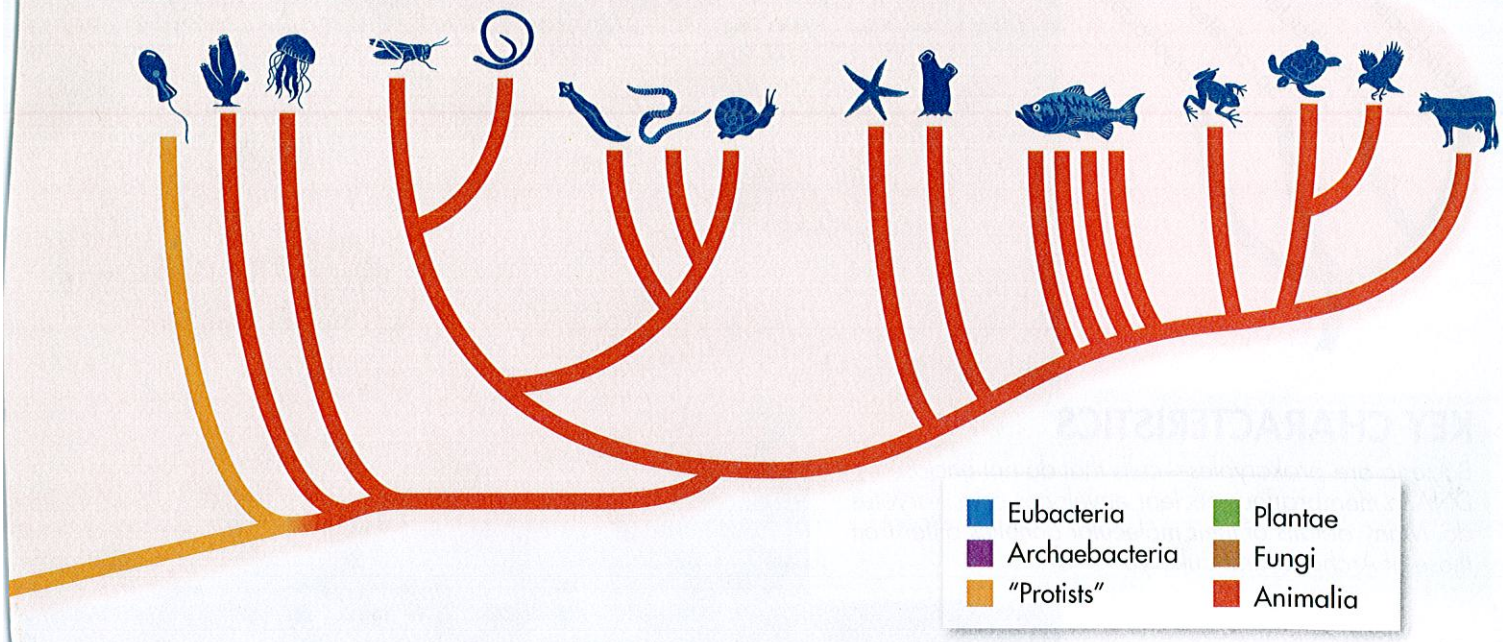
Before you begin your tour through the kingdoms of life, review this big picture from Chapter 18. The pages that follow will give you a glimpse of the incredible diversity found within each of the "branches" shown here.

DOMAIN BACTERIA

Members of the domain Bacteria are unicellular and prokaryotic. The bacteria are ecologically diverse, ranging from free-living soil organisms to deadly parasites. This domain corresponds to the kingdom Eubacteria.

DOMAIN ARCHAEA

Also unicellular and prokaryotic, members of the domain Archaea live in some of the most extreme environments you can imagine, including volcanic hot springs, brine pools, and black organic mud totally devoid of oxygen. The domain Archaea corresponds to the kingdom Archaebacteria.



DOMAIN EUKARYA

The domain Eukarya consists of all organisms that have cells with nuclei. It is organized into the four remaining kingdoms of the six-kingdom system: Protista, Fungi, Plantae, and Animalia.

THE "PROTISTS"

Notice that the branches for the kingdom Protista are not together in one area, as is the case with the other kingdoms. In fact, recent molecular studies and cladistic analyses have shown that "eukaryotes formerly known as Protista" do not form a single clade. Current cladistic analysis divides these organisms into at least six clades. They cannot, therefore, be properly placed into a single taxon.

FUNGI

Members of the kingdom Fungi are heterotrophs. Most feed on dead or decaying organic matter. The most recognizable fungi, including mushrooms, are multicellular. Some fungi, such as yeasts, are unicellular.

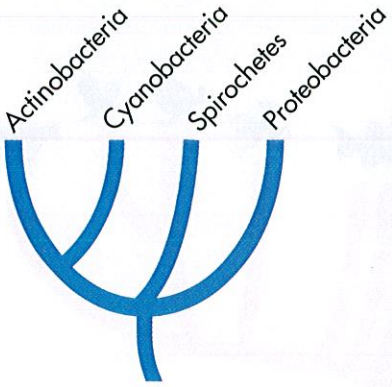
PLANTS

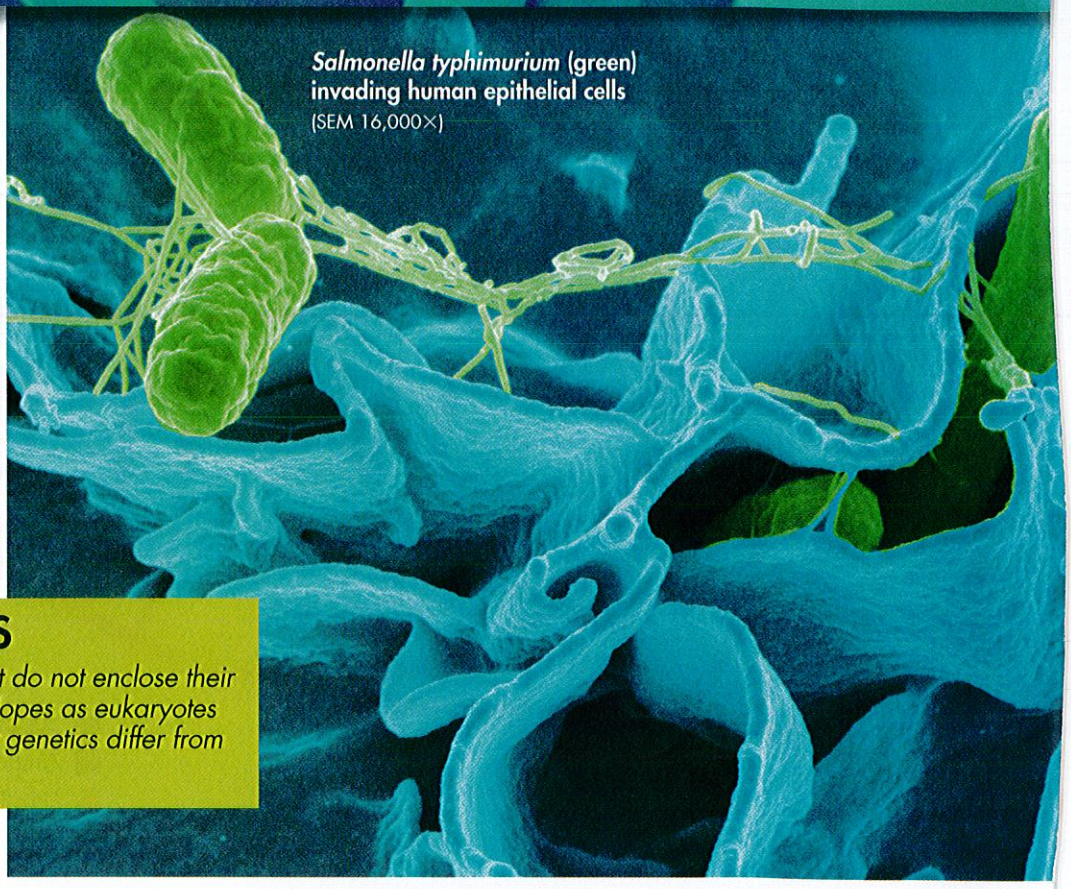
Members of the kingdom Plantae are autotrophs that carry out photosynthesis. Plants have cell walls that contain cellulose. Plants are nonmotile—they cannot move from place to place.

ANIMALS

Members of the kingdom Animalia are multicellular and heterotrophic. Animal cells do not have cell walls. Most animals can move about, at least for some part of their life cycle.

Bacteria





Salmonella typhimurium (green) invading human epithelial cells (SEM 16,000×)

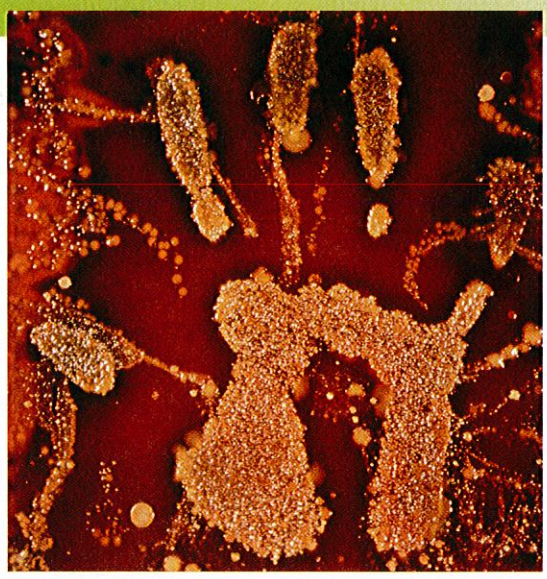
KEY CHARACTERISTICS

Bacteria are prokaryotes—cells that do not enclose their DNA in membranous nuclear envelopes as eukaryotes do. Many details of their molecular genetics differ from those of Archaea and Eukarya.

Cell Structure Variety of cell shapes, including spherical, rodlike, and spiral; most have cell walls containing peptidoglycan. Few if any have internal organelles. Some have external flagella for cell movement.

Genetic Organization All essential genes are in one large DNA double helix that has its ends joined to form a closed loop. Smaller loops of DNA (plasmids) may carry nonessential genes. Simultaneous transcription and translation; introns generally not present; histone proteins absent

Reproduction By binary fission; no true sexual reproduction; some achieve recombination by conjugation.



Did You Know?

A World of Bacteria

Putting Bacteria in Proper Perspective

"Planet of the Bacteria" was the title of an essay by the late Stephen Jay Gould. He pointed out that the dominant life forms on planet Earth aren't humans, or animals, or plants. They are bacteria. They were here first, and they inhabit more places on the planet than any other form of life. In fact, bacteria make up roughly 10 percent of our own dry body weight! In terms of biomass and importance to the planet, bacteria truly do rule this planet. They, not we, are number one.

◀ *The bacterial colonies shown here are growing in the print of a human hand on agar gel.*

GROUPS OF BACTERIA

There is no generally agreed phylogeny for the bacteria. Included here are some of the major groups within the domain.

PROTEOBACTERIA

This large and diverse clade of bacteria includes *Escherichia* (*E. coli*), *Salmonella*, *Helicobacter*, and the nitrogen-fixing soil bacterium *Rhizobium*.

◀ *Helicobacter pylori is rod-shaped and has several flagella used for movement. This bacterium infects the stomach lining and causes ulcers in some people.* (TEM 7100×)

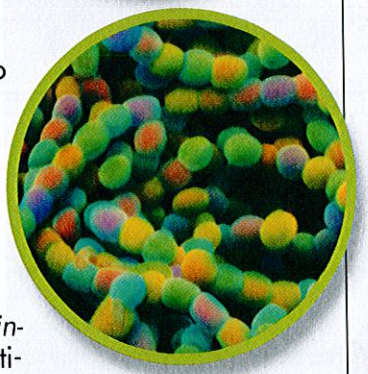
The spiral-shaped bacterium that causes syphilis is Treponema pallidum. (SEM 10,000×) ▼

SPIROCHAETES

The spirochaetes (SPY roh keets) are named for their distinctive spiral shape. They move in a corkscrew-like fashion, twisting along as they are propelled by flagella on both ends of the cell. Most are free-living, but a few cause serious diseases, including syphilis, Lyme disease, and leptospirosis.

ACTINOBACTERIA

A large number of soil bacteria belong to this group. Some form long filaments. Members include the *Streptomyces* and *Actinomyces*, which are natural producers of many antibiotics, including streptomycin. A related group is the *Firmicutes*. The *Firmicutes* include *Bacillus anthracis* (anthrax), *Clostridia* (tetanus and botulism), and *Bacillus thuringensis*, which produces a powerful insecticide used for genetic engineering in plants.



▲ *Chains of spores of soil bacteria, genus* Streptomyces (SEM 3400×)

CYANOBACTERIA

The cyanobacteria are photosynthetic prokaryotes that were once called "blue-green algae." They are among the oldest organisms on Earth, having been identified in rocks dating to more than 3 billion years ago. They are found in salt water and fresh water, in the soil, and even on the surfaces of damp rocks. They are the only organisms on Earth that are able to fix carbon and nitrogen under aerobic conditions, and this enables them to play critical roles in the global ecosystem, where they serve as key sources of carbon and nitrogen.

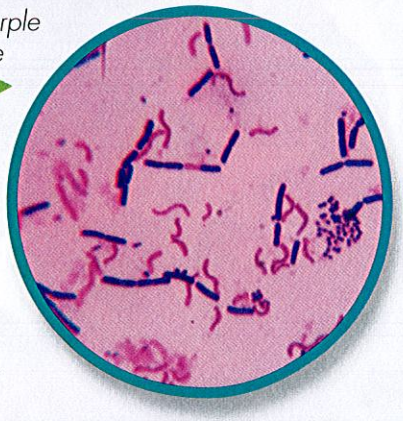
▼ *Many cyanobacteria form long filaments of attached cells, like those shown here (genus* Lyngbya, SEM 540×*).*

•A Closer Look

The Gram Stain

A Microbiologist's Quick Diagnostic

Gram-positive bacteria appear purple after staining, while gram-negative bacteria appear pink. (LM 1000×) ▶



The Gram stain, developed by the nineteenth-century Danish physician Hans Christian Gram, allows microbiologists to categorize bacteria quickly into one of two groups based on their cell wall composition. Gram-positive bacteria lack a membrane outside the cell wall and take up the stain easily. Gram-negative bacteria, on the other hand, have an outer membrane of lipids and carbohydrates that prevents them from absorbing the gram stain. Many gram-negative bacteria are found among the proteobacteria. On the other hand, actinobacteria are mostly gram-positive.

Archaea

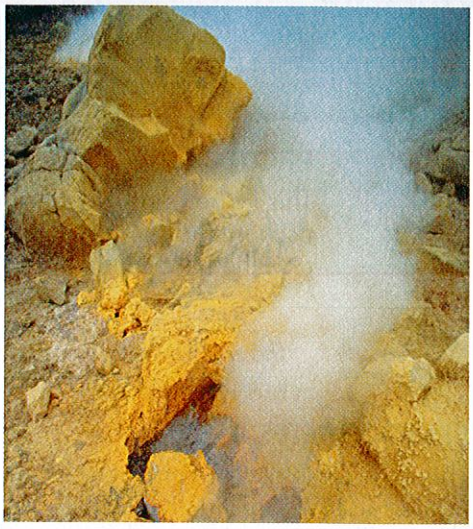
KEY CHARACTERISTICS

Archaea are prokaryotes that differ from bacteria in so many details of structure and metabolism that they are viewed as a different domain than bacteria. Genetically, they have more in common with eukaryotes than with bacteria. Their cell walls do not contain peptidoglycan.

Cell Structure Cells similar to those of bacteria in appearance; many have flagella that are different in structure and biochemical composition from bacterial flagella. Cell membrane lipids also different from those of bacteria; few internal organelles

Genetic Organization As in bacteria, all essential genes are in one large DNA double helix that has its ends joined to form a closed loop. Proteins responsible for transcription and translation are similar to those of eukaryotes. Also like eukaryotes, most species contain introns, and all species contain DNA-binding histone proteins.

Reproduction By binary fission; no true sexual reproduction, but some achieve recombination by conjugation.



▲ *The volcano Solfatara, near Naples, Italy, is home to many archaea in the genus* Sulfolobus.

Did You Know?

Hot Enough for You?

The Original Extremists

Way before extreme sports and extreme reality TV shows came the archaea—the original and ultimate extremists. When archaea were first discovered, biologists called them *extremophiles*, a term that literally means "lovers of the extreme." For many archaea, the name still fits. In fact, they have proven especially difficult to grow in the lab, since they require such extreme temperatures and dangerous chemical conditions to thrive. One species will grow only in sulfuric acid! Archaea found in deep-sea ocean vents thrive in temperatures exceeding 100° Celsius, while others enjoy life in the frigid waters of the Arctic.

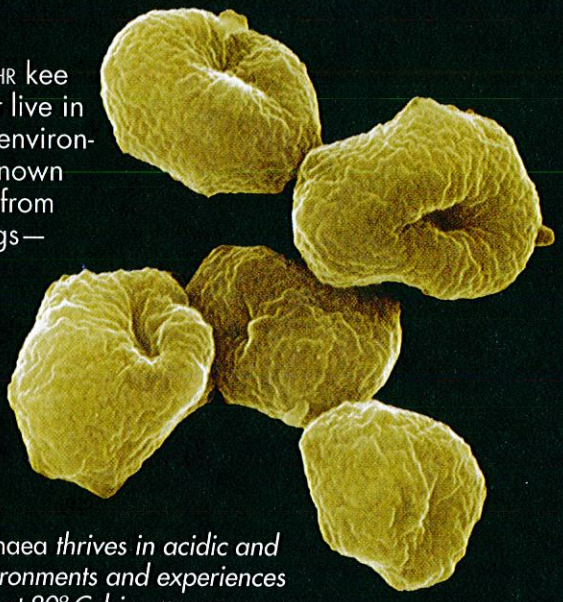
▼ *This scanning electron micrograph shows archaea (yellow) growing on the shell of a diatom (purple).* (SEM 25,000×)

GROUPS OF ARCHAEA

To date, four major clades of archaea have been identified. Biologists continue to debate how these clades are related to one another.

CRENARCHAEOTES

The crenarchaeotes (kren AHR kee ohts) include organisms that live in the hottest and most acidic environments known. Most of the known species have been isolated from thermal vents and hot springs—the prefix *cren-* means "spring." Some species grow using organic compounds as energy sources, but others fix carbon from carbon dioxide, using hydrogen or sulfur to provide chemical energy.



▶ Sulfolobus archaea *thrives in acidic and sulfur-rich environments and experiences optimal growth at 80° Celsius.* (SEM 33,200×)

KORARCHAEOTES

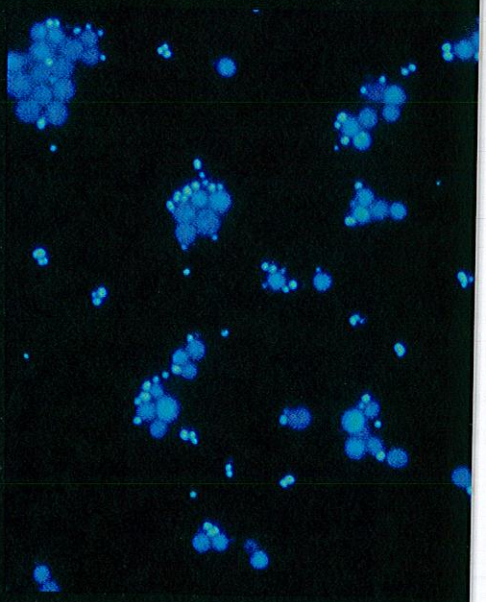
Scientists recently discovered the korarchaeote (kawr AHR kee oht) lineage in Obsidian Pool, Yellowstone National Park, and have since discovered more species in Iceland. Their DNA sequences place them apart from other archaea. The korarchaeotes may in fact be one of the least-evolved lineages of modern life that has been detected in nature so far.

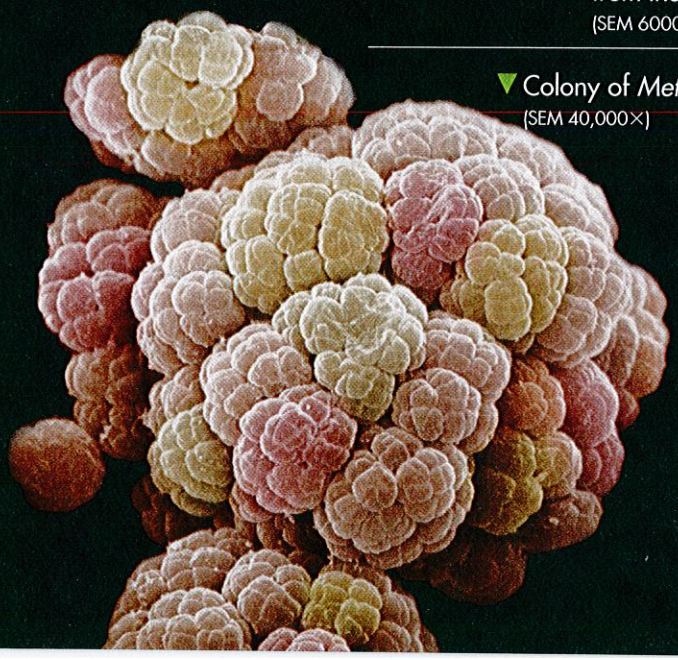
▲ *Korarchaeotes from Obsidian Pool are shown in a lab culture with other microbes from their community.* (SEM 6000×)

NANOARCHAEOTES

Only a single species of this group has been discovered, in 2002, attached to a much larger crenarchaeote! Nanoarchaeotes (na noh AHR kee ohts) grow in hot vents near the coastal regions of the ocean and show definite molecular differences from other archaea. More research is needed to characterize this group, but what is known is that they have the smallest known genome of any organism.

▼ *The newly discovered* Nanoarchaeum equitans *(smaller cells) is shown attached to its host, genus* Ignicoccus *(larger cells).* (LM 2000×)



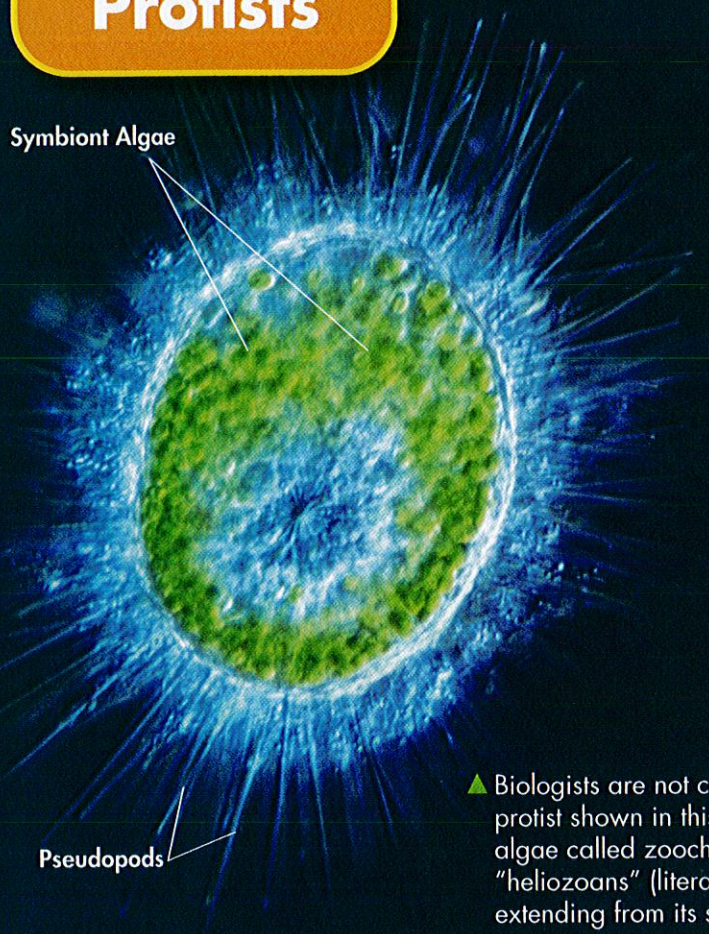


▼ Colony of *Methanosarcina mazei* (SEM 40,000×)

EURYARCHAEOTES

The euryarchaeotes (yoor ee AHR kee ohts) are a very diverse group of archaea, living in a broad range of habitats. The prefix *eury-* comes from a Greek word meaning "broad." The methanogens are a major group of euryarchaeotes that play essential roles in the environment. They help to break down organic compounds in oxygen-poor environments, releasing methane gas in the process. Another group, the *Halobacteria*, are found in salt ponds, where the concentration of sodium chloride approaches saturation.

Protists



KEY CHARACTERISTICS

A protist is a eukaryote, generally single-celled, that does not fit into any of the other major taxonomic groups. The protists do not make up a true kingdom.

Organization Great diversity of cell organelles and organization: some have cell walls, some have chloroplasts, most have mitochondria or organelles related to mitochondria; those that are multicellular have relatively little differentiation into tissues.

Movement Some move by cilia or flagella.

Reproduction Most reproduce by cell division; many have sexual phases to their life cycle; some exchange genetic material by conjugation.

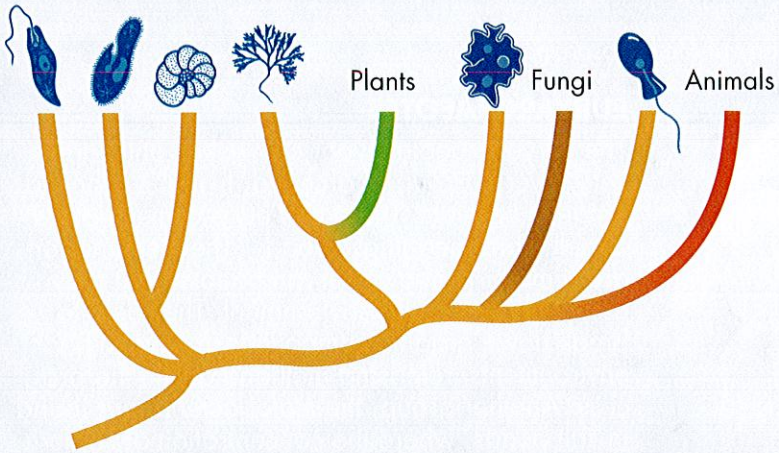
▲ Biologists are not certain how to classify *Heterophrys*, the freshwater protist shown in this micrograph. It harbors symbiotic photosynthetic algae called zoochorellae. *Heterophrys* is one of many protists called "heliozoans" (literally, "sun animals") because of the thin pseudopods extending from its surface, giving it a sun-like appearance.

•Did You Know?

The Kingdom That Isn't

The Challenges of Classifying Protists

Biologists traditionally classified protists by splitting them into funguslike, plantlike, and animal-like groups. This seemed to work for a while, but when they studied protists more carefully with new research tools, including genome-level molecular analysis, this traditional system simply fell apart.



Biologists now think that protists shouldn't be classified as a kingdom at all. In fact, when scientists look for the deepest and most fundamental divisions among eukaryotes, they find that all of those divisions are within the protists themselves, not between protists and other eukaryotes. Starting over, biologists could simply use those divisions to define newer, more accurate "kingdoms," but that might cause new problems. For one thing, it would lump two of the traditional kingdoms (animals and fungi) together, and it would leave a handful of kingdoms that contain only unicellular organisms. There is no perfect solution to this problem. Here, "protists" are considered a kingdom for the sake of convenience, but keep in mind that their differences are really too great for any single kingdom to contain.

Excavates

KEY CHARACTERISTICS

Excavates (EKS kuh vayts) have a characteristic feeding groove, usually supported by microtubules. Most have flagella. A few lack mitochondria and are unable to carry out oxidative phosphorylation, although they do possess remnants of the organelle.

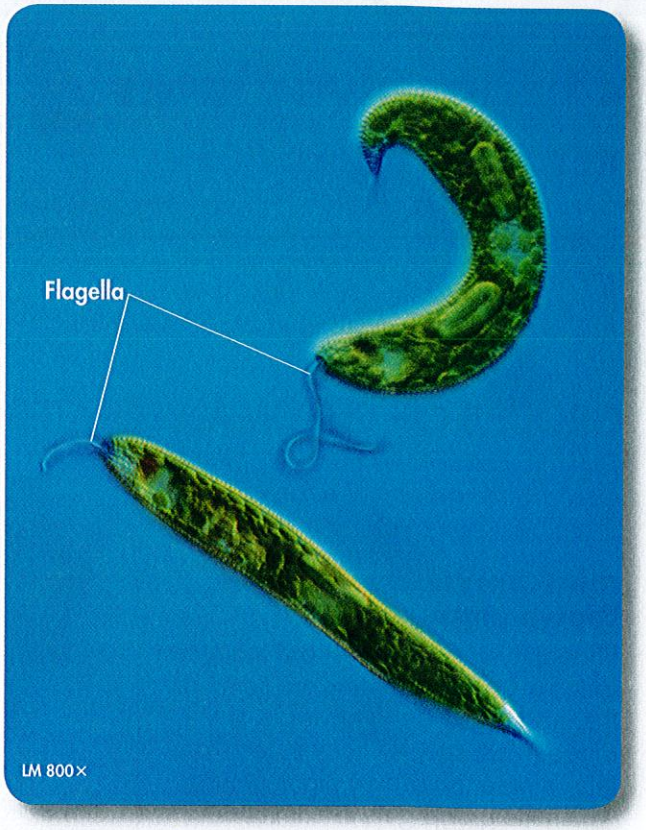
GROUPS OF EXCAVATES

The excavates include a wide diversity of protists, from free-living photosynthesizers to some of humankind's most notorious pathogens.

▲ *The diplomonad* Giardia *is a dangerous intestinal parasite that frequently contaminates freshwater streams.* Giardia *infections are common in wildlife and pet dogs and cats.* (SEM 1800×)

DIPLOMONADS

These organisms get their name from the fact that they possess two distinct and different nuclei (from Greek, diplo = double). The double nuclei probably derived from an ancient symbiotic event in which one species was engulfed by another. Cells contain multiple flagella, usually arranged around the body of the cell. Most species of diplomonads are parasitic.

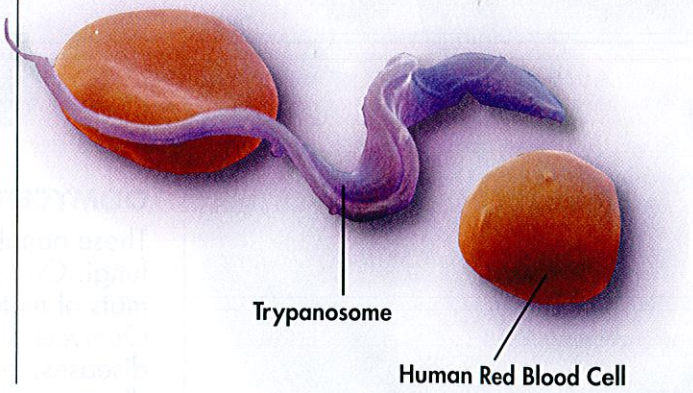


▲ *Photosynthetic* Euglena spirogyra *is commonly found in lakes and ponds.*

DISCICRISTATES

Discicristates (disk ee KRIS tayts) are named for the disc-shaped cristae present in their mitochondria. Some species are photosynthetic and free-living, such as *Euglena*, while others are dangerous parasites.

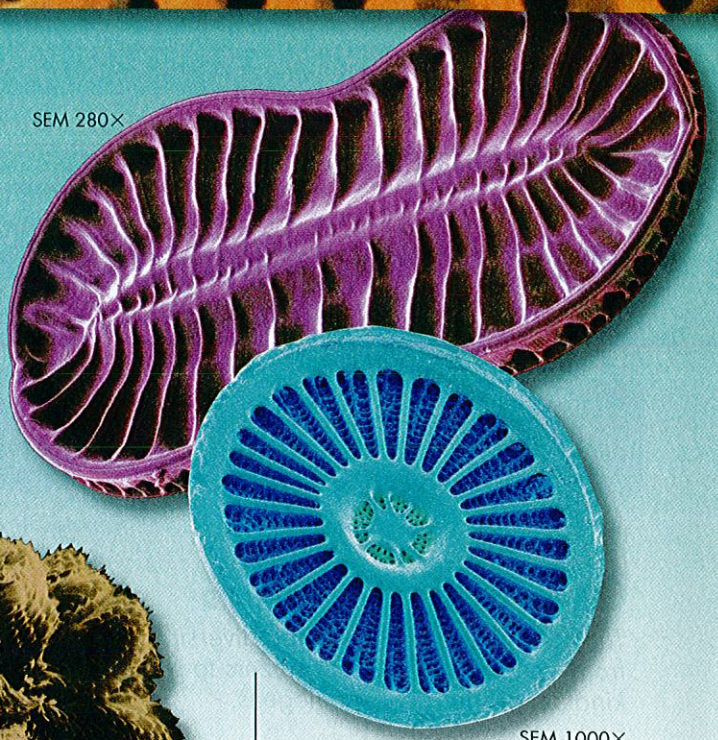
▼ *The ribbonlike cells of* Trypanosoma brucei *cause African sleeping sickness. The parasitic protist is transmitted by tsetse flies to humans, where it infects the blood, lymph, and spinal fluid. Severe nervous system damage and death are the usual result.* (SEM 6700×)



Chromalveolates

KEY CHARACTERISTICS

Chromalveolates (krohm AL vee uh layts) get their name from alveoli, flattened vesicles that line the cell membrane. The prefix chromo-*, meaning "pigment," reflects evidence that members of this clade share a common ancestor that had accessory pigments used in photosynthesis.*



SEM 280×

SEM 1000×

▲ *Diatoms often produce intricate shells made from silicon dioxide that persist long after they die.*

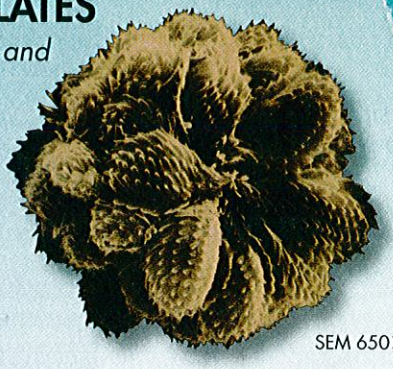
GROUPS OF CHROMALVEOLATES

The chromalveolates are one of the largest and most diverse groups of eukaryotes.

PHAEOPHYTES: Brown algae

Phaeophytes (FAY uh fyts) are mostly found in salt water. They are some of the most abundant and visible of the algae. Most species contain fucoxanthin, a greenish-brown pigment from which the group gets its common name. The multicellular brown alga known as giant kelp can grow as large as 60 meters in length.

▼ *Brown algae in genus* Fucus *are commonly found in tidepools and on rocky shorelines of the Pacific Coast of the United States.*



SEM 650×

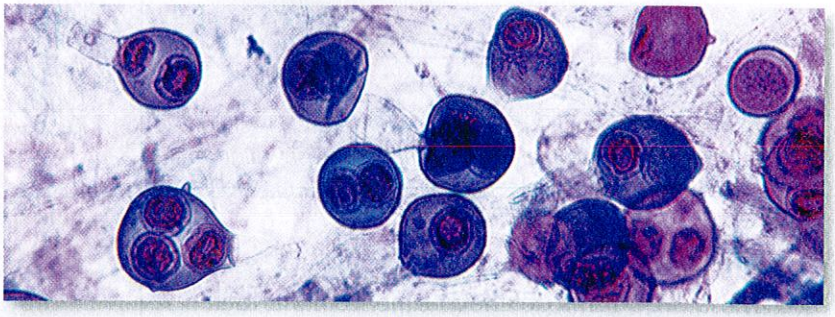
▲ *This species, in genus* Synura, *is a colonial alga. In this photograph, you can see the scales that cover the cell surfaces of the individuals making up the colony.*

CHRYSOPHYTES: Golden algae

Chrysophytes (KRIS oh fyts) are known for colorful accessory pigments in their chloroplasts. Most are found in fresh water and are photosynthetic.

DIATOMS

Diatoms are mostly found in salt water. When they die, they sink to the ocean floor, and their shells pile up in large deposits. Diatomaceous earth, as these deposits are known, can be used to screen out small particles, and is often used in swimming pool filters.



▲ *Water molds in genus* Achlya (LM 140×)

OOMYCETES: Water molds

These nonphotosynthetic organisms are often confused with fungi. Oomycetes (oh uh MY seed eez) typically produce fuzzy mats of material on dead or decaying animals and plants. Oomycetes are also responsible for a number of serious plant diseases, including potato blight, sudden oak death, and ink disease, which infects the American chestnut tree.

LM 220×

▶ Paramecium multimicronucleatum *is the largest paramecium, with cells that are visible to the naked eye.*

CILIATES

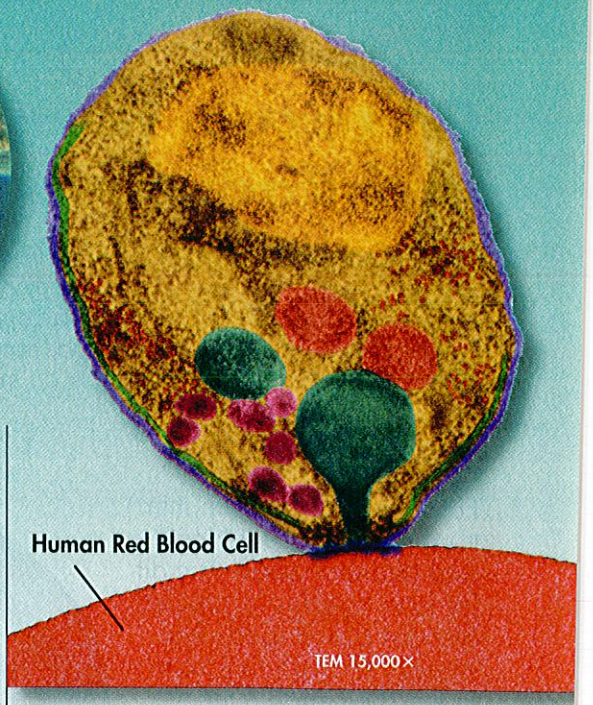
These common organisms may contain hundreds or even thousands of short cilia extending from the surface of the cell. The cilia propel the ciliate through the water, and may sweep food particles into a gullet. Ciliates are large compared to other protists, with some cells exceeding 1 mm in length.

DINOFLAGELLATES

Dinoflagellates are photosynthetic protists found in both fresh and salt water. Their name comes from their two distinct flagella, usually oriented at right angles to each other. Roughly half of dinoflagellate species are photosynthetic; the other half live as heterotrophs. Many dinoflagellate species are luminescent, and when agitated by sudden movement in the water, give off light.

SEM 1360×

▲ *The two flagella of dinoflagellates originate in grooves within thick plates of cellulose that resemble a cross shape, as shown here (genus* Peridinium*).*



▲ *Apicomplexans in genus* Plasmodium *are mosquito-borne parasites. Shown here is the sporozoite stage attached to a human red blood cell.*

APICOMPLEXANS

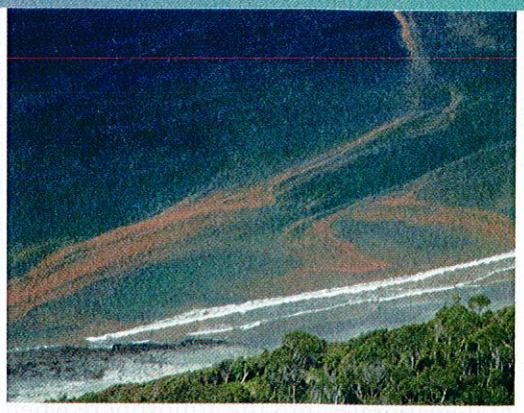
The apicomplexans (AYP ih kum plek sunz) are named for a unique organelle near one end of the cell known as the apical complex. This structure contains vesicles with enzymes that allow apicomplexans to enter other cells and take up residence as parasites.

Eco•Alert

Toxic Blooms

Dangerous Dinoflagellates

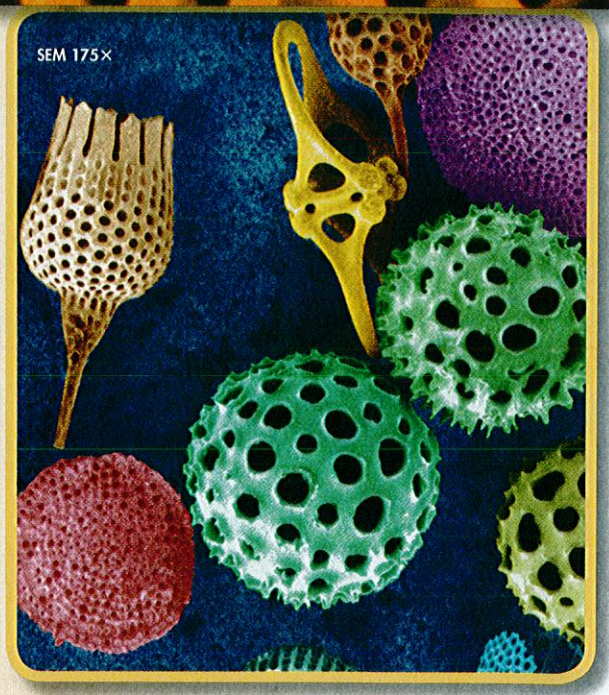
Great blooms of the dinoflagellates *Gonyaulax* and *Karenia* have occurred in recent years on the East Coast of the United States, although scientists are not sure of the reason. These blooms are known as "red tides." *Gonyaulax* and *Karenia* produce a toxin that can become amplified in the food chain when filter-feeding shellfish such as oysters contentrate it in their tissues. Eating shellfish from water affected by red tide can cause serious illness, paralysis, and even death.



▲ *A red tide containing toxic dinoflagellates*

Cercozoa, Foraminiferans, and Radiolarians

There is no single morphological characteristic that unites this diverse trio, but many have extensions of cytoplasm called pseudopods and many produce protective shells. The grouping together of Cercozoa, Foraminifera, and Radiolaria is based almost entirely on molecular analyses and not on morphology.



▲ *Radiolarian shells are composed of silica or strontium sulfate.*

FORAMINIFERANS

Foraminifera (fawr uh min IF uh ra) produce intricate and beautiful shells that differ from species to species. Slender pseudopods that emerge through tiny holes in the shell enable them to capture food, including bacteria. As many as 4000 species exist.

▼ Peneroplis plantus *has a spiral-shaped shell.*

CERCOZOA

Members of this clade are common in soil, where they feed on bacteria as well as decaying organic matter. Many have flagella, and some produce scales made of silica that protect their surfaces.

RADIOLARIANS

These organisms have an intricate structure in which the nucleus is found in an inner region of the cell known as the endoplasm. The outer portion of the cell, known as the ectoplasm, contains lipid droplets and vacuoles. These organisms sometimes form symbiotic relationships with photosynthetic algae, from which they obtain food.

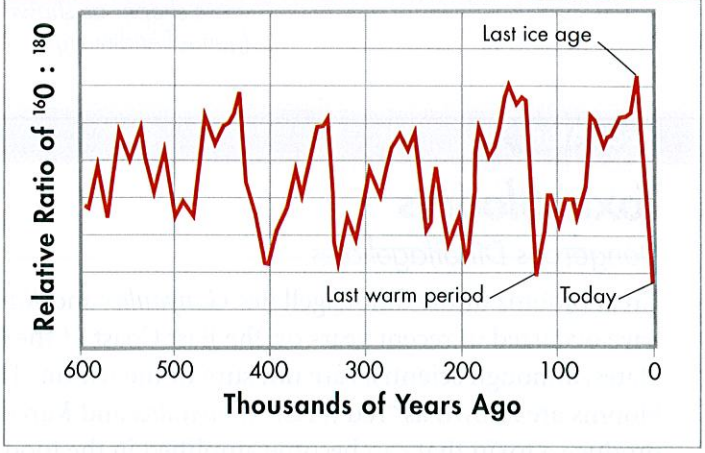
• A Look Back in Time

Foraminiferan Fossils

Ancient Climates Revealed

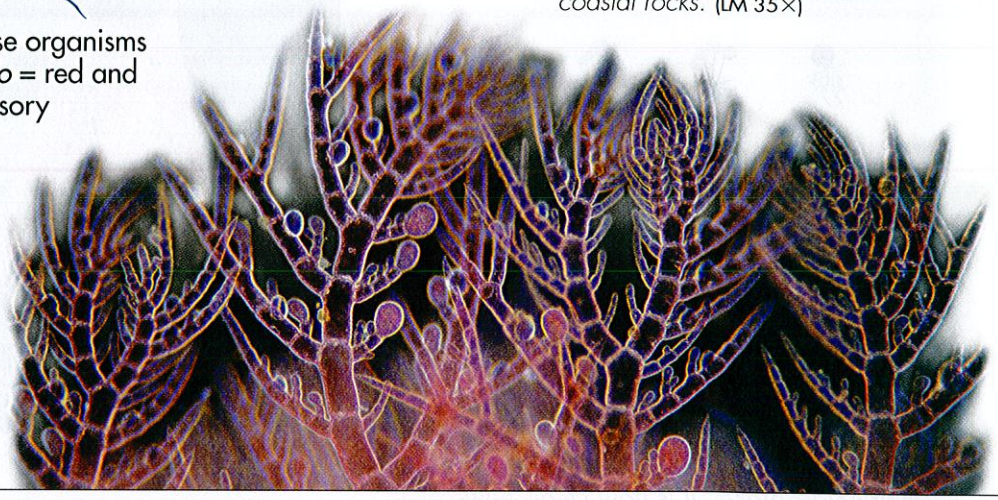
Abundant fossils of foraminiferans have been found in sediments dating to the Cambrian period (560 million years ago). For decades, oil companies have taken advantage of these ancient fossils to locate the sediments most likely to contain oil, but now there is another use for them—measuring the sea temperature of ancient Earth. Foraminiferans take dissolved oxygen from seawater to make the calcium carbonate ($CaCO_3$) in their shells, and when they do so, they take up two isotopes of oxygen, ^{16}O and ^{18}O. Because water made from ^{16}O is less dense, more of it evaporates into the atmosphere when the seas are warm—increasing the amount of ^{18}O in the remaining seawater, and in the fossil shells. The ratio between ^{16}O and ^{18}O in these fossils allows scientists to study the history of seawater temperature, as shown in the graph above.

Foraminiferan Isotope Ratios and Climate Change



Rhodophytes

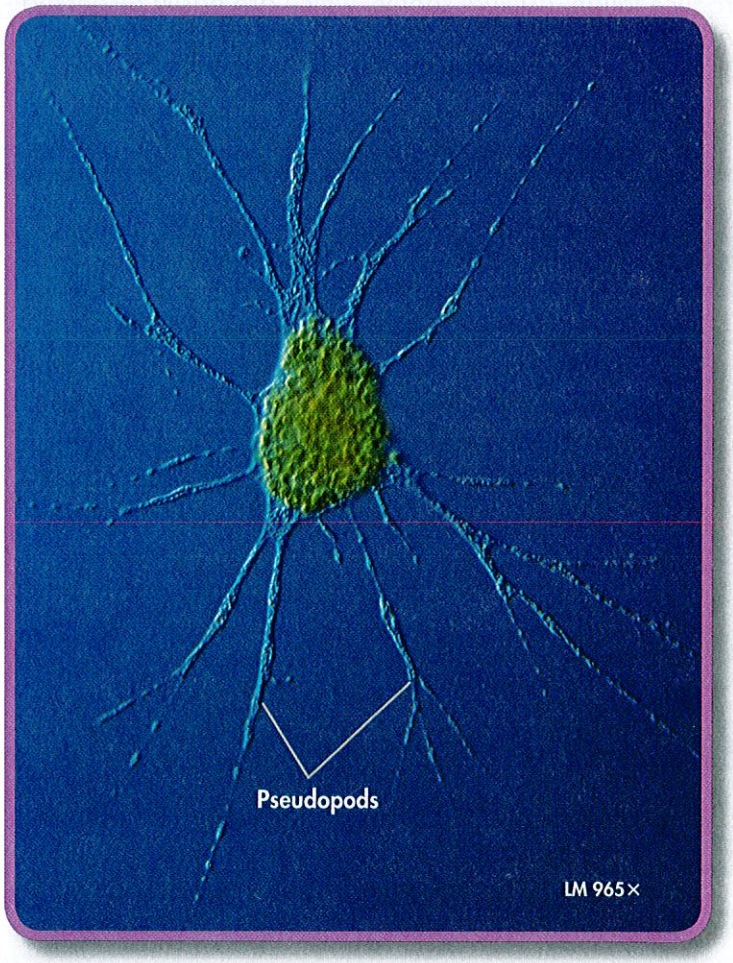
Also known as the red algae, these organisms get their name (from Greek, *rhodo* = red and *phyte* = plant) from reddish accessory pigments called phycobilins (fy koh BIL inz). These highly efficient pigments enable red algae to grow anywhere from the ocean's surface to depths as great as 268 meters. Most species are multicellular. Rhodophytes are the sister group to kingdom Plantae.



▼ *Antithamnion plumula is a marine rhodophyte that lives attached to coastal rocks.* (LM 35×)

Amoebozoa

Members of the Amoebozoa (uh MEE boh zoh ah) are amoebalike organisms that move by means of cytoplasmic streaming, also called amoeboid movement, using pseudopods.



◀ *Slime molds live as single microscopic amoebas in the soil, but aggregate into a colony when conditions are right, forming a multicellular fruiting body.*

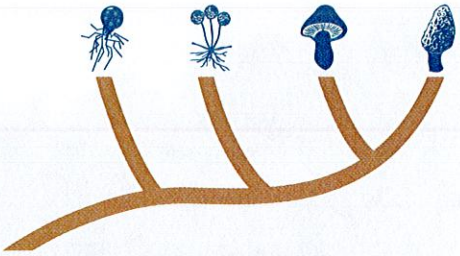
◀ *This solitary amoeba, Penardia mutabilis, has very slender pseudopods.*

Choanozoa

Members of the clade Choanozoa (koh AN uh zoh uh) can be solitary or colonial and are found in aquatic environments around the world. This clade is the sister group to kingdom Animalia.

Choanoflagellates are a major group in the clade Choanozoa. They get their name from a collar of cytoplasm that surrounds their single flagellum (form Greek, *choano* = collar.) Many species trap food within the collar and ingest it.

Fungi



KEY CHARACTERISTICS

Fungi are heterotrophic eukaryotes with cell walls that contain chitin. Fungi were once thought to be plants that had lost their chloroplasts. It is now clear, however, that they are much more closely related to animals than to plants. More than 100,000 species of fungi are known. Distinctions among the phyla are made on the basis of DNA comparisons, cell structure, reproductive structures, and life cycles.

▲ *Stinkhorn fungus (genus* Dictyophora*)*

Organization Some are unicellular yeasts, but most have a multicellular body called a mycelium that consists of one or more slender, branching cells called hyphae.

Feeding and Digestion Obtain food by extracellular digestion and absorption

Reproduction Most have sexual phases to their life cycle and are haploid at most points during the cycle. Most produce tough, asexual spores, which are easily dispersed and able to endure harsh environmental conditions. Asexual reproduction by budding and splitting is also common.

•A Closer Look

▲ *Fly Agaric (*Amanita muscaria*) is poisonous to humans.*

Consumers Beware!

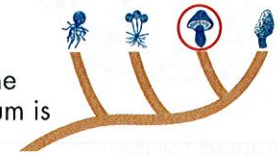
Edible and Inedible Mushrooms

Many types of fungi have long been considered delicacies, and several different species of mushrooms are cultivated for food. You may have already tasted sliced mushrooms on pizza, feasted on delicious sautéed portobello mushrooms, or eaten shiitake mushrooms. When properly cooked and prepared, domestic mushrooms are tasty and nutritious.

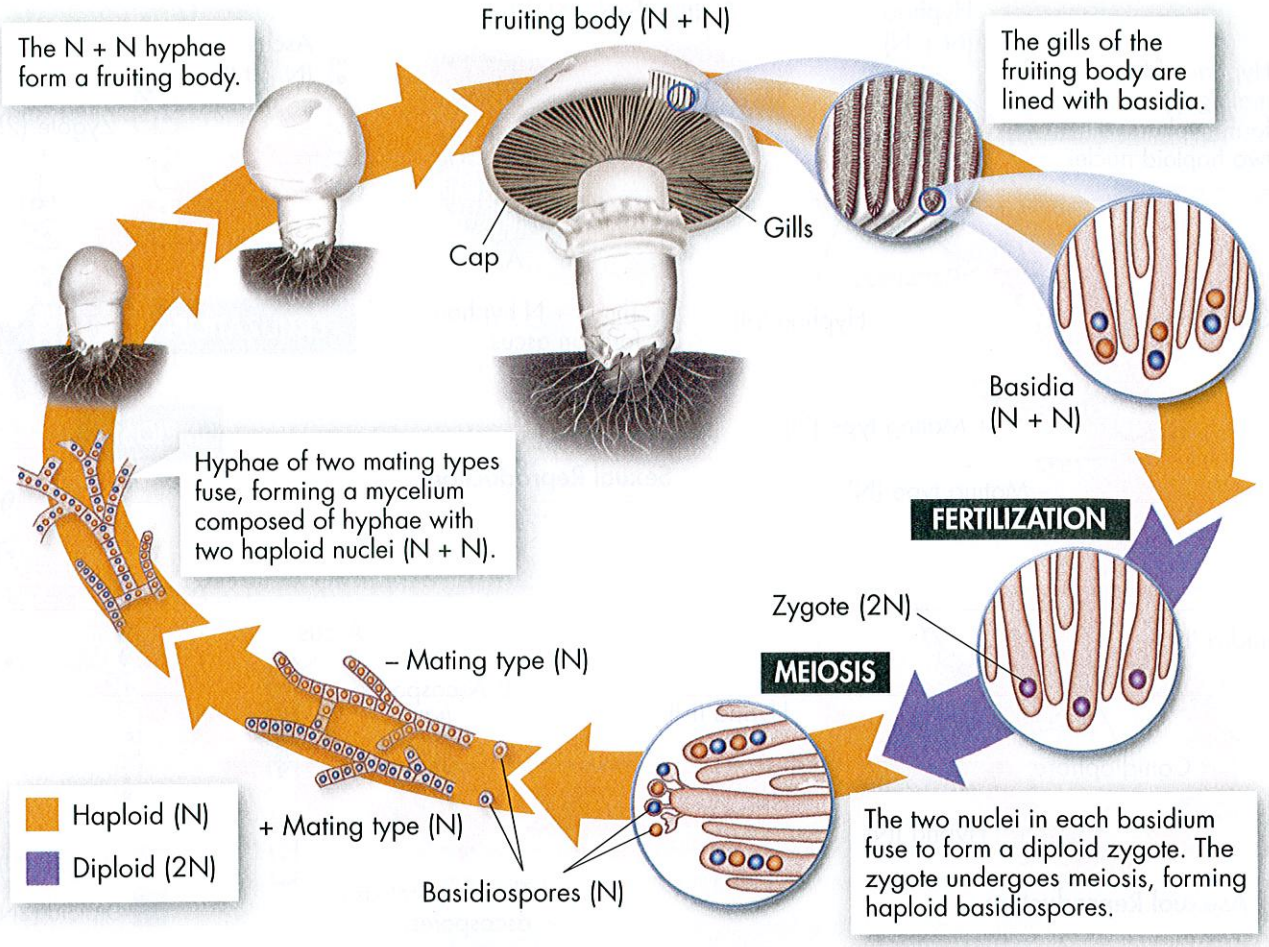
Wild mushrooms are a different story: Although some are edible, many are poisonous. Because many species of poisonous mushrooms look almost identical to edible mushrooms, you should never pick or eat any mushrooms found in the wild. Instead, mushroom gathering should be left to experts who can positively identify each mushroom they collect. The result of eating a poisonous mushroom can be severe illness, or even death.

Basidiomycetes

The basidiomycetes, or club fungi, are named for the basidium (buh SID ee um; plural: basidia). The basidium is a reproductive cell that resembles a club.



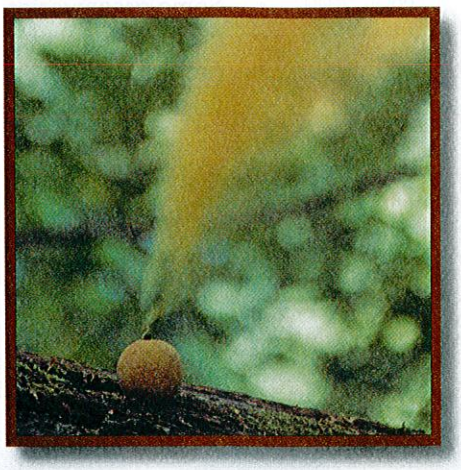
Life Cycle Basidiomycetes undergo what is probably the most elaborate life cycle of all the fungi, shown below.



Diversity More than 26,000 species of basidiomycetes have been described, roughly a third of all known fungal species. Examples include the stinkhorn and fly agaric mushrooms shown on the previous page, and the shelf fungus and puffball at right.

▶ *Shelf fungi (Polypore family) often grow on the sides of dead or dying trees.*

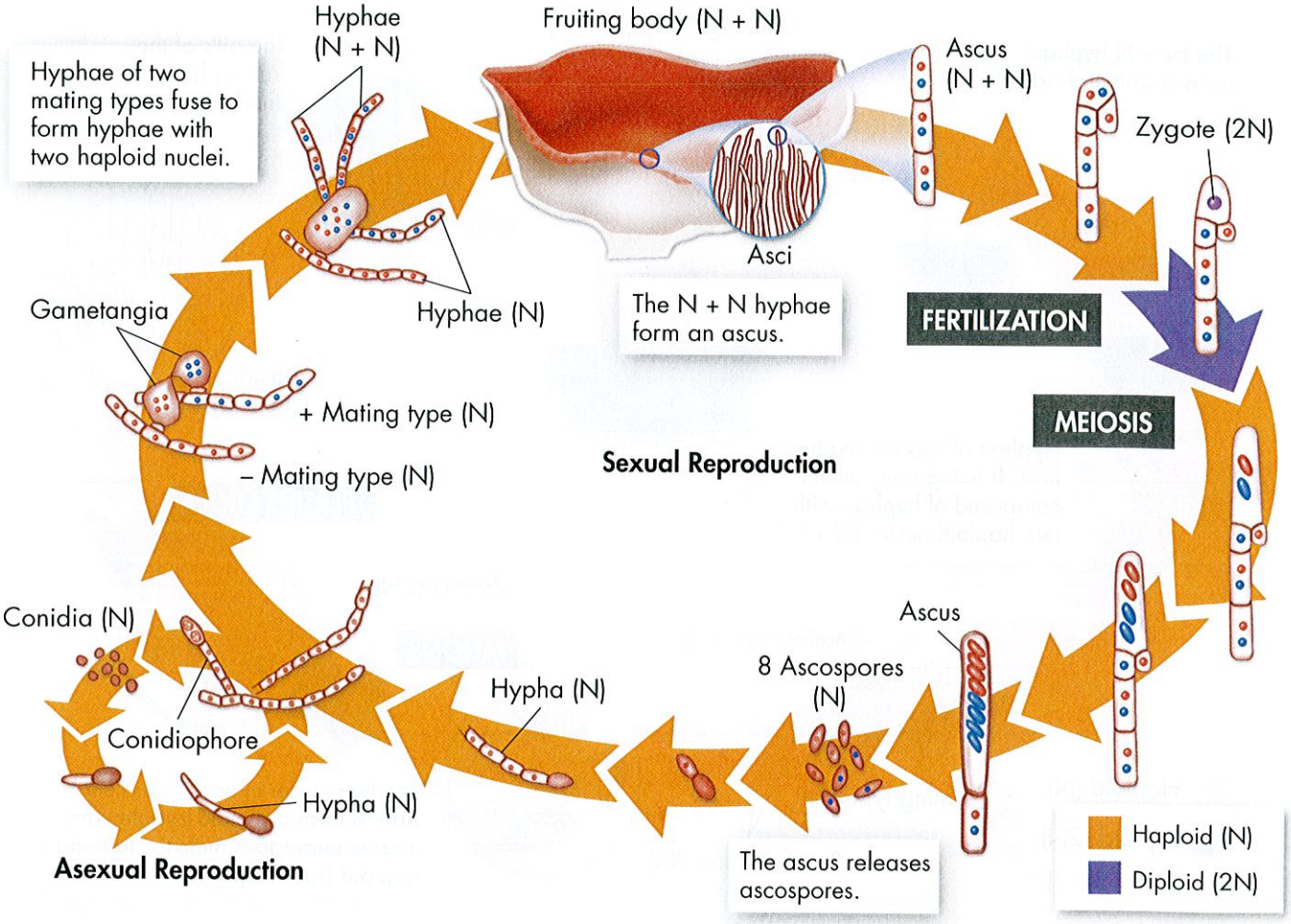
▼ *A puffball releases its spores in an explosive cloud.*



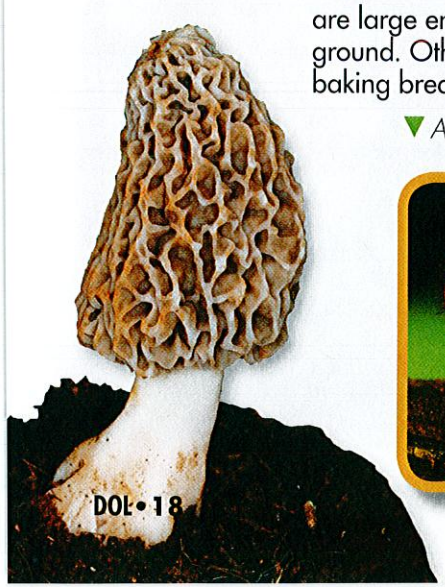
Ascomycetes

The ascomycetes, or sac fungi, are named for the ascus (AS kus), a saclike reproductive structure that contains spores.

Life Cycle The ascomycete life cycle includes an asexual phase, in which haploid spores are released from structures called conidiophores, and a sexual phase.

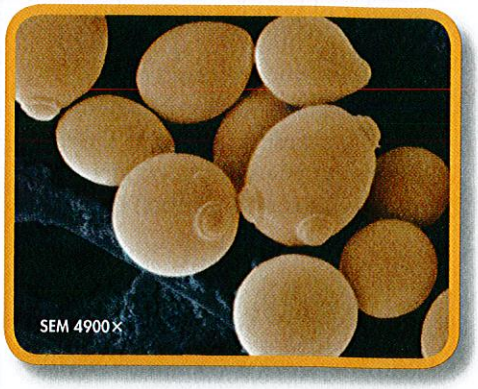


▼ *An edible morel in genus* Morchella



Diversity There are more than 50,000 species of ascomycetes, making it the largest phylum of the Fungi. Some ascomycetes, such as morels and cup fungi, are large enough to be visible when they grow above ground. Others, such as the common yeasts used for baking bread, are microscopic.

▼ *A cup fungus (genus* Cookenia*)*



▲ Saccharomyces cerevisiae, *the yeast used to raise bread dough, is a unicellular ascomycete that reproduces asexually by budding.*

Zygomycetes

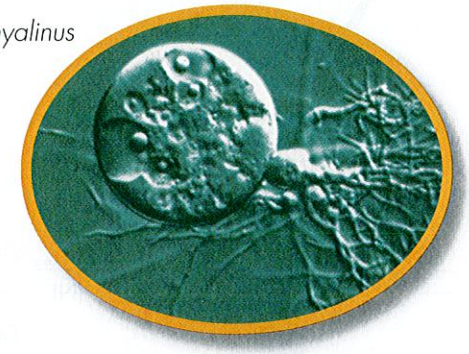
The hyphae of zygomycetes generally lack cross walls between cells. Zygomycetes get their name from the sexual phase of their reproductive cycle, which involves a structure called a zygosporangium that forms between the hyphae of two different mating types. One group within the zygomycetes, the Glomales, form symbiotic mycorrhizae (my koh RY zee) with plant roots.

This micrograph shows mycorrhizal fungi in symbiosis with soybean roots. The soybean plant provides nutrient sugars to the fungus, while the fungus provides water and essential minerals to the plant. (SEM 200×)

The fruiting body of the common black bread mold, Rhizopus stolonifer (SEM 450×)

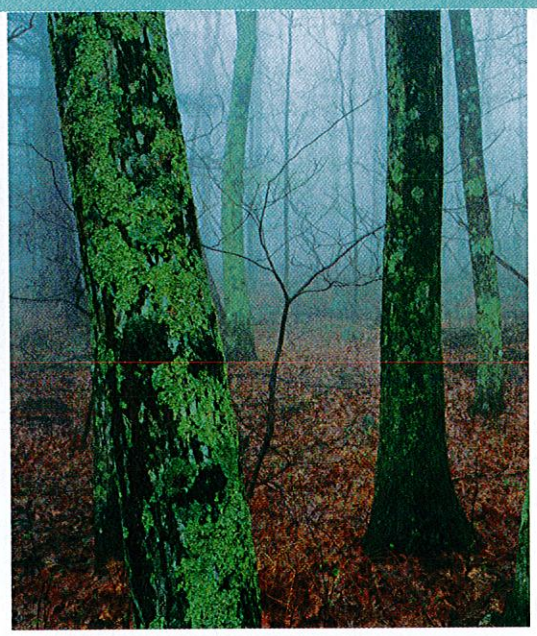
Chytrids

Members of this phylum live in water or moist soil. Their reproductive cells have flagella, making them the only fungi known to have a motile stage to their life cycle. Chytrids are especially good at digesting cellulose, the material of plant cell walls—some live in the digestive systems of cows and deer, helping them to digest plant matter. Others are pathogens—certain chytrids have recently been associated with the decline of frog populations around the world. About 1000 species are known, many of them recently discovered.



Chytriomyces hyalinus (LM 500×)

Eco•Alert



Lichen-covered oak trees in Shenandoah National Park, Virginia

Look to the Lichens

Lichens as Bio-Indicators

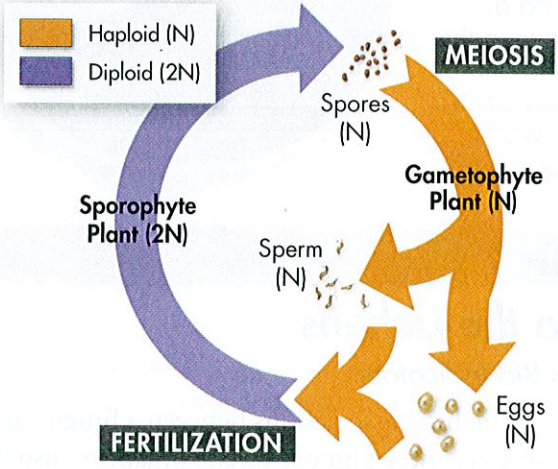
Lichens are mutualistic associations between a fungus, usually an ascomycete, and a photosynthetic organism, usually an alga. They are incredibly durable, and have even been reported to survive in the vacuum of space. However, they are also incredibly sensitive indicators of the state of the atmosphere. In particular, when sulfur dioxide is released into the atmosphere, it often reacts with water to form acids (including sulfuric acid) that pollute rainfall. Lichens can be severely damaged by acidic rainfall, although the degree of damage depends on the substrate upon which they grow. Lichens disappear first from the bark of pine and fir trees, which are themselves somewhat acidic. Lichens on elms, which have alkaline bark, are the last to go. By careful monitoring of the health of lichen populations of various trees, scientists can uses these remarkable organisms as low-tech monitors for the health of the environment.

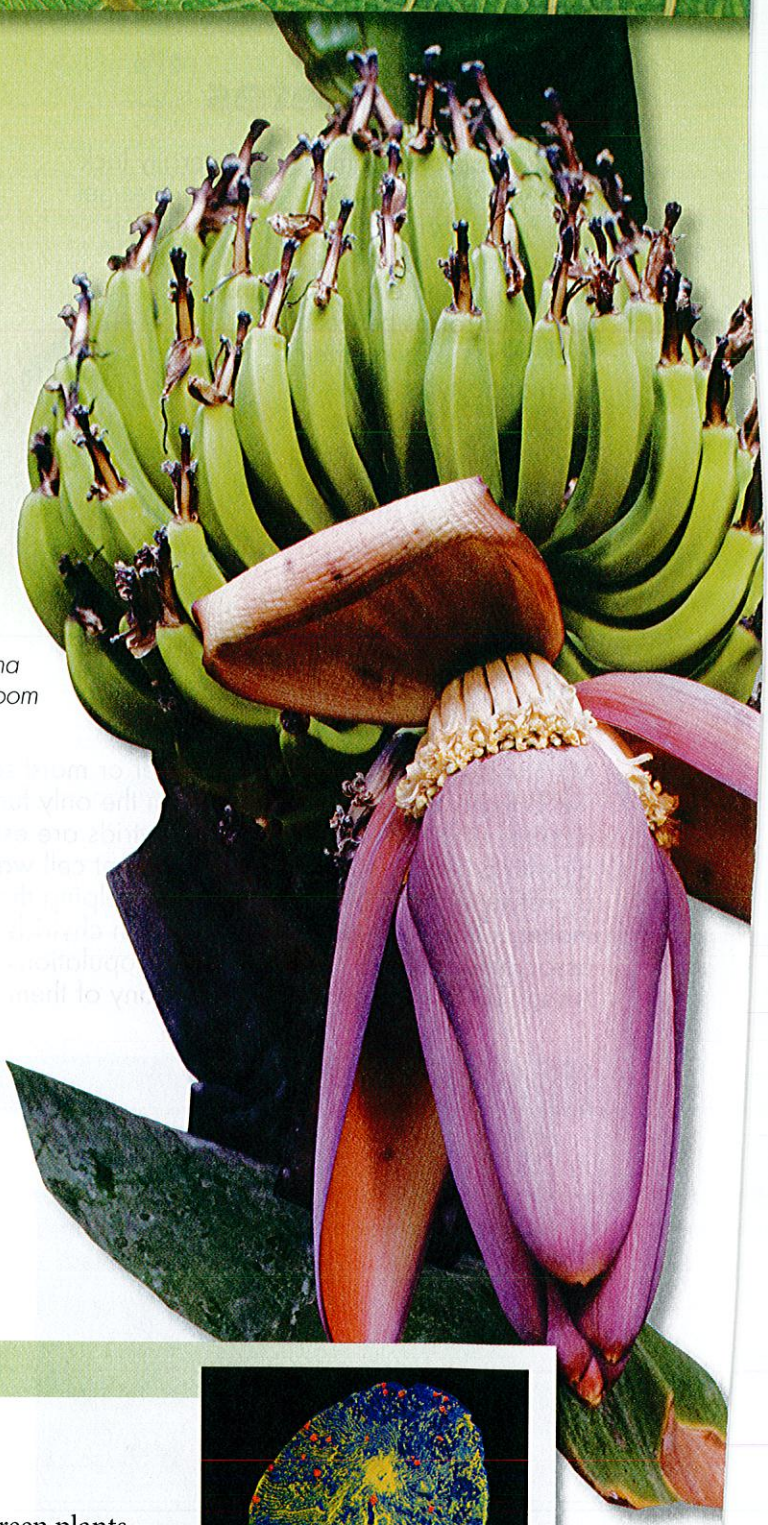
Plants

KEY CHARACTERISTICS

Plants are eukaryotes with cell walls composed of cellulose. Plants carry out photosynthesis using the green pigments chlorophyll a and b, and they store the products of photosynthesis as starch.

▼ *A typical plant life cycle*





▶ *A banana plant in bloom*

•A Closer Look

Prokaryotes Within

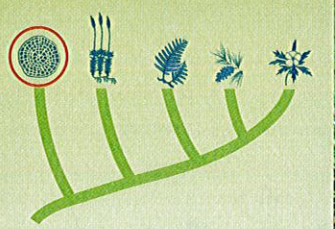
The Origins of Chloroplasts

Chloroplasts, which contain their own DNA, are found in all green plants, but where did they come from? In 1905, the Russian botanist Konstantin Mereschkowsky, noticing the similarities between chloroplasts and cyanobacteria, proposed that these organelles originated from a symbiotic relationship formed with the ancestors of today's plants.

This hypothesis still holds up very well today. New DNA studies suggest that all chloroplasts are descended from a single photosynthetic prokaryote, closely related to today's cyanobacteria.

The photosynthetic membranes (shown in green) visible in this thin section of a cyanobacterium resemble the thylakoid membranes of plant cell chloroplasts. (TEM 14,000×)

Green Algae



KEY CHARACTERISTICS

The green algae are plants that do not make embryos. All other plants form embryos as part of their life cycle. The green algae include both unicellular and multicellular species, and they are primarily aquatic.

Organization Single cells, colonies, and a few truly multicellular species

Movement Many swim using whiplike flagella.

Water Transport Water diffuses in from the environment.

Reproduction Asexual and sexual, with gametes and spores; some species show alternation of generations.

▲ *Clumps of* Spirogyra, *a filamentous green alga, are commonly called water silk or mermaid's tresses.*

GROUPS OF GREEN ALGAE

The three most diverse groups of green algae are profiled below.

CHLOROPHYTES: Classic green algae

These algae usually live as single cells, like *Chlamydomonas*, or in colonies, like *Volvox*. They are found in both fresh and salt water, and some species are even known to live in arctic snowbanks.

▶ Chlamydomonas *is a unicellular green alga. Each cell has two flagella, which are used in movement.* (SEM 3000×)

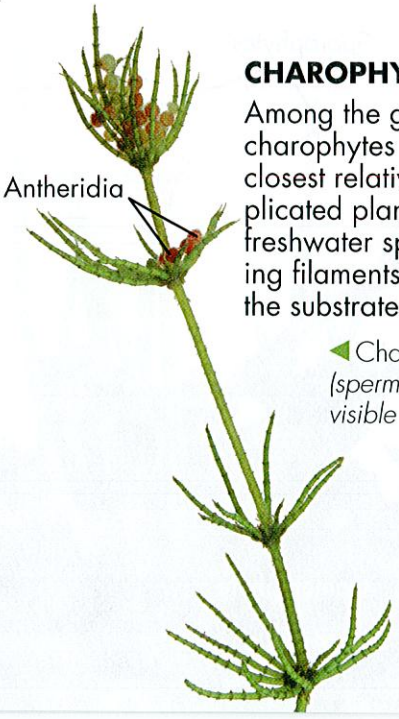
ULVOPHYTES: Sea lettuces

The ulvophytes are large organisms composed of hundreds or thousands of cells. Most form large, flattened green sheets and are often simply called seaweed. They show both haploid and diploid phases in their life cycle, but in many species, such as the common sea lettuce, *Ulva*, it is difficult to tell the two phases apart.

▼ *Ulva lactuca*

CHAROPHYTES: Stoneworts

Among the green algae, the charophytes (KAHR uh fyts) are the closest relatives of more complicated plants. They are mostly freshwater species. Their branching filaments may be anchored to the substrate by thin rhizoids.

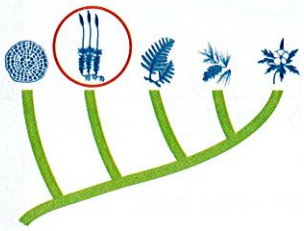


◀ Chara *with antheridia (sperm-producing structures) visible*

Bryophytes

KEY CHARACTERISTICS

Bryophytes (BRY oh fyts), found mostly on land, are multicellular plants that lack true vascular tissue. This lack of vascular tissue limits their height to just a few centimeters and restricts them to moist soils.

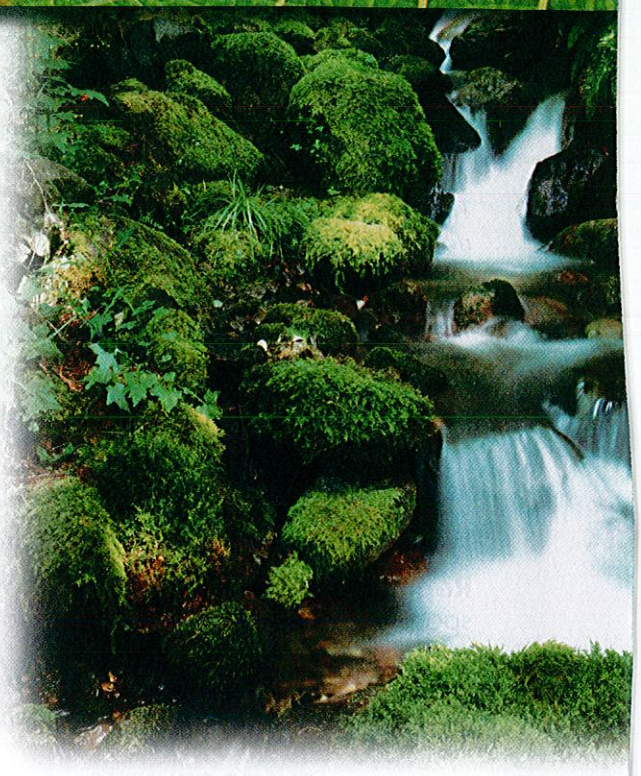


Organization Complex and specialized tissues, including protective external layers and rhizoids

Movement Adults stationary; male gametes swim to egg cells using flagella.

Water Transport Diffusion from cell to cell; in some mosses, water flows through specialized tissue.

Reproduction All reproduce sexually with alternation of generations, producing gametes and spores. Most reproduce asexually, too. The gametophyte stage is dominant, with the sporophyte stage dependent on the gametophyte.



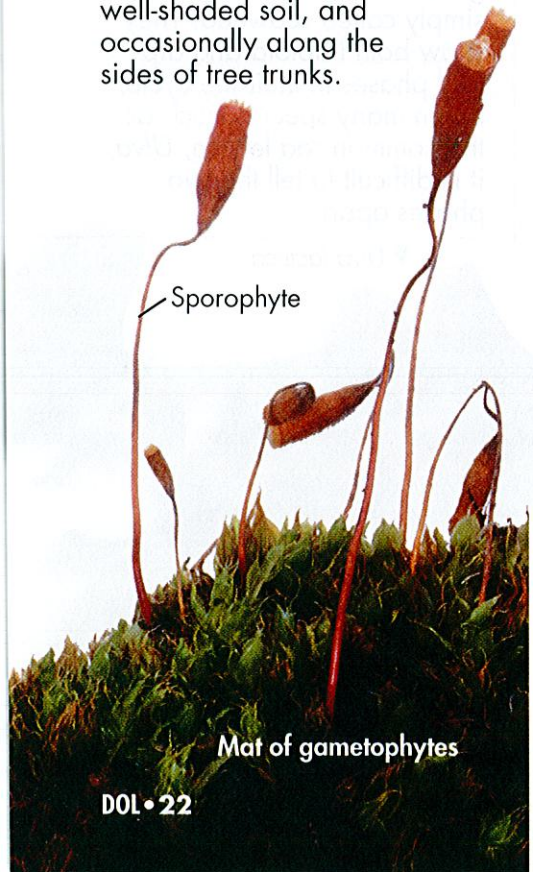
▲ *Mosses thrive in shady, damp locations, such as along the banks of this Oregon creek.*

GROUPS OF BRYOPHYTES

Although they are listed together here, the three major groups of bryophytes are now considered to have evolved independently from each other.

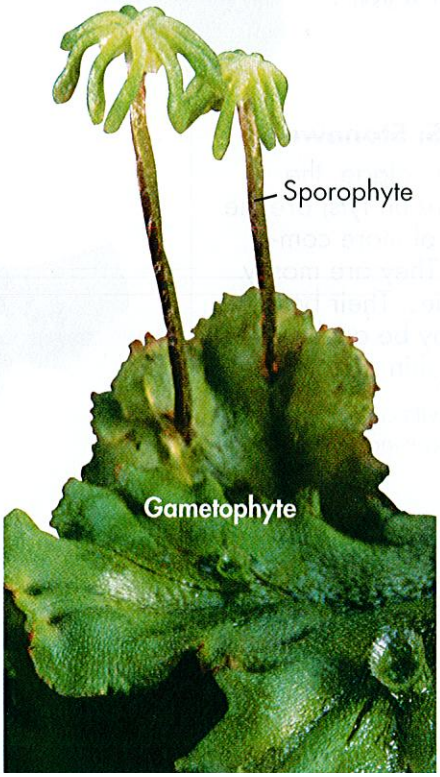
MOSSES: Classic bryophytes

Mosses are found on damp, well-shaded soil, and occasionally along the sides of tree trunks.



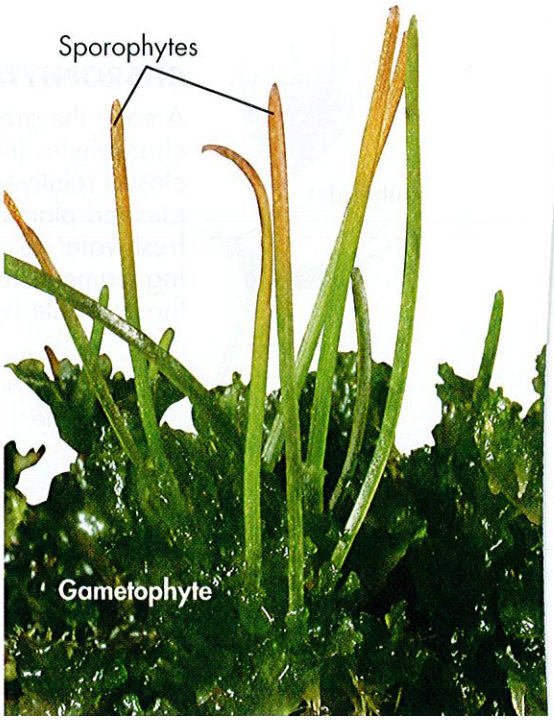
LIVERWORTS

Liverworts are flat, almost leaf-like plants that grow on the damp forest floor. Some species are shaped almost like the liver, from which they get their name.



HORNWORTS

Hornworts get their name from their sporophytes, tiny green structures resembling horns. Like other bryophytes, hornworts are found mostly in damp, well-shaded areas. Only about 100 species are known.



Seedless Vascular Plants

KEY CHARACTERISTICS

This informal grouping lumps together all the plants that have true vascular tissue but lack seeds. Vascular tissue is a key adaptation to life on land. By carrying water and food throughout plant structures, vascular tissue permitted the evolution of roots and tree-size plants, and it allowed plants to spread into dry areas of land.

Organization Complex and specialized tissues, including true roots, stems, and leaves

Movement Adults stationary; male gametes swim to egg cells using flagella.

Water Transport Through vascular tissue

Reproduction Alternation of generations, producing spores, eggs, and swimming sperm; the sporophyte stage is dominant, but the sporophyte is not dependent on the gametophyte as it is in bryophytes.

GROUPS OF SEEDLESS VASCULAR PLANTS

Besides the flowering plants, these organisms make up the most diverse collection of land plants, with more than 10,000 known species.

FERNS

Ferns are common and abundant. Because they need standing water to reproduce, ferns are generally found in areas that are damp at least part of the year. The sporophyte phase of the life cycle is dominant. Spores are produced in prominent clusters known as sori (SOH ry) on the undersides of leaves.

▼ *Polypodium vulgare*

CLUB MOSSES

Not really mosses, these vascular plants are also called lycopods (LY koh pahdz). These plants were especially abundant during the Carboniferous Period 360 to 290 million years ago, when they grew as large as trees. Today, their remains make up a large part of coal deposits mined for fuel.

▼ *The small club moss known as* Lycopodium *can be found growing on the forest floor throughout the temperate regions of North America. They look like tiny pine trees at first glance, but they are, in fact, small, seedless plants.*

HORSETAILS

Only a single living genus of horsetails is known, *Equisetum* (ek wi SEET um). These plants were thought to resemble horses' tails; their name is derived from this perception. Today, only 25 species are known, confined to wet areas of soil. But horsetails were once much more diverse, larger in size, and abundant. Abrasive silica, found in many horsetails, was used in colonial times as a scouring powder to help clean pots and pans.

▼ *Equisetum*

Gymnosperms

KEY CHARACTERISTICS

Gymnosperms are seed-bearing vascular plants whose seeds are exposed to the environment, rather than being enclosed in a fruit. The seeds are usually located on the scales of cones.

Organization True roots, stems, and leaves

Movement Adults stationary; within pollen grains, male gametophytes drift in air or are carried by animals to female structures, where they release sperm that move to eggs.

Water Transport Through vascular tissue

Reproduction Sexual; alternation of generations; the sporophyte stage is dominant. Female gametophytes live within the parent sporophyte. Pollen grains carry sperm to eggs, so open water is not needed for fertilization.

▶ ***Some bristlecone pines are thousands of years old, like this one growing in Nevada.***

Did You Know?

Rising From the Ashes

Fire's Role in Seed Germination

We generally think of forest fires as being natural disasters, and that's typically true. Some gymnosperm species, however, are so well adapted to the arid conditions of the American West that they actually depend upon such fires to spread their seeds.

The best-known example is the Jack Pine, *Pinus banksiana*. Its seed cones are thick and heat resistant. When engulfed in a fire, its seeds escape damage. The fire's high heat helps to open the outer coat of the cone, enabling the seeds to pop out afterward. As a result, Jack Pines are among the very first plants to repopulate a forest that has been damaged by fire.

▲ *The high heat of a forest fire opens the cones of the Jack Pines, releasing their seeds. The inset shows a Jack Pine seedling growing in the charred remains of the fire.*

GROUPS OF GYMNOSPERMS

There are four groups of gymnosperms, representing about 800 species in total.

CONIFERS

Conifers are by far the most diverse group of living gymnosperms, represented by nearly 700 species worldwide. They include the common pine, spruce, fir, and redwood trees that make up a large share of the forests in the temperate regions of the world. Conifers have enormous economic importance. Their wood is used for residential building, to manufacture paper, and as a source of heat. Compounds from their resins are used for a variety of industrial purposes.

▲ *Most conifers retain their leaves year-round.*

CYCADS

Cycads (SY kads) are beautiful palmlike plants that have large cones. Cycads first appeared in the fossil record during the Triassic Period, 225 million years ago. Huge forests of cycads thrived when dinosaurs roamed Earth. Today, only nine genera of cycads exist. Cycads can be found growing naturally in tropical and subtropical places such as Mexico, the West Indies, Florida, and parts of Asia, Africa, and Australia.

▶ *A Sago Palm,* Cycas revoluta

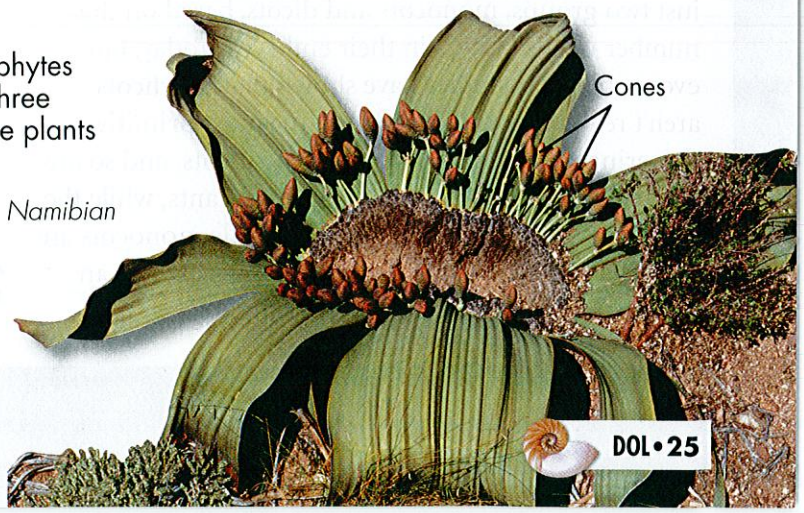
▲ *Ginkgoes are often planted in urban settings, where their toughness and resistance to air pollution make them popular shade trees.*

GINKGOES

Ginkgoes (GING kohs) were common when dinosaurs were alive, but today the group contains only one species, *Ginkgo biloba*. The living *Ginkgo* species looks similar to its fossil ancestors—in fact, *G. biloba* may be one of the oldest seed plant species alive today.

GNETOPHYTES

About 70 present-day species of gnetophytes (NET oh fyts) are known, placed in just three genera. The reproductive scales of these plants are clustered in cones.



▶ Welwitschia mirabilis, *an inhabitant of the Namibian desert in southwestern Africa, is one of the most remarkable gnetophytes. Its huge leathery leaves grow continuously and spread across the ground.*

Angiosperms

KEY CHARACTERISTICS

Angiosperms are plants that bear seeds in a closed ovary. The ovary is part of a reproductive organ known as a flower. Seeds are formed in a double fertilization event, which forms a diploid embryo and a triploid endosperm tissue. As seeds mature, ovaries develop into fruits that help to disperse the seeds.

Organization True roots, stems, and leaves

Movement Adults stationary; within pollen grains, male gametophytes drift in air or are carried by animals to female structures, where they release sperm that move to eggs.

Water Transport Through vascular tissue

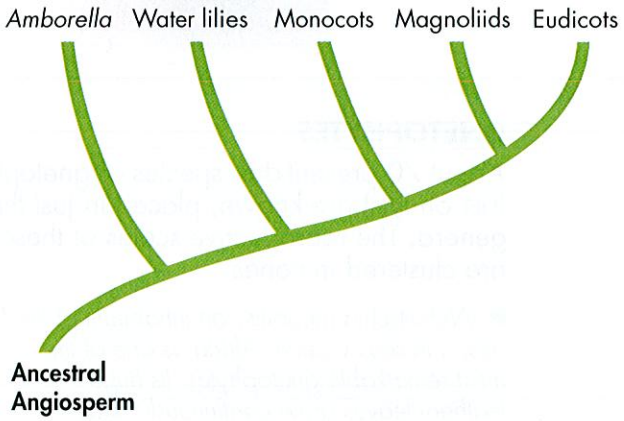
Reproduction Sexual, with alternation of generations; also asexual. The sporophyte stage is dominant. Female gametophytes live within the parent sporophyte. Pollen carries sperm to eggs, so open water is not needed for fertilization.

▶ *A Southern Long-Nosed Bat pollinates the Saguaro Cactus,* Carnegia gigantea, *while collecting nectar from its blossoms.*

A Closer Look

Whatever Happened to Monocots and Dicots?

Traditionally, flowering plants have been divided into just two groups, monocots and dicots, based on the number of seed leaves in their embryos. Today, however, molecular studies have shown that the dicots aren't really one group. Some of the most primitive flowering plants (like *Amborella*) are dicots, and so are some of the most advanced flowering plants, while the monocots fall right in between. So, while monocots are indeed a single group, the term *dicots* is now just an informal, though still useful, grouping.



GROUPS OF ANGIOSPERMS

The great majority of plant species—over 260,000-–are angiosperms.

▲ *Water lilies are aquatic plants that produce flowers and leaves, which float on the surface of the water.*

NYMPHAEACEAE: Water lilies

About 50 species of water lilies are known, and they are of special interest to plant taxonomists. Their DNA and flower structure suggest that they are, along with *Amborella*, one of the earliest groups to have split off from the main line of flowering plant evolution. Examples of water lilies are found throughout the world.

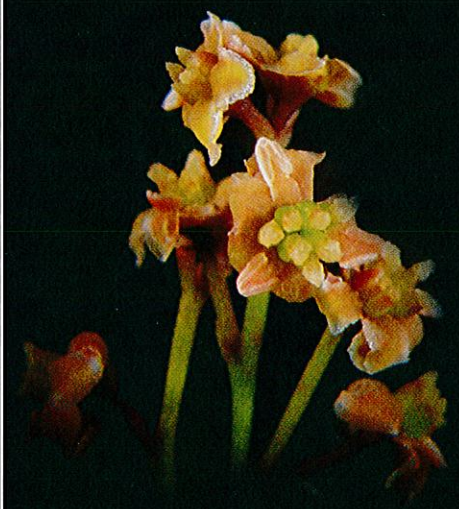
MAGNOLIIDS:
Magnolia trees and others

The most famous genus of these plants is *Magnolia*, which includes nearly 200 species. Laurels and tulip poplars are also magnoliids (mag NOH lee ids). Because of their flower structure, magnoliids were once thought to be nearly as primitive as water lilies. Genetic studies now suggest that they split off from the rest of the angiosperm line after monocots and, therefore, do not represent the earliest flowering plants.

▼ *The Tulip Poplar is a long, straight tree often used as wood for telephone poles. Its flowers are greenish and shaped like tulips.*

AMBORELLA

Amborella does not represent a group of plants but instead just a single species found only on the island of New Caledonia in the South Pacific Ocean. DNA studies show that *Amborella* is equally separated from all other flowering plants living today, suggesting that it is descended from plants that split off from the main line of flowering plant evolution as long ago as 100 million years.



▲ *The flowers of* Amborella trichopoda *are simpler than those of most other plants, and the species has a number of features that place it at the very base of flowering plant evolution.*

▶ *Magnolia trees produce conspicuous flowers, which contain multiple stamens and multiple pistils.*

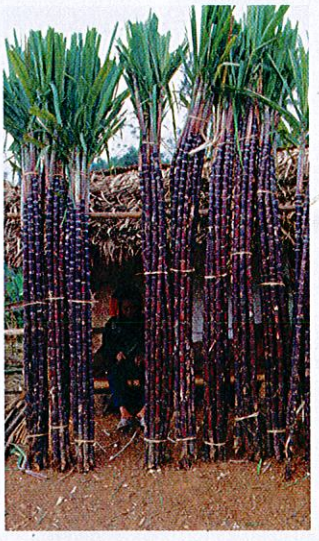
GROUPS OF ANGIOSPERMS CONTINUED...

MONOCOTS

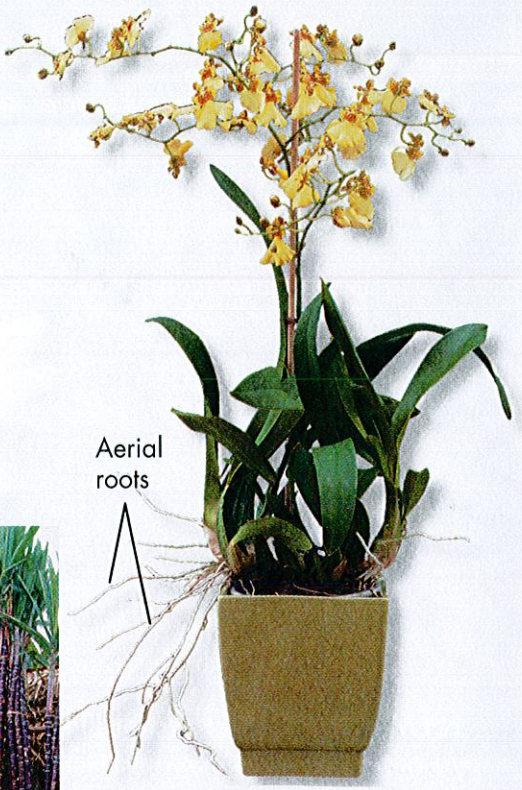
The monocots include an estimated 65,000 species, roughly 20 percent of all flowering plants. They get their name from the single seed leaf found in monocot embryos, and they include some of the plants that are most important to human cultures. Monocots grown as crops account for a majority of the food produced by agriculture. These crops include wheat, rice, barley, corn, and sugar cane. Common grasses are monocots, as are onions, bananas, orchids, coconut palms, tulips, and irises.

▲ *Onions are just one of many examples of monocot crop species.*

▲ *This African hillside is dotted with clumps of Wild Pampas Grass.*



◀ *This sugar cane in Vietnam has been bundled for sale.*



▲ *Many orchid species are grown by enthusiasts for their rare beauty. Notice the aerial roots on this specimen, which grows as an epiphyte in its natural environment.*

Eco • Alert

Coevolution: Losing the Pollinators

The successes of flowering plants are clearly due to coevolution with their insect pollinators. Common honey bees are among the most important of these, gathering nectar from the flowers of hundreds of plant species and spreading pollen from plant to plant as they go.

Unfortunately, beekeepers around the world, including the United States, are facing a serious crisis. "Colony collapse disorder," as beekeepers describe it, causes bees to fly away from the hive and either never return, or return only to weaken and die. The disease threatens to affect scores of important crops, which depend upon bees to produce fruit and seeds. Suspicion has centered on a fungus or a virus that might spread from colony to colony, but at this point there is no definitive cause or cure.

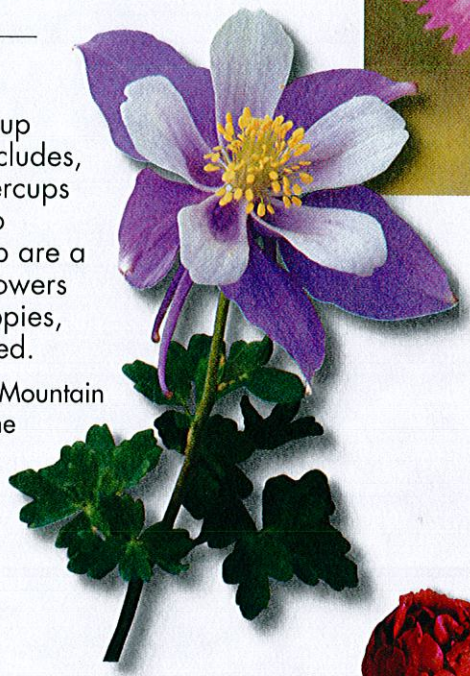
EUDICOTS: "TRUE DICOTS"

Eudicots (YOO dy kahts) account for about 75 percent of all angiosperm species. The name means "true dicots," and these plants are the ones usually given as examples of dicot stem, leaf, and flower structure. Eudicots have distinctive pollen grains with three grooves on their surfaces, and DNA studies strongly support their classification in a single group. They include a number of important subgroups, five of which are described here.

▲ Clusterhead Pinks

Ranunculales

The ranunculales subgroup (ruh NUNH kyu lay les) includes, and is named after, buttercups (genus *Ranunculus*). Also included in this subgroup are a number of well-known flowers such as columbines, poppies, barberries, and moonseed.



▶ Rocky Mountain Columbine

Caryophyllales

Cacti are probably the most well-known plants in the caryophyllales subgroup (KAR ee oh fy lay les). Pinks and carnations, spinach, rhubarb, and insect-eating plants, such as sundews and pitcher plants, are also members.

Saxifragales

Plants in the saxifragales (SAK suh frij ay les) subgroup include peonies, witch hazel, gooseberries, and coral bells.

◀ Peony

▲ Orange

Rosids

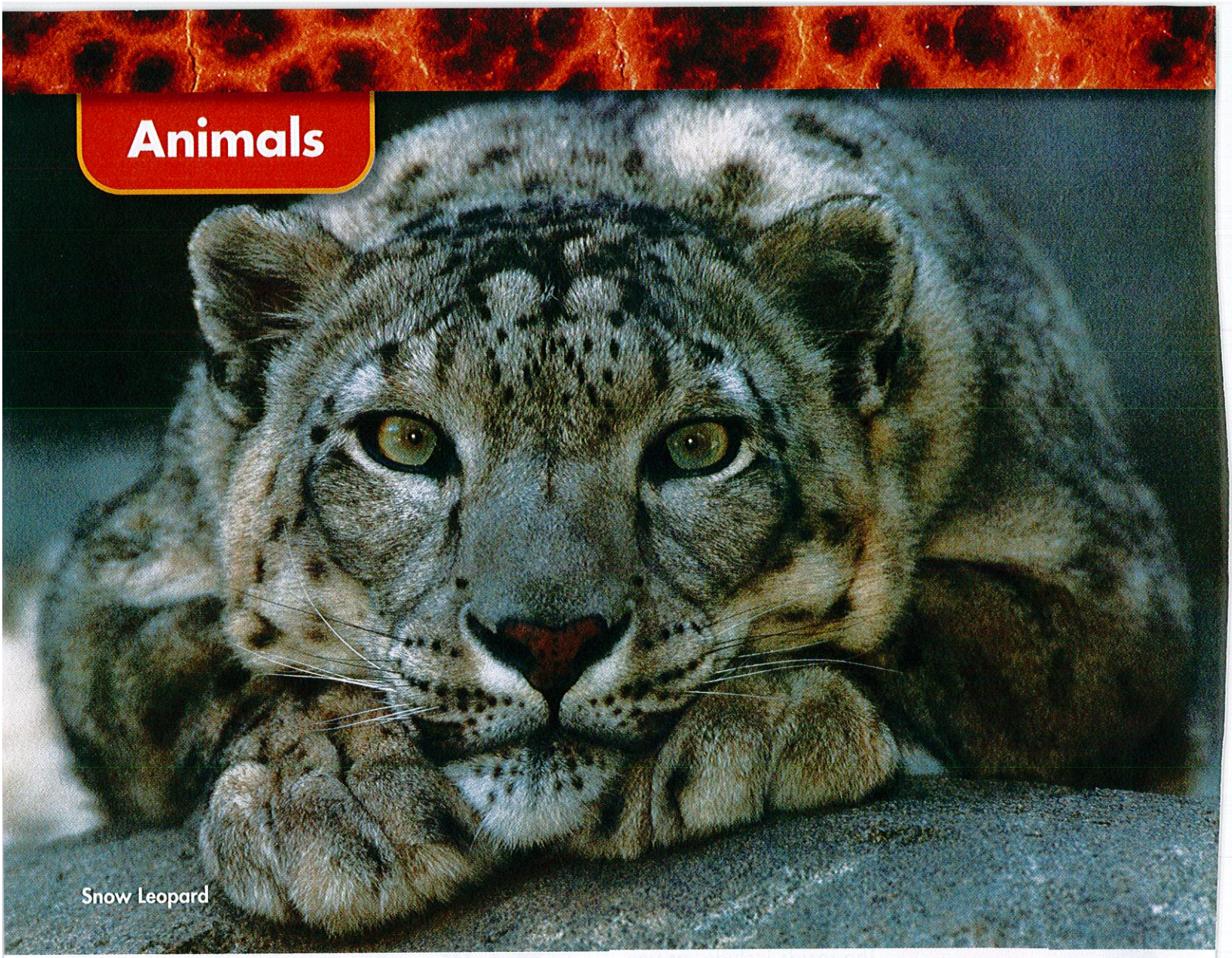
The rosids include, as you might expect, the roses. However, this subgroup also includes many popular fruits, such as oranges, raspberries, strawberries, and apples. Some of the best-known trees, including poplars, willows, and maples, are also members.

Asterids

The nearly 80,000 asterid species include sunflowers, azaleas, snapdragons, blueberries, tomatoes, and potatoes.

▼ *The flower heads in a field of sunflowers all track the sun as it moves across the sky; thus, they all face the same direction.*

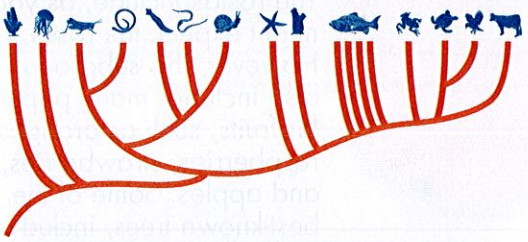
Animals



Snow Leopard

KEY CHARACTERISTICS

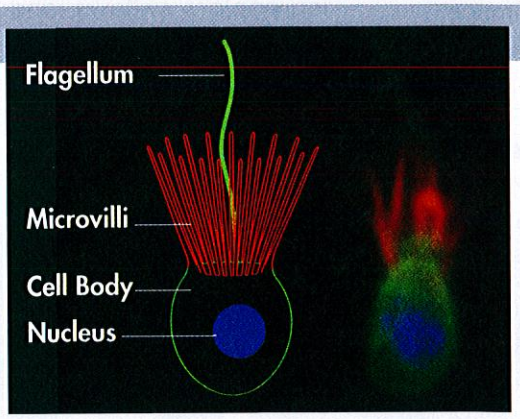
Animals are multicellular, heterotrophic, eukaryotic organisms whose cells lack cell walls.



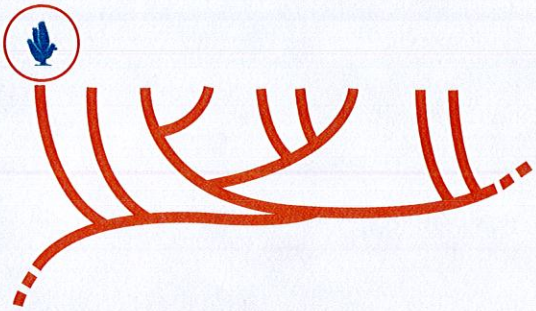
•A Closer Look

A Common Ancestor

Recent molecular studies and cladistic analyses recognize the clade Choanozoa to be the true sister group to all Metazoa—multicellular animals. Choanozoa is one group of organisms formerly called "protists" and is named for choanoflagellates (art and photo right), single-celled, colonial organisms that look like certain cells of sponges and flatworms. Current thinking suggests that the choanoflagellates alive today are the best living examples of what the last common ancestor of metazoans looked like.



Porifera (Sponges)



KEY CHARACTERISTICS

Sponges are the simplest animals. They are classified as animals because they are multicellular, heterotrophic, lack cell walls, and have some specialized cells. They are aquatic, lack true tissues and organs, and have internal skeletons of spongin and/or spicules of calcium carbonate or silica. Sponges have no body symmetry.

Feeding and Digestion Filter feeders; intracellular digestion.

Circulation Via flow of water through body

Respiration Oxygen diffuses from water into cells as water flows through body.

Excretion Wastes diffuse from cells into water as water flows through body.

Response No nervous system; little capacity to respond to environmental changes.

Movement Juveniles drift or swim freely; adults are stationary.

Reproduction Most—sexual with internal fertilization; water flowing out of sponge disperses sperm, which fertilizes eggs inside sponge(s); may reproduce asexually by budding or producing gemmules.

GROUPS OF SPONGES

There are more than 5000 species of sponges; most are marine. Three major groups are described below.

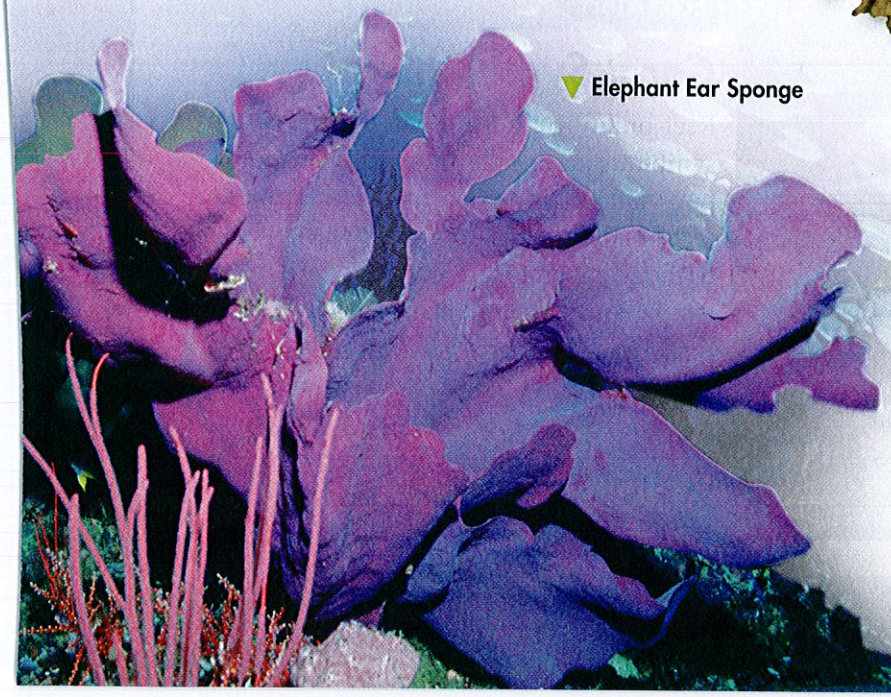
DEMOSPONGIAE: Typical sponges

More than 90 percent of all living sponge species are in this group, including the few freshwater species. They have skeletons made of spongin, a flexible protein. Some species have silica spicules. Examples: Yellow Sponge, bath sponges, Carnivorous Mediterranean Sponge, tube sponges

◀ Cloud Sponge

HEXACTINELLIDA: Glass sponges

Glass sponges live in the deep ocean and are especially abundant in the Antarctic. They are called "glass" sponges because their skeletons are made of glasslike silica spicules. Examples: Venus's Flower Basket, Cloud Sponge



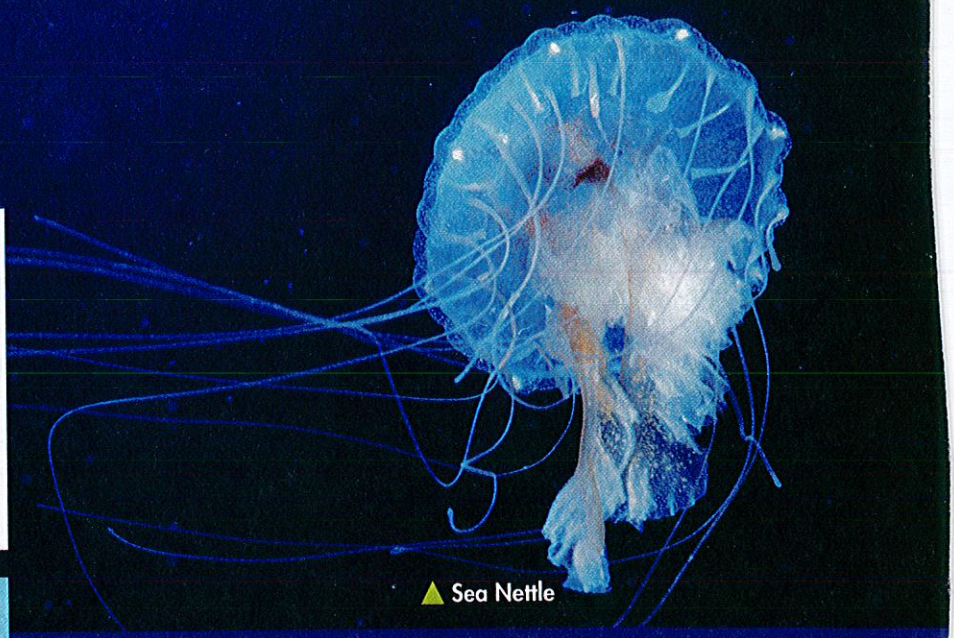
▼ Elephant Ear Sponge

CALCAREA: Calcareous sponges

Calcareous sponges live in shallow, tropical marine waters and are the only sponges with calcium carbonate spicules. Example: *Clathrina*

Yellow Tubular Sponge ▶

Cnidarians



▲ Sea Nettle

KEY CHARACTERISTICS

Cnidarians are aquatic, mostly carnivorous, and the simplest animals to have specialized tissues (outer skin and lining of the gastrovascular cavity) and body symmetry (radial). Their tentacles have stinging cells called nematocysts used in feeding.

Feeding and Digestion Predatory, stinging prey with nematocysts; digestion begins extracellularly in gastrovascular cavity and is completed intracellularly; indigestible materials leave body through single opening; many, especially reef-building corals, also depend on symbiotic algae, or zooxanthellae.

Circulation No internal transport system; nutrients typically diffuse through body.

Respiration Diffusion through body walls

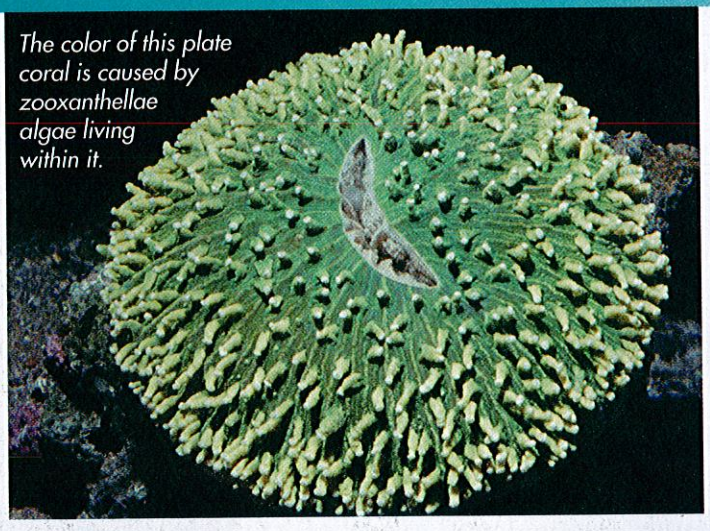
Excretion Cellular wastes diffuse through body walls.

Response Some specialized sensory cells: nerve cells in nerve net, statocysts that help determine up and down, eyespots (ocelli) made of light-detecting cells

Movement Polyps stationary, medusas free-swimming; some, such as sea anemones, can burrow and creep very slowly; others move using muscles that work with a hydrostatic skeleton and water in gastrovascular cavity; medusas such as jellyfish move by jet propulsion generated by muscle contractions.

Reproduction Most—alternate between sexual (most species by external fertilization) and asexual (polyps produce new polyps or medusae by budding)

Eco•Alert



The color of this plate coral is caused by zooxanthellae algae living within it.

Coral Symbionts

Reef-building coral animals depend on symbiotic algae called zooxanthellae for certain vital nutritional needs. In many places, reef-building corals live close to the upper end of their temperature tolerance zone. If water temperatures rise too high, the coral-zooxanthellae symbiosis breaks down, and corals turn white in what is called "coral bleaching." If corals don't recover their algae soon, they weaken and die. This is one reason why coral reefs are in grave danger from global warming.

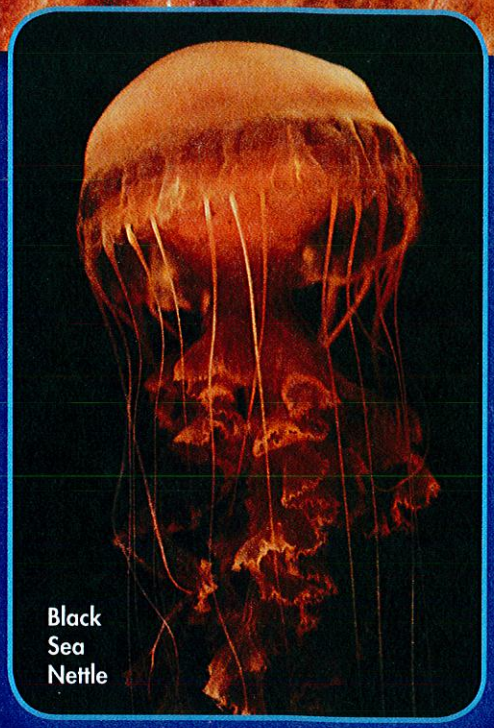
GROUPS OF CNIDARIANS

There are more than 9000 species of cnidarians.

A Portuguese Man-of-War is actually a colony of polyps.

HYDROZOA: Hydras and their relatives

Hydras and their relatives spend most of their time as polyps and are either colonial or solitary. They reproduce asexually (by budding), sexually, or they alternate between sexual and asexual reproduction. Examples: hydra, Portuguese Man-of-War



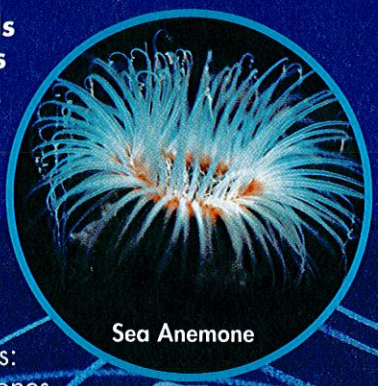
Black Sea Nettle

SCYPHOZOA: Jellyfishes

Jellyfishes spend most of their time as medusas; some species bypass the polyp stage. They reproduce sexually and sometimes asexually by budding. Examples: Lion's Mane Jellyfish, Moon Jelly, Sea wasp

ANTHOZOA: Corals and sea anemones

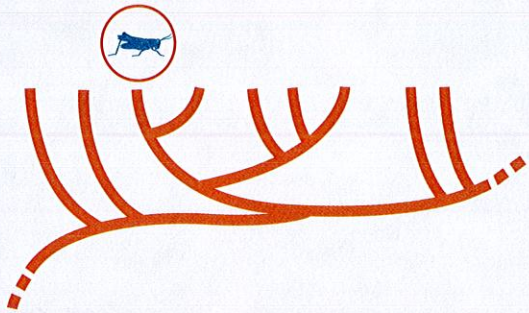
Corals and sea anemones are colonial or solitary polyps with no medusa stage. The central body is surrounded by tentacles. They reproduce sexually or asexually. Examples: reef corals, sea anemones, sea pens, sea fans



Sea Anemone

Jellyfishes such as this sea nettle are beautiful to us but deadly to their prey. The stinging cells on their tentacles can kill prey instantly and can ruin a human swimmer's day at the beach!

Arthropods



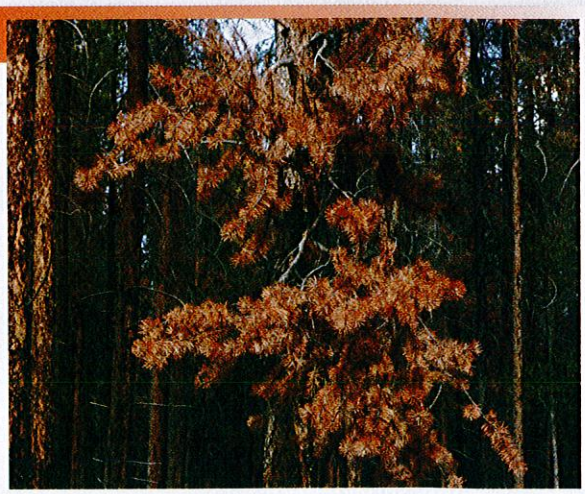
KEY CHARACTERISTICS

Arthropods are the most diverse of all multicellular organisms. They have segmented bodies and jointed appendages. They are supported by tough exoskeletons made of chitin, which they periodically shed as they grow. Arthropods are coelomate protostomes with bilateral symmetry.

Eco • Alert

Beetle Damage

You probably know that some insects can seriously damage crop plants. But insects affect plants in natural habitats, too. One example is the mountain pine beetle, which is dramatically extending its range. Global warming appears to be enabling the beetle to survive farther north, and at higher altitudes, than it used to. The new beetle infestation is causing extensive damage to northern and high-altitude forests in North America. The death of millions of acres of trees has resulted in the release of large amounts of carbon dioxide, a greenhouse gas, into the atmosphere. You can see the sort of damage the beetles cause in the photo at right.



▲ *Mountain pine beetle damage to pine trees in White River National Forest, Colorado*

Feeding and Digestion Extremely diverse: herbivores, carnivores, detritivores, parasites, bloodsuckers, scavengers, filter feeders; digestive system with two openings; many feeding specializations in different groups

Circulation Open circulatory system with heart and arteries

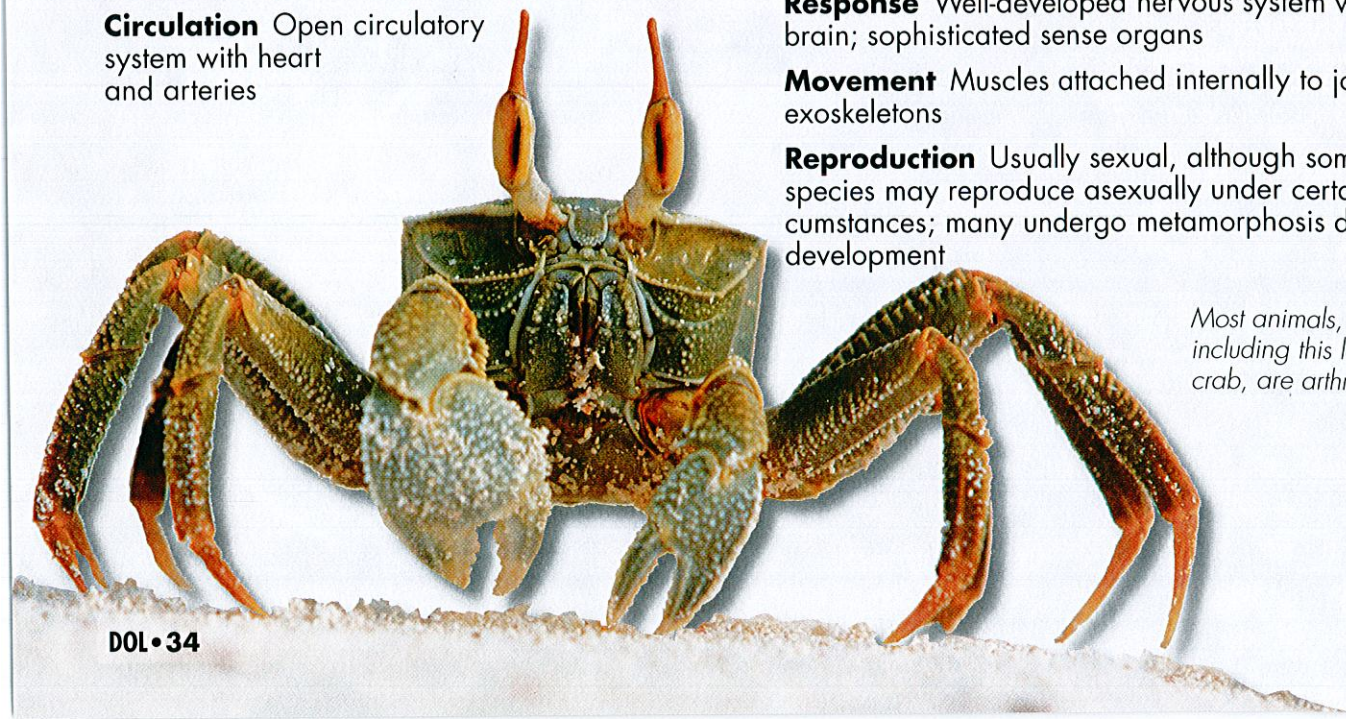
Respiration Terrestrial—tracheal tubes or book lungs; aquatic—gills or book gills (horseshoe crabs)

Excretion Terrestrial—Malpighian tubules; aquatic—diffusion into water

Response Well-developed nervous system with brain; sophisticated sense organs

Movement Muscles attached internally to jointed exoskeletons

Reproduction Usually sexual, although some species may reproduce asexually under certain circumstances; many undergo metamorphosis during development



Most animals, including this land crab, are arthropods.

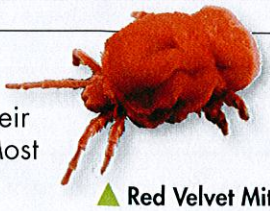
GROUPS OF ARTHROPODS

Phylum Arthropoda contains more known species than any other phylum. Scientists have identified more than 1,000,000 arthropod species, and some scientists expect there are millions yet to be identified. Arthropods are classified based on the number and structure of body segments and appendages.

▲ Lobster

CRUSTACEA: Crustaceans

There are crustacean species in almost every habitat, but most are aquatic, and most of these are marine. They have two or three body sections, two pairs of antennae, and chewing mouthparts called mandibles. Many have a carapace, or "shell," that covers part or all of the body. Examples: crabs, lobsters, crayfish, pill bugs, water fleas, barnacles



▲ Red Velvet Mite

CHELICERATA: Chelicerates

Living chelicerates include horseshoe crabs and arachnids. (Their extinct relatives include trilobites and giant "sea-scorpions.") Most living chelicerates are terrestrial. The body is composed of two parts—the cephalothorax and abdomen. The first pair of appendages are specialized feeding structures called chelicerae. Chelicerates have no antennae.

Horseshoe crabs are actually more closely related to spiders than to crabs!

Merostomata: Horseshoe crabs

The class Merostomata once included many species, but only four species of horseshoe crab survive today. All are marine. They have five pairs of walking legs and a long, spinelike tail.

Arachnida: Arachnids

The vast majority of arachnids are terrestrial. They have four pairs of walking legs and no tail. Examples: spiders, ticks, mites, scorpions, daddy longlegs

▲ Mexican Beauty Tarantula

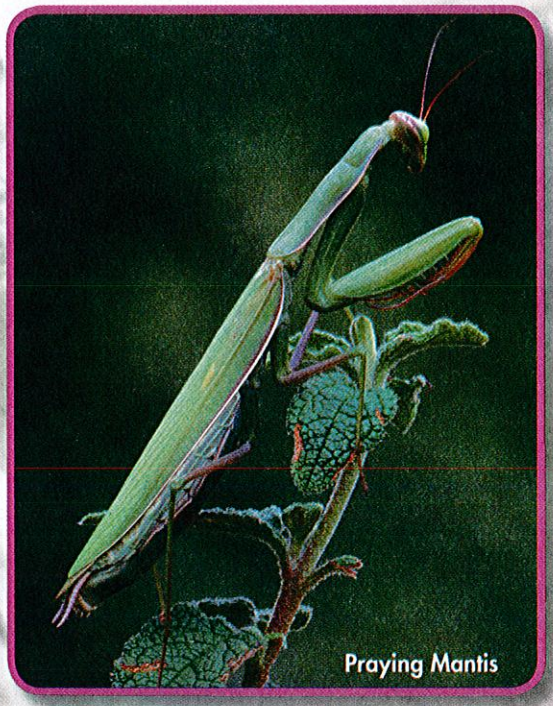
UNIRAMIA: Uniramians

Most uniramians are terrestrial, although some are aquatic for all or part of their lives. They have one pair of antennae, mandibles, and unbranched appendages. Uniramians include at least three fourths of all known animal species!

Uniramians include centipedes, millipedes, and insects—more than three fourths of all known animal species, including this Elephant Hawk Moth.

Insecta: Insects

There are more than 1,000,000 insect species in more than 25 orders. An insect body is divided into three parts—head, thorax, and abdomen. Insects have three pairs of legs and usually one or two pairs of wings attached to the thorax. Some insects undergo complete metamorphosis. Examples: termites, ants, beetles, dragonflies, flies, moths, grasshoppers



Praying Mantis

The Death's-Head Hawk Moth is named for the skull-like shape on the adult's head (above). Like many insects, this moth undergoes complete metamorphosis, during which the larva (below), or caterpillar, turns into a pupa, and, eventually, an adult.

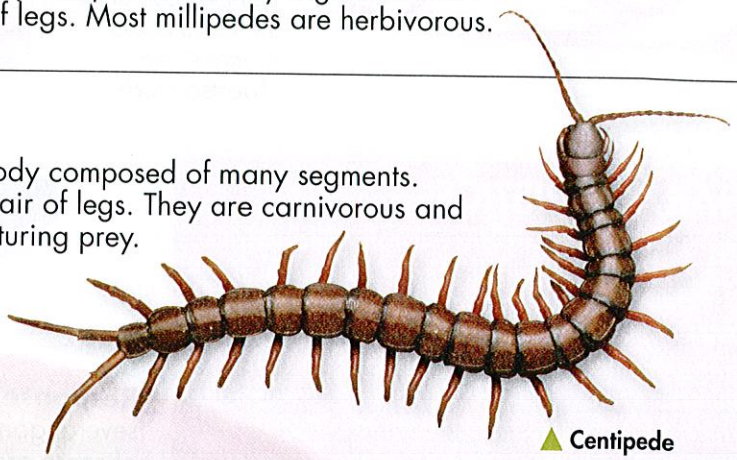
▼ Giant Millipede

Diplopoda: Millipedes

Millipedes have a long body composed of many segments. Each segment bears two pairs of legs. Most millipedes are herbivorous.

Chilopoda: Centipedes

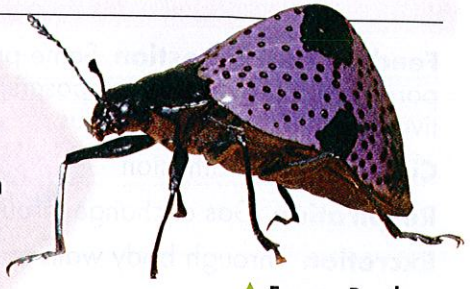
Centipedes have a long body composed of many segments. Each segment bears one pair of legs. They are carnivorous and have poison claws for capturing prey.



▲ Centipede

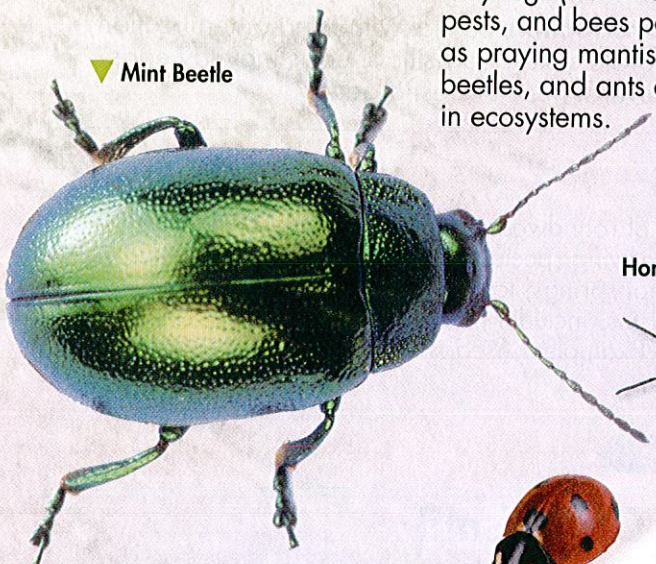
Insecta (continued)

Many "bugs" benefit humans. For example, ladybugs (which are not all "ladies") eat pests, and bees pollinate plants. Insects such as praying mantises, katydids, flies, moths, beetles, and ants also have important roles in ecosystems.

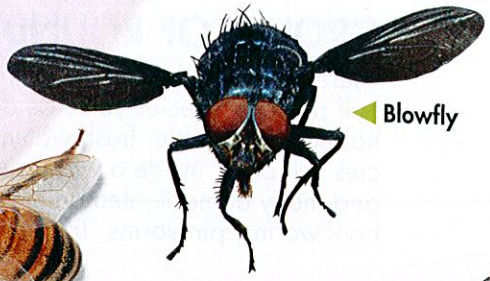


▲ Fungus Beetle

▼ Mint Beetle



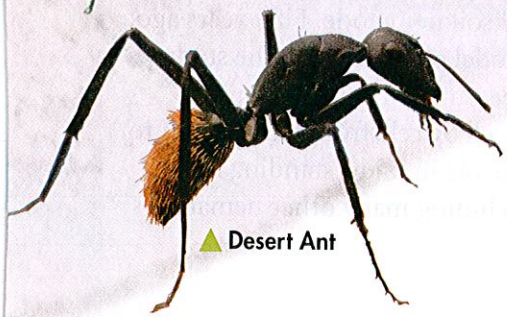
Honeybee ▼



◀ Blowfly

▲ Ladybug

▼ Lobster Katydid



▲ Desert Ant

Nematodes (Roundworms)

"Hooks" in the mouth of a hookworm attach the worms to their hosts so that they can drink the host's blood or ingest their digested foods.

▲ ***Foleyella*** (SEM 130×)

KEY CHARACTERISTICS

Nematodes, or roundworms, are unsegmented worms with a tough outer cuticle, which they shed as they grow. This "molting" is one reason that nematodes are now considered more closely related to arthropods than to other wormlike animals. Nematodes are the simplest animals to have a "one-way" digestive system through which food passes from mouth to anus. They are protostomes and have a pseudocoelom.

Feeding and Digestion Some predators, some parasites, and some decomposers; one-way digestive tract with mouth and anus

Circulation By diffusion

Respiration Gas exchange through body walls

Excretion Through body walls

Response Simple nervous system consisting of several ganglia, several nerves, and several types of sense organs

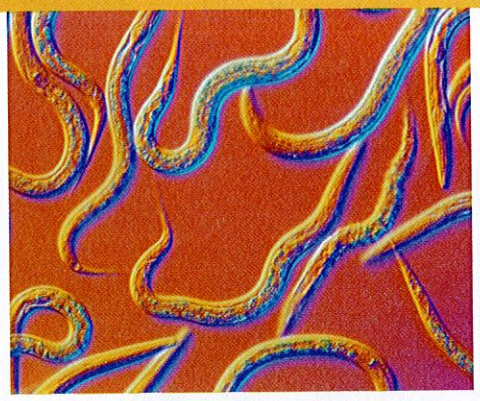
Movement Muscles work with hydrostatic skeleton, enabling aquatic species to move like water snakes and soil-dwelling species to move by thrashing around.

Reproduction Sexual with internal fertilization; separate sexes; parasitic species may lay eggs in several hosts or host organs.

GROUPS OF ROUNDWORMS

There are more than 15,000 known species of roundworms, and there may be half a million species yet to be described. Free-living species live in almost every habitat imaginable: fresh water, salt water, hot springs, ice, soil. Parasitic species live on or inside a wide range of organisms, including insects, humans, and many domesticated animals and plants. Examples: *Ascaris lumbricoides*, hookworms, pinworms, *Trichinella*, *C. elegans*

•A Closer Look

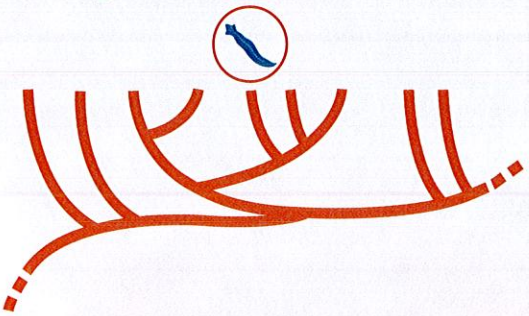


A Model Organism?

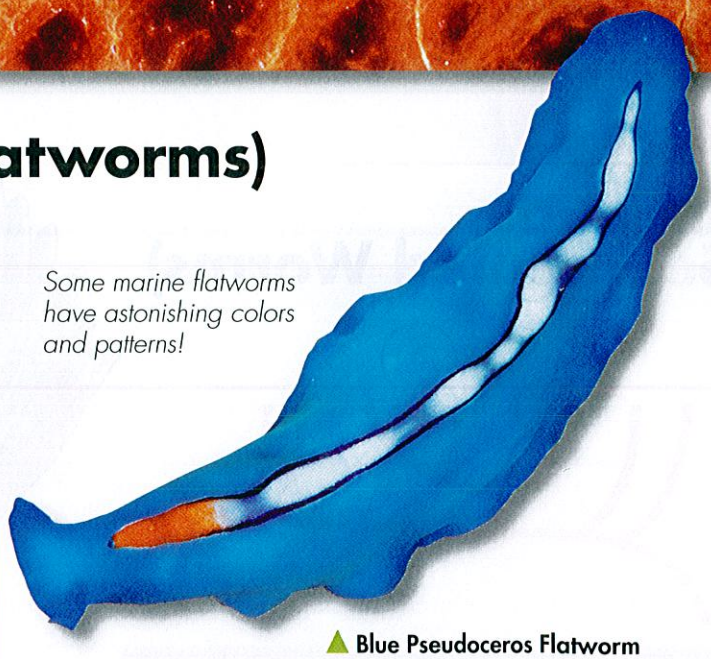
Caenorhabditis elegans is a small soil nematode. Fifty years ago, this species was selected as a "model organism" for the study of genetics and development. We can now chart the growth and development of *C. elegans*, cell by cell, from fertilization to adult. This information is invaluable in understanding the development in other species—including many other nematodes that cause serious disease.

◀ ***C. elegans*** (LM 64×)

Platyhelminthes (Flatworms)



Some marine flatworms have astonishing colors and patterns!



▲ Blue Pseudoceros Flatworm

KEY CHARACTERISTICS

Flatworms are soft worms with tissues and internal organ systems. They are the simplest animals to have three embryonic germ layers, bilateral symmetry, and cephalization. They are acoelomates.

Feeding and Digestion Free-living—predators or scavengers that suck food in through a pharynx and digest it in a system that has one opening. Parasitic—feed on blood, tissue fluids, or cell pieces of the host, using simpler digestive systems than free-living species have. Tapeworms, which absorb nutrients from food that the host has already digested, have no digestive system.

Circulation By diffusion

Respiration Gas exchange by diffusion

Excretion Some—flame cells remove excess water and may remove metabolic wastes such as ammonia and urea. Many flame cells are connected to tubules that release substances through pores in the skin.

Response Free-living—several ganglia connected by nerve cords that run through the body, along with eyespots and other specialized sensory cells; parasitic—simpler nervous system than free-living forms have

Movement Free-living—using cilia and muscle cells.

Reproduction Free-living—most are hermaphrodites that reproduce sexually with internal fertilization; parasitic—commonly reproduce asexually by fission but also often reproduce sexually

GROUPS OF FLATWORMS

Flatworms are an amazingly diverse group of worms that include more than 20,000 species. They have historically been placed into three classes, but these taxa now appear not to be true clades, and will probably change.

TREMATODA: Flukes

Most flukes are parasites that infect internal organs of their hosts, but some infect external parts such as skin or gills. The life cycle typically involves more than one host or organ. Examples: *Schistosoma*, liver fluke

▲ Liver Fluke

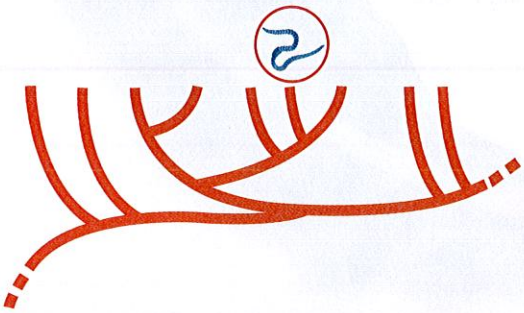
TURBELLARIA: Turbellarians

Turbellarians are free-living aquatic and terrestrial predators and scavengers. Many are colorful marine species. Examples: planarians, polyclad flatworm

CESTODA: Tapeworms

Tapeworms are very long intestinal parasites that lack a digestive system and absorb nutrients directly through their body walls. The tapeworm body is composed of many repeated sections (proglottids) that contain both male and female reproductive organs.

Annelids (Segmented Worms)



Peacock worms, whose feather-shaped gills look somewhat like peacock feathers, are marine annelids, or polychaetes.

KEY CHARACTERISTICS

Annelids are coelomate protostome worms whose bodies are composed of segments separated by internal partitions. The annelid digestive system has two openings.

Feeding and Digestion Filter feeders, carnivores, or parasites; many obtain food using a muscular pharynx, often equipped with "teeth"; widely varied digestive systems—some, such as earthworms, have complex digestive tracts.

Circulation Closed circulatory system with dorsal and ventral blood vessels; dorsal vessel pumps blood like a heart.

Respiration Aquatic—gills; terrestrial—skin

Excretion Digestive waste exits through anus; nitrogenous wastes eliminated by nephridia

Response Nervous system includes a rudimentary brain and several nerve cords; sense organs best-developed in free-living saltwater species

Movement Hydrostatic skeleton based on sealed body segments surrounded by longitudinal and circular muscles; many annelids have appendages that enable movement.

Reproduction Most—sexual, some through external fertilization with separate sexes, but others are simultaneous hermaphrodites that exchange sperm; most have a trochophore larval stage

Did You Know?

▲ *Leech* (Hirudo medicinalis) *drawing blood from a hand*

Not-So-Modern Medicine

You may have heard that medieval healers used leeches to remove "excess" blood from patients and to clean wounds after surgery. But did you know that leeches—or at least compounds from leech saliva—have a place in modern medicine? Leech saliva contains the protein hirudin, which prevents blood from clotting. Some surgeons use leeches to relieve pressure caused by blood that pools in tissues after plastic surgery. Hirudin is also used to prevent unwanted blood clots.

▼ Feather-Duster Worms

GROUPS OF ANNELIDS

There are more than 15,000 species of annelids.

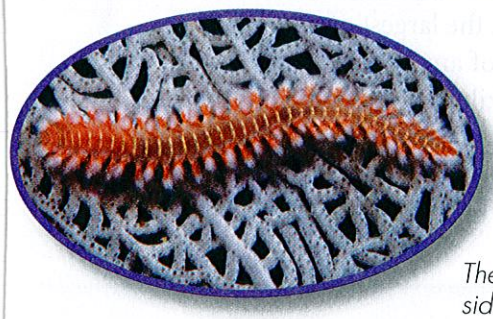
HIRUDINEA: Leeches

Most leeches live in fresh water. They lack appendages. Leeches may be carnivores or blood-sucking external parasites. Example: medicinal leech *(Hirudo medicinalis)*

◀ Giant Earthworm

OLIGOCHAETA: Oligochaetes

Oligochaetes live in soil or fresh water. They lack appendages. Some use setae for movement but have fewer than polychaetes. Examples: *Tubifex*, earthworms

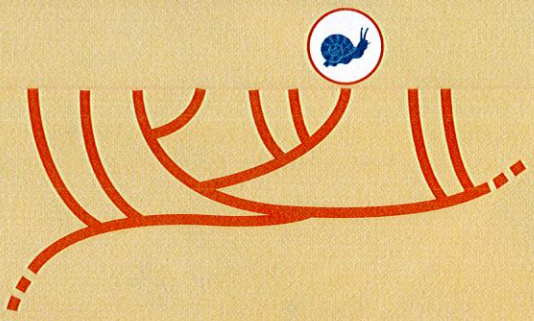


POLYCHAETA: Polychaetes

Polychaetes live in salt water; many move with paddle-like appendages called parapodia tipped with bristle-like setae. Examples: sandworms, bloodworms, fanworms, feather-duster worms

The white, bristle-like structures on the sides of this bearded fireworm are setae.

Mollusks



KEY CHARACTERISTICS

Mollusks have soft bodies that typically include a muscular foot. Body forms vary greatly. Many mollusks possess a hard shell secreted by the mantle, but in some, the only hard structure is internal. Mollusks are coelomate protostomes with bilateral symmetry.

Feeding and Digestion Digestive system with two openings; diverse feeding styles—mollusks can be herbivores, carnivores, filter feeders, detritivores, or parasites

Circulation Snails and clams—open circulatory system; octopi and squid—closed circulatory system

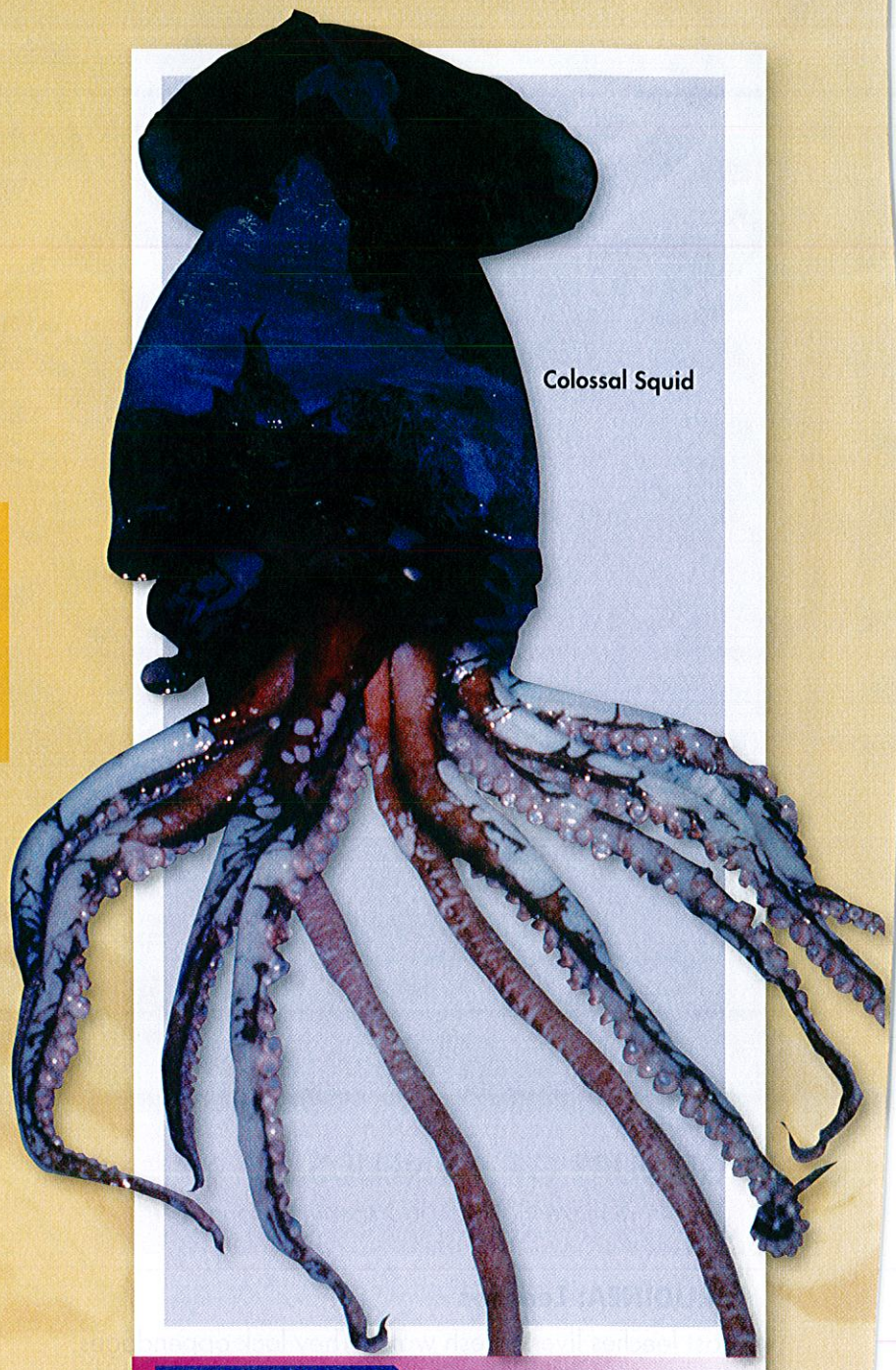
Respiration Aquatic mollusks—gills inside the mantle cavity; land mollusks—a saclike mantle cavity whose large, moist surface area is lined with blood vessels.

Excretion Body cells release ammonia into the blood, which nephridia remove and release outside the body.

Response Complexity of nervous system varies greatly; extremely simple in clams, but complex in some octopi.

Movement Varies greatly, by group. Some never move as adults, while others are very fast swimmers.

Reproduction Sexual; many aquatic species have free-swimming trochophore larval stage.



Colossal Squid

Did You Know?

The Colossal Squid

The Colossal Squid, the largest of all mollusks, has the largest eyes of any known animal. One 8-meter-long, 450-kilogram specimen of the species *Mesonychoteuthis hamiltoni* had eyes 28 centimeters across—larger than most dinner plates! The lens of this huge eye was the size of an orange.

GROUPS OF MOLLUSKS

Mollusks are traditionally divided into several classes based on characteristics of the foot and the shell; specialists estimate that there are somewhere between 50,000 and 200,000 species of mollusks alive today.

▲ Chambered Nautilus

▲ Giant Clam

Garden Snail ▲

BIVALVIA: Bivalves

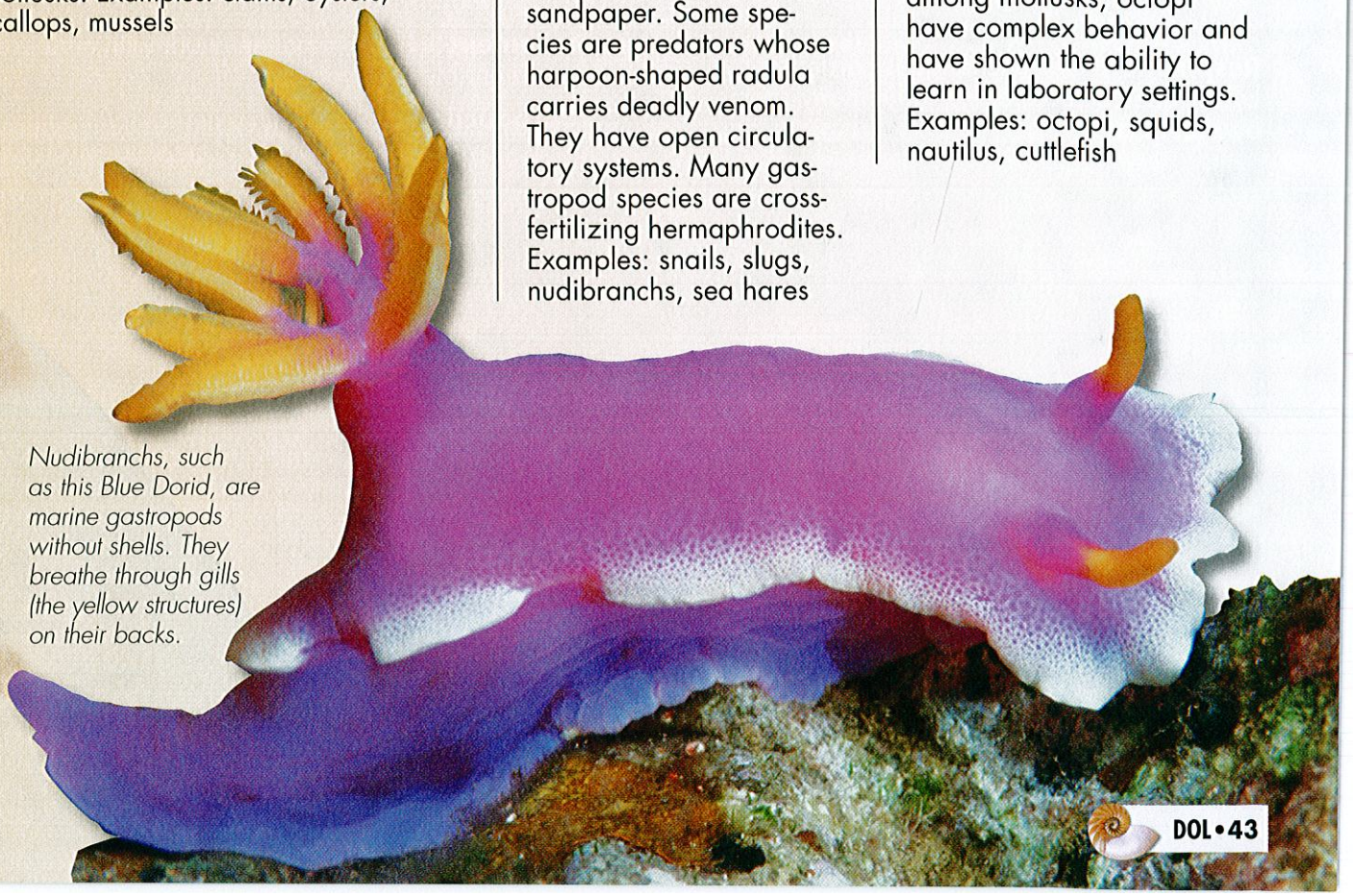
Bivalves are aquatic. They have a two-part hinged shell and a wedge-shaped foot. They are mostly stationary as adults. Some burrow in mud or sand; others attach to rocks. Most are filter feeders that use gill siphons to take in water that carries food. Clams have open circulatory systems. Bivalves have the simplest nervous systems among mollusks. Examples: clams, oysters, scallops, mussels

GASTROPODA: Gastropods

There are both terrestrial and aquatic gastropods. Most have a single spiral, chambered shell. Gastropods use a broad, muscular foot to move and have a distinct head region. Snails and slugs feed with a structure called a radula that usually works like sandpaper. Some species are predators whose harpoon-shaped radula carries deadly venom. They have open circulatory systems. Many gastropod species are cross-fertilizing hermaphrodites. Examples: snails, slugs, nudibranchs, sea hares

CEPHALOPODA: Cephalopods

Cephalopods live in salt water. The cephalopod has a highly developed brain and sense organs. The head is attached to a single foot, which is divided into tentacles. They have closed circulatory systems. Octopi use beaklike jaws for feeding; a few are venomous. Cephalopods have the most complex nervous systems among mollusks; octopi have complex behavior and have shown the ability to learn in laboratory settings. Examples: octopi, squids, nautilus, cuttlefish



Nudibranchs, such as this Blue Dorid, are marine gastropods without shells. They breathe through gills (the yellow structures) on their backs.

Echinoderms

KEY CHARACTERISTICS

Echinoderms are marine animals that have spiny skin surrounding an endoskeleton. Their unique water vascular system includes tube feet with suction-cuplike ends used in moving and feeding. The water vascular system also plays a role in respiration, circulation, and excretion. Echinoderms are coelomate deuterostomes. Adults exhibit 5-part radial symmetry.

Feeding and Digestion Method varies by group—echinoderms can be filter feeders, detritivores, herbivores, or carnivores.

Circulation Via fluid in the coelom, a rudimentary system of vessels, and the water vascular system

Respiration Gas exchange is carried out by surfaces of tube feet, and, in many species, by skin gills.

Crinoid fossil, about 400 million years old

Living modern crinoid (feather star)

A Look Back in Time

Crinoids Then and Now

Echinoderms have a long fossil record that dates all the way back to the Cambrian Period. Although these animals have been evolving for millions of years, some fossil crinoids look a great deal like living crinoids.

Excretion Digestive wastes released through anus; nitrogenous cellular wastes excreted as ammonia through tube feet and skin gills.

Response Minimal nervous system; nerve ring is connected to body sections by radial nerves; most have scattered sensory cells that detect light, gravity, and chemicals secreted by prey.

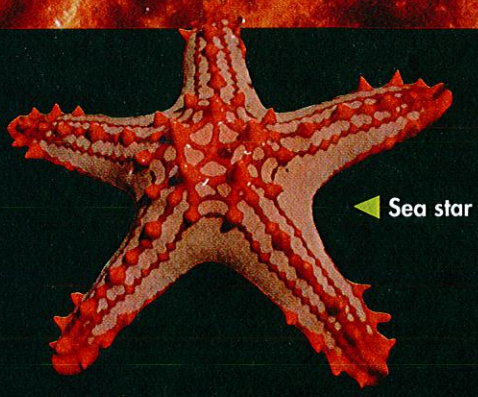
Movement In most, tube feet work with endoskeleton to enable locomotion.

Reproduction Sexual, with external fertilization; larvae have bilateral symmetry, unlike adults.

You can't miss the 5-part radial symmetry of this candy-cane sea star moving across a sea anemone.

GROUPS OF ECHINODERMS

There are more than 7000 species of echinoderms.



Sea star

CRINOIDEA: Crinoids

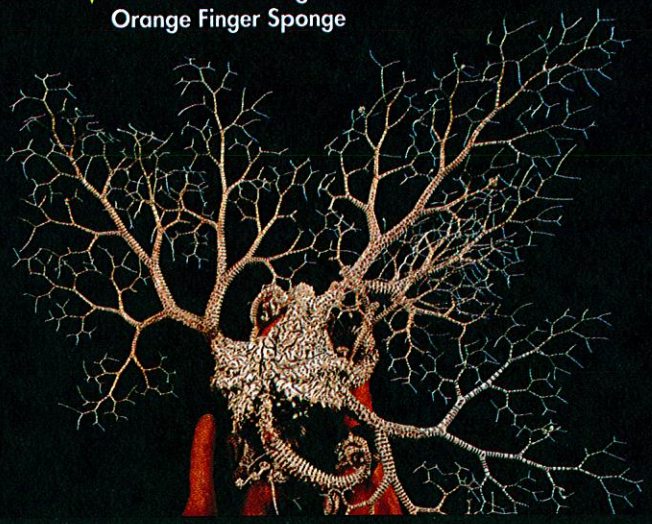
Crinoids are filter feeders; some use tube feet along feathery arms to capture plankton. The mouth and anus are on the upper surface of the body disk. Some are stationary as adults while others can "walk" using short "arms" on the lower body surface. Examples: sea lily, feather star

Feeding crinoid

ASTEROIDEA: Sea stars

Sea stars are bottom dwellers whose star-shaped bodies have flexible joints. They are carnivorous—the stomach pushes through the mouth onto the body tissues of prey and pours out digestive enzymes. The stomach then retracts with the partially digested prey; digestion is completed inside the body. Examples: crown-of-thorns sea star, sunstar

Basket star feeding on Orange Finger Sponge



OPHIUROIDEA: Ophiuroids

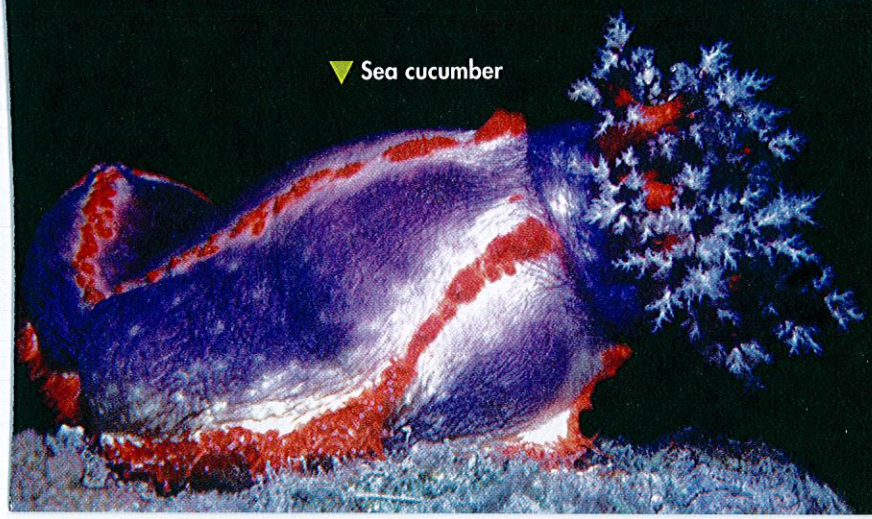
Ophiuroids have small body disks, long, armored arms, and flexible joints. Most are filter feeders or detritivores. Examples: brittle star, basket star

ECHINOIDEA

Echinoids lack arms. Their endoskeleton is rigid and boxlike and covered with movable spines. Most echinoids are herbivores or detritivores that use five-part jawlike structures to scrape algae from rocks. Examples: sea urchin, sand dollar, sea biscuit

Red sea urchins and purple sea urchins feeding on kelp

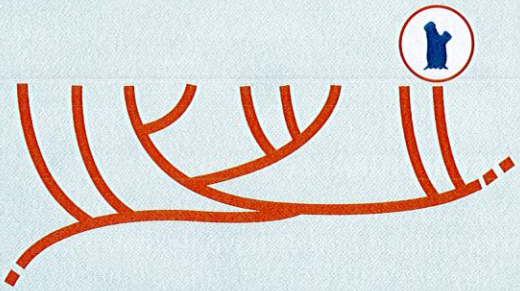
Sea cucumber



HOLOTHUROIDEA: Sea cucumbers

Sea cucumbers have a cylindrical, rubbery body with a reduced endoskeleton and no arms. They typically lie on their side and move along the ocean floor by the combined action of tube feet and body-wall muscles. These filter feeders or detritivores use a set of retractable feeding tentacles on one end to take in sand and detritus, from which they glean food.

Nonvertebrate Chordates



Tunicates are chordates named for the colorful tunic-like covering the adults have. As larvae, tunicates have all the characteristics of chordates, as well as bilateral symmetry, but as adults, they look very, very different.

KEY CHARACTERISTICS

The nonvertebrate chordates are the only chordates that lack a backbone. Like other chordates, they have a nerve cord, notochord, pharyngeal pouches, and a tail at some point during development. They are coelomate deuterostomes. The two subphyla, tunicates and lancelets, differ significantly.

Feeding and Digestion Filter feeders; tunicates—in most, water carrying food particles enters through an incurrent siphon; food is strained out in the pharynx and passed to the digestive system; lancelets—mucus in the pharynx catches food particles carried in by water, which are then carried into digestive tract

Circulation Closed; tunicates—heart pumps blood by "wringing out," and flow periodically reverses direction; lancelets—no heart, but blood vessels pump blood through body in one direction

Respiration Tunicates—gas exchange occurs in the gills and across other body surfaces; lancelets—through pharynx and body surfaces

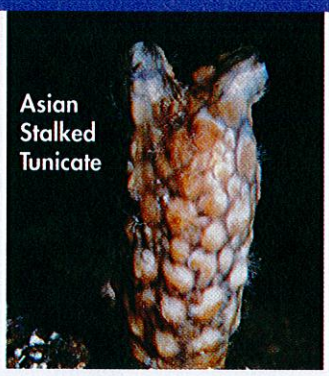
Excretion Tunicates—most through excurrent siphon; lancelets—flame cells in nephridia release water and nitrogenous wastes into the atrium and out through an opening called an atriopore

Response Cerebral ganglion, few specialized sensory organs; tunicates—sensory cells in and on the siphons and other internal surfaces help control the amount of water passing through the pharynx; lancelets—a pair of eyespots detect light

Movement Tunicates—free-swimming larvae, but most are stationary as adults; lancelets—no appendages: they move by contracting muscles paired on either side of the body

Reproduction Tunicates—most sexual and hermaphroditic with external fertilization, but some reproduce by budding; most have free-swimming tadpole-like larvae that metamorphose into adults; lancelets—sexual with external fertilization

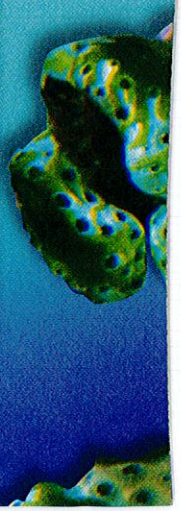
Eco•Alert



Asian Stalked Tunicate

Out-of-Control Tunicates

You've never heard of them, but Asian stalked tunicates are disrupting marine ecosystems in Washington State; Prince Edward Island, Canada; and elsewhere. Tunicate larvae are carried in the ballast water of freight ships and discharged wherever the ships make port. There, away from their usual predators, the tunicates grow out of control, smothering shellfish beds and covering boats, docks, and underwater equipment. Researchers are still trying to figure out how to control them.



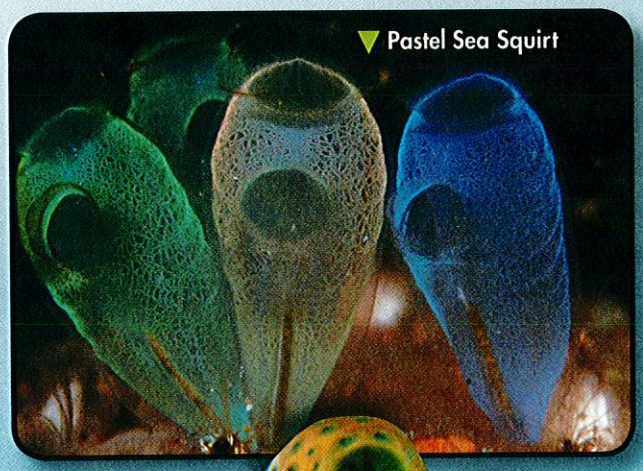
GROUPS OF NONVERTEBRATE CHORDATES

There are two major groups of nonvertebrate chordates: tunicates and lancelets (sometimes called amphioxus).

CEPHALOCHORDATA: Lancelets

Lancelets are fishlike animals that have bilateral symmetry and live in salt water. They are filter feeders and have no internal skeleton. Example: *Branchiostoma*

Two lancelets, Branchiostoma lanceolatum, *poking out of sand.*



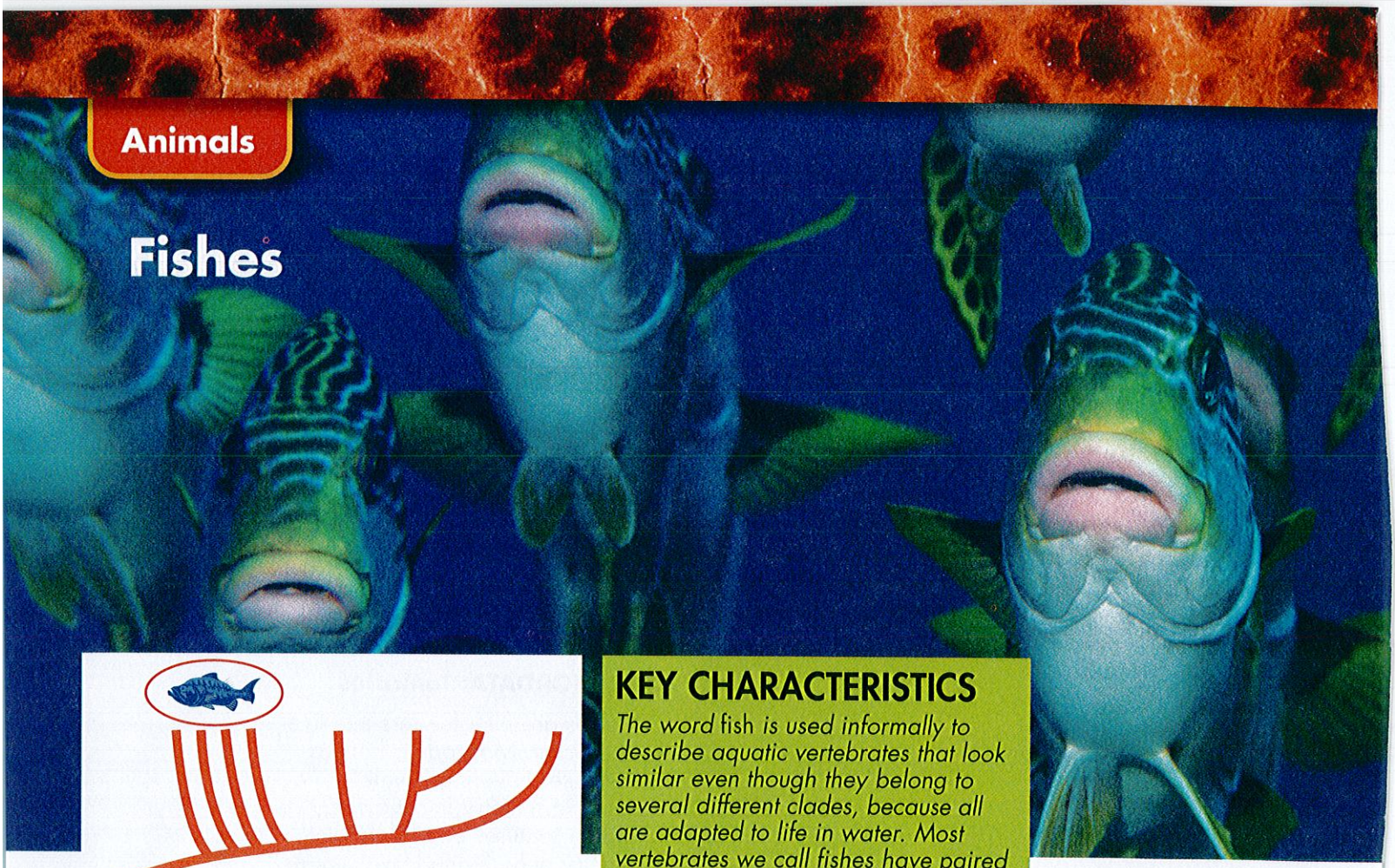
▼ Pastel Sea Squirt

UROCHORDATA: Tunicates

Tunicates are filter feeders that live in salt water. Most adults have a tough outer covering ("tunic") and no body symmetry; most display chordate features and bilateral symmetry only during larval stages. Many adults are stationary; some are free-swimming. Examples: sea squirts, sea peaches, salps

▼ Sea Squirts

Fishes



KEY CHARACTERISTICS

The word fish *is used informally to describe aquatic vertebrates that look similar even though they belong to several different clades, because all are adapted to life in water. Most vertebrates we call fishes have paired fins, scales, and gills.*

Feeding and Digestion Varies widely, both within and between groups: herbivores, carnivores, parasites, filter feeders, detritivores; digestive organs often include specialized teeth and jaws, crop, esophagus, stomach, liver, pancreas

Circulation Closed, single-loop circulatory system; two-chambered heart

Respiration Gills; some have specialized lungs or other adaptations that enable them to obtain oxygen from air.

Excretion Diffusion across gill membranes; kidneys

Response Brain with many parts; highly developed sense organs, including lateral line system

Movement Paired muscles on either side of backbone; many have highly maneuverable fins; the largest groups have two sets of paired fins; some have a gas-filled swim bladder that regulates buoyancy.

Reproduction Methods vary within and between groups: external or internal fertilization; oviparous, ovoviviparous, or viviparous

A Look Back in Time

Live Birth in Devonian Seas

▲ *Artist's conception of* Materpiscis *giving birth*

You might think that live birth is a recent addition to chordate diversity. Guess again. Recent fossil finds of fishes from the Devonian Period show that at least one group of fishes was already bearing live young 380 million years ago. Two incredibly well preserved fossils, including that of the fish *Materpiscis*, show the remains of young with umbilical cords still attached to their mother's bodies. This is the earliest fossil evidence of viviparity in vertebrates.

GROUPS OF FISHES

Fishes are the largest group of vertebrates, including more than 30,000 species. Evolutionary classification of these animals is still a work in progress; many traditional groups are now known not to be clades. "Fishes" actually represent several ancient clades, one of which includes tetrapods, or four-limbed vertebrates. Fishes, as we treat them here, include two groups of jawless fishes (hagfishes and lampreys), cartilaginous fishes, and bony fishes.

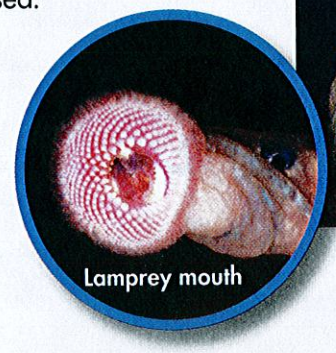
"Sweetlips" are, despite their funny faces, easily recognizable as fish.

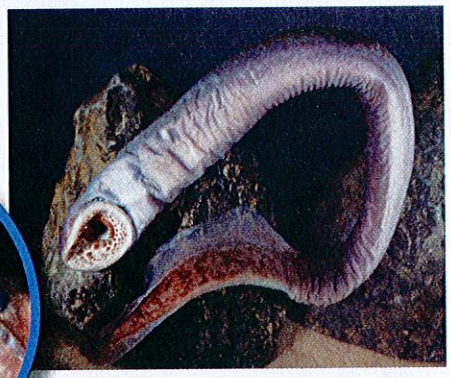
"JAWLESS FISHES"

Hagfishes and lampreys make up separate clades, but their bodies share common features that distinguish them from other fishes. They have no jaws, lack vertebrae, and their skeletons are made of fiber and cartilage.

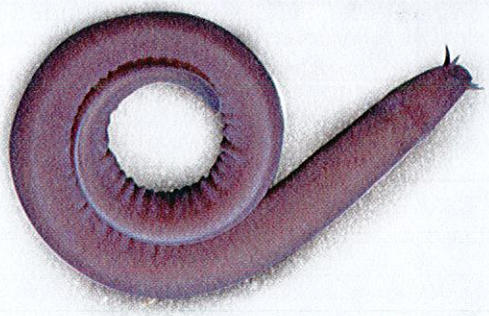
PETROMYZONTIDA: Lampreys

Lampreys are mostly filter feeders as larvae and parasites as adults. The head of an adult lamprey is taken up almost completely by a circular, tooth-bearing, sucking disk with a round mouth. Adult lampreys typically attach themselves to fishes. They hold on to their hosts using the teeth in their sucking disk and then scrape away at the skin with a rasping tongue. Lampreys then suck up their host's tissues and body fluids. Because lampreys feed mostly on blood, they are called "vampires of the sea."





▲ Lamprey



▲ Pacific Hagfish

MYXINI: Hagfishes

Hagfishes have pinkish gray wormlike bodies and four or six short tentacles around their mouths. They retain notochords as adults. Hagfishes lack image-forming eyes, but have light-detecting sensors scattered around their bodies. They feed on dead and dying animals using a rasping tongue that scrapes away layers of flesh.

Tiger Shark

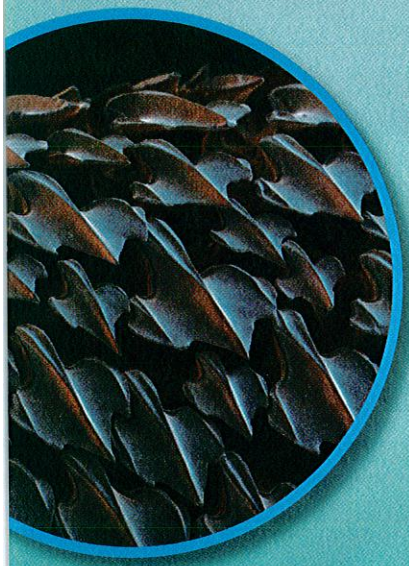
CHONDRICHTHYES: Cartilaginous Fishes

Members of this clade are considered "cartilaginous" because they lack true bone; their skeletons are built entirely of cartilage. Most cartilaginous fishes also have tough, scales, which make their skin as rough as sandpaper.

Holocephalans: Chimaeras

Chimaeras have smooth skin that lacks scales. Most have just a few platelike, grinding teeth and a venomous spine located in front of the dorsal fin. Examples: ghostfish, ratfish, rabbitfish

Spotted Ratfish



Dermal denticles on shark skin reduce drag, helping the shark to swim faster. (SEM 40×)

Elasmobranchii: Sharks, skates, and rays

Sharks, skates, and rays are very diverse, but all have skin covered with toothlike scales known as dermal denticles. Elasmobranchii make up the vast majority of living cartilaginous fish species.

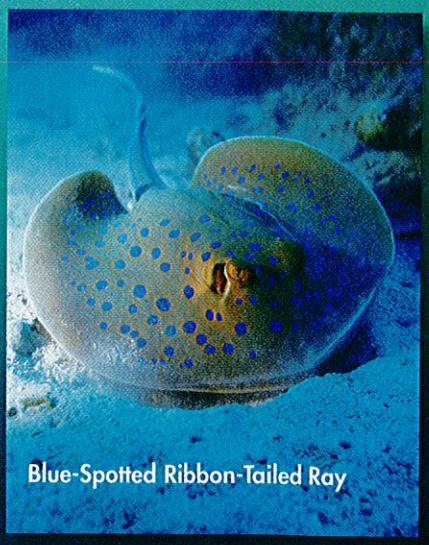
Galeomorphi: Sharks

Most of the 350 or so shark species have large, curved asymmetrical tails, torpedo-shaped bodies, and pointed snouts with a mouth underneath. Predatory sharks, such as the great white, have many teeth arranged in rows. As teeth in the front rows are worn out or lost, new teeth replace them. Some sharks go through 20,000 teeth in their lifetime! Other sharks are filter feeders, and some species have flat teeth for crushing mollusk and crustacean shells. Examples: Great White Shark, Whale Shark, Hammerhead Shark

Squalomorphi: Skates and rays

Skates and rays have diverse feeding habits. Some feed on bottom-dwelling invertebrates by using their mouths as powerful vacuums. Others filter-feed on plankton. When not feeding or swimming, many skates and rays cover themselves with a thin layer of sand and rest on the ocean floor. Example: stingray

Hammerhead Shark



Blue-Spotted Ribbon-Tailed Ray

OSTEICHTHYES: Bony fishes

The skeletons of these vertebrates are made of true bone. This clade includes the ancestors and living members of all "higher" vertebrate groups—including tetrapods.

Rainbow Trout

Actinopterygii: Ray-finned fishes

Almost all living bony fishes belong to a huge group called ray-finned fishes. The name *ray-finned* refers to the slender bony rays that are connected to one another by a layer of skin to form fins.

Coelacanth

Sarcopterygii: Lobe-finned fishes

Seven living species of bony fishes, including lungfishes and coelacanths, are classified as lobe-finned fishes. Lungfishes live in fresh water, but coelacanths are marine. The fleshy fins of lobe-finned fishes are supported by strong bones rather than rays. Some of these bones are homologous to the limb bones of land vertebrates. Examples: lungfish, coelacanths

This clade includes the ancestors of tetrapods, so, technically, all living tetrapods (including us!) are Sarcopterygians! As a result, the bony-fish clade includes almost half of all chordate species!

Amphibians


Marsupial Frog

KEY CHARACTERISTICS

The word amphibian *means "double life," an apt name for these vertebrates, most of which live in water as larvae and on land as adults. Most adult amphibians breathe with lungs, lack scales and claws, and have moist skin that contains mucous glands.*

Feeding and Digestion Tadpoles—usually filter feeders or herbivores with long, coiled intestines to digest plant material; adults—carnivores with shorter intestines for processing meat

Circulation Double-loop system with three-chambered heart

Respiration Larvae breathe through skin and gills; most adult species have lungs, though a few use gills; lungless salamanders breathe through their mouth-cavity lining and skin.

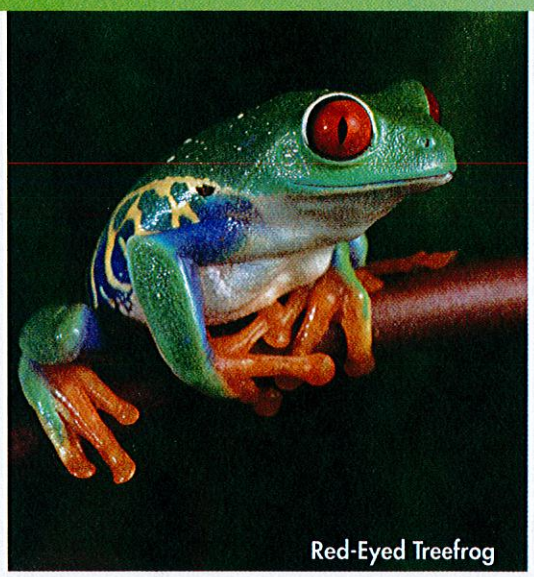
Excretion Kidneys produce urine.

Response Well-developed nervous and sensory systems; organs include protective nictitating membrane over moveable eyes, tympanic membranes, lateral line system

Movement Larvae have tails; adults have limbs (except caecilians); some have specialized toes for climbing.

Reproduction Most lay eggs without shells that are fertilized externally; most undergo metamorphosis from aquatic tadpole larvae that breathe with gills to land-dwelling adults, which usually have lungs and limbs.

Eco•Alert


Red-Eyed Treefrog

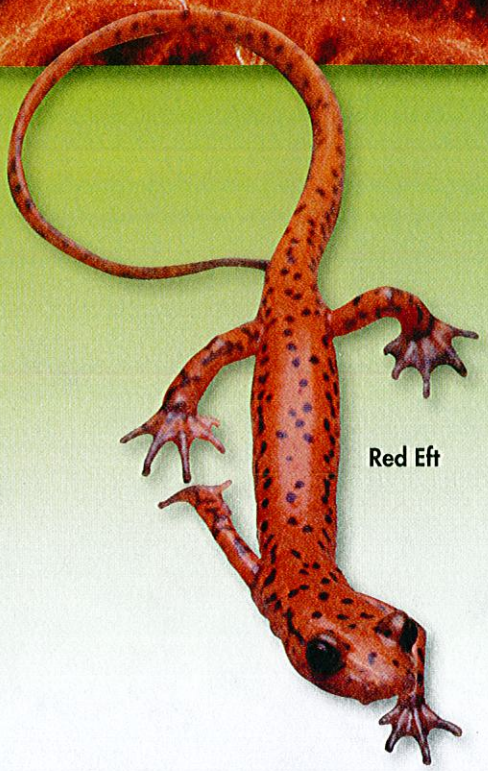
The Frogs Are Disappearing!

For several decades, scientists have noticed that amphibian populations worldwide have been decreasing, and a number of species have become extinct. Scientists have not yet pinpointed a single cause for this problem. It is, however, becoming clear that amphibians are susceptible to a variety of environmental threats, including habitat loss, ozone depletion, acid rain, water pollution, fungal infections, and introduced aquatic predators.

To better understand this decline, biologists worldwide have been focusing their efforts and sharing data about amphibian populations. One amphibian-monitoring program covers all of North America.

GROUPS OF AMPHIBIANS

The three orders of amphibians include more than 6000 species, roughly 5000 of which are frogs and toads.



Red Eft

URODELA: Salamanders and newts

Salamanders and newts have long bodies and tails. Most also have four legs. All are carnivores. Adults usually live in moist woods, where they tunnel under rocks and rotting logs. Some salamanders, such as the mud puppy, keep their gills as adults and live in water all their lives. Examples: Barred Tiger Salamander, Red Eft

American Toad

ANURA: Frogs and toads

Adult frogs and toads are amphibians without tails that can jump. Frogs tend to have long legs and make long jumps, whereas toads have shorter legs that limit them to shorter hops. Frogs are generally more dependent on bodies of fresh water than toads, which may live in moist woods or even deserts. Examples: treefrogs, Leopard Frog, American Toad, spadefoot toads

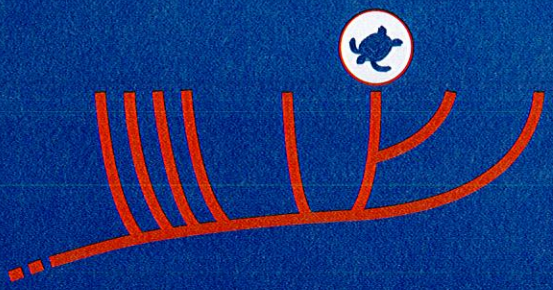
APODA: Caecilians

The least-known and most unusual amphibians are the legless caecilians. They have tentacles, and many have fishlike scales embedded in their skin—which shows that not all amphibians fit the general definition. Caecilians live in water or burrow in moist soil or sediment, feeding on small invertebrates such as termites. Examples: Ringed Caecilian, Yellow-Striped Caecilian

Ringed Caecilian

▶ *Because amphibian eggs must develop in water, most live in moist climates. Some, such as this Alpine Newt, live on cool, rainy mountain slopes.*

Reptiles



Saltwater crocodiles, such as this young one, are the largest living reptiles and sometime reach 6 meters long. But that's still only half as long as their famous dinosaur ancestor, T. rex!

KEY CHARACTERISTICS OF REPTILES

Living reptiles, traditionally classified in the class Reptilia, are ectothermic vertebrates with dry, scaly skin; lungs; and amniotic eggs. Modern evolutionary classification now recognizes a larger clade Reptilia that includes living reptiles, extinct dinosaurs, and birds—the living descendants of one dinosaur group.

Feeding and Digestion Feeding methods vary by group; digestive systems—herbivores have long digestive systems to break down plant materials; carnivores may swallow prey whole

Circulation Two loops; heart with two atria and one or two ventricles

Respiration Spongy lungs provide large surface area for gas exchange; lungs operated by muscles and moveable ribs

Excretion Kidneys; urine contains ammonia or uric acid

Response Brain; well-developed senses including, in some species, infrared detectors that can spot warm-bodied prey in the dark

Movement Strong limbs (except snakes)

Reproduction Internal fertilization via cloaca; amniotic egg with leathery shell

Eco•Alert

Calling Doctor 'Gator!

You might think of alligators mostly as killing machines, but their blood may soon provide medicines that can save lives. An alligator's immune system works quite differently from our own. Proteins in their white blood cells can kill multidrug resistant bacteria, disease-causing yeasts, and even HIV. Remarkably, these proteins work against pathogens to which the animals have never been exposed. Researchers are currently sequencing the genes for these proteins and hope to develop them into human medicines in the near future.

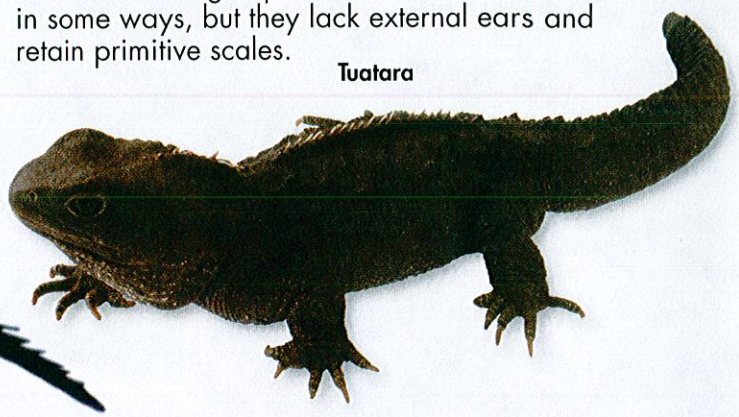
GROUPS OF REPTILES

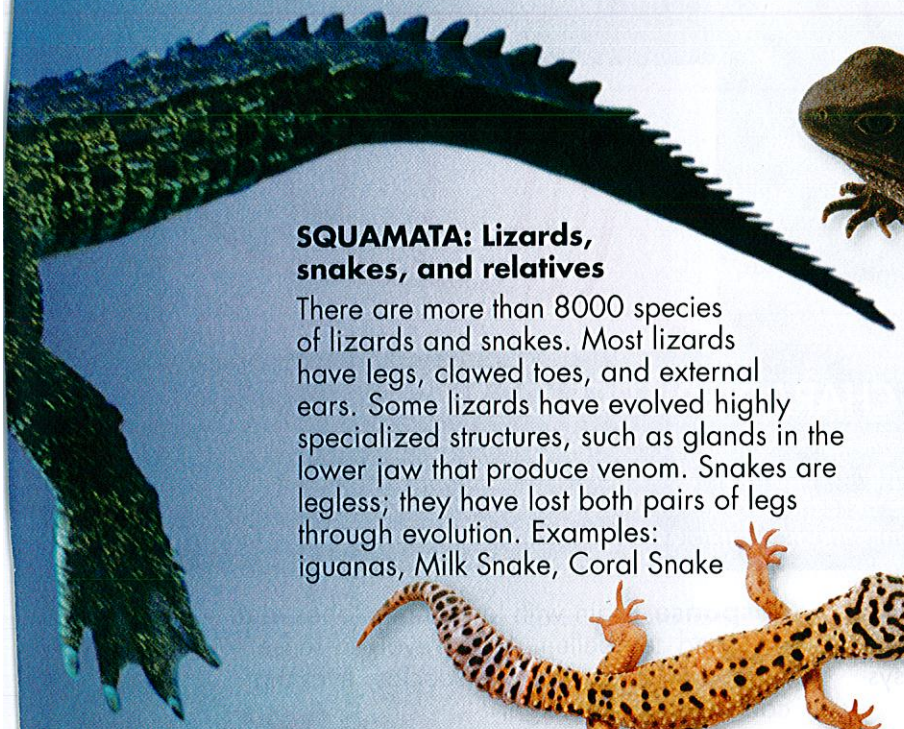
There are nearly 9000 species of reptiles (not including birds).

SPHENODONTA: Tuataras

The tuatara, found only on a few small islands off the coast of New Zealand, is the only living member of this group. Tuataras resemble lizards in some ways, but they lack external ears and retain primitive scales.

Tuatara





SQUAMATA: Lizards, snakes, and relatives

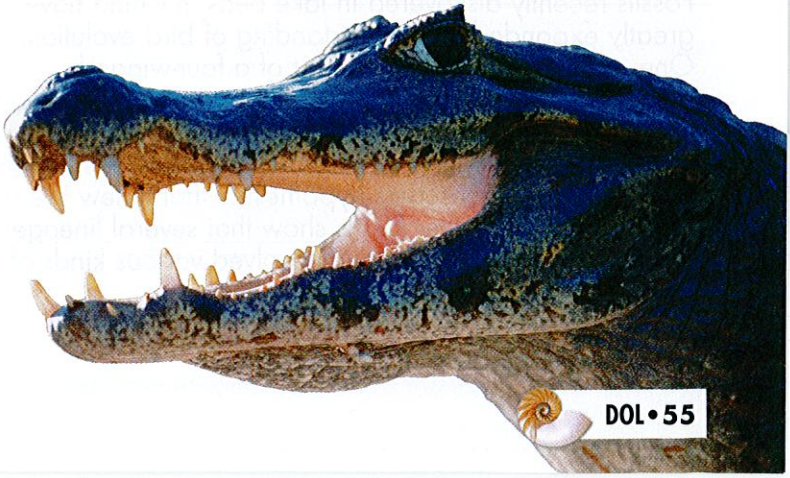
There are more than 8000 species of lizards and snakes. Most lizards have legs, clawed toes, and external ears. Some lizards have evolved highly specialized structures, such as glands in the lower jaw that produce venom. Snakes are legless; they have lost both pairs of legs through evolution. Examples: iguanas, Milk Snake, Coral Snake

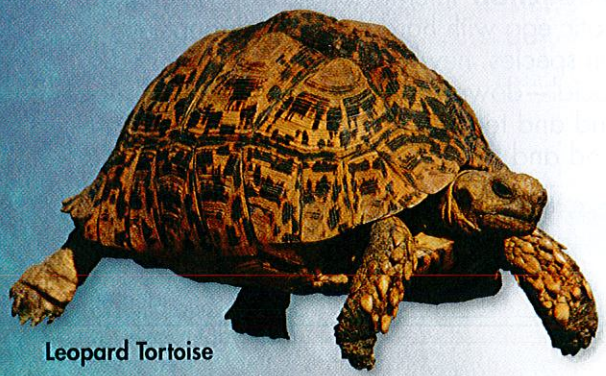
Leopard Gecko

ARCHOSAURS: Crocodilians; pterosaurs and dinosaurs (extinct); and birds

This clade includes some of the most spectacular animals that have ever lived. The extinct dinosaurs and pterosaurs (flying reptiles), whose adaptive radiations produced some of the largest animals ever to walk Earth or fly above it, are the closest relatives of birds. Living crocodilians are short-legged and have long and typically broad snouts. They are fierce carnivorous predators, but the females are attentive mothers. Crocodilians live only in regions where the climate remains warm year-round. We discuss birds separately. Examples: extinct types: *Tyrannosaurus*, *Pteranodon*; living types: alligators, crocodiles, caimans, and birds (see following pages)

Paraguay Caiman



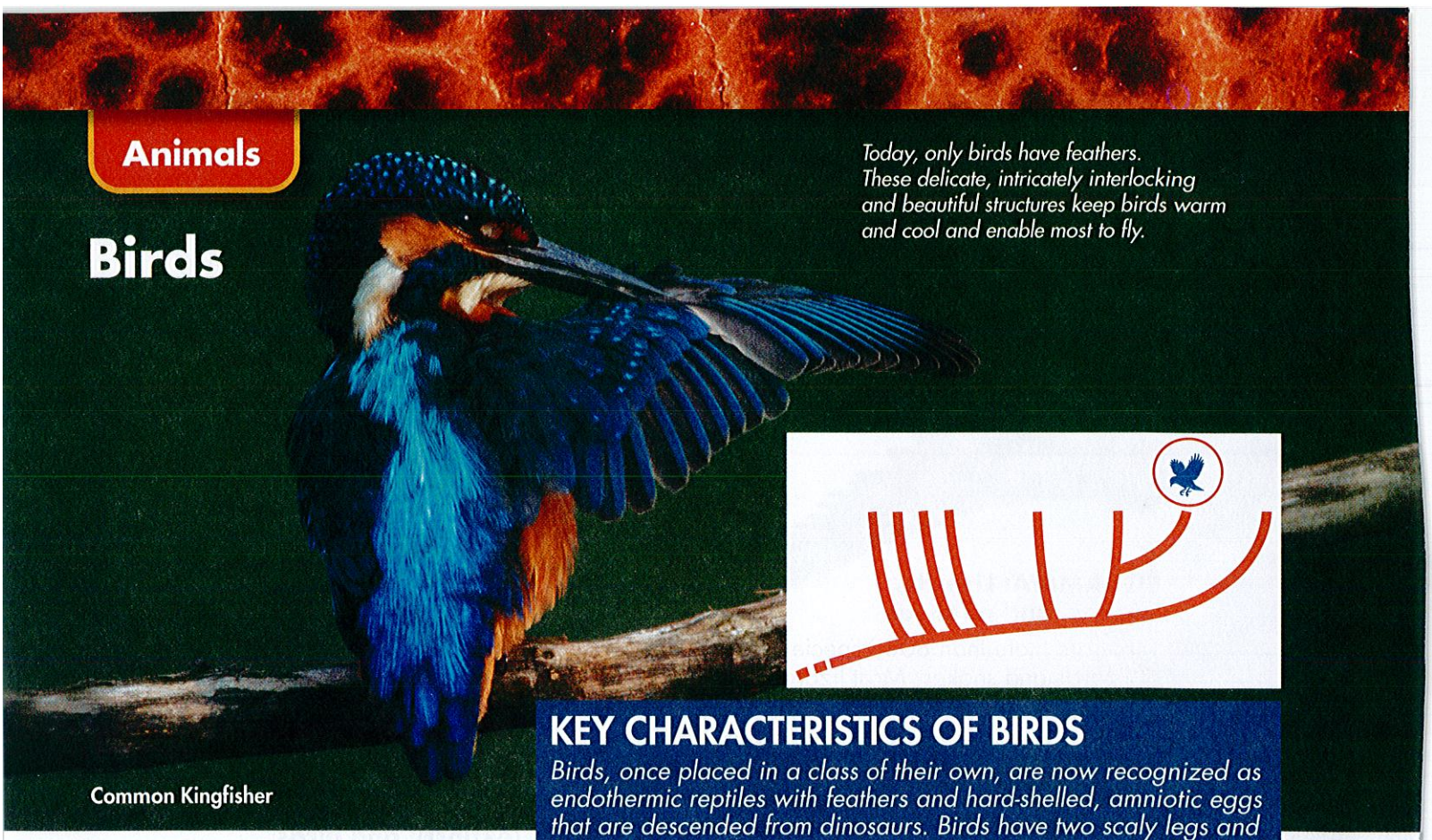


Leopard Tortoise

TESTUDINE: Turtles and tortoises

Turtles and tortoises have a shell built into their skeleton. Most can pull their heads and legs into the shell for protection. Instead of teeth, these reptiles have hornlike ridges covering their jaws equipped with sharp beaklike tips. Strong limbs can lift their body off the ground when walking or, in the case of sea turtles, can drag their body across a sandy shore to lay eggs. Examples: snapping turtles, green sea turtles, Galápagos tortoise

Birds



Common Kingfisher

Today, only birds have feathers. These delicate, intricately interlocking and beautiful structures keep birds warm and cool and enable most to fly.

KEY CHARACTERISTICS OF BIRDS

Birds, once placed in a class of their own, are now recognized as endothermic reptiles with feathers and hard-shelled, amniotic eggs that are descended from dinosaurs. Birds have two scaly legs and front limbs modified into wings, which enable most species to fly.

Feeding and Digestion No teeth; bills adapted to widely varied foods, including insects, seeds, fruits, nectar, fish, meat; organs of the digestive system include crop, gizzard, cloaca

Circulation Two loops with four-chambered heart; separation of oxygen-rich and oxygen-poor blood

Respiration Constant, one-way flow of air through lungs and air sacs increases the efficiency of gas exchange and supports high metabolic rate

Excretion Kidneys remove nitrogenous wastes from blood, converting them to uric acid, which is excreted through cloaca

Response Brain with large optic lobes and enlarged cerebellum; highly evolved sense organs including, in some species, eyes that can see ultraviolet light

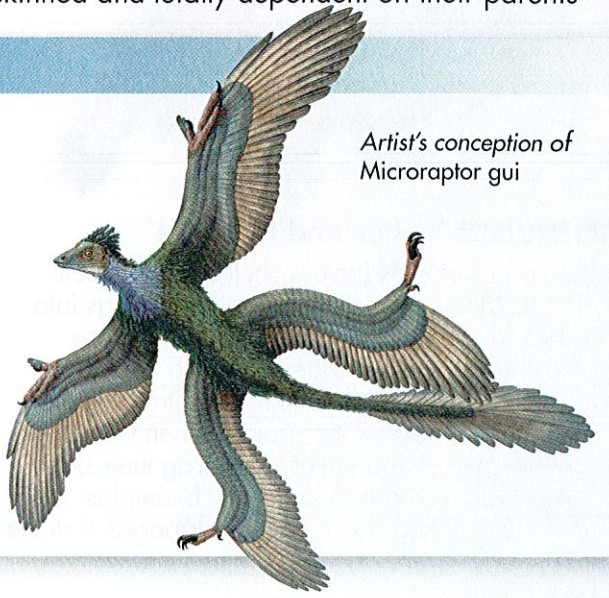
Movement Skeleton made up of lightweight, hollow bones with internal struts for strength; powerful muscles; most fly

Reproduction Internal fertilization via cloaca; amniotic egg with hard, brittle shell; depending on species, newly hatched young may be precocial—downy-feathered chicks able to move around and feed themselves, or altricial—bare-skinned and totally dependent on their parents

• A Look Back in Time

Birds of a Feather

Fossils recently discovered in lake beds in China have greatly expanded our understanding of bird evolution. One exciting discovery was that of a four-winged dinosaur named *Microraptor gui* from about 125 million years ago. *Microraptor gui*, which was related to *Tyrannosaurus rex*, had feathers on both its wings *and* its legs, so some researchers hypothesize that it flew like a biplane! This and other fossils show that several lineages of dinosaurs and ancient birds evolved various kinds of feathers over millions of years.



Artist's conception of Microraptor gui

GROUPS OF BIRDS

Evolutionary classification of living birds is still a work in progress, as different techniques and analyses produce different results. There are about 10,000 species. The groups described below illustrate some of the diversity of birds.

Ostrich

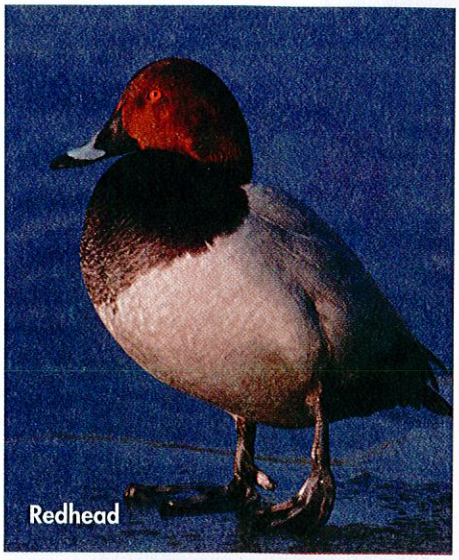
PALEOGNATHAE: Ostriches, emus, kiwis, and relatives

This group represents an early branch of the bird family tree that is separate from all other living birds. This clade includes the largest birds alive today. Ostriches can be 2.5 meters tall and weigh 130 kilograms! Kiwis, however, are only about the size of chickens. Roughly a dozen living species are scattered throughout the Southern Hemisphere. All are flightless, but the larger species can run very fast. They generally eat a variety of plant material, insects, and other small invertebrates. Examples: Ostrich, emus, Brown Kiwi, Greater Rhea, Dwarf Cassowary

SPHENISCIDAE: Penguins

These flightless birds of the Southern Hemisphere are adapted to extreme cold and hunting in water. Though they cannot fly, they use their wings as flippers when they swim. Penguins have more feathers per square centimeter than any other bird; this density allows them to repel water and conserve heat effectively. Some species form large colonies. Examples: Emperor Penguin, Chinstrap Penguin, King Penguin

King Penguins



Redhead

ANATIDAE: Ducks, geese, and swans

These birds spend much of their time feeding in bodies of water. Webbed feet enable them to paddle efficiently across the surface of the water. Most fly well, however, and many species migrate thousands of kilometers between breeding and resting locations. Examples: Redhead, Ross's goose, Trumpeter Swan

Galápagos Hawk

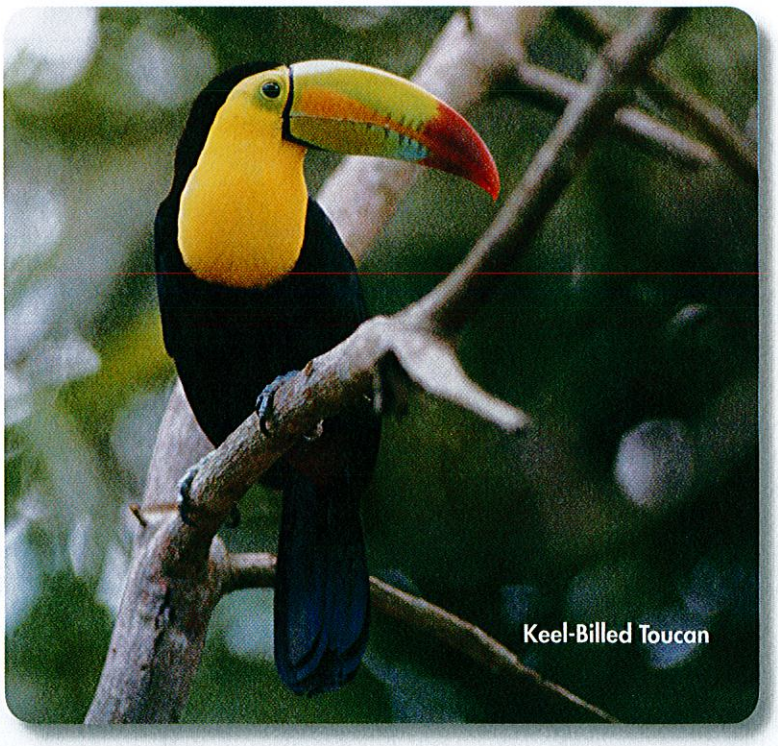
FALCONIDAE AND ACCIPITRIDAE: Falcons, eagles, and hawks

These fierce predators, often called raptors, typically have powerful hooked bills, large wingspans, and sharp talons. Raptors have powerful flight muscles and keen eyesight, enabling them to see prey at a distance. Examples: Eurasian Kestrel, Golden Eagle, Galápagos Hawk

Black Woodpecker with chicks

PICIDAE AND RAMPHASTIDAE: Woodpeckers and toucans

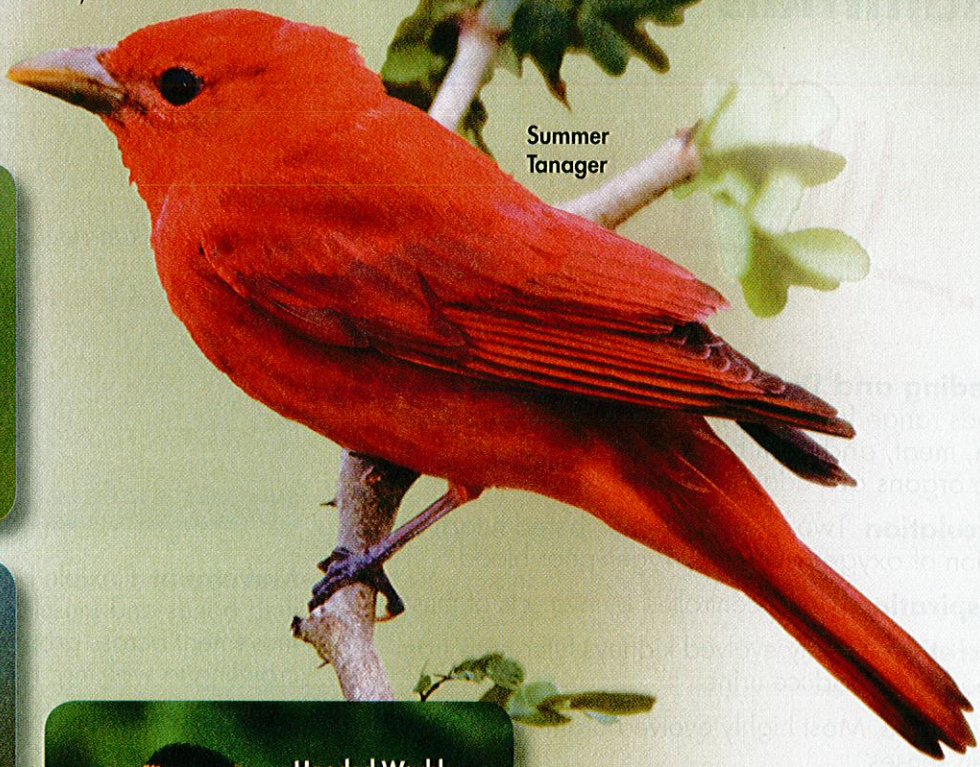
Woodpeckers are tree-dwelling birds with two toes in front and two in back. (Most birds have three in front and one in back; the two-and-two arrangement makes moving up and down tree trunks easier.) Woodpeckers are typically carnivores that eat insects and their larvae. Toucans usually use their huge, often colorful bills to eat fruit. Examples: Black Woodpecker, Keel-Billed Toucan

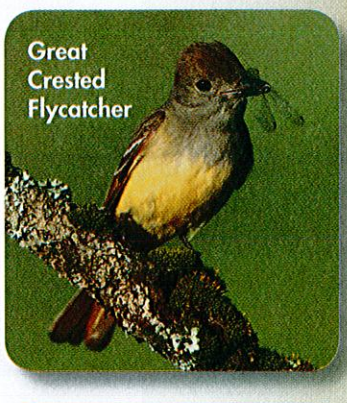


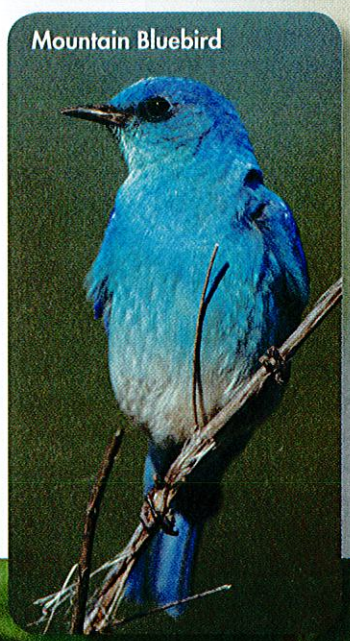
Keel-Billed Toucan

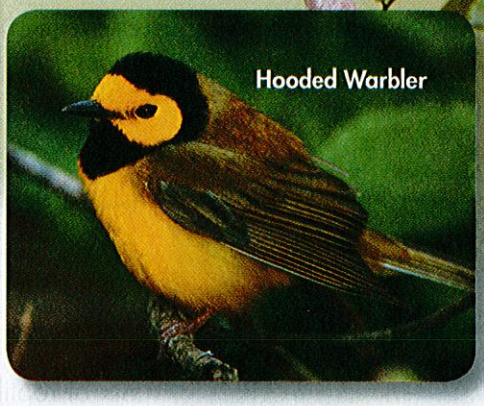
PASSERIFORMES: Passerines

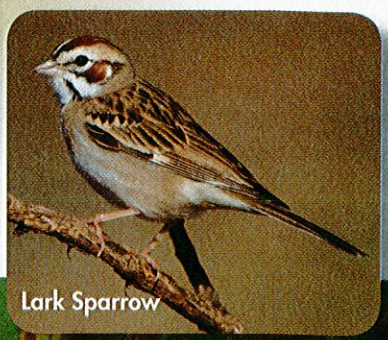
Also called perching birds, this is by far the largest and most diverse group of birds, with about 5000 species. Most are songbirds. Examples: flycatchers, mockingbirds, cardinals, crows, chickadees, and finches.


Summer Tanager


Great Crested Flycatcher

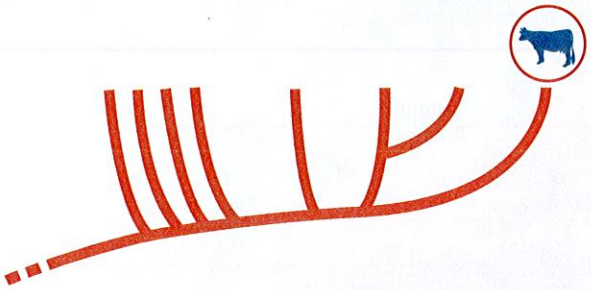

Mountain Bluebird

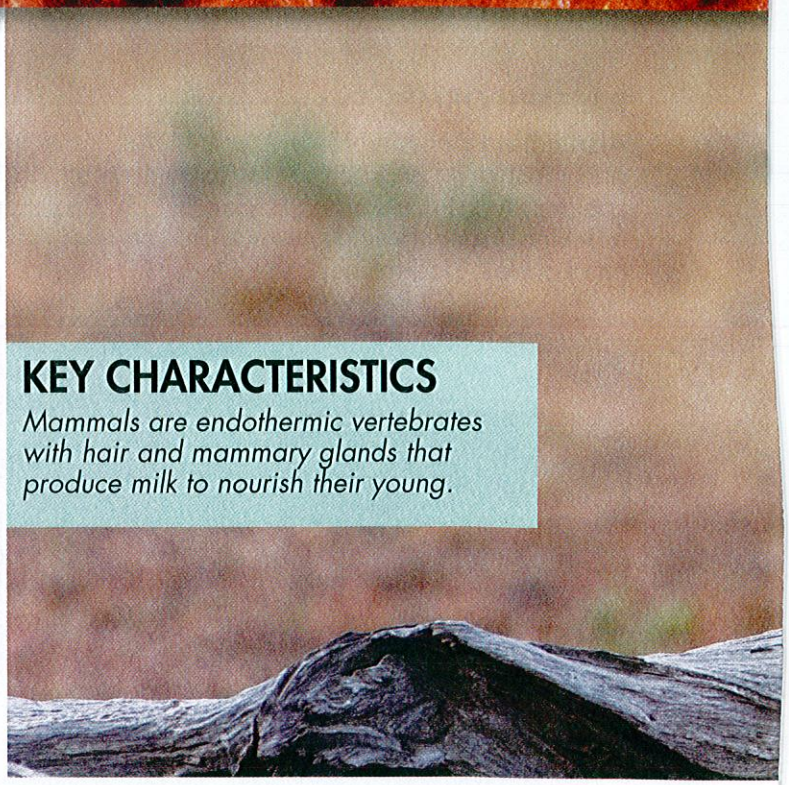

Hooded Warbler


Lark Sparrow


Blue Grosbeak

Mammals





KEY CHARACTERISTICS

Mammals are endothermic vertebrates with hair and mammary glands that produce milk to nourish their young.

Feeding and Digestion Diet varies with group; foods range from seeds, fruits, and leaves to insects, fish, meat, and even blood; teeth, jaws, and digestive organs are adapted to diet

Circulation Two loops; four-chambered heart; separation of oxygen-rich and oxygen-poor blood

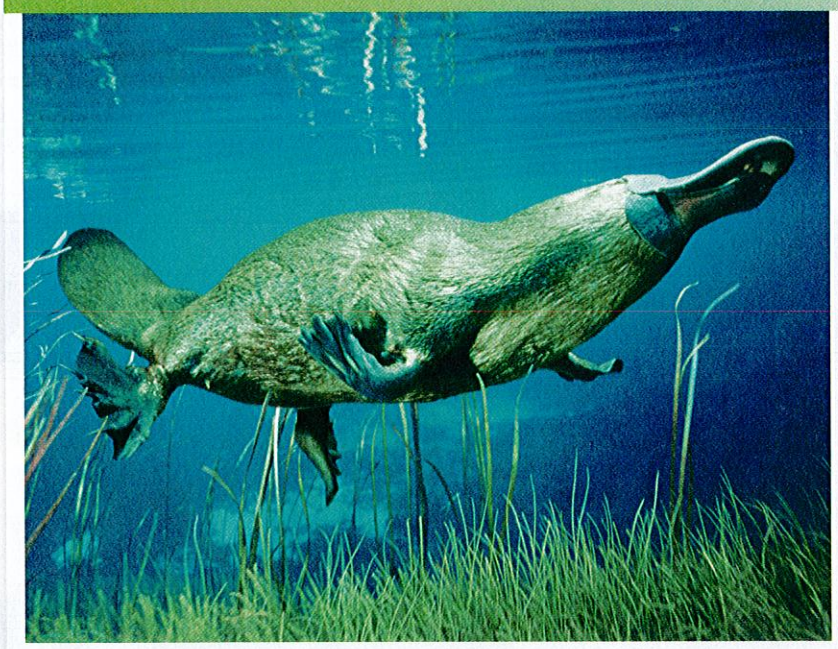
Respiration Lungs controlled by two sets of muscles.

Excretion Highly evolved kidneys filter urea from blood and produce urine.

Response Most highly evolved brain of all animals; keen senses

Movement Flexible backbone; variations in limb bones and muscles enable wide range of movement across groups: from burrowing and crawling to walking, running, hopping, and flying

Reproduction Internal fertilization; developmental process varies with group (monotreme, marsupial, placental)



Did You Know?

Platypus: Mix-and-Match Genome

The duckbill platypus has such an odd mix of reptile and mammal features that some scientists thought the first specimens were hoaxes produced by sticking parts of different animals together! Recent genome studies have revealed an equally odd mix of reptilian and mammalian genes. Genes for reptile-like vision, the production of egg yolk, and the production of venom link the platypus to reptiles. Genes for the production of milk link it to other mammals. The evidence provides confirmation that this monotreme represents a truly ancient lineage, one from the time close to that at which mammals branched off from reptiles.

This black-backed jackal pup is enjoying a moment of independence from its family group. Mammals provide intensive parental care to their young.

GROUPS OF MAMMALS

The three living groups of mammals are the monotremes, the marsupials, and the placentals. There are about 5000 species of mammals, usually divided into about 26 orders, most of which are placentals. There is only one order of monotremes.

Short-Beaked Echidna (Albino)

MONOTREMATA: Monotremes

Monotremes—egg-laying mammals—share two important characteristics with reptiles. First, the digestive, reproductive, and urinary systems of monotremes all open into a cloaca similar to that of reptiles. Second, monotreme development is similar to that of reptiles. Like a reptile, a female monotreme lays soft-shelled eggs incubated outside her body. The eggs hatch in about ten days. Unlike reptiles, however, young monotremes are nourished by mother's milk, which they lick from pores on the surface of her abdomen. Only five monotreme species exist today, all in Australia and New Guinea. Examples: Duckbill Platypus, echidnas

MARSUPIALIA: Marsupials

Marsupials bear live young at an extremely early stage of development. A fertilized egg develops into an embryo inside the mother's reproductive tract. The embryo is then "born" in what would be an embryonic stage for more familiar mammals. It crawls across its mother's fur and attaches to a nipple that, in most species, is located in a pouch called the marsupium. The embryo spends several months attached to the nipple. It continues to nurse until it can survive on its own. Examples: kangaroos, wallabies, wombats, opossums

Wombat

PLACENTALIA: Placental Mammals

Placental mammals are the mammals with which you are most familiar. This group gets its name from a structure called the placenta, which is formed when the embryo's tissues join with tissues within the mother's body. Nutrients, gases, and wastes are exchanged between embryo and mother through the placenta. The placenta allows the embryo to develop inside the mother longer so that placental young are born at a later stage of development than other mammals are. Development may take as little as a few weeks (mice), to as long as two years (elephants). After birth, most placental mammals care for their young and provide them with nourishment by nursing. Examples: Mice, cats, dogs, seals, whales, elephants, humans

Chiroptera: Bats

These are the only mammals capable of true flight. There are more than 900 species of bats! They eat mostly insects or fruit and nectar, although a few species feed on the blood of other vertebrates. Examples: fruit bats, Little Brown Myotis, Vampire Bat

Epauletted Bat, roosting

Lioness attacking Greater Kudu

Carnivora: Carnivores

Many members of this group, such as tigers and hyenas, chase or stalk prey by running or pouncing, then kill with sharp teeth and claws. Dogs, bears, and other members of this group may eat plants as well as meat. Examples: dogs, cats, skunks, seals, bears

Sirenia: Sirenians

Sirenians are herbivores that live in rivers, bays, and warm, coastal waters scattered throughout the world. These large, slow-moving mammals lead fully aquatic lives. Examples: manatees, dugongs

Manatee mother and nursing calf

African Hedgehog mother and baby

Insectivora: Insectivores

These insect eaters have long, narrow snouts and sharp claws that are well suited for digging. Examples: shrews, moles, hedgehogs

Perissodactyla: Hoofed, odd-toed mammals

This group is made up of hoofed animals with an odd number of toes on each foot. Like artiodactyls, this group contains mostly large, grazing animals. Examples: horses, zebras, rhinoceroses

Tapir hoof

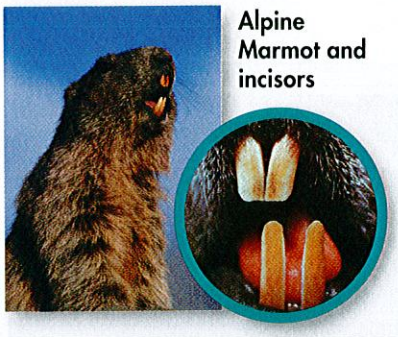
Central American Tapir

Artiodactyla: Hoofed, even-toed mammals

These large, grazing, hoofed mammals have an even number of toes on each foot. Examples: cattle, sheep, pigs, hippopotami

Giraffe hooves

Maasai Giraffe



Alpine Marmot and incisors

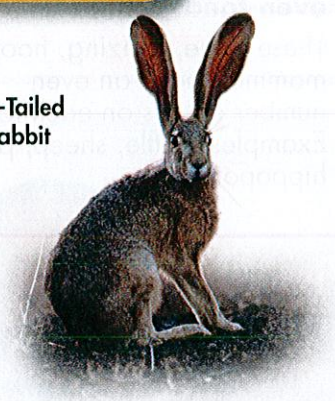
Rodentia: Rodents

Rodents have a single pair of long, curved incisor teeth in both their upper and lower jaws, used for gnawing wood and other tough plant material. Examples: rats, squirrels, porcupines

Cetacea: Cetaceans

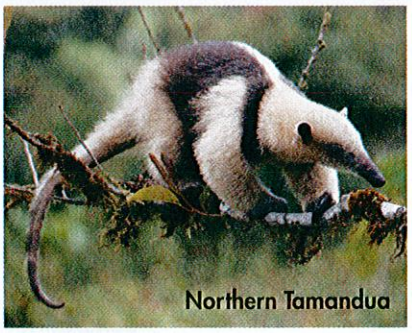
Like sirenians, cetaceans—the group that includes whales and dolphins—are adapted to underwater life, yet must come to the surface to breathe. Most cetaceans live and breed in the ocean. Examples: whales, dolphins

Atlantic Spotted Dolphin


Black-Tailed Jackrabbit

Lagomorpha: Rabbit, hares, and pikas

Lagomorphs are entirely herbivorous. They differ from rodents by having two pairs of incisors in the upper jaw. Most lagomorphs have hind legs that are adapted for leaping.


Northern Tamandua

Xenarthra: Edentates

The word *edentate* means "toothless," which refers to the fact that some members of this group (sloths and anteaters) have simple teeth without enamel or no teeth at all. Armadillos, however, have more teeth than most other mammals! Examples: sloths, anteaters, armadillos

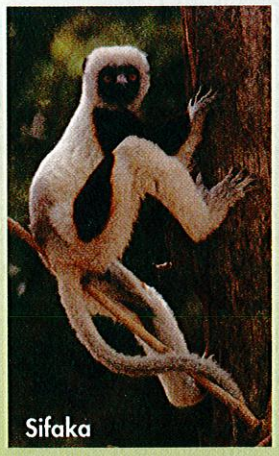
Proboscidea: Elephants

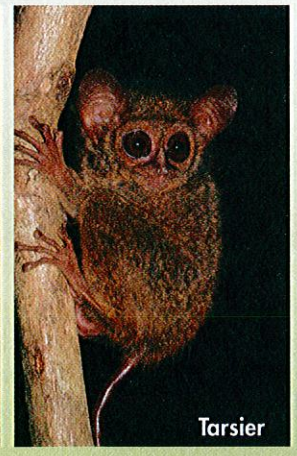
These are the mammals with trunks. Some time ago, this group went through an extensive adaptive radiation that produced many species, including mastodons and mammoths, which are now extinct. Only two species, the Asian Elephant and the African elephant, survive today.

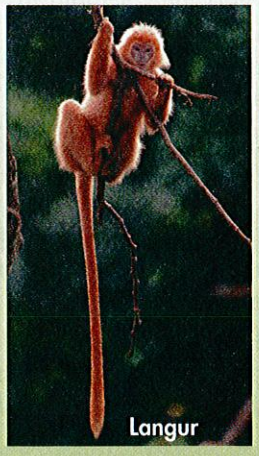

Asian Elephant and calf

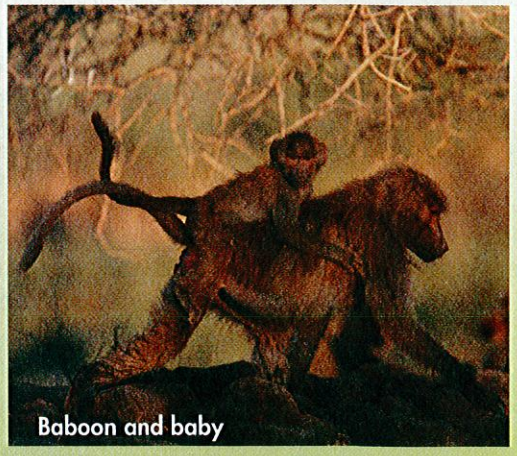
Primates: Lemurs, monkeys, apes, humans, and relatives

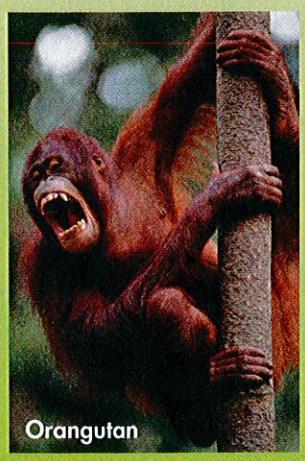
Members of this group are closely related to ancient insectivores but have a highly developed cerebrum and complex behaviors.

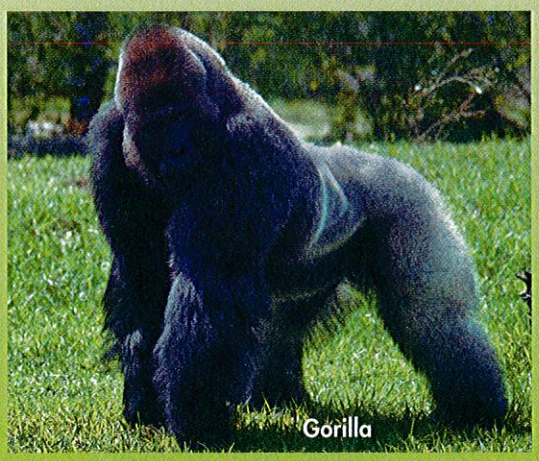

Sifaka

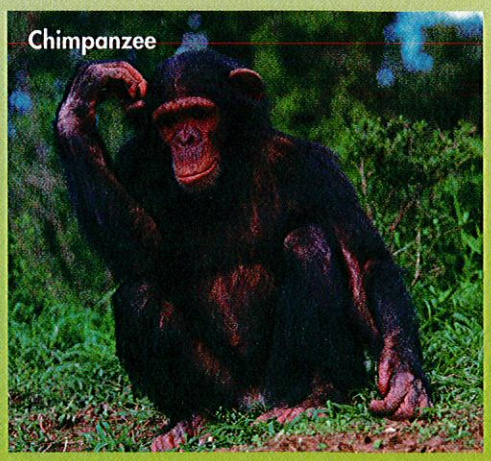

Tarsier


Langur


Baboon and baby


Orangutan


Gorilla


Chimpanzee