

Chapter 28 - Protists

I. What Are the Protists?

- A. Protists are small, often unicellular eukaryotes.
 1. All protists, like other eukaryotes, have a nucleus.
 2. All protists have histones associated with their DNA.
 3. All protists have a cytoskeleton.
- B. Protists can be defined only by what they are not.
 1. Protists are all the eukaryotes that are not fungi, plants, or animals.
 2. As a group, protists are paraphyletic in that they include some, but not all, descendants of the common ancestor of eukaryotes.
- C. Protists exhibit a wide array of morphologies and lifestyles. (Fig. 29.2)
 1. Many are microscopic single cells.
 2. Some are multicellular organisms up to 60 meters long.
 3. Some are parasitic; others are predatory or photosynthetic.
 4. Some are sessile; others are motile.
 5. Some have flexible, changing cell shape; others are encased in rigid outer casings.
- D. A common feature of all protists is their tendency to live in moist habitats: wet soil, water, or inside other organisms.

II. Why Do Biologists Study Protists?

- A. Impacts on Human Health and Welfare
 1. The Irish potato famine
 - a. In 1845 almost 3 million acres of potatoes became infested with *Phytophthora infestans*, a pathogenic protist.
 - b. Potatoes were destroyed, and a famine ensued.
 - c. Many people died or emigrated.
 2. Malaria
 - a. Is the most chronic health problem; over 1 million people worldwide die each year from malaria.
 - b. Caused by the protist *Plasmodium*, a member of the Apicomplexa group of protists (Fig. 29.3)
 - c. *Plasmodium* is transferred from person to person by mosquitoes.
 - (1) Eradication efforts have focused on eliminating mosquitoes.
 - (2) Mosquitoes have continually developed resistance to insecticides.
 - d. Few drugs are available to treat malaria; the protist evolves so quickly.
 - (1) Biologists are trying to understand the basic biology of protists in an effort to develop effective drug therapies.
 - (2) Prevention efforts and combination therapies are the current focus of WHO, the UN, and other organizations that seek to decrease the incidence of malaria.
 - e. Protists from many other lineages also cause human disease. (Table 29.1)
 3. Harmful algal blooms
 - a. Algal blooms occur when photosynthetic protists experience rapid population growth.
 - b. If the species involved in the algal bloom secrete toxins into the water, it is considered a harmful algal bloom.
 - (1) These toxic protists are often dinoflagellates that contain red-colored pigments (xanthophylls).
 - (2) Therefore harmful algal blooms are often called red tides. (Fig. 29.4)
 - c. Algal blooms can be harmful to people because . . .
 - (1) shellfish filter these protists out of the water.
 - (2) toxins accumulate in the shellfish and poison humans who eat them.

B. Ecological Importance of Protists

1. Protists are extremely abundant in their habitats.
 - a. A teaspoon of pond water can contain 1000 flagellated protists.
 - b. Dinoflagellates can reach levels of 60 million per liter of water.
2. The abundance of protists makes them major players in the global carbon cycle. (Fig. 29.6)
 - a. Diatoms are among the leading primary carbon producers in the oceans.
 - b. Primary productivity in the world's oceans is responsible for fixing almost half of the world's carbon.
3. Protists play a key role in marine food chains (Fig. 29.5)
 - a. The organic products of phytoplankton are the basis of marine and freshwater food chains.
 - b. Without these protists, most aquatic food chains would collapse.
4. How could protists help reduce global warming?
 - a. Carbon dioxide levels in Earth's atmosphere are increasing.
 - (1) Due to human activities such as burning fossil fuels and deforestation
 - (2) Accumulated carbon dioxide traps the heat radiating from Earth into space and causes global warming.
 - b. One hope for reducing global warming is to manipulate the carbon cycle and trap more carbon dioxide in terrestrial and marine environments.
 - (1) Trees are a carbon sink because they use carbon atoms to make wood.
 - (2) Phytoplankton are another carbon sink, because they use carbon dioxide for photosynthesis. (Fig. 29.6)
 - (a) Phytoplankton die or are eaten in a matter of days, cycling the carbon through other marine species.
 - (b) When those organisms die, they fall to the bottom of the ocean and become sedimentary rock or petroleum.
 - (c) Increasing the amount of carbon that falls to the ocean floor might be a way to reduce global warming.
 - c. While fertilizing algal blooms may increase the amount of carbon taken into the marine carbon sink, research is still ongoing to determine the overall effect of algal blooms.

III. How Do Biologists Study Protists?

A. Microscopy: Studying Cell Structure

1. Light microscopy studies lead to the naming and initial characterization of many protist species known today.
2. Electron microscopic studies yield even better knowledge of protist structure.
 - a. These data allow biologists to identify synapomorphies, or shared, derived traits that distinguish major monophyletic groups.
 - (1) Special flagella with tiny hairlike projections, known as stramenopiles, were identified on the protist that caused the potato famine and on some types of brown algae. (Fig. 29.7)
 - (2) The identification of these unusual flagella allowed for the identification of other species in that phylum.
 - b. This type of analysis has led to the identification of eight major groups of eukaryotes. (Table 29.2)

B. Evaluating Molecular Phylogenies

1. Molecular analysis of the gene encoding for rRNA in small subunit of ribosome demonstrated that eight major eukaryotic groups were indeed monophyletic.
2. The resulting phylogenetic tree (Fig. 29.8) is the current best estimate of eukaryotic evolutionary history.
3. This tree shows that protists are paraphyletic, meaning they do not comprise *all* the descendants of a single common ancestor. (Fig. 29.8)

C. Combining Data from Microscopy and Phylogenies: Understanding the Origin of Mitochondria and Chloroplasts

1. What did the earliest eukaryotes look like?
 - a. Archaea and the earliest protists are unicellular, so the first eukaryote must have been unicellular.
 - b. All eukaryotes today have a nucleus, cytoskeleton, and mitochondria, so their common ancestor must have had those structures.

- c. Early branching eukaryotes lack cell walls, so the common ancestor must have lacked cell walls.
- 2. The endosymbiotic theory (Lynn Margulis)
 - a. Mitochondria evolved through a series of steps: (Fig. 29.11)
 - (1) Large eukaryotic cells engulfed smaller archaea or bacteria.
 - (2) Archaea or bacteria lived symbiotically in host cell, were not digested.
 - (3) The engulfed cell absorbed and metabolized reduced carbon compounds from the host, using O_2 as an electron acceptor and making ATP.
 - (4) The anaerobic host gained the ability to survive in the presence of O_2 , becoming aerobic, and used ATP made by the endosymbiont.
 - b. Chloroplasts originated in a similar way.
 - (1) A photosynthetic cyanobacterium was engulfed by a eukaryotic cell.
 - (2) The cyanobacterium provided the host with oxygen and glucose.
 - (3) The host cell provided protection for the endosymbiont.
- 3. Do the data support the endosymbiosis theory?
 - a. Bacteria exist that have the same features as the presumed mitochondrial ancestor; some α -proteobacteria absorb reduced carbon from the environment and use O_2 as their electron receptor (aerobic respiration).
 - b. Many anaerobic protists ingest bacteria.
 - c. Endosymbiotic organisms exist today. Example: Cyanobacteria that live inside protist hosts
 - d. Mitochondria and chloroplasts . . .
 - (1) are similar in size to most bacteria.
 - (2) divide independently of the host cell.
 - (3) divide by fission, as bacteria do.
 - (4) have ribosomes and synthesize proteins.
 - (5) have ribosomes of the same size as bacteria.
 - e. Ribosomes in these organelles are poisoned by antibiotics that also poison bacterial ribosomes, but do not affect eukaryotic ribosomes.
 - f. A photosynthetic protist, *Cyanophora*, has a peptidoglycan cell wall, similar to bacterial cell walls.
 - g. Cyanobacteria exist that have the appearance of a chloroplast; they contain chlorophylls *a* and *b*, and they have internal thylakoid membranes.
 - h. Mitochondria and chloroplasts have their own genomes, which are circular and similar to bacterial genomes.
 - i. Mitochondria and chloroplasts produce the enzymes they need to replicate their genome and copy its genes into RNA.
 - j. Phylogenetic analysis of gene sequences compared nuclear DNA of eukaryotes, mitochondrial DNA from the same eukaryote, and DNA from several bacterial species. (Fig. 29.12)
 - (1) Results: Mitochondrial sequences were much more closely related to α -proteobacteria than to the DNA in their own nucleus.
 - (2) Conclusion: Their mitochondrial genome came from an α -proteobacterium and not a eukaryote.
 - k. Chloroplast genes are more closely related to cyanobacteria, and not plants.
 - l. Conclusion: Protists and other eukaryotes are "cut-and-paste" jobs.
 - (1) Protists are chimeras made of parts from different sources.
 - (2) Protists arose when the genomes of eukaryotes and bacteria combined.
- D. Discovering New Lineages via Direct Sequencing
 - 1. Protists are extensively studied because they are important model organisms in biology.
 - 2. However, the study of eukaryotic diversity has been rapidly advancing through the use of direct sequencing.
 - a. Direct sequencing is based on collecting organisms from a habitat and isolating their DNA.
 - b. Specific genes are amplified via PCR from the isolated DNA, and their sequences compared to existing databases.
 - c. Comparison data are used to place the organisms on a phylogenetic tree.
 - 3. One direct sequencing study collected samples from depths of 250-3000 m below the ocean surface in waters off the shore of Antarctica.

- a. A vast array of distinctive RNA sequences were found, indicating the presence of previously unidentified species.
- b. Microscopic studies revealed that the newly discovered eukaryotic species were as small as many bacteria.

IV. What themes occur in the diversification of protists?

A. Morphological Diversity

1. Organelles divide a large cell into compartments.
 - a. Eukaryotic cells are on average 10 times larger than most prokaryotic cells.
 - b. As cells become larger, their volume increases faster than surface area.
 - c. As cell size increases, metabolism in the cell interior can outstrip the transport and exchange processes at the cell surface.
 - (1) The volume of the cell is filled with biosynthetic machinery that requires energy and generates waste.
 - (2) Food molecules and waste molecules must diffuse across the cell surface to enter or leave the cell.
 - d. Eukaryotes solve the surface-area-to-volume ratio problem by creating more surface area inside the cell via compartmentalization into organelles.
 - (1) Compartmentalization provides large amounts of internal membranes.
 - (2) Example: Digestion of food in *Paramecium*
 - (a) *Paramecium* ingests a bacterium, taking it into a membrane-enclosed food vacuole.
 - (b) Membrane-bound lysosomes fuse with the food vacuole.
 - (c) Digestive enzymes from the lysosomes degrade the food.
 - (d) The food components are distributed to the rest of the cell as the vacuole circulates in the cytoplasm.
 - (e) After the food is digested, the food vacuole fuses with the plasma membrane and releases the waste material outside the cell.
 - (3) Other organelles in eukaryotic cells also are membrane bound and are devoted to transport, distribution, and synthesis of molecules.
 - e. Summary: Extensive compartmentalization and differentiation of organelles makes the large cell size of eukaryotes possible.
2. The evolution of multicellularity
 - a. Protists may be unicellular, colonial, or multicellular.
 - (1) Colonial organisms may be small and simple, have only a few cells.
 - (2) Other colonial organisms are large and complex, with different types of cells.
 - (3) Which organisms are colonial and which are truly multicellular?
 - b. Multicellularity is generally defined by two criteria:
 - (1) When individual cells cannot survive independently
 - (2) The cells have differentiated so that different cells perform different functions.
 - (a) Only a subset of the organism's genes is expressed in a differentiated cell.
 - (b) Different types of cells express different genes.
 - (3) Multicellularity is associated with specialization of cells, formation of distinct tissue types, and larger overall size.
3. Structures for support and protection
 - a. Protists evolved many different ways to support and/or protect their cells.
 - b. Some have rigid internal structures, such as the silicon skeletons of heliozoans, which provide support.
 - c. Others have hard external structures, called tests or shells, which provide support and protection.

(Fig. 29.13)

 - (1) Tests and shells are very diverse:
 - (a) Chambers of calcium carbonate (foraminifera)
 - (b) Glass-like shells (diatoms)
 - (c) Mineral particles (some ciliates and amoebae)
 - (d) Organic substances (cellulose walls of green algae).

(2) Tests and shells have evolved many different times, independently.

B. How Do Protists Find Food?

1. The large cell size of protists enabled some of them to develop a unique feeding strategy—ingesting other microbes.
 - a. Archaea, bacteria, and many protists can obtain food only by absorption or photosynthesis.
 - b. Some protists are large enough and have enough structural complexity to engulf, eat, or parasitize their food source.
2. Ingestive feeding (**Fig. 29.14a**)
 - a. Many protists are large enough to engulf bacteria, and sometimes other protists, by phagocytosis.
 - b. Phagocytotic protists lack cell walls and have flexible membranes and cytoskeletons that they can use to surround potential food sources.
 - c. These innovations allow them to eat other cells instead of competing with them for food or sunlight.
 - d. Ingestive protists obtain food in a variety of ways:
 - (1) Some hunt down their food by moving through their habitat and engulfing their prey.
 - (2) Others sit and wait for prey to come by, or have cilia that move the environment by them.
 - (3) Filter feeders collect food by sweeping water into their mouth.
2. Absorptive feeding
 - a. Some protists are decomposers and feed on detritus (dead organic matter).
 - b. Other protists that absorb their food live in other organisms.
 - c. Absorptive protists that damage the host they live in are parasitic.
3. Photosynthesis
 - a. Photosynthetic protists and bacteria are the dominant carbon producers in oceans and lakes.
 - b. Three key themes of the evolution of photosynthesis in protists:
 - (1) Different groups of algae can be distinguished by the photosynthetic pigments they contain. (**Tab. 29.3**)
 - (a) Different pigments absorb different wavelengths of light.
 - (b) Diversity in pigments lets different types of algae inhabiting the same area to absorb different components of available light.
 - (2) Some photosynthetic protists enter into symbiotic relationships with other protists. (**Fig. 28.18**)
 - (3) Protists originally obtained chloroplasts via endosymbiosis. (**Figs. 29.11, 29.16**)
 - (a) By engulfing cyanobacteria
 - (b) By engulfing other photosynthetic protists and retaining their chloroplasts (secondary endosymbiosis)
4. Diversity in lifestyles
 - a. All three types of lifestyles (ingestive, absorptive, photosynthetic) can occur within the same group of species.
 - (1) The group known as alveolates contains three major branches.
 - (2) Each group differs radically in how it obtains food.
 - (a) Ciliates can be predators, herbivores, animal parasites, or mutualists with photosynthetic symbionts.
 - (b) Some dinoflagellates are photosynthetic; others are parasites.
 - (c) Most apicomplexans are animal parasites.
 - b. The diversification of protists was driven by the diversification in methods of obtaining food.

C. How Do Protists Move?

1. Cell crawling (**Fig. 29.19a**)
 - a. Cell extensions, called pseudopodia, stream forward over a substrate.
 - b. The movement of the cytoplasm involves actin, myosin, and ATP.
 - c. The pseudopod surrounds food material, ingests it by phagocytosis.
2. Movement powered by cilia or flagella (**29.19b,c**)
 - a. Flagella and cilia are cell extensions, surrounded by the cell membrane.

- b. Flagella and cilia are identical in structure; each is composed of nine sets of doublet microtubules and two central, single microtubules.
 - c. Cilia are short and numerous on ciliated cells; flagella are long and fewer in number on flagellated cells.
 - d. Cilia and flagella movement is powered by ATP and motor protein dynein.
 - e. Cilia and flagella beat in a whiplash fashion.
 - f. Bacterial flagella are very different; they are composed primarily of the protein flagellin, and they rotate to produce movement.
3. Closely related protists can use very different forms of locomotion.
- D. How Do Protists Reproduce?
- 1. Sexual vs. asexual reproduction
 - a. Asexual reproduction—offspring are genetically identical to parents.
 - (1) Based on mitosis
 - (2) Most protists undergo asexual reproduction routinely.
 - b. Sexual reproduction—offspring are genetically different from the parents.
 - (1) Unlike bacteria, which transfer pieces of the genome of one cell to another, sexual reproduction in eukaryotes involves entire genome.
 - (2) Meiosis makes eukaryotic sexual reproduction possible.
 - (3) Protists undergo sexual reproduction intermittently, at a particular time of year or when conditions demand it.
 - c. The advantages of meiosis and sex
 - (1) Genetically variable offspring have a better chance of surviving if environmental conditions change from one generation to the next.
 - (2) Genetically variable offspring may be resistant to pathogens to which their parents were susceptible.
 - 2. Variation in life cycles
 - a. A life cycle describes the sequence of developmental events that occur as individuals grow, mature, and reproduce.
 - b. The advent of meiosis created a distinction between haploid and diploid phases in life cycles.
 - c. Every aspect of the life cycle is variable within the protists.
 - (1) Some protists undergo meiosis; others do not.
 - (2) Asexual reproduction may or may not occur during a life cycle.
 - (3) Either the haploid or diploid phase may be longer and more prominent than the other. (**Fig. 29.20**)
 - (4) Some protists have multicellular haploid and diploid phases.
 - (a) This is called an alternation of generations. (**Fig. 29.21**)
 - (b) The haploid phase is called the gametophyte, and the diploid phase is called the sporophyte
 - (c) The haploid and diploid phases may be identical in morphology, or they may be different. (**Fig. 29.21a, b**)
 - d. Diversity of life cycles is a major theme in the diversification of protists, but the reason for the diversity is not understood.

V. Key Lineages of Protists

A. Excavates

- 1. Diplomonads (**Fig 28.22**)
 - a. Morphological diversity:
 - (1) Each cell has two nuclei.
 - (2) Some species lack peroxisomes and lysosomes.
 - (3) All species lack cell wall.
 - b. Feeding and locomotion:
 - (1) Most are ingestive.
 - (2) Some are parasitic
 - (3) All swim via flagella.

- c. Reproduction: Only asexual reproduction
 - d. Human and ecological impacts:
 - (1) *Giardia intestinalis* is a common intestinal parasite in humans.
 - (2) *Hexamida* outbreaks kill turkeys each year.
2. Parabasalids (**Fig 29.24**)
- a. Morphological diversity:
 - (1) Lack a cell wall
 - (2) Have a single nucleus
 - b. Feeding and locomotion:
 - (1) Ingestive feeding
 - (2) Move via flagella, although number of flagella is variable
 - c. Reproduction: Most asexual; some sexual
 - d. Human and ecological impacts:
 - (1) *Trichomonas* cause reproductive tract infections in humans.
 - (2) *Histomonas meleagridis* infects chickens and turkeys.
- B. Discicristates: Euglenids (**Fig 29.26**)
- 1. Morphological diversity:
 - a. Lack an external cell wall, but protein filaments strengthen cell membrane
 - b. Have disc-shaped cristae in mitochondria
 - 2. Feeding and locomotion:
 - a. Some have chloroplast and photosynthesize.
 - b. Some have a light-sensitive eyespot and use flagella to swim toward light.
 - 3. Reproduction: Only asexual
 - 4. Human and ecological impacts: Important in freshwater food chains
- C. Alveolates
- 1. Ciliates (**Fig 29.28**)
 - a. Morphological diversity:
 - (1) Cells have two nuclei; a meganucleus and a micronucleus.
 - (2) Some have an external skeleton.
 - b. Feeding and locomotion:
 - (1) Some are filter feeders, predators or parasites.
 - (2) Use cilia to swim.
 - (3) Have a mouth where food is ingested.
 - c. Reproduction:
 - (1) Produce daughter cells asexually
 - (2) Undergo conjugation to exchange micronuclei
 - d. Human and ecological impacts: Live in the digestive tract of grazing animals, helping them digest plant food.
 - 2. Dinoflagellates (**Fig 29.30**)
 - a. Morphological diversity:
 - (1) Most are unicellular, but some are colonial.
 - (2) Form distinctive shapes by plates of cellulose inside cells.
 - (3) Chromosomes do not contain histones.
 - (4) Some species are capable of emitting light, bioluminescence.
 - b. Feeding and locomotion:
 - (1) Some are photosynthetic, but most are planktonic.
 - (2) Swim in a spinning motion using two flagella.
 - c. Reproduction:
 - (1) Both sexual and asexual reproduction can occur.
 - (2) Offspring from sexual reproduction can form tough cysts that can remain dormant until conditions are favorable for growth.
 - d. Human and ecological impacts: Important marine primary producers; some can form red tides

3. Apicomplexa (**Fig 29.28**)
 - a. Morphological diversity:
 - (1) Have a complex of organelles called the apical complex
 - (2) The apical complex can penetrate the plasma membrane of its host.
 - b. Feeding and locomotion:
 - (1) Absorptive feeders that live on/in a host; can be parasitic
 - (2) Move via cell crawling; lack cilia or flagella.
 - c. Reproduction: Sexually or asexually
 - d. Human and ecological impacts:
 - (1) *Plasmodium* causes malaria.
 - (2) *Toxoplasma* is a common infection in people who have HIV.

D. Stramenopiles

1. Oomycetes (**Fig 29.33**)
 - a. Morphological diversity:
 - (1) Some are unicellular.
 - (2) Some are multicellular; form long, branching filaments called hyphae.
 - (3) Have cell walls with cellulose
 - b. Feeding and locomotion:
 - (1) Most are detritivores, some are parasitic.
 - (2) Mature individuals are sessile.
 - c. Reproduction:
 - (1) Most are diploid throughout most of their life cycle.
 - (2) Aquatic species have gametes that swim via flagella.
 - (3) Terrestrial species produce spores that are dispersed via rainwater or wind.
 - d. Human and ecological impacts:
 - (1) Important decomposers in aquatic ecosystems.
 - (2) An oomycete caused the Irish potato famine.
2. Diatoms (**Fig 29.32**)
 - a. Morphological diversity: Cells are supported by an external, silicon-rich glassy shell.
 - b. Feeding and locomotion:
 - (1) Photosynthetic
 - (2) Only reproductive cells have flagella.
 - (3) Photosynthetic cells float in the water.
 - c. Reproduction:
 - (1) Divide by mitosis to reproduce asexually.
 - (2) Can divide via meiosis to form gametes
 - (3) Some species make spores that are dormant until conditions are favorable for growth.
 - d. Human and ecological impacts:
 - (1) Dominate the plankton of cold waters.
 - (2) Are important carbon producers in aquatic habitats.
 - (3) Their shells are mined for use in industry.
3. Brown algae (**Fig 29.34**)
 - a. Morphological diversity:
 - (1) Cells have walls with cellulose.
 - (2) All species are multicellular.
 - (3) Bodies have leaflike blades, a stalk called a stipe, and a rootlike holdfast which attaches to its substrate.
 - b. Feeding and locomotion:
 - (1) Photosynthetic
 - (2) Sessile, although reproductive cells may have flagella.
 - c. Reproduction:
 - (1) Sexual reproduction via swimming gametes
 - (2) Most species exhibit alternation of generation.

- d. Human and ecological impacts:
 - (1) In coastal areas they form forests that are habitats for animals.
 - (2) May form large rafts on the water that house animals.
 - (3) Algin is purified from brown alga and used in cosmetics and paint.
- E. Rhizaria—Foraminifera (**Fig 29.36**)
 - 1. Morphological diversity:
 - a. Cells have multiple nuclei.
 - b. Tests are stiffened by calcium carbonate.
 - c. Have multiple holes (foramen) through which pseudopodia emerge
 - 2. Feeding and locomotion:
 - a. Feed by extending pseudopodia and engulfing their prey
 - b. Simply float in the water
 - 3. Reproduction: Asexual and sexual reproduction
 - 4. Human and ecological impacts: Sediments of tests solidify to form chalk, limestone, or marble
- F. Plants--Red Algae (**Fig 29.38**)
 - 1. Morphological diversity:
 - a. Cell walls have cellulose.
 - b. Some species are unicellular, but most are multicellular.
 - c. Some species are filamentous, but many grow as thin, hard crusts on rock or coral.
 - 2. Feeding and locomotion:
 - a. Most are photosynthetic, some are parasitic.
 - b. Lack flagella
 - 3. Reproduction:
 - a. Asexual reproduction through spores
 - b. Sexual reproduction involving alternation of generations
 - 4. Human and ecological impacts:
 - a. Stabilize coral reefs
 - b. Harvested for food production in East Asia
- G. Ameobozoa--Plasmodial Slime Molds (**Fig 29.40**)
 - 1. Morphological diversity: Some species form a large multinucleated supercell.
 - 2. Feeding and locomotion:
 - a. Feed on decaying vegetation
 - b. Move by cell crawling
 - 3. Reproduction: Sexual reproduction when food is scarce
 - 4. Human and ecological impacts: Important decomposers in forests