ECOLOGY, BIODIVERSITY & EVOLUTION - I (3+0)

HANDOUTS

Lecture # 1

What is an ecosystem?

An ecosystem is a community of living organisms in conjunction with the nonliving components of their environment, interacting as a system. These biotic and abiotic components are linked together through nutrient cycles and energy flows. Energy enters the system through photosynthesis and is incorporated into plant tissue. By feeding on plants and on one-another, animals play an important role in the movement of matter and energy through the system. They also influence the quantity of plant and microbial biomass present. By breaking down dead organic matter, decomposers release carbon back to the atmosphere and facilitate nutrient cycling by converting nutrients stored in dead biomass back to a form that can be readily used by plants and other microbes.

Ecosystems are controlled by external and internal factors. External factors such as climate, parent material which forms the soil and topography, control the overall structure of an ecosystem but are not themselves influenced by the ecosystem. Unlike external factors, internal factors are controlled, for example, decomposition, root competition, shading, disturbance, succession, and the types of species present.

Ecosystems are dynamic entities—they are subject to periodic disturbances and are in the process of recovering from some past disturbance. Ecosystems in similar environments that are located in different parts of the world can end up doing things very differently simply because they have different pools of species present. Internal factors not only control ecosystem processes but are also controlled by them and are often subject to feedback loops .Resource inputs are generally controlled by external processes like climate and parent material. Resource availability within the ecosystem is controlled by internal factors like decomposition, root competition or shading. Although humans operate within ecosystems, their cumulative effects are large enough to influence external factors like climate.

Lecture # 2

Living organisms can use many forms of energy, but not heat?

Organisms cannot convert heat to any of the other forms of energy. Thus, if organisms convert some chemical-bond or light energy to heat, the conversion is one-way; they cannot cycle that energy back into its original form. Living organisms must take in energy from their environment and convert it into to a form their cells can use. Organisms ingest large molecules, like carbohydrates, proteins, and fats, and convert them into smaller molecules like carbon dioxide and water. This process is called cellular respiration, a form of catabolism, and makes energy available for the cell to use. The energy released by cellular respiration is temporarily captured by the formation of adenosine triphosphate (ATP) within the cell. ATP is the principle form of stored energy used for cellular functions and is frequently referred to as the energy currency of the cell.

The nutrients broken down through cellular respiration lose electrons throughout the process and are said to be oxidized. When oxygen is used to help drive the oxidation of nutrients the process is called aerobic respiration. Aerobic respiration is common among the eukaryotes, including humans, and takes place mostly within the mitochondria. Respiration occurs within the cytoplasm of prokaryotes. Several prokaryotes and a few eukaryotes use an inorganic molecule other than oxygen to drive the oxidation of their nutrients in a process called anaerobic respiration. Electron acceptors for anaerobic respiration include nitrate, sulfate, carbon dioxide, and several metal ions.

The energy released during cellular respiration is then used in other biological processes. These processes build larger molecules that are essential to an organism's survival, such as amino acids, DNA, and proteins. Because they synthesize new molecules, these processes are examples of anabolism.

Lecture # 3

Producers

Producers are organisms that make their own food; they are also known as autotrophs. They get energy from chemicals or the sun, and with the help of water, convert that energy into useable energy in the form of sugar, or food. The most common example of a producer are plants. Through a process called photosynthesis, green plants use sunlight and water and make a type of sugar called glucose. Green plants such as trees are found on land, but they can also exist underwater as long as there is enough sunlight. Although algae look like a plant, they're actually a special kind of single-celled organism called a protist. A protist cellular structure is different from a plant's, but it can still make its own food and, therefore, it is a producer. Algae and its relatives can be found in aquatic ecosystems.

Surprisingly, single-celled bacteria can also be producers. Located deep below the ocean surface are areas that get little to no sunlight. Green plants can't survive there, since they are unable make food without sunlight. But, single-celled bacteria use a process to make food called chemo-synthesis, which involves taking chemicals expelled from hydrothermal vents deep in the ocean and converting them into the same type of food that plants make. The food producers create food for themselves in order to grow and reproduce. However, plants also serve as food for the rest of the ecosystem, the consumers.

Primary productivity is the productivity of the primary producers. Primary producers are that not only do they synthesize new organic matter by photosynthesis, but they also break down some of the organic matter to release energy by means of aerobic cellular respiration.

Examples of Trophic Level

Primary Producers

Primary producers, or "*autotrophs"*, are organisms that produce biomass from *inorganic compounds*. In general, these are *photosynthesizing* organisms such as plants or algae, which convert energy from the sun, using carbon dioxide and water, into glucose. This glucose is then stored within the plant as energy, and oxygen, which is released into the atmosphere. In terrestrial ecosystems, almost all of the primary production comes from *vascular plants* such as trees, ferns, and flowering plants. In marine ecosystems, algae and seaweed fill the role of primary production. There are also some deep-sea primary producers that perform oxidization of chemical inorganic compounds instead of using photosynthesis; these organisms are called" chemoautotrophs*"*.

Lecture # 4

Consumers

An organism that generally obtains food by feeding on other organisms or organic matter due to lack of the ability to manufacture own food from inorganic sources; a heterotroph. consumer pertains to any of the organisms in most trophic levels in a food chain, except for producers and decomposers. Consumers are also referred to as heterotrophs in contrast to autotrophs, which are the producers of the food chain. Consumers therefore include animals and heterotrophic bacteria and fungi. Plants that are carnivorous and therefore consume organic matter as well are regarded as both consumers and producers.

In a food chain, the levels of consumers are primary consumers, secondary consumers, and tertiary consumers. Primary consumers are herbivores that feed on producers. Secondary consumers are consumers that feed on primary consumers and/or producers. Tertiary consumers are consumers that feed on secondary and primary consumers, as well as on producers. The trophic levels consist of the heterotrophs—the consumers. All the heterotrophs that feed directly on the primary producers are placed together in a trophic level called the herbivores.

Primary Consumers

Primary consumers are herbivores, that is, animals that are adapted to consuming and digesting plants and algae (autotrophs). Herbivores are generally split into two categories: *grazers*, such as cows, sheep and rabbits, whose diets consist at least 90% of grass, and *browsers*, such as deer and goats, whose diets consist at least 90% of tree leaves or twigs.

Primary consumers may also consume other forms of plant material. Many bats, birds and monkeys eat fruit (*frugivores*); birds, insects, bats and arachnids (spiders) eat nectar (*nectarivores*); and termites and beetles eat wood (*xylophages*). In marine ecosystems, primary consumers are *zooplankton*, tiny crustaceans which feed off photosynthesizing algae known as *phytoplankton*.

Secondary Consumers

Secondary consumers, at trophic level three, are carnivores and omnivores, which obtain at least part of their nutrients from the tissue of herbivores. This includes animals and carnivorous plants that feed on herbivorous insects (*insectivores*). Secondary consumers are usually small animals, fish and birds such as frogs, weasels, and snakes, although larger apex predators, such as lions and eagles, may consume herbivores, and can also exist within the second trophic level of an ecosystem. In marine ecosystems, all species that consume zooplankton are secondary consumers; this ranges from jellyfish to small fish such as sardines and larger crustaceans such as crabs and lobsters, as well as whales, which filter feed, and basking sharks.

Tertiary Consumers

Tertiary consumers acquire energy by eating other carnivores but may be preyed upon. Owls are an example of tertiary consumers; although they feed off mice and other herbivores, they also eat secondary consumers such as stoats. In turn, owls may be hunted by eagles and hawks, and are therefore not apex predators.

Lecture # 5

Decomposers

A subcategory of detritivores is the decomposers, which are mostly microbes and other minute organisms that live on and break up dead organic matter. Decomposers are organisms that break down dead or decaying organisms, and in doing so, they carry out the natural process of decomposition. Like herbivores and predators, decomposers are heterotrophic, meaning that they use organic substrates to get their energy, carbon and nutrients for growth and development. While the terms decomposer and detritivore are often interchangeably used, detritivores must ingest and digest dead matter via internal processes while decomposers can directly absorb nutrients through chemical and biological processes hence breaking down matter without ingesting it. Thus, invertebrates such as earthworms, woodlice, and sea cucumbers are technically detritivores, not decomposers, since they must ingest nutrients and are unable to absorb them externally.

This decomposer is thought of as a primary source of litter and or waste in the ecosystems. Fungi has been known to produce a selection of prescription drugs along with many other antibiotics. Unlike bacteria, which are unicellular organisms and are decomposers as well, most saprotrophic fungi grow as a branching network of hyphae. While bacteria are restricted to growing and feeding on the exposed surfaces of organic matter, fungi can use their hyphae to penetrate larger pieces of organic matter, below the surface. Additionally, only wood-decay fungi have evolved the enzymes necessary to decompose lignin, a chemically complex substance found in wood. These two factors make fungi the primary decomposers in forests, where litter has high concentrations of lignin and often occurs in large pieces. Fungi decompose organic matter by releasing enzymes to break down the decaying material, after which they absorb the nutrients in the decaying material. Hyphae used to break down matter and absorb nutrients are also used in reproduction. When two compatible fungi hyphae grow close to each other, they will then fuse together for reproduction and form another fungus. Examples of decomposers include bacteria, fungi, some insects, and snails, which means they are not always microscopic. Fungi, such as the Winter Fungus, eat dead tree trunks.

Lecture # 6

Energy

Energy is defined as the ability to do work. Energy can be found in many things and can take different forms. For example, kinetic energy is the energy of motion, and potential energy is energy due to an object's position or structure. Energy is never lost, but it can be converted from one form to another. For animals, work includes everything from foraging for food to moving molecules around within cells. To supply their energy needs, animals ingest other organisms; that is, animals are heterotrophic (Gr. hetero, other trophy, feeder). Autotrophic (Gr. autos, self tropho, feeder) organisms (e.g., plants) carry on photosynthesis or other carbon fixing activities that supply their food source.

Kinetic energy

The energy associated with an object's motion is called kinetic energy. A speeding bullet, a walking person, and electromagnetic radiation like light all have kinetic energy. Another example of kinetic energy is the energy associated with the constant, random bouncing of atoms or molecules. This is also called thermal energy – the greater the thermal energy, the greater the kinetic energy of atomic motion, and vice versa. The average thermal energy of a group of molecules is what we call temperature, and when thermal energy is being transferred between two objects, it's known as heat

Lecture #`6

Food Chain

A food chain is a linear network of links in a food web starting from producer organisms (such as grass or trees which use radiation from the Sun to make their food) and ending at apex predator species (like grizzly bears or killer whales), detritivores (like earthworms or woodlice), or decomposer species (such as fungi or bacteria). A food chain also shows how the organisms are related with each other by the food they eat. Each level of a food chain represents a different trophic level. A food chain differs from a food web, because the complex network of different animals' feeding relations are aggregated and the chain only follows a direct, linear pathway of one animal at a time. Natural interconnections between food chains make it a food web. A common metric used to the quantify food web trophic structure is food chain length. In its simplest form, the length of a chain is the number of links between a trophic consumer and the base of the web and the mean chain length of an entire web is the arithmetic average of the lengths of all chains in a food web.

Many food webs have a keystone species (Such as Sharks). A keystone species is a species that has a large impact on the surrounding environment and can directly affect the food chain. If this keystone species dies off it can set the entire food chain off balance. Keystone species keep herbivores from depleting all of the foliage in their environment and preventing a mass extinction.

Food chains were first introduced by the Arab scientist and philosopher Al-Jahiz in the 10th century and later popularized in a book published in 1927 by Charles Elton, which also introduced the food web concept. The sequence of organisms through which energy moves in an ecosystem is a food chain. One relatively simple food chain might look like the following:

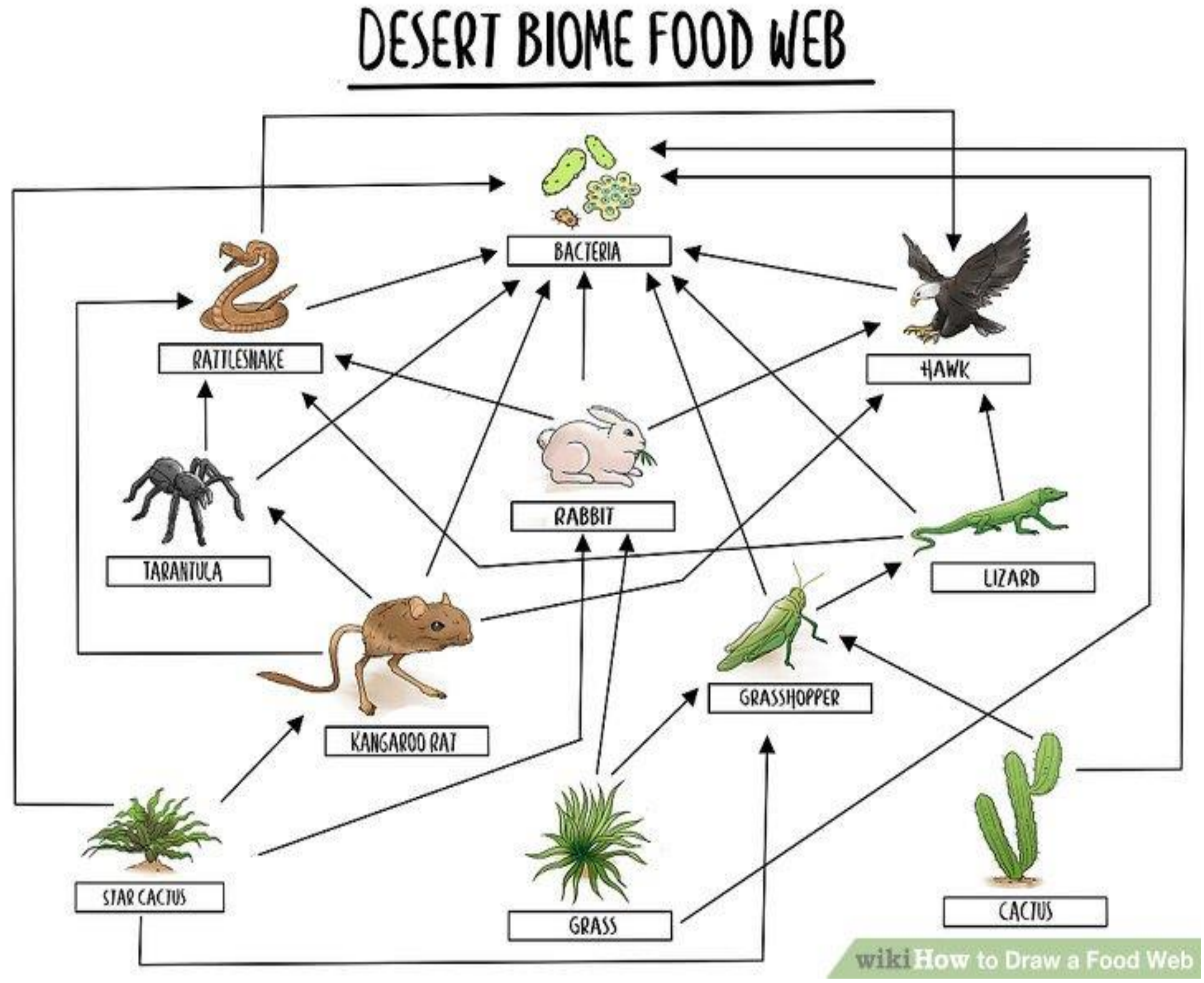
Grass -------grazing insects---- shrews ------owls

Lecture #`7

Food Web

Complexly interconnected food chains, called food webs that involve many kinds of organisms are more realistic. Because food webs can be complex, it is convenient to group organisms according to the form of energy used. These groupings are called trophic levels. Producers (autotrophs) obtain nutrition (complex organic compounds) from inorganic materials and an energy source. They form the first trophic level of an ecosystem. The most familiar producers are green plants. Other trophic levels are made up of consumers (heterotrophs). Consumers eat other organisms to obtain energy. Herbivores (primary consumers) eat producers. Some carnivores (secondary consumers) eat herbivores, and other carnivores (tertiary consumers) eat the carnivores that ate the herbivores. Consumers also include scavengers that feed on large chunks of dead and decaying organic matter.

Decomposers break down dead organisms and feces by digesting organic matter extracellularly and absorbing the products of digestion. The efficiency with which the animals of a trophic level convert food into new biomass depends on the nature of the food (figure 6.11). Biomass conversion efficiency averages 10%, although efficiencies range from less than 1% for herbivorous endotherms to 35% for carnivorous ectoderms.



Lecture # 8

Definitions of trophic levels

The first trophic level in an ecosystem, called the primary producers, consists of all the autotrophs in the system. The other trophic levels consist of the heterotrophs—the consumers. All the heterotrophs that feed directly on the primary producers are placed together in a trophic level called the herbivores. In turn, the heterotrophs that feed on the herbivores (eating them or being parasitic on them) are collectively termed primary carnivores, and those that feed on the primary carnivores are called secondary carnivores.

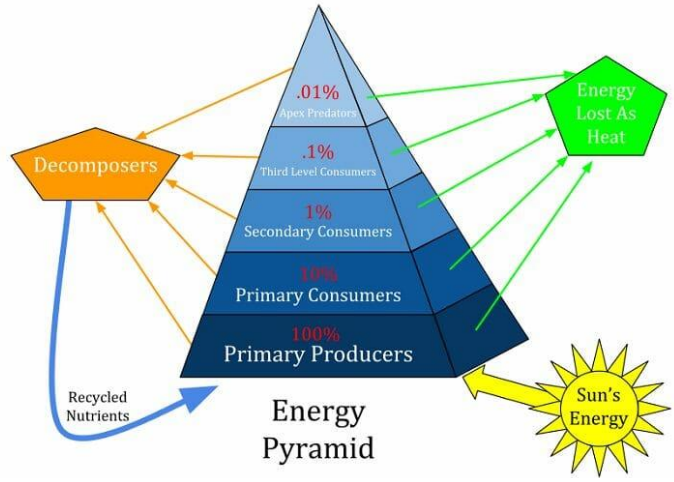
A trophic level is the group of organisms within an ecosystem which occupy the same level in a food chain. There are five main trophic levels within a food chain, each of which differs in its nutritional relationship with the primary energy source. The primary energy source in any ecosystem is the Sun (although there are exceptions in deep sea ecosystems).

The solar radiation from the Sun provides the input of energy which is used by primary producers, also known as autotrophs. Primary producers are usually plants and algae, which perform photosynthesis in order to manufacture their own food source. Primary producers make up the first trophic level. The rest of the trophic levels are made up of consumers, also known as heterotrophs; heterotrophs cannot produce their own food, so must consume other organisms in order to acquire nutrition. The second trophic level consists of herbivores, these organisms gain energy by eating primary producers and are called primary consumers.

Trophic levels three, four and five consist of carnivores and omnivores. Carnivores are animals that survive only by eating other animals, whereas omnivores eat animals and plant material. Trophic level three consists of carnivores and omnivores which eat herbivores; these are the secondary consumers. Trophic level four contains carnivores and omnivores which eat secondary consumers and are known as tertiary consumers. Trophic level five consists of apex predators; these animals have no natural predators and are therefore at the top of the food chain.

Decomposers or detritivores are organisms which consume dead plant and animal material, converting it into energy and nutrients that plants can use for effective growth. Although they do not fill an independent trophic level, decomposers and detritivores, such as fungi, bacteria, earthworms and flies, recycle waste material from all other trophic levels and are an important part of a functioning ecosystem.

Due to the way that energy is utilized as it is transferred between levels, the total biomass of organisms on each trophic level decreases from the bottom-up. Only around 10% of energy consumed is converted into biomass, whereas the rest is lost as heat, as well as to movement and other biological functions. Because of this gradual loss of energy, the biomass of each trophic level is often viewed as a pyramid, called a trophic pyramid.



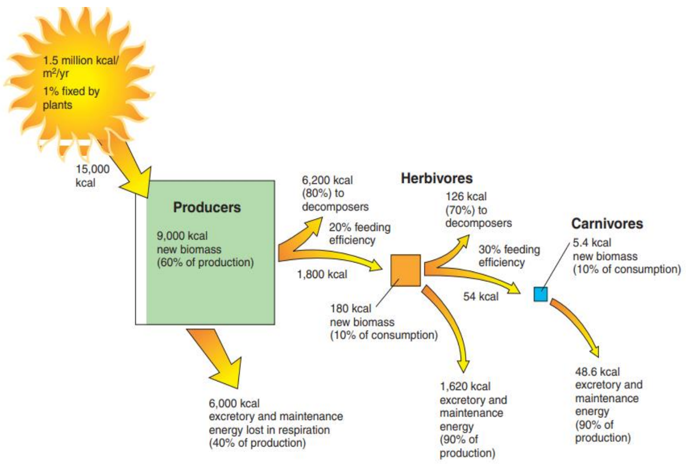
It is important to note that organisms within the trophic levels of natural ecosystems do not generally form a uniform chain, and that many animals can have multiple prey and multiple predators; the non-linear interactions of trophic levels can therefore be best viewed as a food web rather than a food chain. However, disruption within one of the trophic levels, for example, the extinction of a predator, or the introduction of a new species, can have a drastic effect on either the lower or higher trophic levels.

Lecture # 9

Energy flows through trophic levels of ecosystems

Autotrophs synthesize the organic compounds of their bodies from inorganic Precursors such as CO_2, water, and NO_3–using energy from an abiotic source. Some autotrophs use light as their source of energy and therefore are photoautotrophs; they are the photo-synthetic organisms, including plants, algae, and cyanobacteria. Other autotrophs are chemo autotrophs and obtain energy by means of inorganic oxidation reactions, such as the microbes that use hydrogen sulfide available at deep water vents. All chemoautotrophs are prokaryotic. The photo-autotrophs are of greatest importance in most ecosystems, and we focus on them in the remainder of this chapter.

Heterotrophs are organisms that cannot synthesize organic compounds from inorganic precursors, but instead live by taking in organic compounds that other organisms have made. They obtain the energy they need to live by breaking up some of the organic compounds available to them, thereby liberating chemical-bond energy for metabolic use. Animals, fungi, and many microbes are heterotrophs. When living in their native environments, species are of-ten organized into chains that eat each other sequentially. For example, a species of insect might eat plants, and then a species of shrew might eat the insect, and a species of hawk might eat the shrew. Food passes through the four species in the sequence: plants →insect →shrew →hawk. A sequence of species like this is termed a food chain.



In a whole ecosystem, many species play similar roles; there is typically not just a single species in each role. For example, the animals that eat plants might include not just a single insect species, but perhaps 30 species of insects, plus perhaps 10 species of mammals. To organize this complexity, ecologists recognize a limited number of feeding, or trophic, levels.

Approximately 1.5 million kcal of radiant energy strike a square meter of the earth’s surface each year. Plants convert less than 1% (15,000 kcal/m2 /yr) into chemical energy. Of this, approximately 60% is converted into new biomass, and 40% is lost in respiration. The herbivore trophic level harvests approximately 20% of net primary production, and decomposers get the rest. Of the 1,800 kcal moving into the herbivore trophic level, 10% (180 kcal) is converted to new biomass, and 90% (1,620 kcal) is lost in respiration.

Carnivores harvest about 30% of the herbivore biomass, and 10% of that is converted to carnivore biomass. At subsequent trophic levels, harvesting efficiencies of about 30% and new biomass production of about 10% can be assumed. All of these percentages are approximations. Absolute values depend on the nature of the primary production (e.g., forest versus grassland) and characteristics of the herbivores and carnivores (e.g., ectothermic versus endothermic).

Lecture # 9

How trophic levels process energy?

The fraction of incoming solar radiant energy that the primary producers capture is small. Averaged over the course of a year, something around 1% of the solar energy impinging on forests or oceans is captured. Investigators sometimes observe far lower levels, but also see percentages as high as 5% under some conditions. The solar energy not captured as chemical-bond energy through photosynthesis is immediately converted to heat. The primary producers, as noted before, carry out respiration in which they break down some of the organic compounds in their bodies to release chemical-bond energy. They use a portion of this chemical-bond energy to make ATP, which they in turn use to power various energy-requiring processes. Ultimately, the chemical-bond energy they release by respiration turns to heat. All living things require energy in one form or another since energy is required by most, complex, metabolic pathways (often in the form of ATP); life itself is an energy-driven process. Living organisms would not be able to assemble macromolecules (proteins, lipids, nucleic acids, and complex carbohydrates) from their monomeric subunits without a constant energy input. It is important to understand how organisms acquire energy and how that energy is passed from one organism to another through food webs and their constituent food chains. Food webs illustrate how energy flows directionally through ecosystems, including how efficiently organisms acquire it, use it, and how much remains for use by other organisms of the food web. Energy is acquired by living things in three ways:

photosynthesis, chemosynthesis, and the consumption and digestion of other living or previously-living organisms by heterotrophs.

Photosynthetic and chemosynthetic organisms are grouped into a category known as autotrophs: organisms capable of synthesizing their own food (more specifically, capable of using inorganic carbon as a carbon source). Photosynthetic autotrophs (photoautotrophs) use sunlight as an energy source, whereas chemosynthetic autotrophs (chemoautotrophs) use inorganic molecules as an energy source. Autotrophs act as producers and are critical for all ecosystems. Without these organisms, energy would not be available to other living organisms and life itself would not be possible. Photoautotrophs, such as plants, algae, and photosynthetic bacteria, serve as the energy source for a majority of the world's ecosystems. These ecosystems are often described by grazing food webs. Photoautotrophs harness the solar energy of the sun by converting it to chemical energy in the form of ATP (and NADP). The energy stored in ATP is used to synthesize complex organic molecules, such as glucose.

Lecture # 10

Ecological pyramids illustrate the relationship of trophic levels?

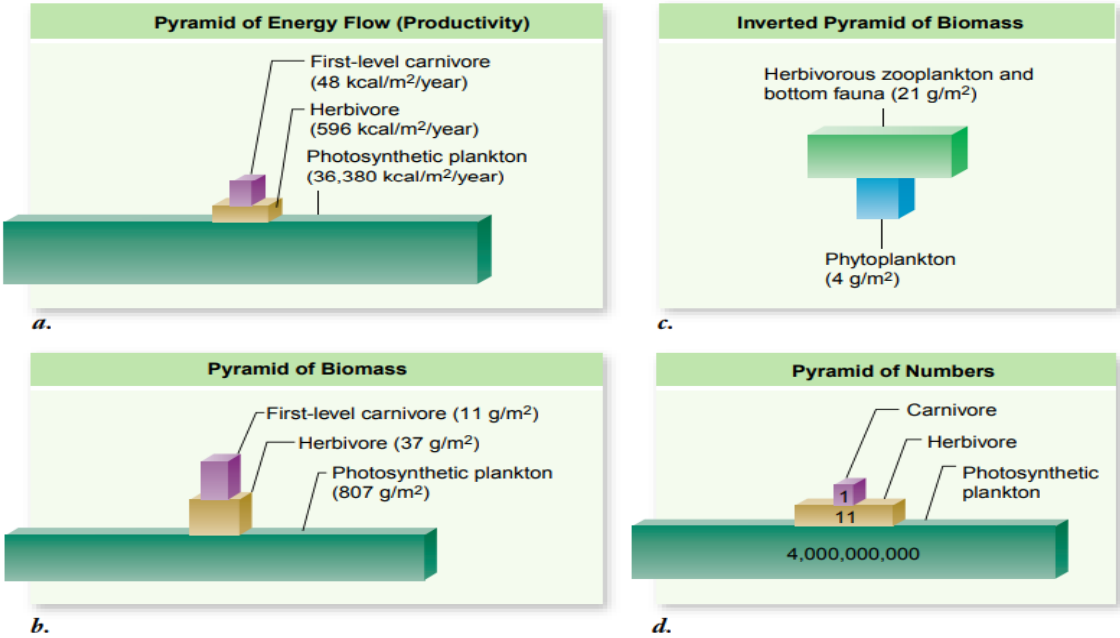
It is a graphic representation of the relationship between organisms at various trophic levels in a food chain. The basis of an ecological pyramid is the biomass, energy, and number. Just as the name suggests ecological pyramids are in the shape of a pyramid. The concept was first introduced by Charles Elton, the pioneer British Ecologist.

The bottom of an ecological pyramid is the broadest and is occupied the producers, which form the first trophic level. Producers are at the lowest level. Just as in a food chain, the producers are consumed by the primary consumers, in an ecological pyramid; the next level is occupied by the primary consumers. The next level of the pyramid is occupied by the secondary consumers and the last, by the tertiary consumers.

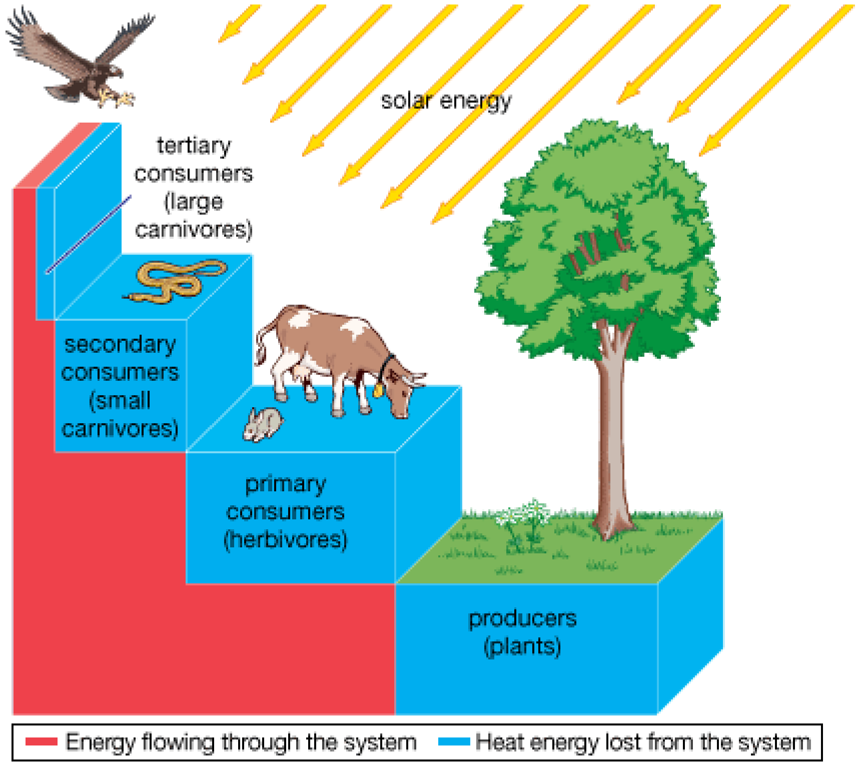
Types of Ecological Pyramids

Depending on the factors that we use to represent an ecological pyramid, there are three types. They are:

- Pyramid of numbers– Here the factor that is taken into account is the number of organisms in each trophic level. As we go up the levels of the pyramid, the number of organisms decreases. The producers form the largest number and hence are at the bottom of the pyramid.
- Pyramid of energy– This is an upright pyramid that represents the flow of energy from the producers to the final consumers.
- Pyramid of biomass – This pyramid represents the amount of biomass of the organisms present at each trophic level. Biomass is nothing but the weight of the organisms.



In general, all ecological pyramids are upright, except in certain cases. For example, in a detritus food chain, the pyramid of numbers is not upright because many organisms feed on one dead plant or animal. The pyramid of biomass in an ocean is also inverted. But a point of note is that the pyramid of energy is always upright as the flow of energy is unidirectional.



Animals and Their Abiotic Environment

The environment in which an animal life is referred to as its habitat. A habitat includes both biotic (living) and abiotic (non-living) components of the animal's environment. An animal’s habitat (environment) includes all living (biotic) and nonliving (abiotic) characteristics of the area in which the animal lives. Abiotic characteristics of a habitat include the availability of oxygen and inorganic ions, light, temperature, and current or wind velocity. Physiological ecologists who study abiotic influences have found that animals live within a certain range of values, called the tolerance range, for any environmental factor.

In biology and ecology, abiotic components or abiotic factors are non-living chemical and physical parts of the environment that affect living organisms and the functioning of ecosystems. Abiotic factors and the phenomena associated with them underpin all biology. Abiotic components include physical conditions and non-living resources that affect living organisms in terms of growth, maintenance, and reproduction. Resources are distinguished as substances or objects in the environment required by one organism and consumed or otherwise made unavailable for use by other organisms. Component degradation of a substance occurs by chemical or physical processes, e.g. hydrolysis. All non-living components of an ecosystem, such as atmospheric conditions and water resources, are called abiotic components.

Abiotic components of an animal's environment include a huge range of characteristics, examples of which include:

- Temperature
- Humidity
- Oxygen
- Wind
- Soil composition
- Day length
- Elevation

Potential energy

This type of energy is known as potential energy, and it is the energy associated with an object because of its position or structure. For instance, the energy in the chemical bonds of a molecule is related to the structure of the molecule and the positions of its atoms relative to one another. Chemical energy, the energy stored in chemical bonds, is thus considered a form of potential energy. Some everyday examples of potential energy include the energy of water held behind a dam, or of a person about to skydive out of an airplane.

Lecture # 12

Temperature

Temperature is a measure of how hot or cold something is; specifically, a measure of the average kinetic energy of the particles in an object, which is a type of energy associated with motion. But how hot is hot, and how cold is cold? The terms hot and cold are not very scientific terms. If we really want to specify how hot or cold something is, we must use temperature. For instance, how hot is melted iron? To answer that question, a physical scientist would measure the temperature of the liquid metal. Using temperature instead of words, like hot or cold, reduces confusion.

An animal expends part of its existence energy in regulating body temperature. Temperature influences the rates of chemical reactions in animal cells (metabolic rate) and affects the animal's overall activity. The body temperature of an animal seldom remains constant because of an inequality between heat loss and heat gain. Temperature is an average measure. Particles of matter are constantly moving, but they don't all move at the same speed and in the same direction all the time. The motion of the particles is random. The particles of matter in an object move in different directions, and some particles move faster than others. As a result, some particles have more kinetic energy than others. So what determines an object's temperature? An object's temperature is the best approximation of the kinetic energy of the particles. When we measure an object's temperature, we measure the average kinetic energy of the particles in the object.

The higher the temperature, the faster the molecules of the substance move, on the average. Dyes will spread more rapidly through hot water than cold water. This is because of the increased motion of the molecules. Temperature does not have to do with the number of molecules involved. Under given conditions, the temperatures of 10-ml and 100-ml samples of boiling water are equal. This means that the average kinetic energy of the molecules is the same for the two different quantities of water.

Measuring Temperature

Since molecules are so small, you must use an indirect method to measure the kinetic energy of the molecules of a substance. As heat is added to a substance, the molecules move more rapidly. This increased motion causes a small increase in the volume, or amount of space, taken up by most materials. There are devices that use the expansion of a substance to give an indirect measure of temperature. Such devices are called **thermometers**.

Lecture # 13

Water

Abiotic factors for animals include moisture, light, geology, and soils. All life's processes occur in the watery environment of the cell. Water that is lost must be replaced. The hydrogen and oxygen atoms within water molecules form polar covalent bonds. The shared electrons spend more time associated with the oxygen atom than they do with hydrogen atoms. There is no overall charge to a water molecule, but there is a slight positive charge on each hydrogen atom and a slight negative charge on the oxygen atom. Because of these charges, the slightly positive hydrogen atoms repel each other and form the unique shape. Each water molecule attracts other water molecules because of the positive and negative charges in the different parts of the molecule. Water also attracts other polar molecules (such as sugars), forming hydrogen bonds. When a substance readily forms hydrogen bonds with water, it can dissolve in water and is referred to as hydrophilic ("water-loving"). Hydrogen bonds are not readily formed with nonpolar substances like oils and fats. These nonpolar compounds are hydrophobic ("water-fearing") and will not dissolve in water.

Water Is an Excellent Solvent

Because water is polar, with slight positive and negative charges, ionic compounds and polar molecules can readily dissolve in it. Water is, therefore, what is referred to as a solvent—a substance capable of dissolving another substance. The charged particles will form hydrogen bonds with a surrounding layer of water molecules. This is referred to as a sphere of hydration and serves to keep the particles separated or dispersed in the water.

In the case of table salt (NaCl) mixed in water, the sodium and chloride ions separate, or dissociate, in the water, and spheres of hydration are formed around the ions. A positively charged sodium ion is surrounded by the partially negative charges of oxygen atoms in water molecules. A negatively charged chloride ion is surrounded by the partially positive charges of hydrogen atoms in water molecules. These spheres of hydration are also referred to as hydration shells. The polarity of the water molecule makes it an effective solvent and is important in its many roles in living systems.

Lecture #`13

Light

The amount of light and the length of the light period in a 24-hour day is an accurate index of seasonal change. Animals use light for timing many activities such as reproduction and migration. As with auditory stimuli, light travels in waves. The compression waves that compose sound must travel in a medium—a gas, a liquid, or a solid. In contrast, light is composed of electromagnetic waves and needs no medium; light can travel in a vacuum (Figure 1). The behavior of light can be discussed in terms of the behavior of waves and also in terms of the behavior of the fundamental unit of light—a packet of electromagnetic radiation called a photon. A glance at the electromagnetic spectrum shows that visible light for humans is just a small slice of the entire spectrum, which includes radiation that we cannot see as light because it is below the frequency of visible red light and above the frequency of visible violet light.

Certain variables are important when discussing perception of light. Wavelength (which varies inversely with frequency) manifests itself as hue. Light at the red end of the visible spectrum has longer wavelengths (and is lower frequency), while light at the violet end has shorter wavelengths (and is higher frequency). The wavelength of light is expressed in nanometers (abbreviated nm); one nanometer is one billionth of a meter. Humans perceive light that ranges between approximately 380 nm and 740 nm. Some other animals, though, can detect wavelengths outside of the human range. For example, bees see near-ultraviolet light in order to locate nectar guides on flowers, and some non-avian reptiles sense infrared light (heat that prey gives off).

Lecture #`14

Population Growth

Animal populations change over time as a result of birth, death, and dispersal. One way to characterize a population with regard to the death of individuals is with survivorship curves. The Y-axis of a survivorship graph is a logarithmic plot of numbers of survivors, and the X-axis is a linear plot of age. There are three kinds of survivorship curves. Individuals in type 1 (convex) populations survive to an old age, and then die rapidly. Environmental factors are relatively unimportant in influencing mortality, and most individuals live their potential life span. Some human populations approach types I survivorship.

Individuals in type II (diagonal) populations have a constant probability of death throughout their lives. The environment has an important influence on death and is no harsher on the young than on the old. Populations of birds and rodents often have type II survivorship curves. Individuals in type III (concave) populations experience very high juvenile mortality. Those reaching adulthood, however, have a much lower mortality rate. Fishes and many invertebrates display type III survivorship curves.

A second attribute of populations concerns population growth. The potential for a population to increase in numbers of individuals is remarkable. Rather than increasing by adding a constant number of individuals to the population in every generation, the population increases by the same ratio per unit time. In other words, populations experience exponential growth. Not all populations display the same capacity for growth. Such factors as the number of offspring produced, the likelihood of survival to reproductive age, the duration of the reproductive period, and the length of time it takes to reach maturity all influence reproductive potential.

Exponential growth cannot occur indefinitely. The constraints that climate, food, space, and other environmental factors place on a population are called environmental resistance

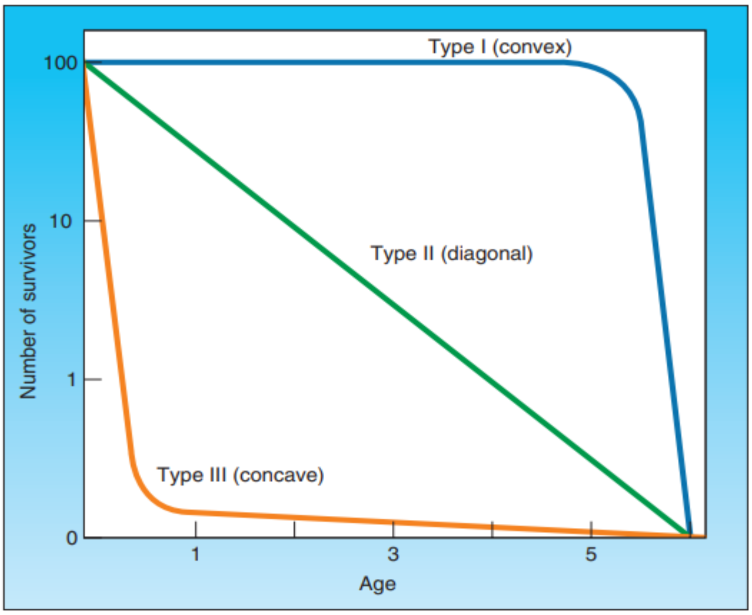


Fig 2. Survivorship curves are a plot of number of survivors (usually a logarithmic plot) versus age. Type I curves apply to populations in which individuals are likely to live out their potential life span. Type II curves apply to populations in which mortality rates are constant throughout age classes. Type III curves apply to populations in which mortality rates are highest for the youngest cohorts.

the maximum number of individuals the environment can support.

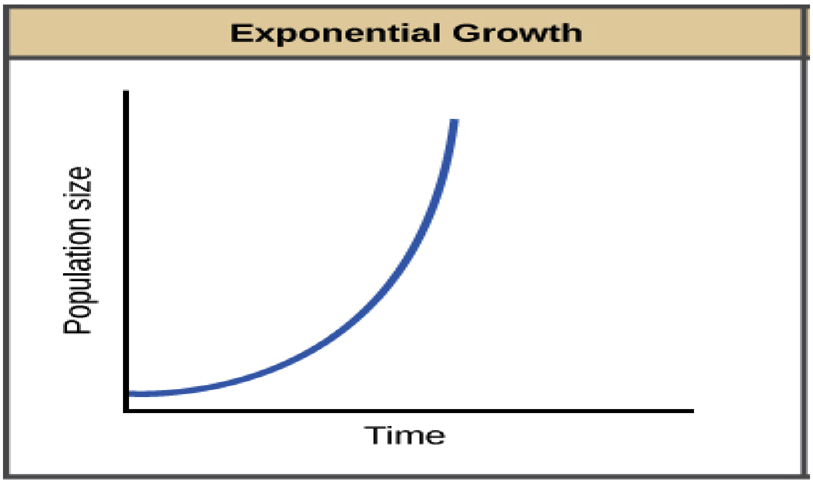
Lecture #`15

Exponential growth

When resources are unlimited, populations exhibit exponential growth, resulting in a J-shaped curve. In logistic growth, population expansion decreases as resources become scarce. It levels off when the carrying capacity of the environment is reached, resulting in an S-shaped curve. The potential for a population to increase in numbers of individuals is remarkable. Rather than increasing by adding a constant number of individuals to the population in every generation, the population increases by the same ratio per unit time. In other words, populations experience exponential growth.

The best example of exponential growth is seen in bacteria. Bacteria are prokaryotes that reproduce by prokaryotic fission. This division takes about an hour for many bacterial species. If

1000 bacteria are placed in a large flask with an unlimited supply of nutrients (so the nutrients will not become depleted), after an hour there will be one round of division (with each organism dividing once), resulting in 2000 organisms. In another hour, each of the 2000 organisms will double, producing 4000; after the third hour, there should be 8000 bacteria in the flask; and so on. The important concept of exponential growth is that the population growth rate, the number of organisms added in each reproductive generation, is accelerating; that is, it is increasing at a greater and greater rate. After 1 day and 24 of these cycles, the population would have increased from 1000 to more than 16 billion. When the population size, N, is plotted over time, a J-shaped growth curve is produced.



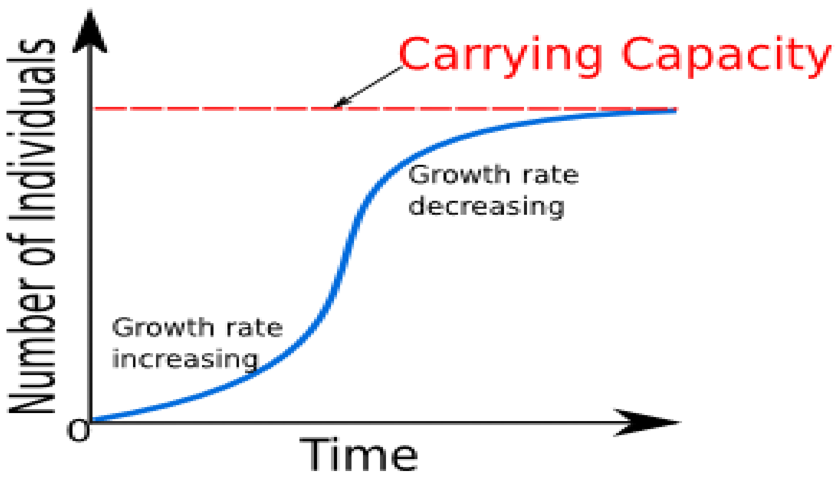
Lecture #`16

Logistic Population Growth

Logistic growth curves reflect limited resources placing an upper limit on population size. A logistic growth curve is an S-shaped (sigmoid) curve that can be used to model functions that increase gradually at first, more rapidly in the middle growth period, and slowly at the end, leveling off at a maximum value after some period of time.

A group of individuals of the same species living in the same area is called a population. The measurement of how the size of a population changes over time is called the population growth rate and it depends upon the population size, birth rate and death rate. As long as there are enough resources available, there will be an increase in the number of individuals in a population over time, or a positive growth rate. However, most populations cannot continue to grow forever because they will eventually run out of water, food, sunlight, space or other resources. As these resources begin to run out, population growth will start to slow down. When the growth rate of a population decreases as the number of individuals increases, this is called logistic population growth.

Graphing Logistic Population Growth



If we look at a graph of a population undergoing logistic population growth, it will have a characteristic S-shaped curve. The population grows in size slowly when there are only a few individuals. Then the population grows faster when there are more individuals. Finally, having lots of individuals in the population causes growth to slow because resources are limited. In logistic growth, a population will continue to grow until it reaches carrying capacity, which is

Lecture #`18

Population Regulation

All populations on Earth have limits to their growth. Even populations of bunnies—that reproduce like bunnies! —don't grow infinitely large. And although humans are giving the idea of infinite growth a run for its money, we too will ultimately reach limits on population size imposed by the environment. What exactly are these environmental limiting factors? Broadly speaking, we can split the factors that regulate population growth into two main groups: density-dependent and density-independent. The conditions that an animal must meet to survive are unique for every species. What many species have in common, however, is that population density and competition affect populations in predictable ways.

Population Density

Density-independent factors influence the number of animals in a population without regard to the number of individuals per unit space (density). For example, weather conditions often limit populations. An extremely cold winter with little snow cover may devastate a population of lizards sequestered beneath the litter of the forest floor. Regardless of the size of the population, a certain percentage of individuals will freeze to death. Human activities, such as construction and deforestation, often affect animal populations in a similar fashion.

Density-dependent factors are more severe when population density is high (or sometimes very low) than they are at other densities. Animals often use territorial behavior, song, and scent marking to tell others to look elsewhere for reproductive space. These actions become more pronounced as population density increases and are thus density dependent. Other density-dependent factors include competition for resources, disease, predation, and parasitism.

Lecture #`19

Communities

All populations living in an area make up a community. Communities are not just random mixtures of species; instead, they have a unique organization. Most communities have certain members that have overriding importance in determining community characteristics. For example, a stream community may have a large population of rainbow trout that helps determine the makeup of certain invertebrate populations on which the trout feed.

A number of ways to categorize types of community have been proposed. One such breakdown is as follows:

Location-based Communities:

Range from the local neighborhood, suburb, village, town or city, region, nation or even the planet as a whole. These are also called communities of place.

Identity-based Communities:

Range from the local clique, sub-culture, ethnic group, religious, multicultural or pluralistic civilization, or the global community cultures of today. They may be included as *communities of need* or *identity*, such as disabled persons, or frail aged people.

Organizationally based Communities:

Range from communities organized informally around family or network-based guilds and associations to more formal incorporated associations, political decision making structures, economic enterprises, or professional associations at a small, national or international scale.

Lecture #`20

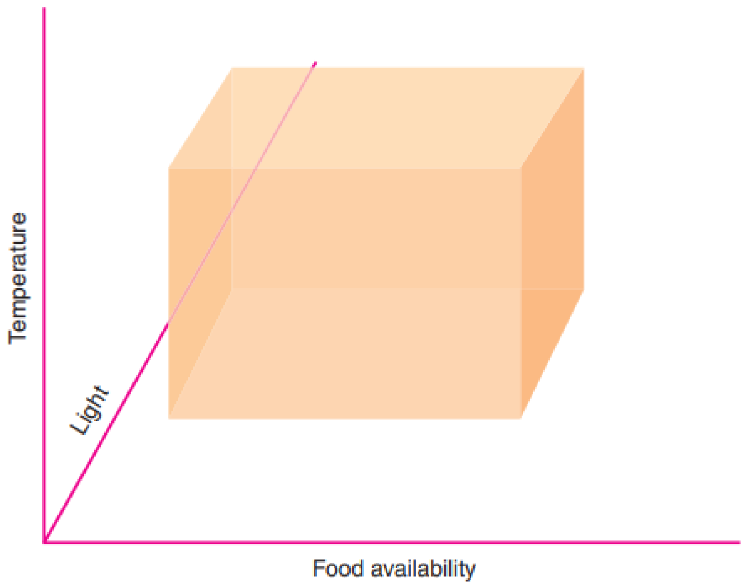
The Ecological Niche

In ecology, a niche is the match of a species to a specific environmental condition. It describes how an organism or population responds to the distribution of resources and competitors (for example, by growing when resources are abundant, and when predators, parasites and pathogens are scarce) and how it in turn alters those same factors (for example, limiting access to resources by other organisms, acting as a food source for predators and a consumer of prey). "The type and number of variables comprising the dimensions of an environmental niche vary from one species to another the relative importance of particular environmental variables for a species may vary according to the geographic and biotic contexts.

A Grinnellian niche is determined by the habitat in which a species lives and its accompanying behavioral adaptations. An Eltonian niche emphasizes that a species not only grows in and responds to an environment, it may also change the environment and its behavior as it grows. The Hutchinsonian niche uses mathematics and statistics to try to explain how species coexist within a given community. The concept of ecological niche is central to ecological biogeography, which focuses on spatial patterns of ecological communities. Species distributions and their dynamics over time result from properties of the species, environmental variation..., and interactions between the two—in particular the abilities of some species, especially our own, to modify their environments and alter the range dynamics of many other species." Alteration of an ecological niche by its inhabitants is the topic of niche construction.

The majority of species exist in a standard ecological niche, sharing behaviors, adaptations, and functional traits similar to the other closely related species within the same broad taxonomic class, but there are exceptions. A premier example of a non-standard niche filling species is the flightless, ground-dwelling kiwi bird of New Zealand, which feeds on worms and other ground creatures, and lives its life in a mammal-like niche. Island biogeography can help explain island species and associated unfilled niches.

The ecological niche is an important concept of community structure. The niche of any species includes all the attributes of an animal's lifestyle: where it looks for food, what it eats, where it nests, and what conditions of temperature and moisture it requires. Theoretically, competition results when the niches of two species overlap.



Lecture #`21

Community Stability

As with individuals, communities are born and they die. Between those events is a time of continual change. Some changes are the result of climatic or geological events. Members of the community are responsible for others. The dominant members of a community often change a community in predictable ways in a process called succession (L. succession, to follow). Communities may begin in areas nearly devoid of life. The first community to become established in an area is called the pioneer community.

Community stability can be defined as the ability of a community to defy change or rebound from change. The concept of rebounding from change is known as resilience. General resilience is a measure of stability that assumes system stability increases as return time to equilibrium/non-equilibrium solution decreases after perturbation/ disturbance. A rapid response means that a system recoils quickly back to its state of equilibrium. The concept of defying changing change is known as resistance. Resistance is a measure of the degree to which a variable change after a perturbation/ disturbance. However, measuring stability in a system can be a difficult task. In 1955, Charles Elton proposed a theory that stated a positive stability-diversity relationship was a result of the stability of aggregate community measures like the total biomass. There is much controversy on the definition of stability and how it is measured.

Stability Diversity Hypothesis

The stability-diversity hypothesis states that the more diverse a community is, the more stable and productive the community is. This hypothesis was formed from the basis that more stable and productive communities can use their resources better and more efficiently as compared to communities of less diversity. There are correlations with stability measures like constancy of community production and community resilience to species loss and also alterations to the relative abundance of different species. Early research has overlooked the possibility that unexpected fluctuations in the abundance of species may be more important than species interactions when it comes to creating stability-diversity associations

Several experimental tests of the stability-diversity hypothesis have been done. An experiment by Nelson Hairston using bacteria and Paramecium in a two tiered trophic system showed that the extinction rate would decrease with an increase of bacteria species, this result had an increased stability and supported the hypothesis. He also found that the extinction rate increased when there was more Paramecium species present, this result showed a decrease in stability and rejected the hypothesis.

Another experiment to research the stability-diversity hypothesis was done by Tilman. He did a field experiment carried out over eleven years and found that variation in community biomass decreases with increased species richness. But when it came to year to year variation the biomass of a particular species increased with increasing species richness. These results concluded that diversity increases community stability but not population stability. The shortcoming of Tilman's experiment was that he only observed one trophic tier.

Lecture #`22

Interspecific Interactions (Herbivory)

Herbivory is the consumption of plant material by animals, and herbivores are animals adapted to eat plants. As in predator-prey interactions, this interaction drives adaptations in both the herbivore and the plant species it eats. For example, to reduce the damage done by herbivores, plants have evolved defenses, including thorns and chemicals. Scientists have identified thousands of plant chemical defense compounds, including familiar compounds such as nicotine and cocaine (Coley & Barone 1996).
To maximize nutrient intake, many herbivores have evolved adaptations that allow them to determine which plants contain fewer defensive compounds and more high-quality nutrients. Some insects, such as butterflies, have chemical sensors on their feet that allow them to taste the plant before they consume any part of it. Mammalian herbivores often use their keen sense of smell to detect bitter compounds, and they preferentially eat younger leaves that contain fewer chemicals.

When members of different species compete for resources, one species may be forced to move or become extinct, or the two species may share the resource and coexist. Animals that feed on plants by cropping portions of the plant, but usually not killing the plant, are herbivores. This conversion provides food for predators that feed by killing and eating other organisms. Interactions between plants and herbivores, and predators and prey, are complex, and many characteristics of the environment affect them.

Lecture #`23

Interspecific Competition

When members of different species compete for resources, one species may be forced to move or become extinct, or the two species may share the resource and coexist. While the first two options (moving or extinction) have been documented in a few instances, most studies have shown that competing species can coexist. Coexistence can occur when species utilize resources in slightly different ways and when the effects of interspecific competition are less severe than the effects of intraspecific competition.

Interspecific competition, in ecology, is a form of competition in which individuals of different species compete for the same resources in an ecosystem (e.g. food or living space). This can be contrasted with mutualism, a type of symbiosis. Competition between members of the same species is called intraspecific competition.

If a tree species in a dense forest grows taller than surrounding tree species, it is able to absorb more of the incoming sunlight. However, less sunlight is then available for the trees that are shaded by the taller tree, thus interspecific competition. Leopards and lions can also be in interspecific competition, since both species feed on the same prey, and can be negatively impacted by the presence of the other because they will have less food.

Competition is only one of many interacting biotic and abiotic factors that affect community structure. Moreover, competition is not always a straightforward, direct, interaction. Interspecific competition may occur when individuals of two separate species share a limiting resource in the same area. If the resource cannot support both populations, then lowered fecundity, growth, or survival may result in at least one species. Interspecific competition has the potential to alter populations, communities and the evolution of interacting species. On an individual organism level, competition can occur as interference or exploitative competition.

Direct competition has been observed between individuals, populations and species, but there is little evidence that competition has been the driving force in the evolution of large groups. For example, between amphibians, reptiles and mammals.

Lecture #`24

Coevolution

The process of reciprocal evolutionary change that occurs between pairs of species or among groups of species as they interact with one another. The activity of each species that participates in the interaction applies selection pressure to the others. In a predator-prey interaction, for example, the emergence of faster prey may select against individuals in the predatory species who are unable to keep pace. Thus, only fast individuals or those with adaptations allowing them to capture prey using other means will pass their genes to the next generation. Coevolution is one of the primary methods by which biological communities are organized. It can lead to very specialized relationships between species, such as those between pollinator and plant and between parasite and host. It may also foster the evolution of new species in cases where individual populations of interacting species separate themselves from their greater meta populations for long periods of time.

Any feature that would decrease the probability of capture should be strongly favored. In turn, the evolution of such features causes natural selection to favor counter adaptations in predator populations. The process by which these adaptations are selected in lockstep fashion in two or more interacting species is termed coevolution. A co-evolutionary “arms race” may ensue in which predators and prey are constantly evolving better defenses and better means of circumventing these defenses. In the sections that follow, you’ll learn more about these defenses and responses.

Coevolution does not necessarily require the presence of antagonism. The interactions or characteristics within groups of unrelated species may converge to allow individual species to exploit valuable resources or enjoy increased protection. Once an interaction evolves between two species, other species within the community may develop traits akin to those integral to the interaction, whereby new species enter into the interaction. This type of convergence of species has occurred commonly in the evolution of mutualistic interactions, including those between pollinators (such as bees) and plants and those between vertebrates (such as birds and bats) and fruits.

Interspecific Interactions (Predation)

When members of different species compete for resources, one species may be forced to move or become extinct, or the two species may share the resource and coexist. The conversion provides food for predators that feed by killing and eating other organisms.

Members of other species can affect all characteristics of a population. Interspecific interactions include herbivory, predation, competition, coevolution, and symbiosis. These artificial categories that zoologists create, however, rarely limit animals. Animals often do not interact with other animals in only one way. The nature of interspecific interactions may change as an animal matures, or as seasons or the environment changes.

Herbivory and predation

Animals that feed on plants by cropping portions of the plant, but usually not killing the plant, are herbivores. This conversion provides food for predators that feed by killing and eating other organisms. Interactions between plants and herbivores, and predators and prey, are complex, and many characteristics of the environment affect them.

Lecture #`26

Parasitism

Parasitism is harmful to the prey organism and beneficial to the parasite. In many cases, the parasite kills its host, and thus the ecological effects of parasitism can be similar to those of predation. In the past parasitism was studied mostly in terms of its effects on individuals and the populations in which they live, but in recent years' researchers have realized that parasitism can be an important factor affecting community structure.

Parasitism is a kind of symbiosis, a close and persistent long-term biological interaction between a parasite and its host. Unlike commensalism and mutualism, the parasitic relationship harms the host, either feeding on it or, as in the case of intestinal parasites, consuming some of its food. However, parasites are different from saprophytes. Because parasites interact with other species, they can readily act as vectors of pathogens, causing disease. Predation is by definition not a symbiosis, as the interaction is brief, but the entomologist E. O. Wilson has characterized parasites as "predators that eat prey in units of less than one". Within that scope are many possible strategies. Taxonomists classify parasites in a variety of overlapping schemes, based on their interactions with their hosts and on their life-cycles, which are sometimes very complex. An obligate parasite depends completely on the host to complete its life cycle, while a facultative parasite does not. Parasite life-cycles involving only one host are called "direct"; those with a definitive host (where the parasite reproduces sexually) and at least one intermediate host are called "indirect".

An **endoparasite** lives inside the host's body; an **ectoparasite** lives outside, on the host's surface. **Mesoparasites**—like some copepods, for example—enter an opening in the host's body and remain partly embedded there. Some parasites can be generalists, feeding on a wide range of hosts, but many parasites, and the majority of protozoans and helminths that parasitise animals, are specialists and extremely host-specific. An early basic, functional division of parasites distinguished **micro parasites** and **macro parasites**. These each had a mathematical model assigned in order to analyses the population movements of the host–parasite groupings. The microorganisms and viruses that can reproduce and complete their life cycle within the host are known as micro parasites. Macro parasites are the multicellular organisms that reproduce and complete their life cycle outside of the host or on the host's body.

Much of the thinking on types of parasitism has focused on terrestrial animal parasites of animals, such as helminths. Those in other environments and with other hosts often have analogous strategies. For example, the snub-nosed eel is probably a facultative endo parasite that opportunistically burrows into and eats sick and dying fish. Plant-eating insects such as scale insects, aphids, and caterpillars closely resemble ectoparasites, attacking much larger plants; they serve as vectors of bacteria, fungi and viruses which cause plant diseases. As female scale-insects cannot move, they are obligate parasites, permanently attached to their hosts.

Lecture #`28

Symbiosis

In symbiosis, two or more kinds of organisms interact in often elaborate and more-or-less permanent relationships. All symbiotic relationships carry the potential for coevolution between the organisms involved, and in many instances the results of this coevolution are fascinatingly complex. Examples of symbiosis include lichens, which are associations of certain fungi with green algae or cyanobacteria. Another important example are mycorrhizae, associations between fungi and the roots of most kinds of plants. The fungi expedite the plant's absorption of certain nutrients, and the plants in turn provide the fungi with carbohydrates (both mycorrhizae and lichens are discussed in greater detail in chapter 31). Similarly, root nodules that occur in legumes and certain other kinds of plants contain bacteria that fix atmospheric nitrogen and make it available to their host plants.

Symbiosis can be obligatory, which means that one or both of the symbionts entirely depend on each other for survival, or facultative (optional) when they can generally live independently.

Symbiosis is also classified by physical attachment; symbiosis in which the organisms have bodily union is called conjunctive symbiosis, and symbiosis in which they are not in union is called disjunctive symbiosis. When one organism lives on the surface of another, such as head lice on humans, it is called ectosymbiosis; when one partner lives inside the tissues of another, such as *Symbiodinium* within coral, it is termed endosymbiosis.

A symbiosis is an evolved interaction or close living relationship between organisms from different species, usually with benefits to one or both of the individuals involved. Symbioses may be 'obligate', in which case the relationship between the two species is so interdependent, that each of the organisms is unable to survive without the other, or 'facultative', in which the two species engage in a symbiotic partnership through choice, and can survive individually. Obligate symbioses are often evolved over a long period of time, while facultative symbioses may be more modern, behavioral adaptions; given time, facultative symbioses may evolve into obligate symbioses.

Endosymbiosis is a symbiotic relationship, occurring when one of the symbiotic partners lives within the body of the other. Endosymbiosis can take place either within the *cells* (intercellular symbiosis) of the 'host' organism, or outside the cells (extracellular symbiosis). On the other hand, *ectosymbiosis* is a symbiotic relationship in which one organism lives on the body surface of the host, including the lining of the digestive tract, or *exocrine* glands such as mucus or sweat glands.

Examples of Symbiosis

Corals and Zooxanthellae

Corals are made up of animals called corals polyps. Coral polyps have highly specialized obligate mutualistic symbiosis with photosynthesizing algae called zooxanthellae which live inside the coral tissue. The zooxanthellae capture sunlight and convert it in to oxygen as well as energy, in the form of sugars and lipids that are transferred to the coral tissues and provide it with nutrients to survive and grow. In return, the zooxanthellae are provided with carbon dioxide, phosphorous and nitrogen as the by-product of the coral's *metabolic* process. Although the corals cannot survive without any zooxanthellae, they can alter the amount within their tissues, by altering the amount of nutrients that the algae receive. However, if the temperature of the water becomes too high for an extended period of time, the corals undergo stress and expel all of their zooxanthellae and are not provided with enough nutrients to survive. This results in *coral bleaching*.

Cleaner Fish

Many fish become infected by ectoparasites, which are spawned in the water and attach to the skin and glands to feed off the host's blood. Some highly specialized species of fish have evolved a facultative mutualistic symbiosis with many species of larger fish, whereby they remove the ectoparasites from the larger fish, providing a ‘cleaning’ service. An example is the Bluestreak Cleaner Wrasse (*Labroides dimidiatus*), tropical fish who wait at ‘cleaning stations’ that the larger fish visit in order to have their parasites removed. The cleaner fish perform a special ‘dance ‘, which attracts the host fish, and advertises the cleaning service. Although the cleaner fish put themselves into apparent great danger by swimming inside the mouth cavities of even the most voracious predators, the service that they provide is so effective that they are very rarely harmed by the host fish and conduct repeated ‘customer’ visitations.

Lecture #`29

Camouflage-1

Interspecific interactions have shaped many other characteristics of animals. Camouflage occurs when an animal’s color patterns help hide the animal, or a developmental stage, from another animal.

Camouflage. The color pattern of this tiger (Panther Tigris) provides effective camouflage that helps when stalking prey

Lecture #`30

Camouflage-2

Cryptic coloration (L. crypticus, hidden) is a type of camouflage that occurs when an animal takes on color patterns in its environment to prevent the animal from being seen by other animals. A species' camouflage depends on several factors. The physical characteristics of the organism are important. Animals with fur rely on different camouflage tactics than those with feathers or scales, for instance. Feathers and scales can be shed and changed fairly regularly and quickly. Fur, on the other hand, can take weeks or even months to grow in. Animals with fur are more often camouflaged by season. The arctic fox, for example, has a white coat in the winter, while its summer coat is brown.
The behavior of a species is also important. Animals that live in groups differ from those that are solitary. The stripes on a zebra, for instance, make it stand out. However, zebras are social animals, meaning they live and migrate in large groups called herds. When clustered together, it is nearly impossible to tell one zebra from another, making it difficult for predators such as lions to stalk an individual animal.
A species' camouflage is also influenced by the behavior or characteristics of its predators. If the predator is color-blind, for example, the prey species will not need to match the color of its surroundings. Lions, the main predator of zebras, are color-blind. Zebras' black-and-white camouflage does not need to blend in to their habitat, the golden savanna of central Africa.

Lecture #`30

Camouflage-3

Countershading is a kind of camouflage common in frog and toad eggs. These eggs are darkly pigmented on top and lightly pigmented on the bottom. When a bird or other predator views the eggs from above, the dark of the top side hides the eggs from detection against the darkness below. On the other hand, when fish view the eggs from below, the light undersurface blends with the bright air-water interface. When light falls from above on a uniformly colored three-dimensional object such as a sphere, it makes the upper side appear lighter and the underside darker, grading from one to the other. This pattern of light and shade makes the object appear solid, and therefore easier to detect. The classical form of countershading, discovered in 1909 by the artist Abbott Henderson Thayer, works by counterbalancing the effects of self-shadowing, again typically with grading from dark to light. In theory this could be useful for military camouflage, but in practice it has rarely been applied, despite the best efforts of Thayer and, later, in the Second World War, of the zoologist Hugh Cott.

The precise function of various patterns of animal coloration that have been called countershading has been debated by zoologists such as Hannah Rowland (2009), with the suggestion that there may be multiple functions including flattening and background matching when viewed from the side; background matching when viewed from above or below, implying separate color schemes for the top and bottom surfaces; outline obliteration from above; and a variety of other largely untested non-camouflage theories. A related mechanism, counter-illumination, adds the creation of light by bioluminescence or lamps to match the actual brightness of a background. Counter-illumination camouflage is common in marine organisms such as squid. It has been studied up to the prototype stage for military use in ships and aircraft, but it too has rarely or never been used in warfare.

The reverse of countershading, with the belly pigmented darker than the back, enhances contrast and so makes animals more conspicuous. It is found in animals that can defend themselves, such as skunks. The pattern is used both in startle or deimatic displays and as a signal to warn off experienced predators. However, animals that habitually live upside-down but lack strong defences, such as the Nile catfish and the Luna moth caterpillar, have upside-down countershading for camouflage.

Lecture #`31

Mimicry

Mimicry (L. mimus, to imitate) occurs when a species resembles one, or sometimes more than one, other species and gains protection by the resemblance.

In evolutionary biology, **mimicry** is an evolved resemblance between an organism and another object, often an organism of another species. Mimicry may evolve between different species, or between individuals of the same species. Often, mimicry functions to protect a species from predators, making it an antipredator adaptation. Mimicry evolves if a receiver (such as a predator) perceives the similarity between a mimic (the organism that has a resemblance) and a model (the organism it resembles) and as a result changes its behavior in a way that provides a selective advantage to the mimic. The resemblances that evolve in mimicry can be visual, acoustic, chemical, tactile, or electric, or combinations of these sensory modalities.

Mimicry may be to the advantage of both organisms that share a resemblance, in which case it is a form of mutualism; or mimicry can be to the detriment of one, making it parasitic or competitive. The evolutionary convergence between groups is driven by the selective action of a signal-receiver or dupe. Birds, for example, use sight to identify palatable insects, whilst avoiding the noxious ones. Over time, palatable insects may evolve to resemble noxious ones, making them mimics and the noxious one's models.

In the case of mutualism, sometimes both groups are referred to as "co-mimics". It is often thought that models must be more abundant than mimics, but this is not so. Mimicry may involve numerous species; many harmless species such as hoverflies are Batesian mimics of strongly defended species such as wasps, while many such well-defended species form Mullerian mimicry rings, all resembling each other. Mimicry between prey species and their predators often involves three or more species.

In its broadest definition, mimicry can include non-living models. The specific terms **masquerade** and **mimesis** are sometimes used when the models are inanimate. For example, animals such as flower mantises, plant hoppers, comma and geometer moth caterpillars resemble twigs, bark, leaves, bird droppings or flowers. Many animals bear eyespots, which are hypothesized to resemble the eyes of larger animals. They may not resemble any specific organism's eyes, and whether or not animals respond to them as eyes is also unclear. Nonetheless, eyespots are the subject of a rich contemporary literature. The model is usually another species, except in auto mimicry, where members of the species mimic other members, or other parts of their own bodies, and in inter-sexual mimicry, where members of one sex mimic members of the other.

Mimesis in *Ctenomorphodes chronus*, camouflaged as a eucalyptus twig

Mimicry can result in an evolutionary arms race if mimicry negatively affects the model, and the model can evolve a different appearance from the mimic. Mimicry should not be confused with other forms of convergent evolution that occurs when species come to resemble each other by adapting to similar lifestyles that have nothing to do with a common signal receiver. Mimics may have different models for different life cycle stages, or they may be polymorphic, with different individuals imitating different models, such as in Heliconius butterflies. Models themselves may have more than one mimic, though frequency dependent selection favors mimicry where models outnumber mimics. Models tend to be relatively closely related organisms, but mimicry of vastly different species is also known. Most known mimics are insects, though many other examples including vertebrates are also known. Plants and fungi may also be mimics, though less research has been carried out in this area.

These six species of Heliconius are all distasteful to bird predators. A bird that consumes any member of the six species is likely to avoid all six species in the future.

Lecture #`32

Aposematic coloration

Some animals that protect themselves by being dangerous or distasteful to predators advertise their condition by conspicuous coloration. The sharply contrasting white stripe(s) of a skunk and bright colors of poisonous snakes give similar messages. These color patterns are examples of warning or aposematic coloration (Gr. apo, away from sematic, sign). This unprofitability may consist of any defences which make the prey difficult to kill and eat, such as toxicity, venom, foul taste or smell, sharp spines, or aggressive nature. Aposematism always involves advertising signals, which may take the form of conspicuous coloration, sounds, odors or other perceivable characteristics. Aposematic signals are beneficial for both predator and prey, since both avoid potential harm.

The term was coined by Edward Bagnall Poulton for Alfred Russel Wallace's concept of warning coloration. Aposematism is exploited in Müllerian mimicry, where species with strong defenses evolve to resemble one another. By mimicking similarly colored species, the warning signal to predators is shared, causing them to learn more quickly at less of a cost to each of the species.

A genuine aposematic signal that a species actually possesses chemical or physical defenses is not the only way to deter predators. In Batesian mimicry, a mimicking species resembles an aposematic model closely enough to share the protection, while many species have bluffing demotic displays which may startle a predator long enough to enable an otherwise undefended prey to escape.

The bright colors of this granular poison frog signal a warning to predators of its toxicity

Lecture #`33

Atmosphere and its origin

An **atmosphere** meaning 'ball' or 'sphere' is a layer or a set of layers of gases surrounding a planet or other material body, that is held in place by the gravity of that body. An atmosphere is more likely to be retained if the gravity it is subject to is high and the temperature of the atmosphere is low.

The atmosphere of Earth is composed of nitrogen (about 78%), oxygen (about 21%), argon (about 0.9%), carbon dioxide (0.04%) and other gases in trace amounts. Oxygen is used by most organisms for respiration; nitrogen is fixed by bacteria and lightning to produce ammonia used in the construction of nucleotides and amino acids; and carbon dioxide is used by plants, algae and cyanobacteria for photosynthesis. The atmosphere helps to protect living organisms from genetic damage by solar ultraviolet radiation, solar wind and cosmic rays. The current composition of the Earth's atmosphere is the product of billions of years of biochemical modification of the paleo atmosphere by living organisms.

The terrestrial atmosphere maintains conditions suitable for life (providing a modest greenhouse effect and a shield against biologically harmful radiation), and has apparently done so for 3.5 billion years, despite a 40% increase in solar luminosity, giant impacts, and the changing tempo of plate tectonics.

Lecture #`35

Composition of atmosphere

A planet's initial atmospheric composition is related to the chemistry and temperature of the local solar nebula during planetary formation and the subsequent escape of interior gases. The original atmospheres started with a rotating disc of gases that collapsed to form a series of spaced rings that condensed to form the planets. The planet's atmospheres were then modified over time by various complex factors, resulting in quite different outcomes.

The atmospheres of the planets Venus and Mars are primarily composed of carbon dioxide, with small quantities of nitrogen, argon, oxygen and traces of other gases. The composition of Earth's atmosphere is largely governed by the by-products of the life that it sustains. Dry air from Earth's atmosphere contains 78.08% nitrogen, 20.95% oxygen, 0.93% argon, 0.04% carbon dioxide, and traces of hydrogen, helium, and other "noble" gases (by volume), but generally a variable amount of water vapor is also present, on average about 1% at sea level.

The low temperatures and higher gravity of the Solar System's giant planets—Jupiter, Saturn, Uranus and Neptune—allow them more readily to retain gases with low molecular masses. These planets have hydrogen–helium atmospheres, with trace amounts of more complex compounds. Two satellites of the outer planets possess significant atmospheres. Titan, a moon of Saturn, and Triton, a moon of Neptune, have atmospheres mainly of nitrogen. When in the part of its orbit closest to the Sun, Pluto has an atmosphere of nitrogen and methane similar to Triton's, but these gases are frozen when it is farther from the Sun.

Other bodies within the Solar System have extremely thin atmospheres not in equilibrium. These include the Moon (sodium gas), Mercury (sodium gas), Europa (oxygen), Io (sulfur), and Enceladus (water vapor).The first exoplanet whose atmospheric composition was determined is HD 209458b, a gas giant with a close orbit around a star in the constellation Pegasus. Its atmosphere is heated to temperatures over 1,000 K, and is steadily escaping into space. Hydrogen, oxygen, carbon and sulfur have been detected in the planet's inflated atmosphere.[

Atmosphere, containing abundant oxygen in gross chemical disequilibrium with surface organic carbon and gases such as methane, is testament to life's ability to efficiently convert light energy into chemical energy, some of which is stored in the chemical disequilibrium between the atmosphere and surface.

most of its global circulation.

Lecture #`36

Layers of atmosphere (Ionosphere)

Ions may also migrate to the polar regions, where the magnetic field lines are open to the tail of the magnetosphere, and they can readily escape along these field lines. In charge exchange, H atoms lose an electron to a heavier ion, typically O1, and the resulting proton is accelerated by the electric field of the solar wind to exceed the escape velocity. The ionization potentials of O and H differ by only 0.02 eV. This difference is smaller than the thermal energies corresponding to typical upper-atmosphere temperatures, and as a consequence the charge transfer process is very efficient.

The ionosphere is defined as the layer of the Earth's atmosphere that is ionized by solar and cosmic radiation. It lies 75-1000 km (46-621 miles) above the Earth. (The Earth’s radius is 6370 km, so the thickness of the ionosphere is quite tiny compared with the size of Earth.) Because of the high energy from the Sun and from cosmic rays, the atoms in this area have been stripped of one or more of their electrons, or “ionized,” and are therefore positively charged. The ionized electrons behave as free particles. The Sun's upper atmosphere, the corona, is very hot and produces a constant stream of plasma and UV and X-rays that flow out from the Sun and affect, or ionize, the Earth's ionosphere. Only half the Earth’s ionosphere is being ionized by the Sun at any time.

During the night, without interference from the Sun, cosmic rays ionize the ionosphere, though not nearly as strongly as the Sun. These high energy rays originate from sources throughout our own galaxy and the universe rotating neutron stars, supernovae, radio galaxies, quasars and black holes. Thus the ionosphere is much less charged at nighttime, which is why a lot of ionospheric effects are easier to spot at night – it takes a smaller change to notice them.

The ionosphere has major importance to us because, among other functions, it influences radio propagation to distant places on the Earth, and between satellites and Earth. For the very low frequency (VLF) waves that the space weather monitors track, the ionosphere and the ground produce a “waveguide” through which radio signals can bounce and make their way around the curved Earth:

Lecture #`36

Layers of atmosphere (Exosphere)

Thermal escape of light atoms such as hydrogen and helium can occur from the exosphere (the uppermost layer of the atmosphere where the mean free path between collisions exceeds the scale height). Escape is efficient if the mean thermal speed is a significant fraction of the escape velocity such that a no negligible number of molecules in the ‘tail’ of the Maxwellian (thermal) distribution have speeds above the escape velocity.

The Earth’s atmosphere is broken up into several distinct layers. We live down in the troposphere, where the atmosphere is thickest. Above that is the stratosphere, then there’s the mesosphere, thermosphere and finally the exosphere. The top of the exosphere marks the line between the Earth’s atmosphere and interplanetary space. The exosphere is the outermost layer of the Earth’s atmosphere. It starts at an altitude of about 500 km and goes out to about 10,000 km. Within this region particles of atmosphere can travel for hundreds of kilometers in a ballistic trajectory before bumping into any other particles of the atmosphere. Particles escape out of the exosphere into deep space. The lower boundary of the exosphere, where it interacts with the thermosphere is called the thermopause. It starts at an altitude of about 250-500 km, but its height depends on the amount of solar activity.

The exosphere is the uppermost region of Earth's atmosphere as it gradually fades into the vacuum of space. Air in the exosphere is extremely thin - in many ways it is almost the same as the airless void of outer space. The layer directly below the exosphere is the thermosphere; the boundary between the two is called the thermopause. The bottom of the exosphere is sometimes also referred to as the exobase. The altitude of the lower boundary of the exosphere varies. When the Sun is active around the peak of the sunspot cycle, X-rays and ultraviolet radiation from the Sun heat and "puff up" the thermosphere - raising the altitude of the thermopause to heights around 1,000 km (620 miles) above Earth's surface. When the Sun is less active during the low point of the sunspot cycle, solar radiation is less intense and the thermopause recedes to within about 500 km (310 miles) of Earth's surface.

Not all scientists agree that the exosphere is really a part of the atmosphere. Some scientists consider the thermosphere the uppermost part of Earth's atmosphere, and think that the exosphere is really just part of space. However, other scientists do consider the exosphere part of our planet's atmosphere. Since the exosphere gradually fades into outer space, there is no clear upper boundary of this layer. One definition of the outermost limit of the exosphere places the uppermost edge of Earth's atmosphere around 190,000 km (120,000 miles), about halfway to the Moon. At this distance, radiation pressure from sunlight exerts more force on hydrogen atoms than does the pull of Earth's gravity. A faint glow of ultraviolet radiation scattered by hydrogen atoms in the uppermost atmosphere has been detected at heights of 100,000 km (62,000 miles) by satellites. This region of UV glow is called the geocorona.

Below the exosphere, molecules and atoms of atmospheric gases constantly collide with each other. However, air in the exosphere is so thin that such collisions are very rare. Gas atoms and molecules in the exosphere move along "ballistic trajectories", reminiscent of the arcing flight of a thrown ball (or shot cannonball!) as it gradually curves back towards Earth under the pull of gravity. Most gas particles in the exosphere zoom along curved paths without ever hitting another atom or molecule, eventually arcing back down into the lower atmosphere due to the pull of gravity. However, some of the faster-moving particles don't return to Earth - they fly off into space instead! A small portion of our atmosphere "leaks" away into space each year in this way.

Lecture #`37

Layers of atmosphere (Troposphere)

The troposphere is the lowest layer of Earth's atmosphere, and is also where nearly all weather conditions take place. It contains 75% of the atmosphere's mass and 99% of the total mass of water vapor and aerosols.[2] The average height of the troposphere is 18 km (11 mi; 59,000 ft.) in the tropics, 17 km (11 mi; 56,000 ft.) in the middle latitudes, and 6 km (3.7 mi; 20,000 ft.) in the polar regions in winter. The total average height of the troposphere is 13 km.

The lowest part of the troposphere, where friction with the Earth's surface influences air flow, is the planetary boundary layer. This layer is typically a few hundred meters to 2 km (1.2 mi; 6,600 ft.) deep depending on the landform and time of day. Atop the troposphere is the tropopause, which is the border between the troposphere and stratosphere. The tropopause is an inversion layer, where the air temperature ceases to decrease with height and remains constant through its thickness. The word *troposphere* is derived from the Greek *tropos* (meaning "turn, turn toward, change") and *sphere* (as in the Earth), reflecting the fact that rotational turbulent mixing plays an important role in the troposphere's structure and behavior. Most of the phenomena associated with day-to-day weather occur in the troposphere.

Composition

By volume, dry air contains 78.08% nitrogen, 20.95% oxygen, 0.93% argon, 0.04% carbon dioxide, and small amounts of other gases. Air also contains a variable amount of water vapor. Except for the water vapor content, the composition of the troposphere is essentially uniform. The source of water vapor is at the Earth's surface through the process of evaporation. The temperature of the troposphere decreases with altitude. And, saturation vapor pressure decreases strongly as temperature drops. Hence, the amount of water vapor that can exist in the atmosphere decreases strongly with altitude and the proportion of water vapor is normally greatest near the surface of the Earth.

Lecture #`38

Layers of atmosphere (Stratosphere)

The **stratosphere** is the second major layer of Earth's atmosphere, just above the troposphere, and below the mesosphere. The stratosphere is stratified (layered) in temperature, with warmer layers higher and cooler layers closer to the Earth; this increase of temperature with altitude is a result of the absorption of the Sun's ultraviolet radiation by the ozone layer.[5] This is in contrast to the troposphere, near the Earth's surface, where temperature decreases with altitude. The border between the troposphere and stratosphere, the tropopause, marks where this temperature inversion begins. Near the equator, the stratosphere starts at as high as 20 km (66,000 ft.; 12 mi), around 10 km (33,000 ft.; 6.2 mi) at mid latitudes, and at about 7 km (23,000 ft.; 4.3 mi) at the poles. Temperatures range from an average of −51 °C (−60 °F; 220 K) near the tropopause to an average of −15 °C (5.0 °F; 260 K) near the mesosphere.[6] Stratospheric temperatures also vary within the stratosphere as the seasons change, reaching particularly low temperatures in the polar night (winter).[7] Winds in the stratosphere can far exceed those in the troposphere, reaching near 60 m/s (220 km/h; 130 mph) in the Southern polar vortex.

Ozone and atmosphere

The mechanism describing the formation of the ozone layer was described by British mathematician Sydney Chapman in 1930. Molecular oxygen absorbs high energy sunlight in the UV-C region, at wavelengths shorter than about 240 nm. Radicals produced from the homolytically split oxygen molecules combine with molecular oxygen to form ozone. Ozone in turn is photolysed much more rapidly than molecular oxygen as it has a stronger absorption that occurs at longer wavelengths, where the solar emission is more intense. Ozone (O_3) photolysis produces O and O_2. The oxygen atom product combines with atmospheric molecular oxygen to reform O_3, releasing heat. The rapid photolysis and reformation of ozone heats the stratosphere resulting in a temperature inversion. This increase of temperature with altitude is characteristic of the stratosphere; its resistance to vertical mixing means that it is stratified. Within the stratosphere temperatures increase with altitude ; the top of the stratosphere has a temperature of about 270 K (−3°C or 26.6°F).

This vertical stratification, with warmer layers above and cooler layers below, makes the stratosphere dynamically stable: there is no regular convection and associated turbulence in this part of the atmosphere. However, exceptionally energetic convection processes, such as volcanic eruption columns and overshooting tops in severe supercell thunderstorms, may carry convection into the stratosphere on a very local and temporary basis. Overall the attenuation of solar UV at wavelengths that damage DNA by the ozone layer allows life to exist on the surface of the planet outside of the ocean. All air entering the stratosphere must pass through the tropopause, the temperature minimum that divides the troposphere and stratosphere. The rising air is literally freeze dried; the stratosphere is a very dry place. The top of the stratosphere is called the Strat pause, above which the temperature decreases with height.

Lecture #`39

Layers of atmosphere (Mesosphere)

The mesosphere is the third major layer of the Earth's atmosphere, directly above the stratosphere and directly below the thermosphere. In the mesosphere, temperature decreases as altitude increases. In the mesosphere, temperature decreases as altitude increases. This characteristic is used to define its limits: it begins at the top of the stratosphere (sometimes called the stratopause), and ends at the mesopause, which is the coldest part of Earth's atmosphere with temperatures below −143 °C (−225 °F; 130 K). The exact upper and lower boundaries of the mesosphere vary with latitude and with season (higher in winter and at the tropics, lower in summer and at the poles), but the lower boundary is usually located at altitudes from 50 to 65 kilometers (31 to 40 mi; 164,000 to 213,000 ft.) above the Earth's surface and the upper boundary (the mesopause) is usually around 85 to 100 kilometers (53 to 62 mi; 279,000 to 328,000 ft.).

The mesosphere is difficult to study, so less is known about this layer of the atmosphere than other layers. Weather balloons and other aircraft cannot fly high enough to reach the mesosphere. Satellites orbit above the mesosphere and cannot directly measure traits of this layer. Scientists use instruments on sounding rockets to sample the mesosphere directly, but such flights are brief and infrequent. Since it is difficult to take measurements of the mesosphere directly using instruments, much about the mesosphere is still mysterious.

Most meteors vaporize in the mesosphere. Some material from meteors lingers in the mesosphere, causing this layer to have a relatively high concentration of iron and other metal atoms. Very strange, high altitude clouds called "noctilucent clouds" or "polar mesospheric clouds" sometime form in the mesosphere near the poles. These peculiar clouds form much, much higher up than other types of clouds. The mesosphere, like the stratosphere below it, is much drier than the moist troposphere we live in; making the formation of clouds in this layer a bit of a surprise. Odd electrical discharges akin to lightning, called "sprites" and "ELVES", occasionally appear in the mesosphere dozens of kilometers (miles) above thunderclouds in the troposphere below.

The stratosphere and mesosphere together are sometimes referred to as the middle atmosphere. At the mesopause (the top of the mesosphere) and below, gases made of different types of atoms and molecules are thoroughly mixed together by turbulence in the atmosphere. Above the mesosphere, in the thermosphere and beyond, gas particles collide so infrequently that the gases become somewhat separated based on the types of chemical elements they contain. Various types of waves and tides in the atmosphere influence the mesosphere. These waves and tides carry energy from the troposphere and the stratosphere upward into the mesosphere, driving

Lecture #`40

Layers of atmosphere (Thermosphere)

Extreme and vacuum ultraviolet radiation from the Sun (mostly in the 121.4 nm Lyman a line of hydrogen) is absorbed and converted into heat in the Earth’s thermosphere. The modern thermosphere lies above 400 km and has a temperature of 1200 K.

The thermosphere is the layer in the Earth's atmosphere directly above the mesosphere and below the exosphere. Within this layer of the atmosphere, ultraviolet radiation causes photoionization/photo dissociation of molecules, creating ions in the ionosphere. meaning heat, the thermosphere begins at about 80 km (50 mi) above sea level. At these high altitudes, the residual atmospheric gases sort into strata according to molecular mass. Thermosphere temperatures increase with altitude due to absorption of highly energetic solar radiation. Temperatures are highly dependent on solar activity, and can rise to 1,700 °C (3,100 °F) or more. Radiation causes the atmosphere particles in this layer to become electrically charge , enabling radio waves to be refracted and thus be received beyond the horizon. In the exosphere, beginning at about 600 km (375 mi) above sea level, the atmosphere turns into space, although by the judicial criteria set for the definition of the Kármán line, the thermosphere itself is part of space.

The highly diluted gas in this layer can reach 2,500 °C (4,530 °F) during the day. Despite the high temperature, an observer or object will experience cold temperatures in the thermosphere, because the extremely low density of gas (practically a hard vacuum) is insufficient for the molecules to conduct heat. A normal thermometer will read significantly below 0 °C (32 °F), at least at night, because the energy lost by thermal radiation would exceed the energy acquired from the atmospheric gas by direct contact. In the an acoustic zone above 160 kilometers (99 mi), the density is so low that molecular interactions are too infrequent to permit the transmission of sound. The dynamics of the thermosphere are dominated by atmospheric tides, which are driven predominantly by diurnal heating. Atmospheric waves dissipate above this level because of collisions between the neutral gas and the ionospheric plasma.

Lecture #`41

Benefits of the atmosphere

Also in contrast to neighboring planets, the terrestrial atmosphere maintains conditions suitable for life (providing a modest greenhouse effect and a shield against biologically harmful radiation), and has apparently done so for 3.5 billion years, despite a 40% increase in solar luminosity, giant impacts, and the changing tempo of plate tectonics. This fact is even more remarkable in light of the relatively short residence time of most gases: water vapor, the most powerful greenhouse gas in the atmosphere, has a residence time of only 10 days before exchanging with the oceans. Even relatively inert nitrogen gas, the principal component of the atmosphere, is recycled by biological fixation (reduction), oxidation, and re-reduction to N2 on a time scale of 10–15 million years. Thus Earth's atmosphere is not only out of chemical equilibrium, but is dynamically maintained, having no intrinsic buffering capacity on geologic time scales.

Lecture #`42

Carbon Cycle

Carbon is a major constituent of the bodies of organisms because carbon atoms help form the framework of all organic compounds - 3); almost 20% of the weight of the human body is carbon. From the viewpoint of the day to-day dynamics of ecosystems, carbon dioxide (CO2) is the most significant carbon-containing compound in the abiotic environments of organisms. It makes up 0.03% of the volume of the atmosphere, meaning the atmosphere contains about 750 billion metric tons of carbon. In aquatic ecosystems, CO2 reacts spontaneously with the water to form bicarbonate ions (HCO3 –).

The basic carbon cycle

The carbon cycle is straightforward, as shown in figure. In terrestrial ecosystems, plants and other photosynthetic organisms take in CO_2 from the atmosphere and use it in photosynthesis to synthesize the carbon-containing organic compounds of which they are composed. The process is sometimes called carbon fixation; fixation refers to metabolic reactions that make nongaseous compounds from gaseous ones. Animals eat the photosynthetic organisms and build their own tissues by making use of the carbon atoms in the organic compounds they ingest. Both the photosynthetic organisms and the animals obtain energy during their lives by breaking down some of the organic compounds available to them, through aerobic cellular respiration. When they do this, they produce CO_2. Decaying organisms also produce CO_2. Carbon atoms returned to the form of CO_2 are available once more to be used in photosynthesis to synthesize new organic compounds. In aquatic ecosystems, the carbon cycle is fundamentally similar, except that inorganic carbon is present in the water not only as dissolved CO_2, but also as HCO3– ions, both of which act as sources of carbon for photosynthesis by algae and aquatic plants. Methane producers Microbes that break down organic compounds by anaerobic cellular respiration provide an additional dimension to the global carbon cycle. Methanogens, for example, are microbes that produce methane (CH4) instead of CO_2. One major source of CH4 is wetland ecosystems, where methanogens live in the oxygen-free sediments.

Methane that enters the atmosphere is oxidized abiotic ally to CO_2, but CH4 that remains isolated from oxygen can persist for great lengths of time. The rise of atmospheric carbon dioxide. Another dimension of the global carbon cycle is that over long stretches of time, some parts of the cycle may precede more rapidly than others. These differences in rate have ordinarily been relatively minor on a year-to-year basis; in any one year, the amount of CO_2 made by breakdown of organic compounds almost matches the amount of CO_2 used to synthesize new organic compounds. Small mismatches, however, can have large consequences if continued for many years. The Earth's present reserves of coal were built up over geologic time. Organic compounds such as cellulose accumulated by being synthesized faster than they were broken down, and then they were transformed by geological processes into the fossil fuels. Most scientists believe that the world's petroleum reserves were created in the same way. Human burning of fossil fuels today is creating large contemporary imbalances in the carbon cycle. Carbon that took millions of years to accumulate in the reserves of fossil fuels is being rapidly returned to the atmosphere, driving the concentration of CO2 in the atmosphere upward year by year and helping to spur fears of global warming.

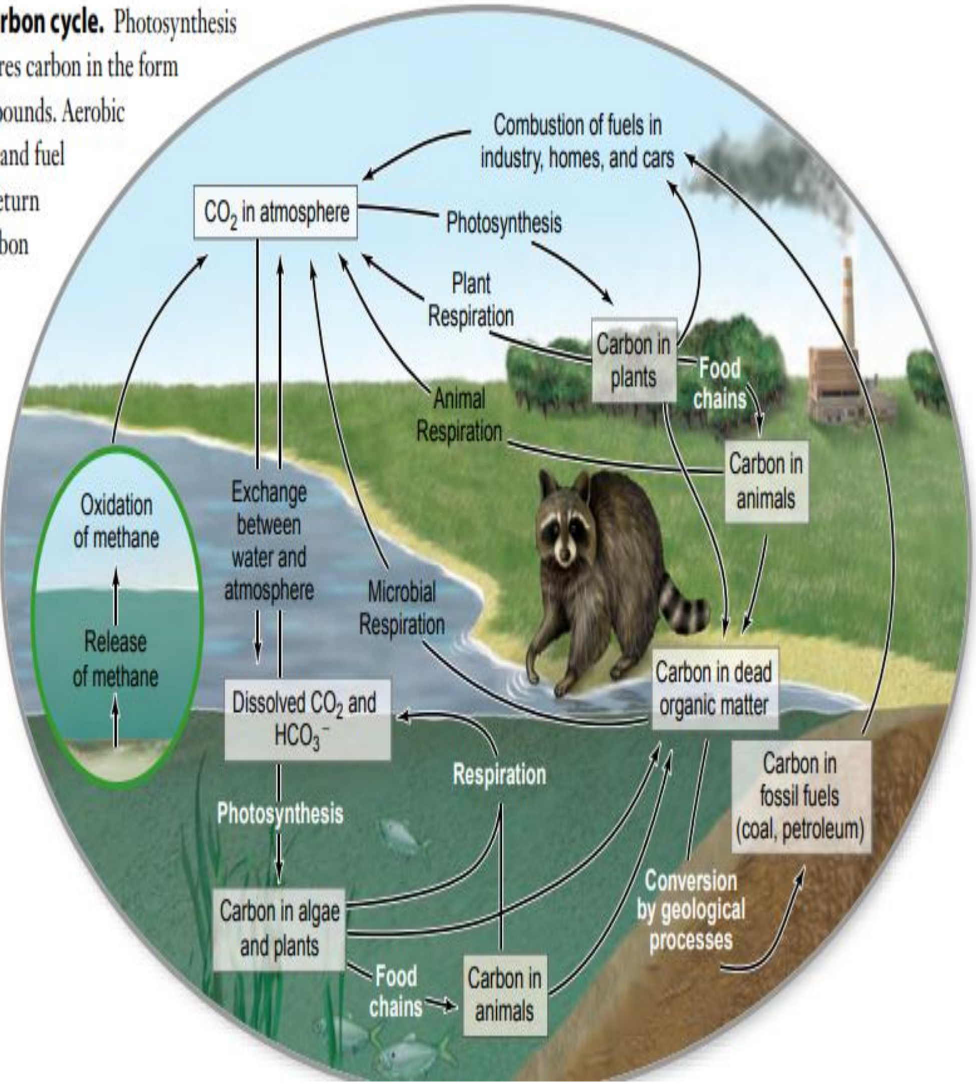


Figure 58.1 The carbon cycle. Photosynthesis by plants and algae captures carbon in the form of organic chemical compounds. Aerobic respiration by organisms and fuel combustion by humans return carbon to the form of carbon dioxide (CO_2) or bicarbonate (HCO_3^{2-}). Microbial methanogens living in oxygen-free microhabitats, such as the mud at the bottom of the pond, might produce methane (CH_4), a gas that would enter the atmosphere and then gradually be oxidized abiotically to carbon dioxide (shown in green circled inset).

Human burning of fossil fuels today is creating large contemporary imbalances in the carbon cycle. Carbon that took millions of years to accumulate in the reserves of fossil fuels is being rapidly returned to the atmosphere, driving the concentration of CO2 in the atmosphere upward year by year and helping to spur fears of global warming.

Lecture #`43

Water cycle

The water cycle is probably the most familiar of all biogeochemical cycles. All life depends on the presence of water; even organisms that can survive without water in resting states require water to regain activity. The bodies of most organisms consist mainly of water. The adult human body, for example, is about 60% water by weight. The amount of water available in an ecosystem often determines the nature and abundance of the organisms present.

The basic water cycle

One key part of the water cycle is that liquid water from the Earth’s surface evaporates into the atmosphere. The change of water from a liquid to a gas requires a considerable addition of thermal energy, explaining why evaporation occurs more rapidly when solar radiation beats down on a surface. Evaporation occurs directly from the surfaces of oceans, lakes, and rivers. In terrestrial ecosystems, however, approximately 90% of the water that reaches the atmosphere passes through plants. Trees, grasses, and other plants take up water from soil via their roots, and then the water evaporates from their leaves and other surfaces through a process called transpiration. Evaporated water exists in the atmosphere as a gas, just like any other atmospheric gas. The water can condense back into liquid form, however, mostly because of cooling of the air. Condensation of gaseous water (water vapor) into droplets or crystals causes the formation of clouds, and if the droplets or crystals are large enough, they fall to the surface of the Earth as precipitation (rain or snow).

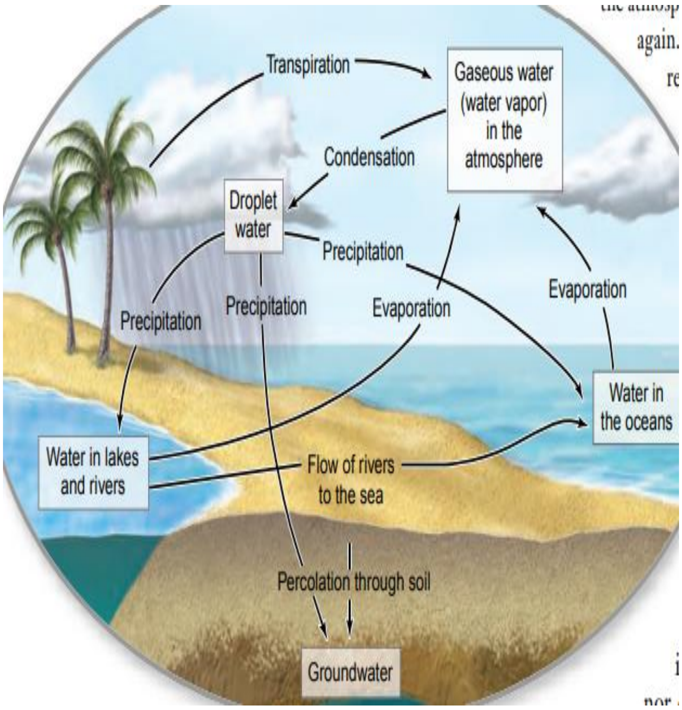
Groundwater

Less obvious than surface water, which we see in rivers and lakes, is water underground termed groundwater. Groundwater occurs in aquifers, which are permeable, underground layers of rock, sand, and gravel that are often saturated with water. Groundwater is the most important reservoir of water on land in many parts of the world, representing over 95% of all fresh water in the United States, for example. Groundwater consists of two subparts. The upper layers of the groundwater constitute the water table, which is unconfined in the sense that it flows into streams and is partly accessible to the roots of plants.

The lower, confined layers of the groundwater are generally out of reach to streams and plants, but can be tapped by wells. Groundwater is recharged by water that percolates downward from above, such as from precipitation. Water in an aquifer flows much more slowly than surface water, anywhere from a few millimeters to a meter or so per day. In the United States, groundwater provides about 25% of the water used by humans for all purposes, and it supplies about 50% of the population with drinking water. In the Great Plains states, the deep Ogallala Aquifer is tapped extensively as a water source for agricultural and domestic needs. The aquifer is being depleted faster than it is recharged—a local imbalance in the water cycle—posing an ominous threat to the agricultural production of the area. Similar threats exist in many of the drier portions of the globe.

Changes in ecosystems brought about by changes in the water cycle Water is so crucial for life that changes in its supply in an ecosystem can radically alter the nature of the ecosystem. Such changes have occurred often during the Earth’s geological history. Consider, for example, the ecosystem of the Serengeti Plain in Tanzania, famous for its seemingly endless grasslands occupied by vast herds of antelopes and other grazing animals. The semiarid grasslands of today's Serengeti were rain forests 25 Mya.

Starting at about that time, mountains such as Mount Kilimanjaro rose up between the rain forests and the Indian Ocean, their source of moisture. The presence of the mountains forced winds from the Indian Ocean upward, cooling the air and causing much of its moisture to precipitate before the air reached the rain forests. The land became much drier, and the forests turned to grasslands. Today, human activities can alter the water cycle so profoundly that major changes occur in ecosystems. Changes in rain forests caused by deforestation provide an example. In healthy tropical rain forests, more than 90% of the moisture that falls as rain is taken up by plants and returned to the air by transpiration. Plants, in a very real sense, create their own rain: The moisture returned to the atmosphere falls back on the forests. When human populations cut down or burn the rain forests in an area, the local water cycle is broken. Water that falls as rain thereafter drains away in rivers instead of rising to form clouds and fall again on the forests. Just such a transformation is occurring today in many tropical rain forests (figure 58.3). Large areas in Brazil, for example, were transformed in the 20th century from lush tropical forest to semiarid desert, depriving many unique plant and animal species of their native habitat.



Nitrogen cycle

Nitrogen is a component of all proteins and nucleic acids and is required in substantial amounts by all organisms; proteins are 16% nitrogen by weight. In many ecosystems, nitrogen is the chemical element in shortest supply relative to the needs of organisms. A paradox is that the atmosphere is 78% nitrogen by volume.

Nitrogen availability

How can nitrogen be in short supply if the atmosphere is so rich with it? The answer is that the nitrogen in the atmosphere is in its elemental form—molecules of nitrogen gas (N2) and the vast majority of organisms, including all plants and animals, have no way to use nitrogen in this chemical form. For animals, the ultimate source of nitrogen is nitrogen containing organic compounds synthesized by plants or by algae or other microbes. Herbivorous animals, for example, eat plant or algal proteins and use the nitrogen-containing amino acids in them to synthesize their own proteins. Plants and algae use a number of simple nitrogen containing compounds as their sources of nitrogen to synthesize proteins and other nitrogen-containing organic compounds in their tissues. Two commonly used nitrogen sources are ammonia (NH3) and nitrate ions (NO3–). certain prokaryotic microbes can synthesize ammonia and nitrate from N2 in the atmosphere, thereby constituting a part of the nitrogen cycle that makes atmospheric nitrogen accessible to plants and algae. Other prokaryotes turn NH3 and NO3– into N2, making the nitrogen inaccessible. The balance of the activities of these two sets of microbes determines the accessibility of nitrogen to plants and algae.

Microbial nitrogen fixation, nitrification, and DE nitrification

The synthesis of nitrogen-containing compounds from N2 is known as nitrogen fixation. The first step in this process is the synthesis of NH3 from N2, and biochemists sometimes use the term nitrogen fixation to refer specifically to this step. After NH3 has been synthesized, other prokaryotic microbes oxidize part of it to form NO3–, a process called nitrification. Certain genera of prokaryotes have the ability to accomplish nitrogen fixation using a system of enzymes known as the nitrogenase complex (the nif gene complex). Most of the microbes are free-living, but on land some are found in symbiotic relationships with the roots of legumes (plants of the pea family, Fabaceae), alders, myrtles, and other plants. Additional prokaryotic microbes (including both bacteria and archaea) are able to convert the nitrogen in NO3– into N2 (or other nitrogen gases such as N2O), a process termed DE nitrification. Ammonia can be subjected to DE nitrification indirectly by being converted first to NO3– and then to N2.

Nitrogenous wastes and fertilizer use most animals; when they break down proteins in their metabolism, excrete the nitrogen from the proteins as NH3. Humans and other mammals excrete nitrogen as urea in their urine. A number of types of microbes convert the urea to NH3. The NH3 from animal excretion can be picked up by plants and algae as a source of nitrogen. Human populations are radically altering the global nitrogen cycle by the use of fertilizers on lawns and agricultural fields. The fertilizers contain forms of fixed nitrogen that crops can use, such as ammonium (NH4) salts manufactured industrially from atmospheric N2. Partly because of the production of fertilizers, humans have already doubled the rate of transfer of N2 in usable forms into soils and waters.

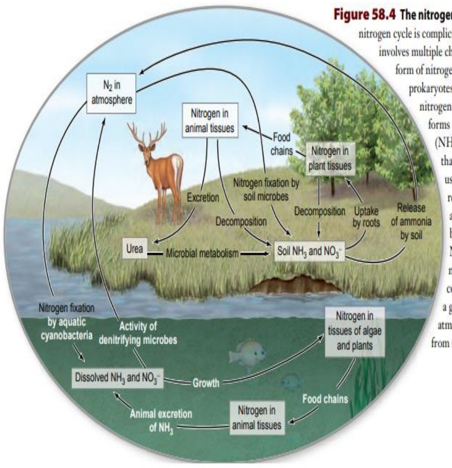


Figure 58.4 The nitrogen cycle. The nitrogen cycle is complicated because it involves multiple changes in the chemical form of nitrogen. Certain prokaryotes fix atmospheric nitrogen (N_2), converting it to forms such as ammonia (NH_3) and nitrate (NO_3^-) that plants and algae can use. Other prokaryotes return nitrogen to the atmosphere as N_2 by breaking down NH_3 or other nitrogen-containing compounds. Ammonia, a gas, can enter the atmosphere directly from soils.

Lecture #`47

Phosphorus cycle

Phosphorus is required in substantial quantities by all organisms; it occurs in nucleic acids, membrane phospholipids, and other essential compounds, such as adenosine triphosphate (ATP). Unlike carbon, water, and nitrogen, phosphorus has no significant gaseous form and does not cycle through the atmosphere. In this respect, the phosphorus cycle exemplifies the sorts of cycles also exhibited by calcium, silicon, and many other mineral elements. Another feature that greatly simplifies the phosphorus cycle compared with the nitrogen cycle is that phosphorus exists in ecosystems in just a single oxidation state, phosphate (PO4 3).

Phosphate availability

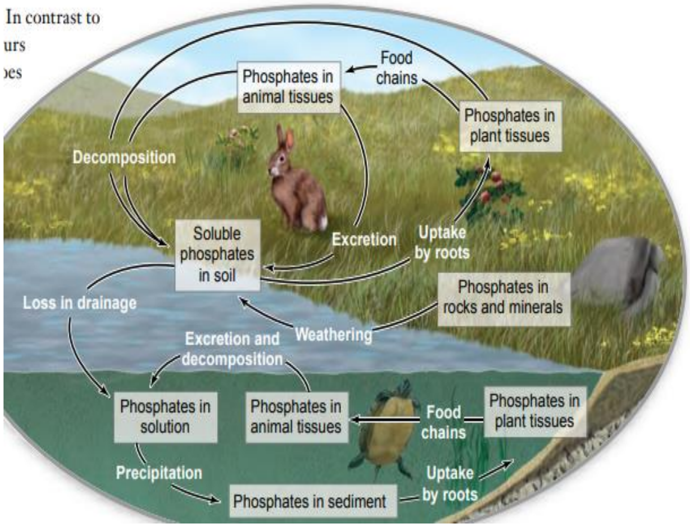
Plants and algae use free inorganic PO43 – in the soil or water for synthesizing their phosphorus-containing organic compounds. Animals then tap the phosphorus in plant or algal tissue compounds to build their own phosphorus compounds. When organisms die, decay microbes—in a process called phosphate r e mineralization—break up the organic compounds in their bodies, releasing phosphorus as inorganic PO43 – that plants and algae again can use. The phosphorus cycle includes critical abiotic chemical and physical processes. Free PO43 – exists in soil in only low concentrations both because it combines with other soil constituents to form insoluble compounds and because it tends to be washed away by streams and rivers. Weathering of many sorts of rocks releases new PO43 – into terrestrial systems, but then rivers carry the PO43 – into the ocean basins. There is a large one-way flux of PO43 – from terrestrial rocks to deep-sea sediments.

Phosphates as fertilizers

Human activities have greatly modified the global phosphorus cycle since the advent of crop fertilization. Fertilizers are typically designed to provide PO43 – because crops might otherwise be short of it; the PO43 – in fertilizers is typically derived from crushed phosphate-rich rocks and bones. Detergents are another potential culprit in adding PO43 – to ecosystems, but laws now mandate low-phosphate detergents in much of the world.

Limiting nutrients in ecosystems are those in short supply relative to need

A chain is only as strong as its weakest link. For the plants and algae in an ecosystem to grow—and to thereby provide food for animals—they need many different chemical elements. The simplest theory is that in any particular ecosystem, one element will be in shortest supply relative to the needs for it by the plants and algae. That element is the limiting nutrient—the weak link—in the ecosystem. The cycle of a limiting nutrient is particularly important because it determines the rate at which the nutrient is made available for use. We gave the nitrogen and phosphorus cycles close attention precisely because those elements are the limiting nutrients in many ecosystems. Nitrogen is the limiting nutrient in about two-thirds of the oceans and in many terrestrial ecosystems. Oceanographers have discovered in just the last 15 years that iron is the limiting nutrient for algal populations (phytoplankton) in about one-third of the world's oceans. In these waters, windborne soil dust seems often to be the chief source of iron. When wind brings in iron-rich dust, algal populations proliferate, provided the iron is in a usable chemical form. In this way, sand storms in the Sahara Desert, by increasing the dust in global winds, can increase algal productivity in Pacific waters.



Lecture #`48

Habitat Loss

Habitat loss is the most important cause of modern-day extinction. Given the tremendous amounts of ongoing destruction of all types of habitat, from rain forest to ocean floor, this should come as no surprise. Natural habitats may be adversely affected by humans in four ways:

- Destruction,
- Pollution,
- Disruption

The three main types of habitat loss are habitat destruction, habitat degradation and habitat fragmentation. As the late Steve Irwin put it, "I believe our biggest issue is the same biggest issue that the whole world is facing, and that's habitat destruction." Habitat loss is a serious problem for wildlife and humans alike. As Wildlife Habitat Canada states, "Without habitat, there is no wildlife. It's that simple." And without wildlife, there is no healthy functioning of the ecosystem services upon which we depend on.

Habitat destruction occurs when natural habitats are no longer able to support the species present, resulting in the displacement or destruction of its biodiversity. Examples include harvesting fossil fuels, deforestation, dredging rivers, bottom trawling, urbanization, filling in wetlands and mowing fields.

Habitat Degradation

A degraded habitat may remain intact, but it's degraded state may render it incapable of functioning properly and lead to species extinction or migration. The main causes of habitat degradation are pollution, invasive species, agricultural development, diminished resources, such as water and food, urban sprawl, logging, mining, destructive fishing practices and the disruption of ecosystem processes, such as altering the intensity and frequency of fires in an ecosystem. These are some of the ways habitats can become so degraded that they no longer support native wildlife.

habitat fragmentation is the spatial separation of habitats from a previous state of greater continuity. The 'cutting up' of habitats into fragments is mainly caused by agricultural land conversion, urbanization, dams, water diversions, pollution, invasive species and deforestation, but can also be caused by geological processes that slowly alter the layout of the physical environment. According to NWF, "These fragments of habitat may not be large or connected enough to support species that need a large territory in which to find mates and food. The loss and fragmentation of habitat make it difficult for migratory species to find places to rest and feed along their migration routes," or to even make it across these ancient and essential migratory paths to begin with.

Lecture #`49

Destruction of habitat

A proportion of the habitat available to a particular species may simply be destroyed. This destruction is a common occurrence in the “clear-cut” harvesting of timber, in the burning of tropical forest to produce grazing land, and in urban and industrial development. Deforestation has been, and continues to be, by far the most pervasive form of habitat disruption. Many tropical forests are being cut or burned at a rate of 1% or more per year.

To estimate the effect of reductions in habitat available to a species, biologists often use the well-established observation that larger areas support more species. Although this relationship varies according to geographic area, type of organism, and type of area, in general a 10-fold increase in area leads to approximately a doubling in the number of species. This relationship suggests, conversely, that if the area of a habitat is reduced by 90%, so that only 10% remains, then half of all species will be lost. Evidence for this hypothesis comes from a study in Finland of extinction rates of birds on habitat islands (that is, islands of a particular type of habitat surrounded by unsuitable habitat) where the population extinction rate was found to be inversely proportional to island size.

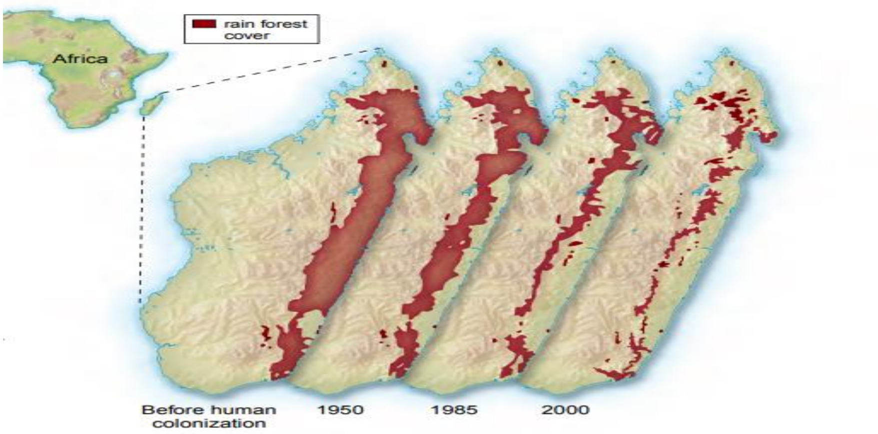


Figure 60.10 Extinction and habitat destruction. The rain forest covering the eastern coast of Madagascar, an island off the coast of East Africa, has been progressively destroyed and fragmented as the island's human population has grown. Ninety percent of the eastern coast's original forest cover is now gone. Many species have become extinct, and many others are threatened, including 16 of Madagascar's 31 primate species.

Lecture #`50

Habitat fragmentation

Loss of habitat by a species frequently results not only in lowered population numbers, but also in fragmentation of the population into unconnected patches. A habitat also may become fragmented in nonobvious ways, as when roads and habitation intrude into forest. The effect is to carve the populations living in the habitat into a series of smaller populations, often with disastrous consequences because of the relationship between range size and extinction rate.

Figure 60.13 A study of habitat fragmentation. Landowners in Manaus, Brazil, agreed to preserve patches of rain forest of different sizes to examine the effect of patch size on species extinction. Biodiversity was monitored in the isolated patches before and after logging. Fragmentation led to significant species loss within patches. Army ants were one of the species that disappeared from smaller patches.

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Habitat fragmentation, also known as species fragmentation, refers to the discontinuity experienced in the populations of species that are separated by human activity.

Habitat fragmentation, also known as species fragmentation, is a process by which large and contiguous habitats get divided into smaller, isolated patches of habitats. The initiation of these smaller habitats has a direct impact on all of the species, their community structure, and the overall ecosystem of those fragments. There are many direct, indirect, natural, and human reasons behind this phenomenon.

Natural Reasons

Habitats can be fragmented because of numerous natural reasons. Out of them, volcanic eruptions, fire, and change in climate are the three major natural factors that lead to the onset of habitat fragmentation.

Human Reasons

Humans are directly responsible for rapid and fast habitat fragmentation. Some of the ways in which human's trigger fragmentation are:

- Urbanization
- Rural development
- Claiming new agricultural lands
- Logging and cutting down forests
- Construction of roads and railway tracks
- Development of housing projects
- Building water reservoirs

All of the factors mentioned above are largely considered the direct causes of habitat fragmentation.

Implementations

Habitat fragmentation is not only responsible for change in the characteristics of a fragment but also causes extinction of many species. To make it simple for you to understand, imagine you woke up on a Sunday and decided to go get your weekly groceries from the supermarket. However, on your way to the market, you found out that a wall has been erected between your home and supermarket. The erection of this wall is going to affect you and your life completely. Next, imagine the same thing happened in many areas of your city, and your city's population has been divided into smaller and disconnected areas – the obstruction would make survival very difficult, right?

When a contagious habitat faces fragmentation, it triggers the edge effect in these smaller and isolated fragments. The edges of these fragments become less suitable for some or many of the species and organisms. The edges of a habitat are usually the least populated areas, and when that habitat divides into many fragments, they become challenging and competitive areas for their inhabitants. This phenomenon also affects territorial animals to the point of extinction, as their territories shrink down. With that, travelling through one fragment to another becomes dangerous as it involves having to cross roads, rail tracks, and even fences.

Next, extensive fragmentation of a habitat means that its inhabitants will have lesser resources. Apart from that, the inhabitants will also have to deal with challenges like increased competition and a comparatively dangerous place to live in. The battle for survival speeds up as new species travel to the fragments. This results in migration or extinction of many species, which further affects the entire ecosystem of the fragment.

Advantages

While there are many downsides of habitat fragmentation, it has a few advantages too. First, it has the potential to increase diversity as it shapes speciation and evolution. Geographical and reproductive isolation triggered by fragmentation leads to allopatric speciation. Apart from that, it diversifies landscapes as well.

All in all, habitat fragmentation has a few advantages to offer. However, its drawbacks far outweigh its benefits.

Lecture #`51

Effects of Habitat fragmentation

The impact of habitat fragmentation can be seen clearly in a study conducted in Manaus, Brazil, where the rain forest was commercially logged. Landowners agreed to preserve patches of rain forest of various sizes, and censuses of these patches were taken before the logging started, while they were still part of a continuous forest. After logging, species began to disappear from the now-isolated patches.

First to go were the monkeys, which have large home ranges. Birds that prey on the insects flushed out by marching army ants followed, disappearing from patches too small to maintain enough army ant colonies to support them. As expected, the extinction rate was negatively related to patch size, but even the largest patches (100 hectares) lost half of their bird species in less than 15 years. Because some species, such as monkeys, require large patches, large fragments are indispensable if we wish to preserve high levels of biodiversity. The take-home lesson is that preservation programs will need to provide suitably large habitat fragments to avoid this effect.

Habitat fragmentation usually occurs because of **human activities** such as new roads, parking lots and housing developments. Organisms need their specific habitat for survival, and fragmentation is a leading threat to many terrestrial animals. Not only are these animals separated from the resources they depend on, but they now have to travel across dangerous areas, such as roads, to reach those resources.

Habitat fragmentation from human activities is not limited to urban areas. Logging is a major cause of habitat fragmentation in forests. Logging creates clear-cut, open ground areas that were once protected by the cover of trees. Logging roads that are built for the logging trucks to travel on can also be cut through forests, disrupting the habitat. Habitats may also become fragmented by **natural processes**. Rivers serve as natural pathways for both terrestrial and aquatic animals. If the river floods, it may make passage across it by terrestrial animals impossible. On the other hand, aquatic animals that depend on the river to move between two different water bodies will not be able to travel from one place to another if the river dries up.

Lecture # 53

Overexploitation

Species that are hunted or harvested by humans have historically been at grave risk of extinction, even when the species is initially very abundant. A century ago, the skies of North America were darkened by huge flocks of passenger pigeons, but after being hunted as free and tasty food, they were driven to extinction. The bison that used to migrate in enormous herd cross the central plains of North America only narrowly escaped the same fate.

Most of the land animals we eat are farm-raised, not hunted in the wild. Fish, on the other hand, are often still fished from the wild. Humans have to eat, but we have been taking fish for food faster than they can replenish their wild populations. It is estimated that 63% of commercial fisheries are overfished to some extent.

Overfishing happens mostly because humans have gotten really good at fishing. We have big boats, fancy GPS systems, and mechanized fishing lines. The fishing techniques called bottom trawling and dredging involve dragging huge heavy nets across the ocean floor, picking up everything along the way. This includes plants and animals that are not the target fish. These unwanted things usually get tossed out. All this other, non-target catch is called **by catch**. By catch can include sea turtles, sharks, corals, and lots of other animals. These fishing methods are super destructive of habitats on the bottom of the ocean, especially slow-growing corals, in both warm and cold water.

The tuna, cod, halibut and haddock fisheries in the North Atlantic Ocean have declined to one-third of what they used to be. The overexploitation of fisheries is an example of a **tragedy of the commons**—people take more and more of a common resource until it is no longer available.

What about farm-raised fish? Is aquaculture the answer? Maybe. Aquaculture is on the rise for both freshwater and saltwater organisms. Sometimes aquaculture is bad for ecosystems and results in fish that are not as nutritious as wild-caught fish. Abalone, catfish, clams, and mussels that are farmed are both sustainably raised and nutritious.

Farm-raised shrimp are another story. Shrimp farms are usually located in the intertidal zone of tropical areas, right where mangrove forests live. Mangrove habitats provide many ecosystem services, such as nurseries for fish, protecting land from storm surges, protecting coral reefs and seagrass beds from sedimentation, and carbon storage, to name a few. However, mangroves are one of the most threatened ecosystems in the world, and many of them have been clear-cut for shrimp farms, coastal development, and agriculture.

Sometimes organisms are harvested for purposes other than food. Many animals and plants are collected to be pets, souvenirs, or trophies in a collection of exotic species. Many of these collecting efforts are illegal and are also known as **poaching**, which is the illegal capture of protected organisms.

Poachers collect rhinoceros horns, parrots, orchids, and many other living things illegally from tropical forests, and also collect fish or corals from marine ecosystems. The problem is that collecting these animals is bad for their populations and habitats, especially when it is a species that forms a habitat, like coral reefs. Not to mention what it does to the organism itself—many animals die while they are being smuggled for the pet trade, and corals are killed off to make trinkets for souvenir shops.

Lecture #`53

Introduced species threaten native species and habitats & Human influence on colonization

Colonization, a natural process by which a species expands its geographic range, occurs in many ways: A flock of birds gets blown off course, a bird eats a fruit and defecates its seed miles away, or lowered sea levels connect two previously isolated landmasses, allowing species to freely move back and forth. Such events—particularly those leading to successful establishment of a new population—probably occur rarely, but when they do, the resulting change to natural communities can be large. The reason is that colonization brings together species with no history of interaction.

Consequently, ecological interactions maybe particularly strong because the species have not evolved ways of adjusting to the presence of one another, such as adaptations to avoid predation or to minimize competitive effects. The paleontological record documents many cases in which geologic changes brought previously isolated species together, such as when the Isthmus of Panama emerged above the sea approximately 3 Mya, connecting the previously isolated fauna and flora of North and South America. In some cases, the result has been an increase in species diversity, but in other cases, invading species have led to the extinction of natives.

Lecture #`54

Land pollution

Land pollution is the deterioration (destruction) of the earth's land surfaces, often directly or indirectly as a result of man's activities and their misuse of land resources.

Causes of Land Pollution

There are several known causes of land pollution. Of those, there are six factors that contribute more than others.

Deforestation and soil erosion When forests are cleared for development and to meet the demand for wood supply, the soil is loosened in the process. Without the protection of the trees, the land becomes barren over time and starts to erode.

Agricultural chemicals Part of the farming process often involves the use of harmful pesticides and insecticides to protect crops. However, the chemicals can cause the land to become barren. The once-fertile soil is then more susceptible to environmental elements, such as the wind.

Industrialization The Industrial Revolution may have resulted in significant positive changes to the economy and society, but it also led to significant pollution of the land. Through unsafe disposal practices for chemicals used in manufacturing, poor regulation, and the overwhelming number of industries and factories that are polluting the land daily, industrialization has become one of the main contributors to the pollution problem

Mining The mining process can lead to the creation of large open spaces beneath the surface of the earth. This can result in the land caving in, which compromises the integrity of the land. Mining also results in harmful chemicals, such as uranium, being disturbed and released into the environment.

Landfills The garbage found at landfills is filled with toxins that eventually seep into the earth. During rains, the toxins are washed into other areas and the pollution is spread. As the population grows, the amount of garbage filling landfills also grows.

Human sewage Untreated human waste can produce toxic gases that can seep into the ground. As with air pollution, the soil quality is negatively impacted, and land nearby can be contaminated. In addition to this, the probability of human illnesses occurring increases.

Effects of Land Pollution

The contamination of the land has far-reaching consequences that can be catastrophic for water, soil, and animals. There are several possible consequences of land pollution to the environment and animals, including these top five:

Ground water poisoning

Depending on the soil and whether the chemicals were improperly disposed of on the land, the chemicals could end up in the ground water. The process is known as leaching. It can occur on farms, industrial sites, and landfills.

Water nutrient enrichment

Chemicals, such as nitrogen, are used frequently on farms. Only a small portion of the nutrients end up benefitting the crops. The remainder usually ends up in water that is populated by fish, algae, and other lifeforms. The nutrient-heavy water saps up most of the oxygen in the water, which leaves little for fish and other life. When this happens, the water is unable to support most lifeforms. For more information on water pollution.

Loss of topsoil

As chemical fertilizers and pesticides are used to maintain crops, the topsoil's composition becomes altered. The soil becomes more susceptible to harmful fungus species and begins to erode. It is important to conserve our soil to maximize land productivity.

Shifting habitat

As deforestation and soil erosion progress, animals are forced to move to find shelter and food. For some animals, the change is too traumatic, and this has led to some dying. As a result, some species are at a greater risk of extinction.

5. Increased risk of wildfires

The dry conditions created by pollutants in the soil help to create the perfect environment for wildfires. The fires can grow quickly because of the dry conditions and widening area of polluted land.

Lecture #`56

Water pollution

Water pollution is the pollution of bodies of water, such as lakes, rivers, seas, the oceans, as well as groundwater. It occurs when pollutants reach these bodies of water, without treatment. Waste from homes, factories and other buildings get into the water bodies and as a result water gets contaminated.

Water pollution causes

Sewage and waste water Inadequate sewage collection and treatment are sources of water pollution. According to the United Nations, more than 80% of the worldwide wastewater goes back in the environment without being treated or reused.

Urbanization and deforestation Even though it does not have a direct impact on water quality, urbanization and deforestation have a lot of indirect effects. For instance, cutting down trees and concreting over large areas generates an acceleration of flows which does not give enough time for water to infiltrate and be purified by the ground.

Agriculture has an impact on water pollution due to the use of chemicals such as fertilizers, pesticides, fungicides, herbicides or insecticides running off in the water, as well as livestock excrement, manure and methane (greenhouse effect). Regarding aquaculture, pollution is directly in the water, as excess food and fertilizers are causing dystrophication

Industries produce a lot of waste containing toxic chemicals and pollutants. A huge amount of the industrial waste is drained in the fresh water which then flows into canals, rivers and eventually in the sea. Another source of water pollution is the burning of fossil fuels, causing air pollution like acid rain which then flows to streams, lakes, and other stretches of water.

Water pollution effects

On environment Water pollution truly harms biodiversity and aquatic ecosystems. The toxic chemicals can change the color of water and increase the amount of minerals - also known as eutrophication - which has a bad impact on life in water. Thermal pollution, defined by a rise in the temperature of water bodies, contributes to global warming and causes serious hazard to water organisms**.**

On human health Water pollution has very negative effects on public health. A lot of diseases result from drinking or being in contact with contaminated water, such as diarrhea, cholera, typhoid, dysentery or skin infections. In zones where there is no available drinking water, the main risk is dehydration obviously.

Water pollution prevention

Wastewater treatment Wastewater treatment consists of removing pollutants from wastewater through a physical, chemical or biological process. The more efficient these processes are, the cleaner the water becomes.

Green agriculture Globally, agriculture accounts for 70% of water resources, so it is essential to have climate-friendly crops, efficient irrigation that reduces the need for water and energy-efficient food production. Green agriculture is also crucial to limit the chemicals that enter the water.

Storm water management Storm water management is the effort to reduce runoff of rainwater or melted snow into streets, lawns and other sites and the improvement of water quality" according to the US Environmental Protection Agency (EPA). It is important to avoid pollutants from contaminating the water and helps to use water more efficiently.

Lecture #`58

Air pollution

Air pollution is a mixture of solid particles and gases in the air. Car emissions, chemicals from factories, dust, pollen and mold spores may be suspended as particles. Air pollution isn't just outside - the air inside buildings can also be polluted and affect your health.

Air pollution causes

Air pollution is caused by the presence in the atmosphere of toxic substances, mainly produced by human activities, even though sometimes it can result from natural phenomena such as volcanic eruptions, dust storms and wildfires, also depleting the air quality.

Anthropogenic air pollution sources are: Combustion of fossil fuels, like coal and oil for electricity and road transport, producing air pollutants like nitrogen and sulfur dioxide2.Emissions from industries and factories, releasing large amount of carbon monoxide, hydrocarbon, chemicals and organic compounds into the air3.Agricultural activities, due to the use of pesticides, insecticides, and fertilizers that emit harmful chemicals 4.Waste production, mostly because of methane generation in landfills.

Air pollution effects

On environment Air pollution has a major impact on the process of plant evolution by preventing photosynthesis in many cases, with serious consequences for the purification of the air we breathe. It also contributes to the formation of acid rain, atmospheric precipitations in the form of rain, frost, snow or fog, which are released during the combustion of fossil fuels and transformed by contact with water steam in the atmosphere.

Global warming On top of that, air pollution is a major contributor to global warming and climate change. In fact, the abundance of carbon dioxide in the air is one of the causes of the greenhouse effect. Normally, the presence of greenhouse gases should be beneficial for the planet because they absorb the infra-red radiation produced by the surface of the earth. But the excessive concentration of these gases in the atmosphere is the cause of the recent climate change.

Human health Our continual exposure to air pollutants is responsible for the deterioration of human health. Air pollution is indeed a significant risk factor for human health conditions, causing allergies, respiratory and cardiovascular diseases as well as lung damage.

Air pollution prevention

1.Renewable fuel and clean energy production The most basic solution for air pollution is to move away from fossil fuels, replacing them with alternative energies like solar, wind and geothermal.

2.Energy conservation and efficiency Producing clean energy is crucial. But equally important is to reduce our consumption of energy by adopting responsible habits and using more efficient devices.

Lecture #`60

Light pollution

We all know that human activities can cause adverse changes in ecosystems. In discussing these, it is important to recognize that creative people can often come up with rational solutions to such problems. An outstanding example is provided by the history of DDT in the United States. DDT is a highly effective insecticide that was sprayed widely in the decades following World War II, often on wetlands to control mosquitoes. During the years of heavy DDT use, populations of ospreys, bald eagles, and brown pelicans—all birds that catch large fish— plummeted. Ultimately, the use of DDT was connected with the demise of these birds. Scientists established that DDT and its metabolic products became more and more concentrated in the tissues of animals as the compounds were passed along food chains.

In **disrupting ecosystems**, light pollution poses a serious threat in particular to nocturnal wildlife, having negative impacts on plant and animal physiology. It can confuse the migratory patterns of animals, alter competitive interactions of animals, change predator-prey relations, and cause physiological harm. The rhythm of life is orchestrated by the natural diurnal patterns of light and dark; so disruption to these patterns impacts the ecological dynamics.

With respect to **adverse health effects**, many species, especially humans, are dependent on natural body cycles called circadian rhythms and the production of melatonin, which are regulated by light and dark (e.g., day and night). If humans are exposed to light while sleeping, melatonin production can be suppressed. This can lead to sleep disorders and other health problems such as increased headaches, worker fatigue, medically defined stress, some forms of obesity due to lack of sleep and increased anxiety. And ties are being found to a couple of types of cancer. There are also effects of glare on aging eyes. (See text below.) Health effects are not only due to over-illumination or excessive exposure of light over time, but also improper spectral composition of light (**e.g., certain colors of light**).

With respect to energy wastage, lighting is responsible for at least one-fourth of all electricity consumption worldwide. Over illumination can constitute energy wastage, especially upward directed lighting at night. Energy wastage is also a waste in cost and carbon footprint.

The good news is that **light pollution can be reduced** fairly easily by shielding lights properly, by only using light when and where it is needed, by only using the amount that is needed, by using energy efficient bulbs, and by using bulbs with appropriate spectral power distributions for the task at hand.

Lecture #`62

Acid rain

Deforestation can be a problem in temperate regions, as well as in the tropics. In addition, acid rain affects forests as well as lakes and streams; large tracts of trees in temperate regions have been adversely affected by acid rain. By changing the acidity of the soil, acid rain can lead to widespread tree mortality.

Causes

The term acid rain was coined in 1852 by Scottish chemist Robert Angus Smith, according to the Royal Society of Chemistry, which calls him the "father of acid rain." Smith decided on the term while examining rainwater chemistry near industrial cities in England and Scotland. He wrote about his findings in 1872 in the book "Air and Rain: The Beginnings of a Chemical Climatology." In the 1950s, scientists in the United States started studying the phenomenon, and in the 1960s and early 1970s, acid rain became recognized as a regional environmental issue that affected Western Europe and eastern North America.

Though manmade pollutants are currently affecting most acidic precipitation, natural disasters can be a factor as well. For example, volcanoes can cause acid rain by blasting pollutants into the air. These pollutants can be carried around the world in jet streams and turned into acid rain far from the volcano. After an asteroid supposedly wiped out the dinosaurs 65.5 million years ago, sulfur trioxide was blasted into the air. When it hit the air, it turned into sulfuric acid, generating a downpour of acid rain, according to a paper published in 2014 in the journal Nature Geoscience.

Even before that, over 4 billion years ago, it is suspected that the air may have had 10,000 times as much carbon dioxide as today. Geologists from the University of Wisconsin-Madison backed up this theory be studying rocks and publishing the results in a 2008 issue of the journal Earth and Planetary Science Letters. "At [those levels of carbon dioxide], you would have had vicious acid rain and intense greenhouse [effects]. That is a condition that will dissolve rocks," said study team member John Valley.

Sulfur dioxide (SO_2) and nitrogen oxides (NOx) released into the air by fossil-fuel power plants, vehicles and oil refineries are the biggest cause of acid rain today, according to the EPA. Two thirds of sulfur dioxide and one fourth of nitrogen oxide found in the atmosphere come from electric power generators. A chemical reaction happens when sulfur dioxide and nitrogen oxides mix with water, oxygen and other chemicals in the air. They then become sulfuric and nitric acids that mix with precipitation and fall to the ground. Precipitation is considered acidic when its pH level is about 5.2 or below, according to Encyclopedia Britannica. The normal pH of rain is around 5.6.

Effects

Acid rain affects nearly everything. Plants, soil, trees, buildings and even statues can be transformed by the precipitation. Acid rain has been found to be very hard on trees. It weakens them by washing away the protective film on leaves, and it stunts growth. A paper released in the online version of the journal of Environmental Science and Technology in 2005 showed evidence of acid rain stunting tree growth.

"By providing the only preserved soil in the world collected before the acid rain era, the Russians helped our international team track tree growth for the first time with changes in soil from acid rain," said Greg Lawrence, a U.S. Geological Survey scientist who headed the effort. "We've known that acid rain acidifies surface waters, but this is the first time we've been able to compare and track tree growth in forests that include soil changes due to acid rain." Acid rain can also change the composition of soil and bodies of water, making them uninhabitable for local animals and plants. For example, healthy lakes have a pH of 6.5 or higher. As acid rain raises the level of acidity, fish tend to die off. Most fish species can't survive a water pH of below 5. When the pH becomes a 4, the lake is considered dead, according to National Atmospheric Deposition Program. It can additionally deteriorate limestone and marble buildings and monuments, like gravestones.

Solutions

There are several solutions to stopping manmade acid rain. Regulating the emissions coming from vehicles and buildings is an important step, according to the EPA. This can be done by restricting the use of fossil fuels and focusing on more sustainable energy sources such as solar and wind power. Also, each person can do their part by reducing their vehicle use. Using public transportation, walking, riding a bike or carpooling is a good start, according to the EPA. People can also reduce their use of electricity, which is widely created with fossil fuels, or switch to a solar plan. Many electricity companies offer solar packages to their customers that require no installation and low costs.

Figure 59.23 **Damage to trees by acid precipitation at Clingman's Dome, Tennessee.** Acid precipitation weakens trees and makes them more susceptible to pests and predators.

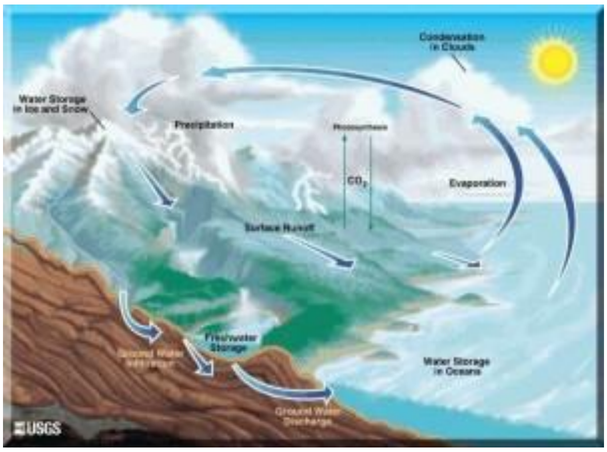
Lecture #`63

Disruption of the water cycle & Coastal ecosystem

Cutting of a tropical rain forest often interrupts the local water cycle in ways that permanently alter the landscape. After an area of tropical rain forest is cleared, rain water often runs off the land to distant places, rather than being returned to the atmosphere immediately above by transpiration. This change may render conditions unsuitable for the rain forest trees that originally lived there. Then the poorly vegetated land—exposed and no longer stabilized by thick root systems—may be ravaged by erosion.

Rain forests store vast quantities of water, and when those trees are cut down, the water they store is lost. As trees and plants are responsible for extracting groundwater from the soil and returning it the atmosphere, deforestation results in the water not being able to be released back into the atmosphere, affecting the balance of the water cycle. This results in lush rainforests turning into barren.

The resulting dry climate would result in increased probability of fire on peat land because of higher temperature and lower rainfall during the dry season. This is worsened by the fact that peatland fires are extremely difficult to extinguish as they burn underneath the surface, resulting in haze and contributing to air pollution.



Lecture #`63

Destruction of coastal ecosystems

Second to overfishing, the greatest problem in the ocean realm is deterioration of coastal ecosystems. Estuaries along coastlines are often subject to severe eutrophication; since about 1970, for example, the bottom waters of the Chesapeake Bay near Washington, DC, have become oxygen-free each summer because of the decay of excessive amounts of organic matter. Another coastal problem is destruction of salt marshes, which (like freshwater wetlands) are often perceived as disposable.

Most authorities believe that the loss of salt marshes in the 20th century was a major contributing factor to the destruction of New Orleans by Hurricane Katrina in 2005; had the salt marshes and cypress swamps been present at their full extent, they would have absorbed a great deal of the flooding water and buffered the city from some of the storm's violence.

Overexploitation of local fisheries

Fisheries are a vital employment activity to hundreds of thousands of families on the coast. At least as many again are involved in the post-harvest activities of marketing and processing. The products of the industry (fish, molluscs, shrimps and crabs) provide the main protein component of the diet of the majority of the coastal people and many more people inland (where dried or salted products are sold).

In Tanzania, for example, the estimated average consumption of seafood per person (9.4 kg/year) is greater than the combined consumption of meat and poultry. For the entire region at least 500 species of fish constitute the bulk of catches, yielding an estimated 200,000 tonnes each year.

Most of the catch is from fishers equipped with simple, artisanal gears such as hook and line, hand spears, woven fish traps and various types of nets. Total catches from Mozambique are about 115,000 tonnes, with between 90-95% being caught by about 80,000 artisanal fishers.

Other more industrialized fishing methods also exist, including motorised vessels equipped with trawl nets hauled by power winches. In Mozambique alone the industrial and semi-industrial fishing fleet exceeds 150 vessels, earning the economy over US$ 100 million per year, mostly through the export of shrimps. These trawlers are also active in Tanzania and Kenya, though not to the same scale as in Mozambique which has far greater areas around river mouths suitable for shrimps.

Destructive fishing practices

Over the last few decades destructive fishing methods, such as the use of dynamite and small-meshed nets, have destroyed seagrass beds and coral reefs. These practices still continue in many places despite being illegal in all countries. Preliminary research along the coast of Kenya and Tanzania indicates that human activities such as these have reduced fish catches from coral reefs by 30-40%.

Large proportions of the by-catch (e.g. non-commercial or unwanted species) of shrimp trawlers are juvenile fish. The loss of these immature individuals threatens future fishery resources. Offshore fishing grounds, some of the only areas on earth from where fish catches are increasing, are also open to plundering, often by industrial foreign fleets.

Lecture #`64

Carbon dioxide is a major greenhouse gas

Carbon dioxide is the gas usually emphasized in discussing the cause of global warming although other atmospheric gases are also involved. A monitoring station on the top of the 13,700-foot (4200-m) Mauna Loa volcano on the island of Hawaii has monitored the concentration of atmospheric CO_2 since the 1950s. This station is particularly important because it is in the middle of the Pacific Ocean, far from the great continental landmasses where most people live, and it is therefore able to monitor the state of the global atmosphere without confounding influences of local events. In 1958, the atmosphere was 0.031% CO_2. By 2004, the concentration had risen to 0.038%. All authorities agree that the cause of this steady rise in atmospheric CO_2 is the burning of coal and petroleum products by the increasing (and increasingly energy-demanding) human population.

Greenhouse gas, any gas that has the property of absorbing infrared radiation (net heat energy) emitted from Earth’s surface and reradiating it back to Earth’s surface, thus contributing to the greenhouse effect. Carbon dioxide, methane, and water vapour are the most important greenhouse gases. (To a lesser extent, surface-level ozone, nitrous oxides, and fluorinated gases also trap infrared radiation.) Greenhouse gases have a profound effect on the energy budget of the Earth system despite making up only a fraction of all atmospheric gases. Concentrations of greenhouse gases have varied substantially during Earth’s history, and these variations have driven substantial climate changes at a wide range of timescales. In general, greenhouse gas concentrations have been particularly high during warm periods and low during cold periods.

A number of processes influence greenhouse gas concentrations. Some, such as tectonic activities, operate at timescales of millions of years, whereas others, such as vegetation, soil, wetland, and ocean sources and sinks, operate at timescales of hundreds to thousands of years. Human activities—especially fossil-fuel combustion since the Industrial Revolution—are responsible for steady increases in atmospheric concentrations of various greenhouse gases, especially carbon dioxide, methane, ozone, and chlorofluorocarbons (CFCs).

Lecture #`

How carbon dioxide affects temperature

The atmospheric concentration of CO2 affects global temperature because carbon dioxide strongly absorbs electromagnetic radiant energy at some of the wavelengths that are critical for the global heat budget. The Earth not only receives radiant energy from the Sun, but also emits radiant energy into outer space. The Earth's temperature will be constant only if the rates of these two processes are equal. The incoming solar energy is at relatively short wavelengths of the electromagnetic spectrum: Wavelengths that are visible or near-visible. The outgoing energy from the Earth is at different, longer wavelengths. Carbon dioxide absorbs energy at certain of the important long-wave infrared wavelengths.

This means that although carbon dioxide does not interfere with the arrival of radiant energy at short wavelengths, it retards the rate at which energy travels away from the Earth at long wavelengths into outer space. Carbon dioxide is often called a greenhouse gas because its effects are analogous to those of a greenhouse. The reason that a glass greenhouse gets warm inside is that window glass is transparent to light but only slightly transparent to long-wave infrared radiation. Energy that strikes a greenhouse as light enters the greenhouse freely. Once inside, the energy is absorbed as heat and then re-radiated as long-wave infrared radiation. The infrared radiation cannot easily get out through the glass, and therefore energy accumulates inside.

Lecture #`64

Other greenhouse gases

Carbon dioxide is not the only greenhouse gas. Others include methane and nitrous oxide. The effect of any particular greenhouse gas depends on its molecular properties and concentration.

For example, molecule-for-molecule, methane has about 20 times the heat-trapping effect of carbon dioxide; on the other hand, methane is less concentrated and less long-lived in the atmosphere than carbon dioxide. Methane is produced in globally significant quantities in anaerobic soils and in the fermentation reactions of ruminant mammals, such as cows. Huge amounts of methane are presently locked up in Arctic permafrost. Melting of the permafrost could cause a sudden and large perturbation in global temperature by releasing methane rapidly. Agricultural use of fertilizers is the largest source of nitrous oxide emissions, with energy consumption second and industrial use third.

The danger lies in the rapid increase of carbon dioxide and other greenhouse gases that intensify this natural greenhouse effect. For thousands of years, the global carbon supply was essentially stable as natural processes removed as much carbon as they released. Modern human activity—burning fossil fuels, deforestation, intensive agriculture—has added huge quantities of carbon dioxide and other greenhouse gases.

Today’s atmosphere contains 42 per cent more carbon dioxide than it did at the start of the industrial era. Levels of methane and carbon dioxide are the highest they have been in nearly half a million years. The Kyoto Protocol covers six greenhouse gases: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride. Of these six gases, three are of primary concern because they are closely associated to human activities. Carbon dioxide is the main contributor to climate change, especially through the burning of fossil fuels. Methane is produced naturally when vegetation is burned, digested or rotted without the presence of oxygen. Large amounts of methane are released by cattle farming, waste dumps, rice farming and the production of oil and gas. Nitrous oxide, released by chemical fertilizers and burning fossil fuels, has a global warming potential 310 times that of carbon dioxide.

Lecture #`65

Stratospheric ozone depletion has led to an ozone “hole”

Different concentrations of ozone (O3) located 20 to 25 km above the Earth’s surface in the stratosphere. Stratospheric ozone is depleted over Antarctica (purple region in the figure) to between one-half and one-third of its historically normal concentration, a phenomenon called the ozone hole. Although depletion of stratospheric ozone is most dramatic over Antarctica, it is a worldwide phenomenon. Over the United States, the ozone concentration has been reduced by about 4%, according to the U.S. Environmental Protection Agency.

The ozone "hole" is really a reduction in concentrations of ozone high above the earth in the stratosphere. The ozone hole is defined geographically as the area wherein the total ozone amount is less than 220 Dobson Units. The ozone hole has steadily grown in size (up to 27 million sq. km.) and length of existence (from August through early December) over the past two decades.

After a series of rigorous meetings and negotiations, the Montreal Protocol on Substances that Deplete the Ozone Layer was finally agreed upon on 16 september 1987 at the Headquarters of the International Civil Aviation Organization in Montreal. The Montreal Protocol stipulates that the production and consumption of compounds that deplete ozone in the stratosphere--chlorofluorocarbons (CFCs), halons, carbon tetrachloride, and methyl chloroform--are to be phased out by 2000 (2005 for methyl chloroform). Scientific theory and evidence suggest that, once emitted to the atmosphere, these compounds could significantly deplete the stratospheric ozone layer that shields the planet from damaging UV-B radiation. Man-made chlorines, primarily chloroflourobcarbons (CFCs), contribute to the thinning of the ozone layer and allow larger quantities of harmful ultraviolet rays to reach the earth.

Lecture # 65

Stratospheric ozone and UV-B

Stratospheric ozone is important because it absorbs ultraviolet (UV) radiation—specifically the wavelengths called UV-B— from incoming solar radiation. UV-B is damaging to living organisms in a number of ways; for instance, it increases risks of cataracts and skin cancer in people. Depletion of stratospheric ozone permits more UV-B to reach the Earth's surface and therefore increases the risks of UV-B damage. Every 1% drop in stratospheric ozone is estimated to lead to a 6% increase in the incidence of skin cancer, for example. UV exposure also may be detrimental to many types of animals, such as amphibians. Ozone is comparatively rare in the atmosphere - there are only 3 molecules of ozone for every ten million air molecules. 90% of the planet's ozone is in the "ozone layer" which exists in the lower level (20-25 kilometres above sea level) of the stratosphere.

The stratosphere is the region of the atmosphere which exists between 10 and 50 kilometres above the surface of the earth. Solar wavelengths in the ultraviolet range (180-240 nanometers) are absorbed by and break apart oxygen molecules (which are made of two oxygen atoms). Some of the resulting unattached pairs of oxygen atoms then recombine into triplets to form ozone. A different range of wavelengths of ultraviolet (290-300 nm) are strongly absorbed by ozone, which breaks down as a result and reforms into molecular oxygen again.

The higher up in the atmosphere you go, the thinner the air is, and thus the less oxygen there is to absorb the 180-240 nm ultraviolet to form ozone. This means that ozone amounts tend to decrease as you go higher. The lower down in the atmosphere you go, the more oxygen the ultraviolet has to pass through to get there, and the greater the chances are that it has already been absorbed to create ozone somewhere higher up. This means that very low down, the ozone concentrations tend to be lower. From roughly 12 to 30 km, the two tendencies balance out, and the highest ozone concentrations are found there, in what is called the "ozone layer". This is why the ozone layer exists in the lower part of the stratosphere.

The lower layer of the atmosphere that immediately surrounds the Earth is called the troposphere. Stratospheric ozone is a naturally-occurring gas that filters the sun's ultraviolet (UV) radiation. This is typically regarded as 'good' ozone since it reduces the harmful effects of ultraviolet (UV-B) radiation. A diminished ozone layer allows more radiation to reach the Earth's surface. Excessive exposure to UV-B at the surface of the earth has been shown to cause harmful effects in plants and animals. Absorption of UV-B by ozone in the stratosphere reduces the amount of UV-B reaching the earth's surface and also generates heat that plays a role in maintaining the temperature structure of the atmosphere.

Ozone that occurs in the troposphere is a much smaller proportion of the total planetary ozone and is regarded as 'bad' ozone since it reacts easily with other Molecules making it highly toxic to living organisms. Tropospheric ozone is known to have negative impacts on such things as crop production, forest growth and human health. Tropospheric ozone is a key component of photochemical smogs which are observed in many cities.

Lecture #`65

Ozone depletion and CFCs

The major cause of the depletion of stratospheric ozone is the addition of industrially produced chlorine- and bromine containing compounds to the atmosphere. Of particular concern are chlorofluorocarbons (CFCs), used until recently as refrigerants in air conditioners and refrigerators, and in manufacturing. CFCs released into the atmosphere can ultimately liberate free chlorine atoms, which in the stratosphere catalyze the breakdown of ozone molecules (O3) to form ordinary oxygen (O_2).

The extreme depletion of ozone seen in the ozone hole is a consequence of the unique weather conditions that exist over Antarctica. During the continuous dark of the Antarctic winter, a strong stratospheric wind, the polar-night jet, develops and, blowing around the full circumference of the Earth, isolates the stratosphere over Antarctica from the rest of the atmosphere. The Antarctic stratosphere stays extremely cold (–80°C or lower) for many weeks as a consequence, permitting unique types of ice clouds to form. Reactions associated with the particles in these clouds lead to accumulation of diatomic chlorine, Cl2. When sunlight returns in the early Antarctic spring, the diatomic chlorine is photo chemically broken up to form free chlorine atoms in great abundance, and the ozone-depleting reactions ensue.

Ozone depletion consists of two related events observed since the late 1970s: a steady lowering of about four percent in the total amount of ozone in Earth's atmosphere (the ozone layer), and a much larger springtime decrease in stratospheric ozone around Earth's polar regions. The latter phenomenon is referred to as the **ozone hole**. There are also springtime polar tropospheric ozone depletion events in addition to these stratospheric events.

The main cause of ozone depletion and the ozone hole is manufactured chemicals, especially manufactured halocarbon refrigerants, solvents, propellants and foam-blowing agents (chlorofluorocarbons (CFCs), HCFCs, halons), referred to as **ozone-depleting substances** (**ODS**). These compounds are transported into the stratosphere by turbulent mixing after being emitted from the surface, mixing much faster than the molecules can settle. Once in the stratosphere, they release halogen atoms through photodissociation, which catalyze the breakdown of ozone (O_3) into oxygen (O_2). Both types of ozone depletion were observed to increase as emissions of halocarbons increased.

Ozone depletion and the ozone hole have generated worldwide concern over increased cancer risks and other negative effects. The ozone layer prevents most harmful UV wavelengths of ultraviolet light (UV light) from passing through the Earth's atmosphere. These wavelengths cause skin cancer, sunburn and cataracts, which were projected to increase dramatically as a result of thinning ozone, as well as harming plants and animals. These concerns led to the adoption of the Montreal Protocol in 1987, which bans the production of CFCs, halons and other ozone-depleting chemicals.

Lecture #`65

Phase-out of CFCs

After research revealed the causes of stratospheric ozone depletion, worldwide agreements were reached to phase out the production of CFCs and other compounds that lead to ozone depletion. Manufacture of such compounds ceased in the United States in 1996, and there is now a great deal of public awareness about the importance of using “ozone-safe” alternative chemicals. The atmosphere will cleanse itself of ozone depleting compounds only slowly because the substances are chemically stable. Nonetheless, the problem of ozone depletion is diminishing and is expected to be substantially corrected by the second half of the 21st century.

The CFC story is an excellent example of how environmental problems arise and can be solved. Initially, CFCs were heralded as an efficient and cost-effective way to provide cooling, a clear improvement over previous technologies. At that time, their harmful consequences were unknown. Once the problems were identified, international agreements led to an effective solution, and creative technological advances led to replacements that solved the problem at little cost.

CFCs are unlikely to have any direct impact on the environment in the immediate vicinity of their release. As VOCs, they may be slightly involved in reactions to produce ground level ozone, which can cause damage to plants and materials on a local scale. At a global level however, releases of CFCs have serious environmental consequences. Their long lifetimes in the atmosphere mean that some end up in the higher atmosphere (stratosphere) where they can destroy the ozone layer, thus reducing the protection it offers the earth from the sun's harmful UV rays. CFCs also contribute to Global Warming (through "the Greenhouse Effect"). Although the amounts emitted are relatively small, they have a powerful warming effect (a very high "Global Warming Potential").

Chlorofluorocarbons enter the body primarily by inhalation of air containing chlorofluorocabons, but can also enter by ingestion of contaminated water, or by dermal contact with chlorofluorocarbons. Inhalation of high levels of chlorofluorocarbons can affect the lungs, central nervous system, heart, liver and kidneys. Symptoms of exposure to chlorofluorocarbons can include drowsiness, slurred speech, disorientation, tingling sensations and weakness in the limbs. Exposure to extremely high levels of chlorofluorocarbons can result in death. Ingestion of chlorofluorocarbons can lead to nausea, irritation of the digestive tract and diarrhoea. Dermal contact with chlorofluorocarbons can cause skin irritation and dermatitis. Chlorofluorocarbons are involved in the destruction of the stratospheric ozone layer resulting in increased exposure to UV radiation which is known to cause skin cancer. The International Agency for Research on Cancer has not designated chlorofluorocarbons as a group in terms of their carcinogenicity. The International Agency for Research on Cancer has designated chlorofluoromethane and chlorodifluoromethane as being not classifiable as to their carcinogenicity to humans. However, exposure to chlorofluorocarbons at normal background levels is unlikely to have any adverse effect on human health.

Lecture #`66

Global temperature change has affected ecosystems

Evidence for warming can be seen in many ways. For example, on a worldwide statistical basis, ice on lakes and rivers forms later and melts sooner than it used to; on average, ice-free seasons are now 2.5 weeks longer than they were a century ago. Also, the extent of ice at the North Pole has decreased substantially, and glaciers are retreating around the world.

Unchecked global warming could affect most terrestrial ecoregions. Increasing global temperature means that ecosystems will change; some species are being forced out of their habitats (possibly to extinction) because of changing conditions, while others are flourishing. Secondary effects of global warming, such as lessened snow cover, rising sea levels, and weather changes, may influence not only human activities but also the ecosystem.

For the IPCC Fourth Assessment Report, experts assessed the literature on the impacts of climate change on ecosystems. concluded that over the last three decades, human-induced warming had likely had a discernible influence on many physical and biological systems (p. 81). Schneider *et al*. (2007) concluded, with very high confidence, that regional temperature trends had already affected species and ecosystems around the world. With high confidence, they concluded that climate change would result in the extinction of many species and a reduction in the diversity of ecosystems.

- **Terrestrial ecosystems and biodiversity**: With a warming of 3 °C, relative to 1990 levels, it is likely that global terrestrial vegetation would become a net source of carbon (Schneider *et al*., 2007:792). With high confidence, Schneider *et al*. (2007:788) concluded that a global mean temperature increase of around 4 °C (above the 1990-2000 level) by 2100 would lead to major extinctions around the globe.
- **Marine ecosystems and biodiversity**: With very high confidence, Schneider *et al*. (2007:792) concluded that a warming of 2 °C above 1990 levels would result in mass mortality of coral reefs globally. In addition, several studies dealing with planktonic organisms and modelling have shown that temperature plays a transcendental role in marine microbial food webs, which may have a deep influence on the biological carbon pump of marine planktonic pelagic and mesopelagic ecosystems.
- **Freshwater ecosystems**: Above about a 4 °C increase in global mean temperature by 2100 (relative to 1990-2000), Schneider *et al*. (2007:789) concluded, with high confidence, that many freshwater species would become extinct

Figure 59.29 Disappearing glaciers. Mount Kilimanjaro in Tanzania in 1970 (*top*) and 2000 (*bottom*). Note the decrease in glacier coverage over three decades.

Lecture #`67

Global warming affects human populations as well

Global warming could affect human health and welfare in a variety of ways. Some of these changes may be beneficial, but even if they are detrimental, some countries—particularly the wealthier ones—will be able to adjust. But poorer countries may not be able to transform as quickly, and some changes will require extremely costly countermeasures that even wealthy countries will be hard-pressed to afford.

Climate change has brought about possibly permanent alterations to Earth's geological, biological and ecological systems. These changes have led to the emergence of large-scale environmental hazards to human health, such as extreme weather, ozone depletion, increased danger of wildland fires, loss of biodiversity, stresses to food-producing systems and the global spread of infectious diseases. In addition, climatic changes are estimated to cause over 150,000 deaths annually. To date, a neglected aspect of the climate change debate, much less research has been conducted on the impacts of climate change on health, food supply, economic growth, migration, security, societal change, and public goods, such as drinking water, than on the geophysical changes related to global warming. Human impacts can be both negative and positive. Climatic changes in Siberia, for instance, are expected to improve food production and local economic activity, at least in the short to medium term. Whereas, Bangladesh has experienced an increase in climate-sensitive diseases such as malaria, dengue, childhood diarrhea, and pneumonia, among vulnerable communities. Numerous studies suggest, however, that the current and future impacts of climate change on human society are and will continue to be overwhelmingly negative.

The majority of the adverse effects of climate change are experienced by poor and low-income communities around the world, who have much higher levels of vulnerability to environmental determinants of health, wealth and other factors, and much lower levels of capacity available for coping with environmental change. A report on the global human impact of climate change published by the Global Humanitarian Forum in 2009, estimated more than 300,000 deaths and about $125 billion in economic losses each year, and indicating that most climate change induced mortality is due to worsening floods and droughts in developing countries.

Lecture #`68

Rising sea levels

During the second half of the 20th century, sea level rose at 2 to 3 cm per decade. The U.S. Environmental Protection Agency predicts that sea level is likely to rise two or three times faster in the 21st century because of two effects of global warming: (1) the melting of polar ice and glaciers, adding water to the ocean, and (2) the increase of average ocean temperature, causing an increase in volume because water expands as it warms. Such an increase would cause increased erosion and inundation of low-lying land and coastal marshes, and other habitats would also be imperiled. As many as 200 million people would be affected by increased flooding. Should sea levels continue to rise, coastal cities and some entire islands, such as the Maldives in the Indian Ocean, would be in danger of becoming submerged.

As humans continue to pour greenhouse gases into the atmosphere, oceans have tempered the effect. The world's seas have absorbed more than 90 percent of the heat from these gases, but it’s taking a toll on our oceans: 2018 set a new record for ocean heating. Many people think of global warming and climate change as synonyms, but scientists prefer to use “climate change” when describing the complex shifts now affecting our planet’s weather and climate systems. Rising seas is one of those climate change effects. Average sea levels have swelled over 8 inches (about 23 cm) since 1880, with about three of those inches gained in the last 25 years. Every year, the sea rises another .13 inches (3.2 mm). The change in sea levels is linked to three primary factors, all induced by ongoing global climate change:

- **Thermal expansion:** When water heats up, it expands. About half of the sea-level rise over the past 25 years is attributable to warmer oceans simply occupying more space.
- **Melting glaciers:** Large ice formations such as mountain glaciers naturally melt a bit each summer. In the winter, snows, primarily from evaporated seawater, are generally sufficient to balance out the melting. Recently, though, persistently higher temperatures caused by global warming have led to greater-than-average summer melting as well as diminished snowfall due to later winters and earlier springs. That creates an imbalance between runoff and ocean evaporation, causing sea levels to rise.

- **Loss of Greenland and Antarctica's ice sheets:** As with mountain glaciers, increased heat is causing the massive ice sheets that cover Greenland and Antarctica to melt more quickly. Scientists also believe that meltwater from above and seawater from below is seeping beneath Greenland's ice sheets, effectively lubricating ice streams and causing them to move more quickly into the sea. While melting in West Antarctica has drawn considerable focus from scientists, especially with the 2017 break in the Larsen C ice shelf, glaciers in East Antarctica are also showing signs of destabilizing.
- When sea levels rise as rapidly as they have been, even a small increase can have devastating effects on coastal habitats farther inland, it can cause destructive erosion, wetland flooding, aquifer and agricultural soil contamination with salt, and lost habitat for fish, birds, and plants.
- Higher sea levels are coinciding with more dangerous hurricanes and typhoons that move more slowly and drop more rain, contributing to more powerful storm surges that can strip away everything in their path. One study found that between 1963 and 2012, almost half of all deaths from Atlantic hurricanes were caused by storm surges.
- Already, flooding in low-lying coastal areas is forcing people to migrate to higher ground, and millions more are vulnerable from flood risk and other climate change effects. The prospect of higher coastal water levels threatens basic services such as Internet access, since much of the underlying communications infrastructure lies in the path of rising seas.

Lecture #`68

Effects on agriculture

Global warming may have both positive and negative effects on agriculture. On the positive side, warmer temperatures and increased atmospheric carbon dioxide tend to increase growth of some crops and thus may increase agricultural yields. Other crops, however, may be negatively affected. Furthermore, most crops will be affected by increased frequencies of droughts. Moreover, although crops in north temperate regions may flourish with higher temperatures, many tropical crops are already growing at their maximal temperatures, so increased temperatures may lead to reduced crop yields. Also on the negative side, changes in rainfall patterns, temperature, pest distributions, and various other factors will require many adjustments. Such changes may come relatively easily for farmers in the developed world, but the associated costs may be devastating for those in the developing countries.

For any particular crop, the effect of increased temperature will depend on the crop's optimal temperature for growth and reproduction. In some areas, warming may benefit the types of crops that are typically planted there, or allow farmers to shift to crops that are currently grown in warmer areas. Conversely, if the higher temperature exceeds a crop's optimum temperature, yields will decline.

- Higher CO_2 levels can affect crop yields. Some laboratory experiments suggest that elevated CO_2 levels can increase plant growth. However, other factors, such as changing temperatures, ozone, and water and nutrient constraints, may counteract these potential increases in yield. For example, if temperature exceeds a crop's optimal level, if sufficient water and nutrients are not available, yield increases may be reduced or reversed. Elevated CO_2 has been associated with reduced protein and nitrogen content in alfalfa and soybean plants, resulting in a loss of quality. Reduced grain and forage quality can reduce the ability of pasture and rangeland to support grazing livestock.
- More extreme temperature and precipitation can prevent crops from growing. Extreme events, especially floods and droughts, can harm crops and reduce yields. For example, in 2010 and 2012, high nighttime temperatures affected corn yields across the U.S. Corn Belt, and premature budding due to a warm winter caused $220 million in losses of Michigan cherries in 2012.
- Dealing with drought could become a challenge in areas where rising summer temperatures cause soils to become drier. Although increased irrigation might be possible in some places, in other places water supplies may also be reduced, leaving less water available for irrigation when more is needed.
- Many weeds, pests, and fungi thrive under warmer temperatures, wetter climates, and increased CO_2 levels. Currently, U.S. farmers spend more than $11 billion per year to fight weeds, which compete with crops for light, water, and nutrients.The ranges and distribution of weeds and pests are likely to increase with climate change. This could cause new problems for farmers' crops previously unexposed to these species.
- Though rising CO_2 can stimulate plant growth, it also reduces the nutritional value of most food crops. Rising levels of atmospheric carbon dioxide reduce the concentrations of protein and essential minerals in most plant species, including wheat, soybeans, and rice. This direct effect of rising CO_2 on the nutritional value of crops represents a potential threat to human health. Human health is also threatened by increased pesticide use due to increased pest pressures and reductions in the efficacy of pesticides.

Lecture #`68

Effects on human health

Increasingly frequent storms, flooding, and drought will have adverse consequences on human health. Aside from their direct effect, such events often disrupt the fragile infrastructure of developing countries, leading to the loss of safe drinking water and other problems. As a result, epidemics of cholera and other diseases may be expected to occur more often. In addition, as temperatures rise, areas suitable for tropical organisms will expand northward. Of particular concern are those organisms that cause human diseases.

Many diseases currently limited to tropical areas may expand their range and become problematic in no tropical countries. Diseases transmitted by mosquitoes, such as malaria, dengue fever, and several types of encephalitis, are examples. The distribution of mosquitoes is limited by cold; winter freezes kill many mosquitoes and their eggs. As a result, malaria only occurs in areas where temperatures are usually above 16°C, and yellow fever and dengue fever, transmitted by a different mosquito species from malaria, occur in areas where temperatures are normally above 10°C. Moreover, at higher temperatures, the malaria pathogen matures more rapidly.

Malaria already kills 1 million people every year; some projections suggest that the percentage of the human population at risk for malaria may increase by 33% by the end of the 21st century. Moreover, as predicted, malaria already appears to be on the move. By 1980, malaria had been eradicated from all of the United States except California, but in recent years it has appeared in a variety of southern, and even a few northern, states. Dengue fever (sometimes called "breakbone fever" because of the pain it causes) is also spreading. Previously a disease restricted to the tropics and subtropics, where it infects 50 to 100 million people a year, it now occurs in the United States, southern South America, and northern Australia. One of the most alarming aspects of these diseases is that no vaccines are available. Drug treatment is available (for malaria), but the parasites are rapidly evolving resistance and rendering the drugs ineffective. There is no drug treatment for dengue fever.

Lecture #`69

Biological magnification

When wastes and poisons enter food webs, organisms at the highest trophic levels usually suffer the most. Tiny amounts of a toxin incorporated into primary production can quickly build up as carnivores feed on herbivores that have concentrated toxins in their tissues. This problem is especially severe when the material is not biodegradable (not broken down by biological processes). The accumulation of matter in food webs is called biological magnification.

Bio-magnification, also known as bio-amplification or biological magnification, is the increasing concentration of a substance, such as a toxic chemical, in the tissues of tolerant organisms at successively higher levels in a food chain. This increase can occur as a result of:

- Persistence – where the substance cannot be broken down by environmental processes
- Food chain energetics – where the substance's concentration increases progressively as it moves up a food chain
- Low or non-existent rate of internal degradation or excretion of the substance – mainly due to water-insolubility

Bio-magnification is the buildup of toxins in a food chain. The DDT concentration is in parts per million. As the trophic level increases in a food chain, the amount of toxic build up increases. The x's represent the amount of toxic build up accumulating as the trophic level increases. Toxins build up in organism's fat and tissue. Predators accumulate higher toxins than prey.

Biological magnification often refers to the process whereby certain substances such as pesticides or heavy metals work their way into lakes, rivers and the ocean, and then move up the food chain in progressively greater concentrations as they are incorporated into the diet of aquatic organisms such as zooplankton, which in turn are eaten perhaps by fish, which then may be eaten by bigger fish, large birds, animals, or humans. The substances become increasingly concentrated in tissues or internal organs as they move up the chain. Bio-accumulates are substances that increase in concentration in living organisms as they take in contaminated air, water, or food because the substances are very slowly metabolized or excreted.

Lecture #`70

Types of Waste Water & Impacts on Environment

Types of Waste Water

1. Domestic or sanitary wastewater. This comes from residential sources including toilets, sinks, bathing, and laundry. It can contain body wastes containing intestinal disease organisms.

2. Industrial wastewater. This is discharged by manufacturing processes and commercial enterprises. Process wastewater can contain rinse waters including such things as residual acids, plating metals, and toxic chemicals.

Impacts on Environment

Production sites are commonly located near bodies of water due to industrial dependence on large amounts of water as an input. Many areas that are becoming industrialized do not yet have the resources or technology to dispose of waste with lesser effects on the environment. Both untreated and partially treated wastewater is commonly fed back into a near lying body of water. Metals, chemicals and sewage released into bodies of water directly affect marine ecosystems and the health of those who depend on the waters as food or drinking water sources. Toxins from the wastewater can kill off marine life or cause varying degrees of illness to those who consume these marine animals, depending on the contaminant. Metals and chemicals released into bodies of water affect the marine ecosystems. Wastewater containing nitrates and phosphates often causes Eutrophication which can kill off existing life in the water

Lecture #`72

Types of Treatment of waste water

Rural un-sewered areas, for the most part, use septic systems. In these, a large tank, known as the septic tank, settles out and stores solids, which are partially decomposed by naturally occurring anaerobic bacteria. The solids have to be pumped out and hauled by tank truck to be disposed of separately. They often go to municipal wastewater treatment plants or are reused as fertilizer in closely regulated land-application programs. Liquid wastes are dispersed through perforated pipes into soil fields around the septic tank. Most urban areas with sewers first used a process called primary treatment, which was later upgraded to secondary treatment. Some areas, where needed, employ advanced or tertiary treatment. Common treatment schemes are presented in the following paragraphs.

Primary treatment. In primary treatment, floating and suspended solids are settled and removed from sewage. Flow from the sewers enters a screen/bar rack to remove large, floating material such as rags and sticks. It then flows through a grit chamber where heavier inorganics such as sand and small stones are removed. Grit removal is usually followed by a sedimentation tank/clarifiers where inorganic and organic suspended solids are settled out. To kill pathogenic bacteria, the final effluent from the treatment process is disinfected prior to discharge to receiving water.

Chlorine, in the form of a sodium hypochlorite solution, is normally used for disinfection. Since more chlorine is needed to provide adequate bacteria kill than would be safe for aquatic life in the stream, excess chlorine is removed by DE chlorination. Alternate 2 disinfection methods, such as ozone or ultraviolet light, are utilized by some treatment plants. Sludge that settles to the bottom of the clarifier is pumped out and dewatered for use as fertilizer, disposed of in a landfill, or incinerated. Sludge that is free of heavy metals and other toxic contaminants is called Bio solids and can be safely and beneficially recycled as fertilizer, for example.

Secondary treatment, a biological process, removes 85 percent or more of the organic matter in sewage compared with primary treatment, which removes about 50 percent. The basic processes are variations of what is called the "activated sludge" process or "trickling filters," which provide a mechanism for bacteria, with air added for oxygen, to come in contact with the wastewater to purify it. In the activated sludge process, flow from the sewer or primary clarifiers goes into an aeration tank, where compressed air is mixed with sludge that is recycled from secondary clarifiers which follow the aeration tanks. The recycled, or activated, sludge provides bacteria to consume the "food" provided by the new wastewater in the aeration tank, thus purifying it. In a trickling filter the flow trickles over a bed of stones or synthetic media on which the purifying organisms grow and contact the wastewater, removing contaminants in the process.

The flow, along with excess organisms that build up on the stones or media during the purification, then goes to a secondary clarifier. Air flows up through the media in the filters, to provide necessary oxygen for the bacteria organisms. Clarified effluent flows to the receiving water, typically a river or bog, after disinfection. Excess sludge is produced by the process and after collection from the bottom of the secondary clarifiers it is dewatered, sometimes after mixing with primary sludge, for use as fertilizer, disposed of in a landfill, or incinerated.

Lecture #`73

Industrial Waste Treatment

Depending on the type of industry and the nature of its wastes, industries must utilize methods such as those used for advanced treatment of sewage to purify wastewater containing pollutants such as heavy metals and toxic chemicals before it can be discharged. Industries are permitted to discharge directly to receiving waters under the National Pollution Discharge Elimination System (NPDES) permit system or to municipal sewers under the Industrial Pretreatment Program. Pollution prevention programs are very effective in helping industries reduce discharged pollutants, by eliminating them at the source through recycling or through the substitution of safer materials. More and more industries are approaching or attaining zero discharge by cleaning and reusing their water over and over and over.

Process water re-use

By recycling water within a closed industrial wastewater treatment system, companies can achieve savings by feeding less clean water into a plant, and can reduce carbon and other pollutants entering the environment. Industrial wastewater treatment and re-use also help to free up potable water for distribution to communities.

Industrial process water from seawater

With industry-leading desalination techniques, Veolia can turn high-salinity seawater into suitable for use in industrial processes. It is a well-established process of removing salts from water to produce process water using technologies like reverse osmosis, multiple effect distillation, multi-stage flash and hybrid systems that use thermal and reverse osmosis

Industrial wastewater treatment for human consumption

Cutting-edge technologies are able to transform industrial wastewater into a fresh water resource for human consumption through various water purification technologies. Veolia uses leading water purification technologies and, worldwide, Veolia's global company has built more than 5 000 water purification plants.

Value recovery from industrial wastewater

Industrial wastewater treatment technologies are able to extract valuable substances from process water before discharge or re-use within a plant, achieving greater sustainability and lower carbon footprints. By acting sustainably, customers recognize the value of water, help to save energy and produce it, and optimise costs. Reducing your carbon footprint helps create responsible value and a whole lot more.

Lecture #`74

Process of preserving endangered species

Once the cause of a species' endangerment is known, it becomes possible to design a recovery plan. If the cause is commercial overharvesting, regulations can be issued to restrict harvesting and protect the threatened species. If the cause is habitat loss, plans can be instituted to restore the habitat. Loss of genetic variability in isolated subpopulations can be countered by transplanting individuals from genetically different populations. Populations in immediate danger of extinction can be captured, introduced into a captive-breeding program, and later reintroduced to other suitable habitat.

All of these solutions are extremely expensive. But as Bruce Babbitt, Secretary of the Interior in the Clinton administration, noted, it is much more economical to prevent "environmental trainwrecks" from occurring than to clean them up afterward. Preserving ecosystems and monitoring species before they are threatened is the most effective means of protecting the environment and preventing extinctions.

Although it is in principle possible to reestablish each of the original species in their original proportions, rebuilding a community requires knowing the identities of all the original inhabitants and the ecologies of each of the species. We rarely have this much information, so no restoration is ever truly pristine. Increasingly, restoration biologists are working on restoring the functioning of an ecosystem, rather than trying to recreate the same community composition. This approach shifts the focus from restoring species to reconstructing the processes that operated in the natural habitat.

Removing introduced species

Sometimes the habitat has been destroyed by a single introduced species. In such a case, habitat restoration involves removing the introduced species. Restoration of the once-diverse cichlid fishes to Lake Victoria will require more than breeding and restocking the endangered species. The introduced water hyacinth and Nile perch populations will have to be brought under control or removed, and eutrophication will have to be reversed. It is important to act quickly if an introduced species is to be removed. When aggressive African bees (the so-called "killer bees") were inadvertently released in Brazil.

Cleanup and rehabilitation

Habitats seriously degraded by chemical pollution cannot be restored until the pollution is cleaned up. The successful restoration of the Nashua River in New England is one example of how a concerted effort can succeed in restoring a heavily polluted habitat to a relatively pristine condition. Once so heavily polluted by chemicals from dye manufacturing plants that it was different colors in different places, the river is now clean and used for many recreational activities.

Lecture #`75

Evolution

Organic evolution, according to Charles Darwin, is "descent with modification." This simply means that species change over time. Evolution by itself does not imply any particular lineage or any particular mechanism, and virtually all scientists agree that the evidence for change in organisms over long time periods is overwhelming. Further, most scientists agree that natural selection, the mechanism for evolution that Charles Darwin outlined, is one explanation of how evolution occurs. In spite of the scientific certainty of evolution and an acceptance of a general mechanism, much is still to be learned about the details of evolutionary processes. Scientists will be debating these details for years to come.

Divergent Evolution

When people hear the word "evolution," they most commonly think of divergent evolution, the evolutionary pattern in which two species gradually become increasingly different. This type of evolution often occurs when closely related species diversify to new habitats. On a large scale, divergent evolution is responsible for the creation of the current diversity of life on earth from the first living cells. On a smaller scale, it is responsible for the evolution of humans and apes from a common primate ancestor.

Convergent Evolution

Convergent evolution causes difficulties in fields of study such as comparative anatomy. Convergent evolution takes place when species of different ancestry begin to share analogous traits because of a shared environment or other selection pressure. For example, whales and fish have some similar characteristics since both had to evolve methods of moving through the same medium: water.

Parallel Evolution

Parallel evolution occurs when two species evolve independently of each other, maintaining the same level of similarity. Parallel evolution usually occurs between unrelated species that do not occupy the same or similar niches in a given habitat.

Lecture #`76

Biogeography

Biogeography is the study of the geographic distribution of plants and animals. Bio-geographers try to explain why organisms are distributed as they are. Biogeographic studies show that life-forms in different parts of the world have distinctive evolutionary histories. One of the distribution patterns that bio geographers try to explain is how similar groups of organisms can live in places separated by seemingly impenetrable barriers. For example, native cats are inhabitants of most continents of the earth, yet they cannot cross expanses of open oceans. Obvious similarities suggest a common ancestry, but similarly obvious differences result from millions of years of independent evolution. Bio geographers also try to explain why plants and animals, separated by geographical barriers, are often very different in spite of similar environments.

Ecological Biogeography

Ecological biogeography looks at the current factors responsible for the distribution of plants and animals, and the most common fields of research within ecological biogeography are climatic equability, primary productivity, and habitat heterogeneity. Climatic equability looks at the variation between daily and annual temperatures as it is harder to survive in areas with high variation between day and night and seasonal temperatures. Because of this, there are fewer species at high latitudes because more adaptations are needed to be able to survive there. In contrast, the tropics have a steadier climate with fewer variations in temperature. This means plants do not need to spend their energy on being dormant and then regenerating their leaves or flowers, they don't need a flowering season, and they do not need to adapt to extreme hot or cold conditions.

Primary productivity looks at the evapotranspiration rates of plants. Where evapotranspiration is high and so is plant growth. Therefore, areas like the tropics that are warm and moist foster plant transpiration allowing more plants to grow there. In high latitudes, it is simply too cold for the atmosphere to hold enough water vapor to produce high rates of evapotranspiration and there are fewer plants present.

Conservation Biogeography

In recent years, scientists and nature enthusiasts alike have further expanded the field of biogeography to include conservation biogeography—the protection or restoration of nature and its flora and fauna, whose devastation is often caused by human interference in the natural cycle. Scientists in the field of conservation biogeography study ways in which humans can help restore the natural order of plant and animal life in a region. Often times this includes reintegration of species into areas zoned for commercial and residential use by establishing public parks and nature preserves at the edges of cities. Biogeography is important as a branch of geography that sheds light on the natural habitats around the world. It is also essential in understanding why species are in their present locations and in developing protecting the world's natural habitats.

Lecture #`77

Paleontology

Paleontology (Gr. *palaios,* old on, existing logos, to study), which is the study of the fossil record, provides some of the most direct evidence for evolution. **Fossils** (L. *fossilis,* to dig) are evidence of plants and animals that existed in the past and have become incorporated into the earth's crust (e.g., as rock or mineral) For fossilization to occur, sediments must quickly cover an organism to prevent scavenging and in a way that seals out oxygen and slows decomposition. Fossilization is most likely to occur in aquatic or semiaquatic environments. The fossil record is, therefore, more complete for those groups of organisms living in or around water and for organisms with hard parts. This documentation provides some of the most convincing evidence for evolution. In spite of gaps in the fossil record, paleontology has resulted in nearly complete understanding of many evolutionary lineages. Paleontologists estimate that the earth is about 4.6 billion years old. They have also used the fossil record to describe the history of life on the earth.

Paleontology has played a key role in reconstructing Earth's history and has provided much evidence to support the theory of evolution. Data from paleontological studies, moreover, have aided petroleum geologists in locating deposits of oil and natural gas. The occurrence of such fossil fuels is frequently associated with the presence of the remains of certain ancient life-forms. Paleontological research dates back to the early 1800s. In 1815 the English geologist William Smith demonstrated the value of using fossils for the study of strata. About the same time, the French zoologist Georges Cuvier initiated comparative studies of the structure of living animals with fossil remains.

Lecture #`78

Comparative anatomy

A structure in one animal may resemble a structure in another animal because of a common evolutionary origin. **Comparative anatomy** is the sub discipline of zoology that is fundamentally based on this relationship. Comparative anatomists study the structure of fossilized and living animals, looking for similarities that could indicate evolutionarily close relationships. Structures derived from common ancestry are **homologous** (Gr. *homologos*, agreeing) (i.e., having the same or a similar relation). Some examples of homology are obvious. For example, vertebrate appendages have a common arrangement of similar bones, even though the function of the appendages may vary. Along with other evidence, this similarity in appendage structure indicates that the vertebrates evolved from a common ancestor.

<u>Homologous and Analogous Traits</u>

A major problem in determining evolutionary relationships based on comparative anatomy can be seen when we look at a commonly found structure: the wing. Wings are present in a number of very different groups of organisms. Birds, bats and insects all have wings, but what does this say about how closely related the three groups are? It is tempting to say that the three groups must have had a common winged ancestor. However, were you actually to take the bait and say it, you would be wrong. Dead wrong. The wings of bats and birds are both derived from the forelimb of a common, probably wingless, ancestor. Both have wings with bone structures similar to the forelimbs of ancestral and current tetrapod, or four-legged, animals. Such traits that are derived from a trait found in a common ancestor are called homologous traits. Structurally speaking, though, the wings of bats and birds have little in common with those of insects. Bird wings and insect wings are an analogous trait, or a trait that has developed independently in two groups of organisms from unrelated ancestral traits.

Embryology

Another difficulty in comparing traits between species rests on the fact that homologous structures not present in the adult organism often do appear in some stage of embryonic development. In this way, the embryo serves as a microcosm for evolution, passing through many of the stages of evolution to produce the current state of the organism. Species that bear little resemblance in their adult form may have strikingly similar embryonic stages. For example, in humans, the embryo passes through a stage in which it has gill structures like those of the fish from which all terrestrial animals evolved. For a large portion of its development the human embryo also possesses a tail, much like those of our close primate relatives. This tail is usually reabsorbed before birth, but occasionally children are born with the ancestral structure intact. Tails and even gills could be considered homologous traits between humans and primates or humans and fish, even though they are not present in the adult organism.

Lecture #`79

Molecular Biology

Recently, molecular biology has yielded a wealth of information on evolutionary relationships. Just as animals can have homologous structures, animals may also have homologous biochemical processes. Ultimately, structure and function are based on the genetic blueprint found in all living animals: the DNA molecule. Related animals have similar DNA derived from their common ancestor. Because DNA carries the codes for proteins that make up each animal, related animals have similar proteins. With the modern laboratory technologies now available, zoologists can extract and analyze the structure of proteins from animal tissue, and compare the DNA of different animals. By looking for dissimilarities in the structure of related proteins and DNA, and by assuming relatively constant mutation rates, molecular biologists can estimate the elapsed time since divergence from a common ancestral molecule.

The field overlaps with other areas of biology and chemistry, particularly genetics and biochemistry. Molecular biology chiefly concerns itself with understanding the interactions between the various systems of a cell, including the interrelationship of DNA, RNA and protein synthesis and learning how these interactions are regulated. Researchers in molecular biology use specific techniques native to molecular biology, but increasingly combine these with techniques and ideas from genetics and biochemistry. There is not a hard-line between these disciplines as there once was.

Molecular biology is the study of molecular underpinnings of the process of replication, transcription and translation of the genetic material. The central dogma of molecular biology where genetic material is transcribed into RNA and then translated into protein, despite being an oversimplified picture of molecular biology, still provides a good starting point for understanding the field. Much of the work in molecular biology is quantitative, and recently much work has been done at the interface of molecular biology and computer science in bioinformatics and computational biology. As of the early 2000s, the study of gene structure and function, molecular genetics, has been amongst the most prominent sub-field of molecular biology.

Lecture #`80

Lamarckism

Jean Baptiste Lamarck (1744–1829) was a distinguished French zoologist. His contributions to zoology include important studies of animal classification. Lamarck, however, is remembered more for a theory of how change occurs. He believed that species are not constant and that existing species were derived from preexisting species. Lamarck's rather elaborate explanation for evolutionary change involved a theory that was widely accepted in the early 1800s called the **theory of inheritance of acquired characteristics.** Lamarck believed that organisms develop new organs or modify existing organs as environmental problems present themselves. In other words, organs change as the need arises.

Lamarck illustrated this point with the often-quoted example of the giraffe. He contended that ancestral giraffes had short necks, much like those of any other mammal. Straining to reach higher branches during browsing resulted in their acquiring higher shoulders and longer necks. These modifications, produced in one generation, were passed on to the next generation. Lamarck went on to state that the use of any organ resulted in that organ becoming highly developed and that disuse resulted in degeneration. Thus, the evolution of highly specialized structures, such as vertebrate eyes, could be explained. Lamarck published his theory in 1802 and defended it in the face of social and scientific criticism. Society in general was unaccepting of the ideas of evolutionary change, and evidence for evolution had not been developed thoroughly enough to convince most scientists.

Thus, Lamarck was criticized in his day more for advocating ideas of evolutionary change than for the mechanism he proposed for that change. Today, he is criticized for defending a mechanism of inheritance and evolutionary change that is now known to lack reasonable supporting evidence. For a change to be passed on to the next generation, it must be carried by gametes. Changes in the giraffes' necks, as envisioned by Lamarck, could not be passed on because they did not originate as changes in the genetic material. Even though Lamarck's mechanism of change was incorrect, he should be remembered for his steadfastness in promoting the idea of evolutionary change and for his other accomplishments in zoology

Lecture # 81

`Darwin's early years and his journey; voyage of the HMS beagle

Charles Robert Darwin (1809–1882) was born on February 12, 1809. His father, like his grandfather, was a physician. During Darwin's youth in Shrewsbury, England, his interests centered on dogs, collecting, and hunting birds—all popular pastimes in wealthy families of nineteenth-century England. These activities captivated him far more than the traditional education he received at boarding school. At the age of 16 (1825), he entered medical school in Edinburgh, Scotland. For two years, he enjoyed the company of the school's well-established scientists.

Darwin, however, was not interested in a career in medicine because he could not bear the sight of pain. This prompted his father to suggest that he train for the clergy in the Church of England. With this in mind, Charles enrolled at Christ's College in Cambridge and graduated with honors in 1831. This training, like the medical training he received, was disappointing for Darwin. Again, his most memorable experiences were those with Cambridge scientists. During his stay at Cambridge, Darwin developed a keen interest in collecting beetles and made valuable contributions to beetle taxonomy.

Voyage of the HMS beagle

One of his Cambridge mentors, a botanist by the name of John S. Henslow, nominated Darwin to serve as a naturalist on a mapping expedition that was to travel around the world. Darwin was commissioned as a naturalist on the HMS Beagle, which set sail on December 27, 1831 on a 5-year voyage. Darwin helped with routine seafaring tasks and made numerous collections which he sent to Cambridge. The voyage gave him ample opportunity to explore tropical rain forests, fossil beds, the volcanic peaks of South America, and the coral atolls of the South-pacific**.** . Most importantly, Darwin spent 5 weeks on the Galápagos Islands, a group of volcanic islands 900 km off the coast of Ecuador. Some of his most revolutionary ideas came from his observations of plant and animal life on these islands. At the end of the voyage, Darwin was just 27 years old. He spent the rest of his life examining specimens, rereading notes, making new observations, and preparing numerous publications. His most important publication, On the Origin of Species by Means of Natural Selection, was published in 1859 and revolutionized biology.

Early development of Darwin's ideas of evolution

The development of Darwin's theory of evolution by natural selection was a long, painstaking process. Darwin had to become convinced that change occurs over time. Before leaving on his voyage, Darwin accepted the prevailing opinion that the earth and its inhabitants had been created 6,000 years ago and had not changed since. Because his observations during his voyage suggested that change does occur, he realized that 6,000 years could not account for the diversity of modern species if they arose through gradual change. Once ideas of change were established in Darwin's thinking, it took about 20 years of study to conceive, and thoroughly document, the mechanism by which change occurs.

Darwin died without knowing the genetic principles that support his theory.

Lecture #`82

Alfred Russel Wallace

Alfred Russel Wallace (1823–1913) was an explorer of the Amazon Valley and led a zoological expedition to the Malay Archipelago, which is an area of great biogeographical importance. Wallace, like Darwin, was impressed with evolutionary change and had read the writings of Thomas Malthus on human populations. In the midst of a bout with malarial fever, he synthesized a theory of evolution similar to Darwin's theory of evolution by natural selection. After writing the details of his theory, Wallace sent his paper to Darwin for criticism. Darwin recognized the similarity of Wallace's ideas and prepared a short summary of his own theory. Both Wallace's and Darwin's papers were published in the *Journal of the Proceedings of the Linnean Society* in 1859.

Darwin's insistence on having Wallace's ideas presented along with his own shows Darwin's integrity. Darwin then shortened a manuscript he had been working on since 1856 and published it as *On the Origin of Species by Means of Natural Selection* in November 1859. The 1,250 copies prepared in the first printing sold out the day the book was released. In spite of the similarities in the theories of Wallace and Darwin, there were also important differences. Wallace, for example, believed that every evolutionary modification was a product of selection and, therefore, had to be adaptive for the organism.

Darwin, on the other hand, admitted that natural selection may not explain all evolutionary changes. He did not insist on finding adaptive significance for every modification. Further, unlike Darwin, Wallace stopped short of attributing human intellectual functions and the ability to make moral judgments to evolution. On both of these matters, Darwin's ideas are closer to the views of most modern scientists. Wallace's work motivated Darwin to publish his own ideas. The theory of natural selection, however, is usually credited to Charles Darwin. Darwin's years of work and massive accumulations of evidence led even Wallace to attribute the theory to Darwin. Wallace wrote to Darwin in 1864: I shall always maintain the theory of evolution by natural selection] to be actually yours and yours only. You had worked it out in details I had never thought of years before I had a ray of light on the subject.

Lecture #`82 - 84

Geology

Darwin began his voyage by reading Charles Lyell's (1779–1875) Principles of Geology. In this book, Lyell developed the ideas of another geologist, James Hutton, into the theory of uniformitarianism. His theory was based on the idea that the forces of wind, rain, rivers, volcanoes, and geological uplift shape the earth today, just as they have in the past. Lyell and Hutton contended that it was these forces, not catastrophic events, that shaped the face of the earth over hundreds of millions of years. This book planted two important ideas in Darwin's mind:

(1) the earth could be much older than 6,000 years

(2) if the face of the earth changed gradually over long periods, could not living forms also change during that time

Geologists study Earth processes: Many processes such as **landslides**, **earthquakes**, floods, and **volcanic eruptions** can be hazardous to people. Geologists work to understand these processes well enough to avoid building important structures where they might be damaged. If geologists can prepare maps of areas that have flooded in the past, they can prepare maps of areas that might be flooded in the future. These maps can be used to guide the development of communities and determine where flood protection or flood insurance is needed.

Geologists study Earth materials: People use Earth materials every day. They use **oil** that is produced from wells, **metals** that are produced from mines, and water that has been drawn from streams or from underground. Geologists conduct studies that locate **rocks** that contain important metals, plan the mines that produce them and the methods used to remove the metals from the rocks. They do similar work to locate and produce oil, natural gas, and groundwater.

Geologists study Earth history: Today we are concerned about climate change. Many geologists are working to learn about the past climates of Earth and how they have changed across time. This historical geology news information is valuable to understand how our current climate is changing and what the results might be.

Lecture #`82 - 84

Fossil evidence

Once the HMS *Beagle* reached South America, Darwin spent time digging in the dry riverbeds of the pampas (grassy plains) of Argentina. He found the fossil remains of an extinct hippopotamus like animal, now called *Toxodon,* and fossils of a horse like animal, *Thoantherium.* Both of these fossils were from animals that were clearly different from any other animal living in the region. Modern horses were in South America, of course, but Spanish explorers had brought these horses to the Americas in the 1500s. The fossils suggested that horses had been present and had become extinct long before the 1500s. Darwin also found fossils of giant armadillos and giant sloths. Except for their large size, these fossils were very similar to forms Darwin found living in the region. Fossils were not new to Darwin. They were popularly believed to be the remains of animals that perished in catastrophic events, such as Noah's flood. In South America, however, Darwin understood them to be evidence that the species composition of the earth had changed.

Types of Fossil Evidence

Why are there so few fossils relative to the number of species that have existed? It is most likely because organisms decompose before they have a chance to become fossilized. Only those organisms that are quickly buried in sediment after their death become preserved.

There are numerous types of fossil evidence that have been left behind by organisms. Some of the types of fossil evidence commonly used by scientists include trace fossils, molds and casts, replacement fossils, petrified fossils, amber and original material fossils.

A **trace fossil** is any indirect evidence left by an organisms. Examples of trace fossils include footprints, burrows and fossilized feces that have been left behind by organisms. They simply leave material evidence that the organisms existed rather than evidence of the actual structure of the organism.

Molds and casts are also important fossil evidence. **Molds** are impressions of entire organisms that have been left behind. **Casts** are molds that have been filled with sediment over time.

Lecture # 82 - 84

`Galapagos Islands

On its trip up the western shore of South America, the HMS *Beagle* stopped at the Galápagos Islands, which are named after the large tortoises that inhabit them (Sp. *Galapagos,* tortoise). The tortoises weigh up to 250 kg, have shells up to 1.8 m in diameter, and live for 200 to 250 years. The islands' governor pointed out to Darwin that the shapes of the tortoise shells from different parts of Albemarle Island differed. Darwin noticed other differences as well. Tortoises from the drier regions had longer necks than tortoises from wetter habitats. In spite of their differences, the tortoises were quite similar to each other and to the tortoises on the mainland of South

America. Darwin reasoned that the island forms were derived from a few ancestral animals that managed to travel from the mainland, across 900 km of ocean.

Because the Galápagos Islands are volcanic and arose out of the seabed, no land connection with the mainland ever existed. One modern hypothesis is that tortoises floated from the mainland on mats of vegetation that regularly break free from coastal riverbanks during storms. Without predators on the islands, tortoises gradually increased in number. Darwin also explained some of the differences that he saw. In dryer regions, where vegetation was sparse, tortoises with longer necks would be favored because they could reach higher to get food. In moister regions, tortoises with longer necks would not necessarily be favored, and the shorter-necked tortoises could survive. Darwin made similar observations of a group of dark, sparrow like birds.

Although he never studied them in detail, Darwin noticed that the Galápagos finches bore similarities suggestive of common ancestry. Scientists now think that Galápagos finches also descended from an ancestral species that originally inhabited the mainland of South America. The chance arrival of a few finches, in either single or multiple colonization events, probably set up the first bird populations on the islands. Early finches encountered many different habitats, all empty of other birds and predators. Ancestral finches, probably seed eaters, multiplied rapidly and filled the seed-bearing habitats most attractive to them. Fourteen species of finches arose from this ancestral group, including one species found on small Cocos Island northeast of the Galápagos Islands. Each species is adapted to a specific habitat on the islands.

Lecture #`85

Theory of Natural selection; First Postulate

All organisms have a far greater reproductive potential than is ever realized. For example, a female oyster releases about 100,000 eggs with each spawning, a female sea star releases about 1 million eggs each season, and a female robin may lay four fertile eggs each season. What if all of these eggs were fertilized and developed to reproductive adults by the following year? A half million female sea stars (half of the million eggs would produce females and half would produce males), each producing another million eggs, repeated over just a few generations would soon fill up the oceans! Even the adult female robins, each producing four more robins, would result in unimaginable resource problems in just a few years.

Lecture #`86

Theory of Natural selection; Second Postulate

2. Inherited variations arise by random mutation. Seldom are any two individuals exactly alike. Some of these genetic variations may confer an advantage to the individual possessing them. In other instances, variations may be harmful to an individual. In still other instances, particular variations may be neither helpful nor harmful. (These are said to be neutral.) These variations can be passed on to offspring.

Lecture #`87

Theory of Natural selection; Third Postulate

3. Because resources are limited, existence is a constant struggle. Many more offspring are produced than resources can support; therefore, many individuals die. Darwin reasoned that the individuals that die are those with the traits (variations) that make survival and successful reproduction less likely. Traits that promote successful reproduction are said to be adaptive

Lecture #`87

Theory of Natural selection; Fourth Postulate

4. Adaptive traits are perpetuated in subsequent generations. Because organisms with maladaptive traits are less likely to reproduce, the maladaptive traits become less frequent in a population and eventually are eliminated

Lecture #`87

Natural selection reexamined

The theory of natural selection remains preeminent in modern biology. Natural selection occurs whenever some phenotypes are more successful at leaving offspring than other phenotypes. The tendency for natural selection to occur—and upset Hardy-Weinberg equilibrium—is selection pressure. Natural selection acts on the phenotype, the characteristics of the organism which actually interact with the environment, but the genetic (heritable) basis of any phenotype that gives that phenotype a reproductive advantage may become more common in a population. Over time, this process can result in populations that specialise for particular ecological niches (microevolution) and may eventually result in speciation (the emergence of new species, macroevolution). In other words, natural selection is a key process in the evolution of a population.

Lecture #`88

Adaptation

Adaptation occurs when a change in a phenotype increases an animal's chance of successful reproduction. It is likely to be expressed when an organism encounters a new environment and may result in the evolution of multiple new groups if an environment can be exploited in different ways. No terms in evolution have been more laden with confusion than adaptation and fitness. Adaptation is sometimes used to refer to a process of change in evolution. That use of the term is probably less confusing than when it is used to describe the result of the process of change. In this text, adaptations are defined as characteristics that increase the potential of an organism or species to successfully reproduce in a specified environment.

Lecture #`89

Population size, genetic drift, and neutral selection

Chance often plays an important role in the perpetuation of genes in a population, and the smaller the population, the more significant chance may be. Fortuitous circumstances, such as a chance encounter between reproductive individuals, may promote reproduction. Some traits of a population survive, not because they convey increased fitness, but because they happen to be in gametes involved in fertilization. Chance events influencing the frequencies of genes in populations result in **genetic drift.**

Because gene frequencies are changing independently of natural selection, genetic drift is often called **neutral selection.** The process of genetic drift is analogous to flipping a coin. The likelihood of getting a head or a tail is equal. The 50:50 ratios of heads and tails is most likely in a large number of tosses. In only 10 tosses, for example, the ratio may be a disproportionate 7 heads and 3 tails. Similarly, the chance of one or the other of two equally adaptive alleles being incorporated into a gamete, and eventually into an individual in a second generation, is equal. Gamete sampling in a small population may show unusual proportions of alleles in any one generation of gametes because meiotic events, like tossing a coin, are random. Assuming that both alleles have equal fitness, these unusual proportions are reflected in the genotypes of the next generation. These chance events may result in a particular allele increasing or decreasing in frequency in small populations, inbreeding is also common. Genetic drift and inbreeding are likely to reduce genetic variation within a population. The likelihood of genetic drift occurring in small populations suggests that a Hardy-Weinberg equilibrium will not occur

Lecture #`89

Neutralist/Selectionist Controversy

Most biologists recognize that both natural selection and neutral selection occur, but they may not be equally important in all circumstances. For example, during long periods when environments are relatively constant and stabilizing selection is acting on phenotypes, neutral selection may operate at the molecular level. Certain genes could be randomly established in a population. Occasionally, however, the environment shifts, and directional or disruptive selection begins to operate resulting in gene frequency changes.

Polymorphisms are different forms of a particular protein that can co-exist within a species. Selectionists claimed that polymorphisms are maintained by balancing selection, while neutralists view the variation of a protein as a transient phase of molecular evolution. Selectionists, on the other hand, contribute environmental conditions to be the major determinants of polymorphisms rather than structural and functional factors.

According to the neutral theory of molecular evolution, the amount of genetic variation within a species should be proportional to the effective population size. Levels of genetic diversity vary much less than census population sizes, giving rise to the "paradox of variation". While high levels of genetic diversity were one of the original arguments in favor of neutral theory, the paradox of variation has been one of the strongest arguments against neutral theory

Lecture #`90

Founder effect

Two special cases of genetic drift have influenced the genetic makeup of some populations. When a few individuals from a parental population colonize new habitats, they seldom carry a representative sample of the gene pool from which they came. The new colony that emerges from the founding individuals is likely to have a distinctive genetic makeup with far less variation than the larger population. This form of genetic drift is the **founder effect.**

Bottle-neck effect

A similar effect can occur when the number of individuals in a population is drastically reduced. For example, cheetah populations in South and East Africa are endangered. Their depleted populations have reduced genetic diversity to the point that even if populations are restored, they will have only a remnant of the original gene pool. This form of genetic drift is called the **bottleneck effect**. A similar example concerns the northern elephant seal, which was hunted to near extinction in the late 1800s. Legislation to protect the seal was enacted in 1922, and now the population is greater than 100,000 individuals. In spite of this relatively large number, genetic variability in the population is low.

FIGURE 5.3

Bottleneck Effect. The northern elephant seal *(Mirounga angustirostris)* was severely overhunted in the late 1800s. Even though its population numbers are now increasing, its genetic diversity is low.

Lecture #`90

Populations contain ample genetic variation

Genetic variation refers to diversity in gene frequencies. Genetic variation can refer to differences between individuals or to differences between populations. Mutation is the ultimate source of genetic variation, but mechanisms such as sexual reproduction and genetic drift contribute to it as well. Genetic variation can be caused by mutation (which can create entirely new alleles in a population), random mating, random fertilization, and recombination between homologous chromosomes during meiosis (which reshuffles alleles within an organism's offspring).

Genetic variation is important to the processes of **natural selection** and biological evolution. The genetic variations that arise in a population happen by chance, but the process of natural selection does not. Natural selection is the result of the interactions between genetic variations in a population and the environment. The environment determines which genetic variations are more favorable or better suited for survival. As organisms with these environmentally selected genes survive and reproduce, more favorable traits are passed on to the population as a whole.

Lecture #`

Genes within Populations; Many processes can lead to evolutionary change

Gene flow may change the frequency and/or the range of alleles in the populations due to the migration of individuals or gametes that can reproduce in a different population. The introduction of new alleles increases variability within a population and allows for new combinations of traits.

There are a number of factors that affect the rate of gene flow between different populations. Gene flow is expected to be lower in species that have low dispersal or mobility, that occur in fragmented habitats, where there is long distances between populations, and when there are small population sizes. Mobility plays an important role in the migration rate, as highly mobile individuals tend to have greater migratory prospects. Although animals are thought to be more mobile than plants, pollen and seeds may be carried great distances by animals or wind. When gene flow is impeded, there can be an increase in inbreeding, measured by the inbreeding coefficient (F) within a population.

Lecture #`92

Selection favors some genotypes over others

As Darwin pointed out, some individuals leave behind more progeny than others, and the rate at which they do so is affected by phenotype and behavior. We describe the results of this process as selection in artificial selection, a breeder selects for the desired characteristics. In natural selection, environmental conditions determine which individuals in a population produce the most offspring. For natural selection to occur and to result in evolutionary change, three conditions must be met:

1. Variation must exist among individuals in a population. Natural selection works by favoring individuals with some traits over individuals with alternative traits. If no variation exists, natural selection cannot operate.

2. Variation among individuals must result in differences in the number of offspring surviving in the next generation. This is the essence of natural selection. Because of their phenotype or behavior, some individuals are more successful than others in producing offspring. Although many traits are phenotypically variable, individuals exhibiting variation do not always differ in survival and reproductive success.

3.Variation must be genetically inherited. For natural selection to result in evolutionary change, the selected differences must have a genetic basis. Not all variation has a genetic basis—even genetically identical individuals may be phenotypically quite distinctive if they grow up in different environments.

Lecture #`92

Selection to avoid predators

The result of evolution driven by natural selection is that populations become better adapted to their environment. Many of the most dramatic documented instances of adaptation involve genetic changes that decrease the probability of capture by a predator. The caterpillar larvae of the common Sulphur butterfly Colias eurytheme usually exhibit a pale green color, providing excellent camouflage against the alfalfa plants on which they feed. An alternative bright yellow color morph is kept at very low frequency because this color renders the larvae highly visible on the food plant, making it easier for bird predators to avoid.
One of the most dramatic examples of background matching involves ancient lava flows in the deserts of the American Southwest. In these areas, the black rock formations produced when the lava cooled contrast starkly with the surrounding bright glare of the desert sand. Populations of many species of animals occurring on these rocks—including lizards, rodents, and a variety of insects—are dark in color, whereas sand-dwelling populations in surrounding areas are much lighter.
Predation is the likely cause for these differences in color. Laboratory studies have confirmed that predatory birds such as owls are adept at picking out individuals occurring on backgrounds to which they are not adapted

Lecture #`92

Selection to match climatic conditions

Many studies of selection have focused on genes encoding enzymes, because in such cases the investigator can directly assess the consequences to the organism of changes in the frequency of alternative enzyme alleles. Often investigators find that enzyme allele frequencies vary with latitude, so that one allele is more common in northern populations, but is progressively less common at more southern locations. A superb example is seen in studies of a fish, the mummichog (Fundulus heteroclitus), which ranges along the eastern coast of North America. In this fish, geographic variation occurs in allele frequencies for the gene that produces the enzyme lactate dehydrogenase, which catalyzes the conversion of pyruvate to lactate Biochemical studies show that the enzymes formed by these alleles function differently at different temperatures, thus explaining their geographic distributions. The form of the enzyme more frequent in the north is a better catalyst at low temperatures than is the enzyme from the south. Moreover, studies indicate that at low temperatures, individuals with the northern allele swim faster, and presumably survive better, than individuals with the alternative allele

Lecture #`92

Selection for pesticide and microbial resistance

A particularly clear example of selection in natural populations is provided by studies of pesticide resistance in insects. The widespread use of insecticides has led to the rapid evolution of resistance in more than 500 pest species. The cost of this evolution, in terms of crop losses and increased pesticide use, has been estimated at $3-8 billion per year. In the housefly, the resistance allele at the pen gene decreases the uptake of insecticide, whereas alleles at the genes decrease the number of target sites, thus decreasing the binding ability of the insecticide.

Other alleles enhance the ability of the insects' enzymes to identify and detoxify insecticide molecules. Single genes are also responsible for resistance in other organisms. For example, Norway rats are normally susceptible to the pesticide warfarin, which diminishes the clotting ability of the rat's blood and leads to fatal hemorrhaging. However, a resistance allele at a single gene reduces the ability of warfarin to bind to its target enzyme and thus renders it ineffective. Selection imposed by humans has also led to the evolution of resistance to antibiotics in many disease-causing pathogens. For example, Staphylococcus aureus, which causes staph infections, was initially treated by penicillin. However, within four years of mass-production of the drug, evolutionary change in S. aureus modified an enzyme so that it would attack penicillin and render it inactive. Since that time, several other drugs have been developed to attack the microbe, and each time resistance has evolved. As a result, staph infections have re-emerged as a major health threat.

Lecture #`93

Fitness and Its Measurement;

A phenotype with greater fitness usually increases in frequency Selection occurs when individuals with one phenotype leave more surviving offspring in the next generation than individuals with an alternative phenotype. Evolutionary biologists quantify reproductive success as fitness, the number of surviving offspring left in the next generation. Fitness is a relative concept; the fit phenotype is simply the one that produces, on average, the greatest number of offspring. A phenotype with greater fitness usually increases in frequency suppose, for example, that in a population of toads, two phenotypes exist: green and brown.

Lecture #`93

Fitness and Its Measurement; Fitness may consist of many components

Although selection is often characterized as “survival of the fittest,” differences in survival are only one component of fitness. Even if no differences in survival occur, selection may operate if some individuals are more successful than others in attracting mates. In many territorial animal species, for example, large males mate with many females, and small males rarely get to mate. Selection with respect to mating success is termed sexual selection; we describe this topic more fully in the discussion of behavioral biology in chapter 54. In addition, the number of offspring produced per mating is also important. Large female frogs and fish lay more eggs than do smaller females, and thus they may leave more offspring in the next generation. Fitness is therefore a combination of survival, mating success, and number of offspring per mating. Selection favors phenotypes with the greatest fitness, but predicting fitness from a single component can be tricky because traits favored for one component of fitness may be at a disadvantage for others.

Lecture #`94

Gene flow

The Hardy-Weinberg theorem assumes that no individuals enter a population from the outside (immigrate) and that no individuals leave a population (emigrate). Immigration or emigration upsets the Hardy-Weinberg equilibrium, resulting in changes in gene frequency (evolution). Changes in gene frequency from migration of individuals are **gene flow.** Although some natural populations do not have significant gene flow, most populations do.

Gene flow is the exchange of alleles between two or more populations. For this reason it is sometimes referred to as *allele flow* or *gene migration*. While migrating animals often carry new alleles from one population to another, they must interbreed with the new population for gene flow to occur. In the image below, a beetle from a population of brown beetles migrates into a population of green beetles.

Lecture #`94

Interactions among Evolutionary Forces; Mutation and genetic drift may counter selection

In theory, if allele B mutates to allele b at a high enough rates, allele b could be maintained in the population, even if natural selection strongly favored allele B. In nature, however, mutation rates are rarely high enough to counter the effects of natural selection. The effect of natural selection also may be countered by genetic drift. Both of these processes may act to remove variation from a population. But selection is a nonrandom process that operates to increase the representation of alleles that enhance survival and reproductive success, whereas genetic drift is a random process in which any allele may increase. Thus, in some cases, drift may lead to a decrease in the frequency of an allele that is favored by selection. In some extreme cases, drift may even lead to the loss of a favored allele from a population. Remember, however, that the magnitude of drift is inversely related to population size; consequently, natural selection is expected to overwhelm drift, except when populations are very small.

Lecture #`94

Interactions among Evolutionary Forces; Gene flow may promote or constrain evolutionary change

Gene flow can be either a constructive or a constraining force. On one hand, gene flow can spread a beneficial mutation that arises in one population to other populations. On the other hand, gene flow can impede adaptation within a population by the continual flow of inferior alleles from other populations. Consider two populations of a species that live in different environments. In this situation, natural selection might favor different alleles—B and b—in the two populations. In the absence of other evolutionary processes such as gene flow, the frequency of B would be expected to reach 100% in one population and 0% in the other.

However, if gene flow occurred between the two populations, then the less favored allele would continually be reintroduced into each population. As a result, the frequency of the alleles in the populations would reflect a balance between the rate at which gene flow brings the inferior allele into a population, and the rate at which natural selection removes it. A classic example of gene flow opposing natural selection occurs on abandoned mine sites in Great Britain. Although mining activities ceased hundreds of years ago, the concentration of metal ions in the soil is still much greater than in surrounding areas. Large concentrations of heavy metals are generally toxic to plants, but alleles at certain genes confer the ability to grow on soils high in heavy metals. The ability to tolerate heavy metals comes at a price, however; individuals with the resistance allele exhibit lower growth rates on non-polluted soil.

Heavy-metal tolerance has been studied intensively in the slender bent grass Agrostis tenuis, in which the resistance allele occurs at intermediate levels in many areas. The explanation relates to the reproductive system of this grass, in which pollen, the floral equivalent of sperm, is dispersed by the wind.

Effects of natural selection

In general, the extent to which gene flow can hinder the effects of natural selection should depend on the relative strengths of the two processes. In species in which gene flow is generally strong, such as in birds and wind-pollinated plants, the frequency of the allele less favored by natural selection may be relatively high. In more sedentary species that exhibit low levels of gene flow, such as salamanders, the favored allele should occur at a frequency near 100%.

Lecture #`95

Maintenance of Variation; Frequency-dependent selection may favor either rare or common phenotypes

Frequency-dependent selection may favor either rare or common phenotypes in some circumstances, the fitness of a phenotype depends on its frequency within the population, a phenomenon termed frequency-dependent selection. This type of selection favors certain phenotypes depending on how commonly or uncommonly they occur. Negative frequency-dependent selection in negative frequency-dependent selection, rare phenotypes are favored by selection. Assuming a genetic basis for phenotypic variation, such selection will have the effect of making rare alleles more common, thus maintaining variation. Negative frequency-dependent selection can occur for many reasons. For example, it is well known that animals or people searching for something form a “search image.”

That is, they become particularly adept at picking out certain objects. Consequently, predators may form a search image for common prey phenotypes. Rare forms may thus be preyed upon less frequently an example is fish predation on an insect, the water boatman, which occurs in three different colors. Experiments indicate that each of the color types is preyed upon disproportionately when it is the most common one; fish eat more of the common-colored insects than would occur by chance alone.

Another cause of negative frequency dependence is resource competition. If genotypes differ in their resource requirements, as occurs in many plants, then the rarer genotype will have fewer competitors. When the different resource types are equally abundant, the rarer genotype will be at an advantage relative to the more common genotype.

Positive frequency-dependent selection Positive frequency-dependent selection has the opposite effect; by favoring common forms, it tends to eliminate variation from a population. For example, predators don’t always select common individuals. In some cases, “oddballs” stand out from the rest and attract attention. The strength of selection should change through time as a result of frequency-dependent selection.

Negative e frequency-dependent selection

Rare genotypes should become increasingly common, and their selective advantage will decrease correspondingly. Conversely, in positive frequency dependence, the rarer a genotype becomes, the greater the chance it will be selected against

Lecture #`96

Maintenance of Variation; in oscillating selection, the favored phenotype changes as the environment changes

In oscillating selection, the favored phenotype changes as the environment changes in some cases, selection favors one phenotype at one time and another phenotype at another time, a phenomenon called oscillating selection. If selection repeatedly oscillates in this fashion, the effect will be to maintain genetic variation in the population. One example, concerns the medium ground finch of the Galápagos Islands. In times of drought, the supply of small, soft seeds is depleted, but there are still enough large seeds around. Consequently, birds with big bills are favored. However, when wet conditions return, the ensuing abundance of small seeds favors birds with smaller bills.

Oscillating selection and frequency-dependent selection they are similar because in both cases the form of selection changes through time. But it is important to recognize that they are not the same: In oscillating selection, the fitness of a phenotype does not depend on its frequency; rather, environmental changes lead to the oscillation in selection. In contrast, in frequency dependent selection, it is the change in frequencies themselves that leads to the changes in fitness of the different phenotypes.

Lecture #`96

Maintenance of Variation; In some cases, heterozygotes may exhibit greater fitness than homozygotes

In some cases, heterozygotes may exhibit greater fitness than homozygotes If heterozygotes are favored over homozygotes, then natural selection actually tends to maintain variation in the population. This heterozygote advantage favors individuals with copies of both alleles, and thus works to maintain both alleles in the population. Some evolutionary biologists believe that heterozygote advantage is pervasive and can explain the high levels of polymorphism observed in natural populations. Others, however, believe that it is relatively rare. The best documented example of heterozygote advantage is sickle cell anemia, a hereditary disease affecting hemoglobin in humans. Individuals with sickle cell anemia exhibit symptoms of severe anemia and abnormal red blood cells that are irregular in shape.

The average incidence of the S allele in central African populations is about 0.12, far higher than that found among African Americans. From the Hardy–Weinberg principle, you can calculate that 1 in 5 central African individuals is heterozygous at the S allele, and 1 in 100 is homozygous and develops the fatal form of the disorder. People who are homozygous for the sickle cell allele almost never reproduce because they usually die before they reach reproductive age. Why, then, is the S allele not eliminated from the central African population by selection rather than being maintained at such high levels? As it turns out, one of the leading causes of illness and death in central Africa, especially among young children, is malaria.

People who are heterozygous for the sickle cell allele (and thus do not suffer from sickle cell anemia) are much less susceptible to malaria. The reason is that when the parasite that causes malaria, Plasmodium falciparum, enters a red blood cell, it causes extremely low oxygen tension in the cell, which leads to sickling in cells of individuals either homozygous or heterozygous for the sickle cell allele (but not in individuals that do not have the sickle cell allele). Such cells are quickly filtered out of the bloodstream by the spleen, thus eliminating the parasite. (The spleen's filtering effect is what leads to anemia in persons homozygous for the sickle cell allele because large numbers of red blood cells become sickle-shaped and are removed; in the case of heterozygotes, only those cells containing the Plasmodium parasite sickle, whereas the remaining cells are not affected, and thus anemia does not occur.)

Lecture #`97

Modes of Selection (Directional selection)

Directional selection occurs when individuals at one phenotypic extreme are at a disadvantage compared to all other individuals in the population. In response to this selection, the deleterious gene(s) decreases in frequency, and all other genes increase in frequency. Directional selection may occur when a mutation gives rise to a new gene, or when the environment changes to select against an existing phenotype.

Examples:

Industrial melanism, a classic example of directional selection, occurred in England during the Industrial Revolution. Museum records and experiments document how environmental changes affected selection against one phenotype of the peppered moth, *Biston betularia*. In the early 1800s, a gray form made up about 99% of the peppered moth population. The gray phenotype, previously advantageous, had become deleterious. The nature of the selection pressure was understood when investigators discovered that birds prey more effectively on moths resting on a contrasting background. Prior to the Industrial Revolution, gray moths were favored because they blended with the bark of trees on which they rested.

Pioneer evolutionary scientist Charles Darwin (1809–1882) studied what later became known as directional selection while he was in the Galapagos Islands. He observed that the beak length of the Galapagos finches changed over time due to available food sources. When there was a lack of insects to eat, finches with larger and deeper beaks survived because the beak structure was useful for cracking seeds. Over time, as insects became more plentiful, directional selection began to favor finches with smaller and longer beaks that were more useful for catching insects.

Fossil records show that black bears in Europe decreased in size during periods between continental glacial coverage during the ice ages, but increased in size during the glacial period. This was likely because larger individuals enjoyed an advantage under conditions of limited food supplies and extreme cold.

Lecture #`97

Selection Acting on Traits Affected by Multiple Genes; Disruptive selection removes intermediates

Disruptive selection removes intermediates in some situations, selection acts to eliminate intermediate types, a phenomenon called disruptive selection. A clear example is the different beak sizes of the African black-bellied seed cracker finch Pyrenestes ostrinus. Populations of these birds contain individuals with large and small beaks, but very few individuals with intermediate-sized beaks.

As their name implies, these birds feed on seeds, and the available seeds fall into two size categories: large and small. Only large-beaked birds can open the tough shells of large seeds, whereas birds with the smaller beaks are more adept at handling small seeds. Birds with intermediate-sized beaks are at a disadvantage with both seed types—they are unable to open large seeds and too clumsy to efficiently process small seeds. Consequently, selection acts to eliminate the intermediate phenotypes, in effect partitioning (or “disrupting”) the population into two phenotypically distinct groups.

Lecture #`97

Selection Acting on Traits Affected by Multiple Genes; Directional selection eliminates phenotypes on one end of a range

When selection acts to eliminate one extreme from an array of phenotypes, the genes promoting this extreme become less frequent in the population and may eventually disappear. This form of selection is called directional selection. Thus, in the Drosophila population eliminating flies that move toward light causes the population over time to contain fewer individuals with alleles promoting such behavior. If you were to pick an individual at random from a later generation of flies, there is a smaller chance that the fly would spontaneously move toward light than if you had selected a fly from the original population. Artificial selection has changed the population in the direction of being less attracted to light. Directional selection often occurs in nature when the environment changes; one example is the widespread evolution of pesticide resistance.

Lecture #`97

Selection Acting on Traits Affected by Multiple Genes; Stabilizing selection favors individuals with intermediate phenotypes

When selection acts to eliminate both extremes from an array of phenotypes, the result is to increase the frequency of the already common intermediate type. This form of selection is called stabilizing selection. In effect; selection is operating to prevent change away from this middle range of values. Selection does not change the most common phenotype of the population, but rather makes it even more common by eliminating extremes. Many examples are known. In humans, infants with intermediate weight at birth have the highest survival rate in ducks and chickens, eggs of intermediate weight have the highest hatching success.

Lecture #`97

Disruptive selection

Disruptive selection, also called **diversifying selection**, describes changes in population genetics in which extreme values for a trait are favored over intermediate values. In this case, the variance of the trait increases and the population is divided into two distinct groups. In this more individuals acquire peripheral character value at both ends of the distribution curve. Disruptive selection produces distinct subpopulations.

Example:

Consider, for example, what could happen in a population of snails with a range of shell colors between white and dark brown and living in a marine tide pool habitat with two background colors. The sand, made up of pulverized mollusc shells, is white, and rock outcroppings are brown. In the face of shorebird predation, what phenotypes are going to be most common? Although white snails may not actively select a white background, those present on the sand are less likely to be preyed on than intermediate phenotypes on either sand or rocks similarly, brown snails on rocks are less likely to be preyed on than intermediate phenotypes on either substrate. Thus, disruptive selection could produce two distinct subpopulations, one white and one brown.

Lecture #`97

Stabilizing selection

When both phenotypic extremes are deleterious, a third form of natural selection—**stabilizing selection**—narrows the phenotypic range. During long periods of environmental constancy, new variations that arise, or new combinations of genes that occur, are unlikely to result in more fit phenotypes than the genes that have allowed a population to survive for thousands of years, especially when the new variations are at the extremes of the phenotypic range.

Stabilizing selection commonly uses negative selection to select against extreme values of the character. Stabilizing selection is the opposite of disruptive selection. Instead of favoring individuals with extreme phenotypes, it favors the intermediate variants. Stabilizing selection tends to remove the more severe phenotypes, resulting in the reproductive success of the norm or average phenotypes. This means that most common phenotype in the population is selected for and continues to dominate in future generations. Because most traits change little over time, stabilizing selection is thought to be the most common type of selection in most populations. A good example of stabilizing selection is the horseshoe crab *(Limulus)*, which lives along the Atlantic coast of the United States .Comparison of the fossil record with living forms indicates that this body form has changed little over 200 million years. Apparently, the combination of characteristics present in this group of animals is adaptive for the horseshoe crab's environment.

Lecture #`98

Balanced polymorphism and heterozygote superiority

Polymorphism occurs in a population when two or more distinct forms exist without a range of phenotypes between them. **Balanced polymorphism** (Gr. *poly*, many *morphe*, and form) occurs when different phenotypes are maintained at relatively stable frequencies in the population and may resemble a population in which disruptive selection operates. Sickle-cell anemia results from a change in the structure of the hemoglobin molecule. Some of the red blood cells of persons with the disease are misshapen, reducing their ability to carry oxygen. In the heterozygous state, the quantities of normal and sickled cells are roughly equal. Sickle-cell heterozygotes occur in some African populations with a frequency as high as 0.4. The maintenance of the sickle-cell heterozygotes and both homozygous genotypes at relatively unchanging frequencies makes this trait an example of a balanced polymorphism.

Lecture #`98

Enzyme polymorphism

A phenomenon that, in the course of evolution, characterizes enzymes that are able to maintain their catalytic capability on the same chemical reaction, even though their amino acid sequences and/or amino acid composition are modified via mutagenesis and/or natural selection.

Enzyme polymorphism is a well documented phenomenon in human populations. Estimates derived from electrophoretic studies indicate that approximately one third of all human enzymes exhibit genetic polymorphism where "polymorphism" is defined as the occurrence of heterozygotes with a frequency greater than 2%. Taken as a whole the data indicate that the average heterozygosity per locus is about 0.06 and this implies that any single individual in any human population is likely to be heterozygous at about 6% of the loci encoding enzyme proteins, for alleles which give rise to electrophoretically distinct isozyme forms. The complexity of the isozyme patterns varies according to the subunit structure of the enzyme proteins and on average monomeric enzymes exhibit a higher incidence of genetic polymorphism than multimeric enzymes The data derived from electrophoretiC studies of enzyme proteins can be used to obtain crude estimates of the incidence of mutation in the coding regions of the DNA of the structural genes for comparisons with the estimates derived from the direct molecular analysis of non coding (viz, the flanking and intervening) DNA sequences. Since the average enzyme polypeptide size is about 45,000 Daltons, corresponding to about 400 amino acid residues, it must be encoded by about 1,200 base pairs (bp) of DNA. About a third of all human enzymes exhibit polymorphism

Lecture #`98

DNA sequence polymorphism

The analysis of DNA sequence polymorphisms and SNPs (single nucleotide polymorphisms) can provide insights into the evolutionary forces acting on populations and species. ... Dna SP is a multi-propose program that allows conducting exhaustive DNA polymorphism analysis using a graphical user-friendly interface.

A **single-nucleotide polymorphism** (**SNP**, pronounced *snip*) is a DNA sequence variation occurring when a single nucleotide adenine (A), thymine (T), cytosine (C), or guanine (G]) in the genome (or other shared sequence) differs between members of a species or paired chromosomes in an individual. For example, two sequenced DNA fragments from different individuals, AAGC**C**TA to AAGC**T**TA, contain a difference in a single nucleotide. In this case we say that there are two *alleles*: C and T. Almost all common SNPs have only two alleles.

Within a population, SNPs can be assigned a minor allele frequency — the lowest allele frequency at a locus that is observed in a particular population. This is simply the lesser of the two allele frequencies for single-nucleotide polymorphisms. There are variations between human populations, so a SNP allele that is common in one geographical or ethnic group may be much rarer in another.

Lecture #`99

The Limits of Selection; Genes have multiple effects

Genes have multiple effects Alleles often affect multiple aspects of a phenotype (the phenomenon of pleiotropy; these multiple effects tend to set limits on how much a phenotype can be altered. For example, selecting for large clutch size in chickens eventually leads to eggs with thinner shells that break more easily. For this reason, we could never produce chickens that lay eggs twice as large as the best layers do now. Likewise, we cannot produce gigantic cattle that yield twice as much meat as our leading breeds, or corn with an ear at the base of every leaf, instead of just at the bases of a few leaves.

Lecture #`99

The Limits of Selection; Evolution requires genetic variation

Over 80% of the gene pool of the thoroughbred horses racing today goes back to 31 ancestors from the late eighteenth century. Despite intense directional selection on thoroughbreds, their performance times have not improved for more than 50 years. Decades of intense selection presumably have removed variation from the population at a rate greater than mutation can replenish it, such that little genetic variation now remains, and evolutionary change is not possible. In some cases, phenotypic variation for a trait may never have had a genetic basis. The compound eyes of insects are made up of hundreds of visual units, termed ommatidia In some individuals, the left eye contain more ommatidia than the right. In other individuals, the right eye contains more than the left. However, despite intense selection experiments in the laboratory, scientists have never been able to produce a line of fruit flies that consistently has more ommatidia in the left eye than in the right. The reason is that separate genes do not exist for the left and right eyes. Rather, the same genes affect both eyes, and differences in the number of that occur as the eyes are formed in the development process.
Thus, despite the existence of phenotypic variation, no underlying genetic variation is available for selection to favor.

Lecture #`99

The Limits of Selection; Gene interactions affect fitness of alleles

Epistasis is the phenomenon in which an allele for one gene may have different effects, depending on alleles present at other genes. Because of epistasis, the selective advantage of an allele at one gene may vary from one genotype to another. If a population is polymorphic for a second gene, then selection on the first gene may be constrained because different alleles are favored in different individuals of the same population. Studies on bacteria illustrate how selection on alleles for

one gene can depend on which alleles are present at other genes. In E. coli, two biochemical pathways exist to break down gluconate, each using enzymes produced by different genes. One gene produces the enzyme 6-PGD, for which there are several alleles. When the common allele for the second gene, which codes for the other biochemical pathway, is present, selection does not favor one allele over another at the 6-PGD gene. In some E. coli, however, an alternative allele at the second gene occurs that is not functional. The bacteria with this alternative allele are forced to rely only on the 6-PGD pathway, and in this case, selection favors one 6-PGD allele over another. Thus, epistatic interactions exist between the two genes, and the outcome of natural selection on the 6-PGD gene depends on which alleles are present at the second gene

Lecture #`100

Species and speciation

The fundamental unit of classification is the species. Unfortunately, formulating a universally applicable definition of species is difficult. According to a biological definition, a **species** is a group of populations in which genes are actually, or potentially, exchanged through interbreeding the fundamental unit of classification is the species. Unfortunately, formulating a universally applicable definition of species is difficult. According to a biological definition, a **species** is a group of populations in which genes are actually, or potentially, exchanged through interbreeding hat all of these have a genetic basis.

Speciation is the formation of new species. A requirement of speciation is that subpopulations are prevented from interbreeding. This is called reproductive isolation. When subpopulations are reproductively isolated, natural selection and genetic drift can result in evolution taking a different course in each subpopulation. Reproductive isolation can occur in different ways. Premating isolation prevents mating from taking place.

For example, impenetrable barriers, such as rivers or mountain ranges, may separate subpopulations. Other forms of premating isolation are subtler. If courtship behavior patterns of two animals are not mutually appropriate, mating does not occur **Post mating isolation** prevents successful fertilization and development, even though mating may have occurred. For example, conditions in the reproductive tract of a female may not support the sperm of another individual, which prevents successful fertilization. Post mating isolation also occurs because hybrids are usually sterile (e.g., the mule produced from a mating of male donkey and a mare is a sterile hybrid). Mismatched chromosomes cannot synapse properly during meiosis, and any gametes produced are not viable. Other kinds of post mating isolation include developmental failures of the fertilized egg or embryo.

Lecture #`101

Reproductive isolation

Speciation is the formation of new species. A requirement of speciation is that subpopulations are prevented from interbreeding. This is called **reproductive isolation.** When subpopulations are reproductively isolated, natural selection and genetic drift can result in evolution taking a different course in each subpopulation. Reproductive isolation can occur in different ways.

A **species** is a group of living organisms, such as animals or plants, that can interbreed or exchange genes. The above example of the deer is a case of **speciation**, or when one species becomes two or more, due to evolution. Many things can separate one population into two or more groups, like shifting continents or lava flows. During their time apart, the deer experienced changes to the point of **reproductive isolation**. This refers to when two groups of animals live close enough to one another to interact but are unable to interbreed with one another. There are many reasons why two organisms cannot mate and they can be divided into the two major divisions - pre-zygotic barriers and post-zygotic barriers.

Pre-Zygotic Barriers

Pre-zygotic barriers are obstacles that are present before an egg can be fertilized. A **zygote** is an egg that has been fertilized by a sperm. Some examples of pre-zygotic barriers include temporal isolation, ecological isolation, behavioral isolation, and mechanical isolation.

With **temporal isolation**, the two species never come into contact with each other because they are not active at the same time, or they have different mating seasons. For example, the northern red-legged frog and the foothill yellow-legged frog both live in California but their mating seasons do not overlap, so these two species never get the chance to mate.

Some organisms prefer certain types of food, habitat or have specific mating sites. With **ecological isolation**, the species have the same range but do not come across one another because they are eating different foods, living in different habitats, or are mating in different areas. We can use the red-legged frog in this example, as well. Even though they live in the same region, the red-legged frog does not mate with the bullfrog because the red-legged frog breeds in fast-moving streams and bullfrogs breed in ponds.

With **behavioral isolation**, one species does not know the mating ritual of the other species or rituals are slightly different, so no mating occurs between them. There are two species of grasshoppers that will not interbreed because they have slightly different mating songs.

Some species have complex mating rituals. For example, some male birds perform dances for the female and male porcupines urinate on the females before mating. Only charming if you're a porcupine, I guess.

With **mechanical isolation**, the animals actually try to mate, but are physically unable. A certain species of snail is unable to mate if the shell is not coiled in the same direction, so only right-coiled shelled snails can mate with right-coiled shelled snails; the same applies to left-coiled snails.

Post-Zygotic Barriers

In cases when **post-zygotic barriers** are in place, the organisms mate but no offspring are produced. Post-zygotic barriers mean the animals mated but no offspring occurred after they did so. It can also mean the offspring is a hybrid and is not viable, sterile or both. One type of post-zygotic barrier is gametic incompatibility, where the sperm and egg are not compatible, unable to combine. A **gamete** is a mature sperm or egg, capable of transferring genetic code. An example of this can be seen in sea urchins, which release their sperm or eggs into the water. The gametes of the giant red urchin and the purple urchin are not compatible so, even though the sperm and egg come into contact with one another, they do not fuse together to make a baby urchin. Another type of barrier is **zygotic mortality**, where the egg and sperm have met and fused, but the zygote dies without further development. Remember, the term '*zygote*' refers to an egg and sperm that have fused together. The creation of an unsuccessful hybrid is also a form of post-zygotic barrier.

Lecture #`102

Allopatric speciation

Allopatric (Gr. *allos,* other patria, fatherland) **speciation** occurs when subpopulations become geographically isolated from one another. For example, a mountain range or river may permanently separate members of a population. Adaptations to different environments or neutral selection in these separate populations may result in members not being able to mate successfully with each other, even if experimentally reunited.

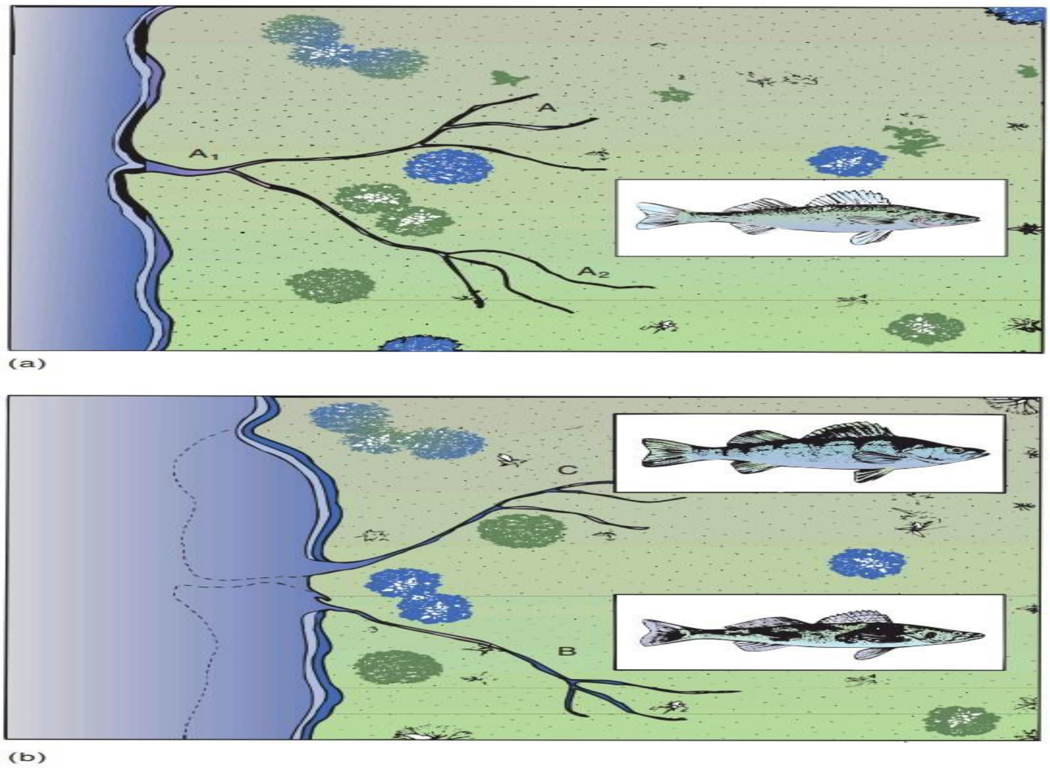


Fig. rates of evolution

Many biologists believe that allopatric speciation is the most common kind of speciation. The finches that Darwin saw on the Galápagos Islands are a classic example of allopatric speciation, as well as adaptive radiation *Adaptive* radiation occurs when a number of new forms diverge from an ancestral form, usually in response to the opening of major new habitats. Fourteen species of finches evolved from the original finches that colonized the Galápagos Islands. Ancestral finches, having emigrated from the mainland, probably were distributed among a few of the islands of the Galápagos.

Lecture #`103

Parapatric speciation another form of speciation, called **parapatric** (Gr. *para*, beside) **speciation,** occurs in small, local populations, called **demes.** For example, all of the frogs in a particular pond or all of the sea urchins in a particular tide pool make up a deme. Individuals of a deme are more likely to breed with one another than with other individuals in the larger population, and because they experience the same environment, they are subject to similar selection pressures. Demes are not completely isolated from each other because individuals, developmental stages, or gametes can move among demes of a population. On the other hand, the relative isolation of a deme may mean that its members experience different selection pressures than other members of the population. If so, speciation can occur. Although most evolutionists theoretically agree that parapatric speciation is possible, no certain cases are known. Parapatric speciation is therefore considered of less importance in the evolution of animal groups than allopatric speciation.

Parapatric speciation is extremely rare. It occurs when populations are separated not by a geographical barrier, such as a body of water, but by an extreme change in habitat. While populations in these areas may interbreed, they often develop distinct characteristics and lifestyles. Reproductive isolation in these cases is not geographic but rather temporal or behavioral. For example, plants that live on boundaries between very distinct climates may flower at different times in response to their different environments, making them unable to interbreed.

Lecture #`104

Sympatric speciation

The third kind of speciation, called **sympatric** (Gr. *seem*, together) **speciation,** occurs within a single population. Even though organisms are sympatric, they still may be reproductively isolated from one another. Many plant species are capable of producing viable forms with multiple sets of chromosomes. Such events could lead to sympatric speciation among groups in the same habitat. While sympatric speciation in animals is uncommon, it has been documented in two species of bats and several species of insects and fish**.**

Sympatric speciation occurs when populations of a species that share the same habitat become reproductively isolated from each other. This speciation phenomenon most commonly occurs through polyploidy, in which an offspring or group of offspring will be produced with twice the normal number of chromosomes. Where a normal individual has two copies of each chromosome (diploidy), these offspring may have four copies (tetraploidy). A tetraploid individual cannot mate with a diploid individual, creating reproductive isolation.

Sympatric speciation is rare. It occurs more often among plants than animals, since it is so much easier for plants to self-fertilize than it is for animals. A tetraploidy plant can fertilize itself and create offspring. For a tetraploidy animal to reproduce, it must find another animal of the same species but of opposite sex that has also randomly undergone polyploidy.

Lecture #`105

Rates of evolution

Charles Darwin perceived evolutionary change as occurring gradually over millions of years. This concept, called **phyletic gradualism,** has been the traditional interpretation of the tempo, or rate, of evolution. Some evolutionary changes, however, happen very rapidly. Studies of the fossil record show that many species do not change significantly over millions of years. These periods of stasis (Gr. *stasis,* standing still), or equilibrium, are interrupted when a group encounters an ecological crisis, such as a change in climate or a major geological event. Over the next 10,000 to 100,000 years, a variation that previously was selectively neutral or disadvantageous might now be advantageous.

Alternatively, geological events might result in new habitats becoming available. (Events that occur in 10,000 to 100,000 years are almost instantaneous in an evolutionary time frame.) This geologically brief period of change "punctuates" the previous million or so years of equilibrium and eventually settles into the next period of stasis. In this model, stabilizing selection characterizes the periods of stasis, and directional or disruptive selection characterizes the periods of change Long periods of stasis interrupted by brief periods of change is called the **punctuated equilibrium model** of evolution Biologists have observed such rapid evolutionary changes in small populations.

Examples include the rapid pesticide and antibiotic resistance that insect pests and bacteria acquire. In addition, in a series of studies over a 20-year period, Peter R. Grant has shown that natural selection results in rapid morphological changes in the bills of Galápagos finches. A long, dry period from the middle of 1976 to early January 1978 resulted in birds with larger, deeper bills. Early in this dry period, birds quickly consumed smaller, easily cracked seeds. As they were forced to turn to larger seeds, birds with weaker bills were selected against, resulting in a measurable change in the makeup of the finch population of the island Daphne Major.

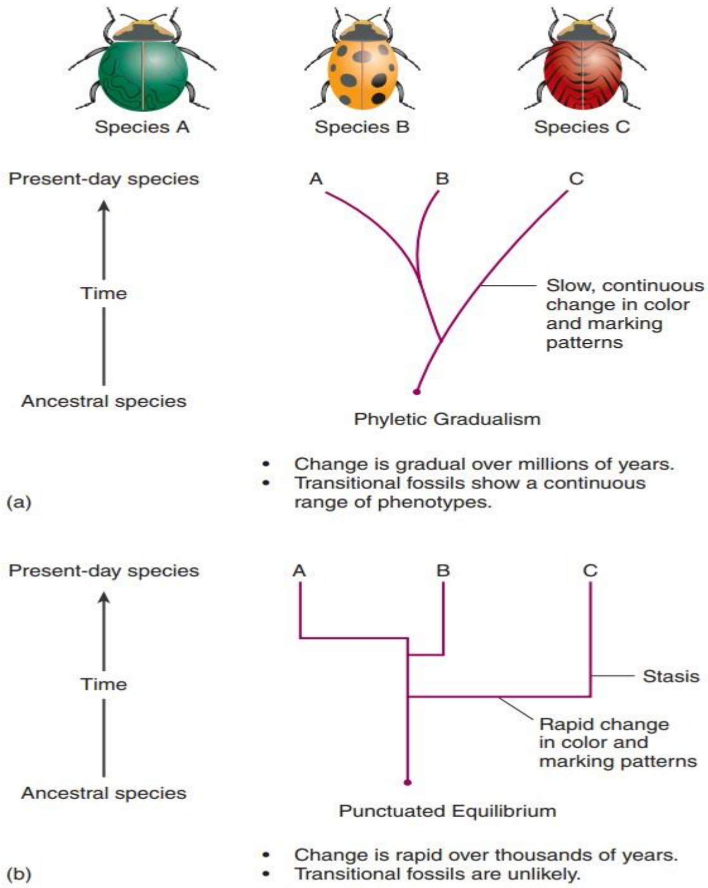


Fig. rates of evolution

Lecture #`106

Molecular evolution

Many evolutionists study changes in animal structure and function that are observable on a large scale—for example, changes in the shape of a bird's bill or in the length of an animal's neck. All evolutionary change, however, results from changes in the base sequences in DNA and amino acids in proteins. Molecular evolutionists investigate evolutionary relationships among organisms by studying DNA and proteins. For example, cytochrome *c* is a protein present in the cellular respiration pathways in all eukaryotic organisms. Organisms that other research has shown to be closely related have similar cytochrome *c* molecules.

That cytochrome *c* has changed so little during hundreds of millions of years suggests that mutations of the cytochrome *c* gene are nearly always detrimental, and are selected against. Because it has changed so little, cytochrome *c* is said to have been conserved evolutionarily. Not all proteins are conserved as rigorously as cytochrome *c*. Although variations in highly conserved proteins can help establish evolutionary relationships among distantly related organisms, less conserved proteins are useful for looking at relationships among more closely related animals. Because some proteins are conserved and others are not, the best information regarding evolutionary relationships requires comparing as many proteins as possible in any two species.

Lecture #`107

Gene duplication

Recall that most mutations are selected against. Sometimes, however, an extra copy of a gene is present. One copy may be modified, but as long as the second copy furnishes the essential protein the organism is likely to survive. Gene duplication, the accidental duplication of a gene on a chromosome, is one way that extra genetic material can arise. Vertebrate hemoglobin and myoglobin are believed to have arisen from a common ancestral molecule.

Hemoglobin carries oxygen in red blood cells, and myoglobin is an oxygen storage molecule in muscle. The ancestral molecule probably carried out both functions. However, about 1 billion years ago, gene duplication followed by mutation of one gene resulted in the formation of two polypeptides: myoglobin and hemoglobin. Further gene duplications over the last 500 million years probably explain why most vertebrates, other than primitive fishes, have hemoglobin molecules consisting of four polypeptides.

Lecture #`107

Mutation

Mutations are changes in the structure of genes and chromosomes. The Hardy-Weinberg theorem assumes that no mutations occur or that mutational equilibrium exists. Mutations, however, are a fact of life. Most importantly, mutations are the origin of all new genes and a source of variation that may prove adaptive for an animal. Mutation counters the loss of genetic material from natural selection and genetic drift, and it increases the likelihood that variations will be present that allow a group to survive future environmental shocks.

Types of Mutations

There are three types of DNA Mutations: base substitutions, deletions and insertions.

1. Base Substitutions

Single base substitutions are called point mutations. For example, the point mutation Glu -----> Val which causes sickle-cell disease. Point mutations are the most common type of mutation. Point mutations that occur in DNA sequences encoding proteins are either silent, missense or nonsense.

Silent: If a base **substitution** occurs in the third position of the codon there is a good chance that a synonymous codon will be generated. Thus the amino acid sequence encoded by the gene is not changed and the mutation is said to be silent.

Missence: When base **substitution** results in the generation of a codon that specifies a different amino acid and hence leads to a different polypeptide sequence. Depending on the type of amino acid substitution the missense mutation is either conservative or nonconservative. For example if the structure and properties of the substituted amino acid are very similar to the original amino acid the mutation is said to be conservative and will most likely have little effect on the resultant proteins structure / function. If the substitution leads to an amino acid with very different structure and properties the mutation is nonconservative and will probably be deleterious (bad) for the resultant proteins structure / function (i.e. the sickle cell point mutation).

Nonsense: When a base **substitution** results in a stop codon ultimately truncating translation and most likely leading to a nonfunctional protein.

2. Deletions

A deletion, resulting in a frameshift, results when one or more base pairs are lost from the DNA. If one or two bases are deleted the translational frame is altered resulting in a garbled message and nonfunctional product. A deletion of three or more bases leave the reading frame intact. A deletion of one or more codons results in a protein missing one or more amino acids. This may be deleterious or not.

3. Insertions

The insertion of additional base pairs may lead to frameshifts depending on whether or not multiples of three base pairs are inserted. Combinations of insertions and deletions leading to a variety of outcomes are also possible.

Lecture #`108

Mosaic evolution

A species is a mosaic of different molecules and structures that have evolved at different rates. Some molecules or structures are conserved in evolution; others change more rapidly. The basic design of a bird provides a simple example. All birds are easily recognizable as birds because of highly conserved structures, such as feathers, bills, and a certain body form. Particular parts of birds, however, are less conservative and have a higher rate of change. Wings have been modified for hovering, soaring, and swimming. Similarly, legs have been modified for wading, swimming, and perching. These are examples of **mosaic evolution.**

Mosaic evolution, the occurrence, within a given population of organisms, of different rates of evolutionary change in various body structures and functions. An example can be seen in the patterns of development of the different elephant species. The Indian elephant underwent rapid early molar modification with little foreshortening of the forehead. The African elephant underwent parallel changes but at different rates: the foreshortening of the forehead took place in an early stage of development, molar modification occurring later.

Similarly, in man there was early evolution of structures for bipedal locomotion, but during the same time there was little change in skull form or brain size; later, both skull and brain evolved rapidly into the state of development associated with modern human species. The phenomenon of mosaic evolution would seem to indicate that the process of natural selection acts differently upon the various structures and functions of evolving species. Thus, in the case of human development, the evolutionary pressures for upright posture took precedence over the need for a complex brain. Furthermore, the elaboration of the brain was probably linked to the freeing of the forelimbs made possible by bipedal locomotion. Analysis of incidences of mosaic evolution adds greatly to the body of general evolutionary theory.

Lecture #`109

Kingdoms of life

In 1969, Robert H. Whittaker described a system of classification that distinguished between kingdoms according to cellular organization and mode of nutrition. According to this system, members of the kingdom **Monera** are the bacteria and the cyanobacteria. They are distinguished from all other organisms by being prokaryotic. Members of the kingdom **Protista** are eukaryotic and consist of single cells or colonies of cells. This kingdom includes Amoeba, Paramecium, and many others. Members of the kingdom **Plantae** are eukaryotic, multicellular, and photosynthetic. Plants have walled cells and are usually non motile.

Members of the kingdom **Fungi** are also eukaryotic and multicellular. They also have walled cells and are usually non motile. Mode of nutrition distinguishes fungi from plants. Fungi digest organic matter extracellularly and absorb the breakdown products. Members of the kingdom

Animalia are eukaryotic and multicellular, and they usually feed by ingesting other organisms or parts of other organisms. Their cells lack walls and they are usually motile. In recent years, new information has challenged the five kingdom classification system. For the first two billion years of life on the earth, the only living forms were prokaryotic microbes. Fossil evidence from this early period is scanty; however, molecular studies of variations in base sequences of ribosomal RNA from more than two thousand organisms are providing evidence of relationships rooted within this two billion-year period. The emerging picture is that the five previously described kingdoms do not represent distinct evolutionary lineages. Ribosomal RNA is excellent for studying the evolution of early life on earth. It is an ancient molecule, and it is present and retains its function in virtually all organisms. In addition, ribosomal RNA changes very slowly. This slowness of change, called **evolutionary conservation,** indicates that the protein-producing machinery of a cell can tolerate little change and still retain its vital function

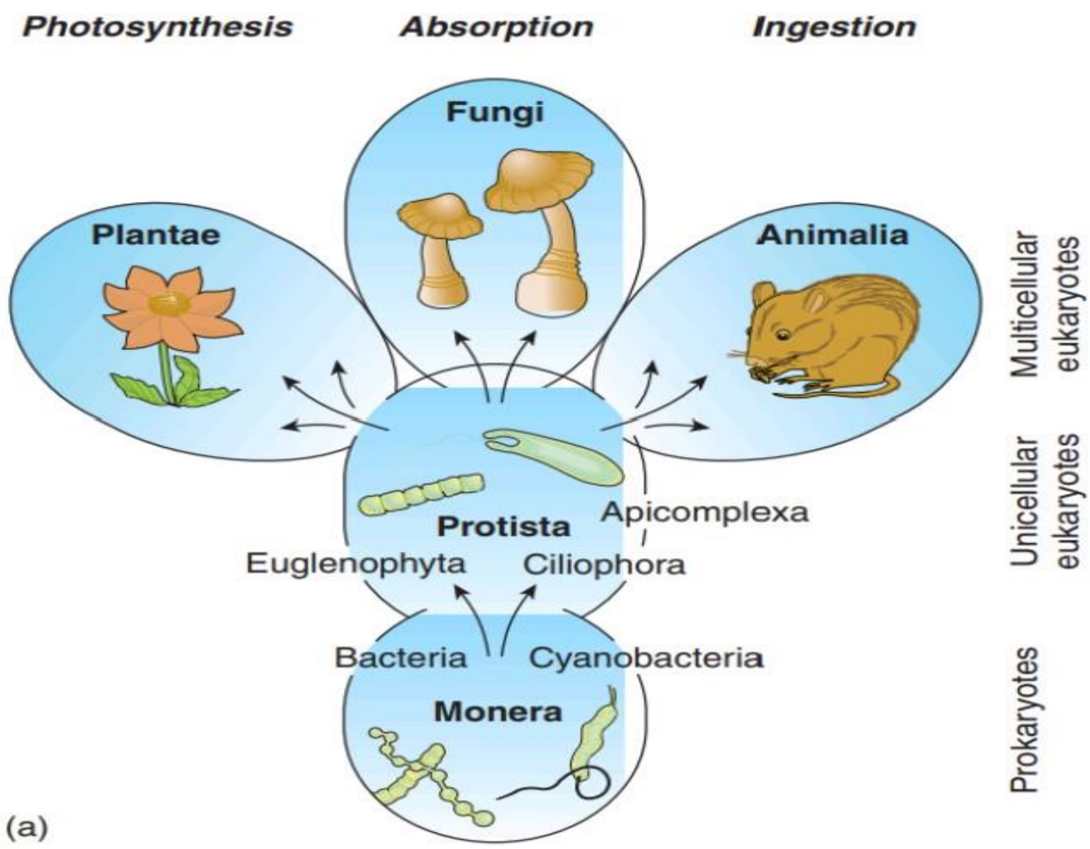


Fig. kingdom of life

Lecture #`109

Animal systematics

The 1goal of animal systematic is to arrange animal into groups that reflects evolutionary relationship these groups should include single incestral species and its decendanats such group is called monophyletic. A **character** is virtually anything that has a genetic basis and can be measured—from an anatomical feature to a sequence of nitrogenous bases in DNA or RNA. **Polyphyletic groups** have members that can be traced to separate ancestors. Since each group should have a single ancestor, a polyphyletic group reflects insufficient knowledge of the group. A **paraphyletic group** includes some, but not all, members of a lineage. Paraphyletic groups also result when knowledge of the group is insufficient.

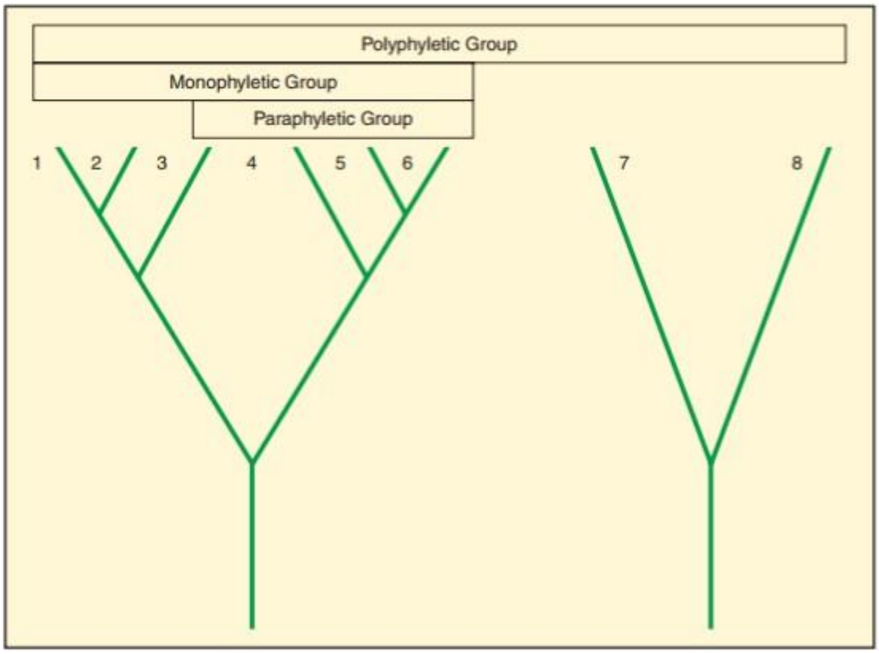


Fig. evolutionary groups

Evolutionary systematics is the oldest of the three approaches. It is sometimes called the "traditional approach," although it has certainly changed since the beginnings of animal systematics. A basic assumption of evolutionary systematists is that organisms closely related to an ancestor will resemble that ancestor more closely than they resemble distantly related organisms

Numerical taxonomy emerged during the 1950s and 1960s and represents the opposite end of the spectrum from evolutionary systematics. The founders of numerical taxonomy believed that the criteria for grouping taxa had become too arbitrary and vague. They tried to make taxonomy more objective. Numerical taxonomists use mathematical models and computer-aided techniques to group samples of organisms according to overall similarity.

Lecture #`110

Phylogenetic systematics (cladistics)

Phylogenetic systematics (cladistics) is a third approach to animal systematics. The goal of cladistics is similar to that described for evolutionary systematics–the generation of hypotheses of genealogical relationships among monophyletic groups of organisms. Cladists contend, however, that their methods are more open to analysis and testing, and thus are more scientific, than those of evolutionary systematists. As do evolutionary systematists, cladists differentiate between homologies and analogies. They believe, however, that homologies of recent origin are most useful in phylogenetic studies. Characters that all members of a group share are referred to as symplesiomorphies (Gr. sym, together plesio, near morphe, form). These characters are homologies that may indicate a shared ancestry, but they are useless in describing relationships within the group.

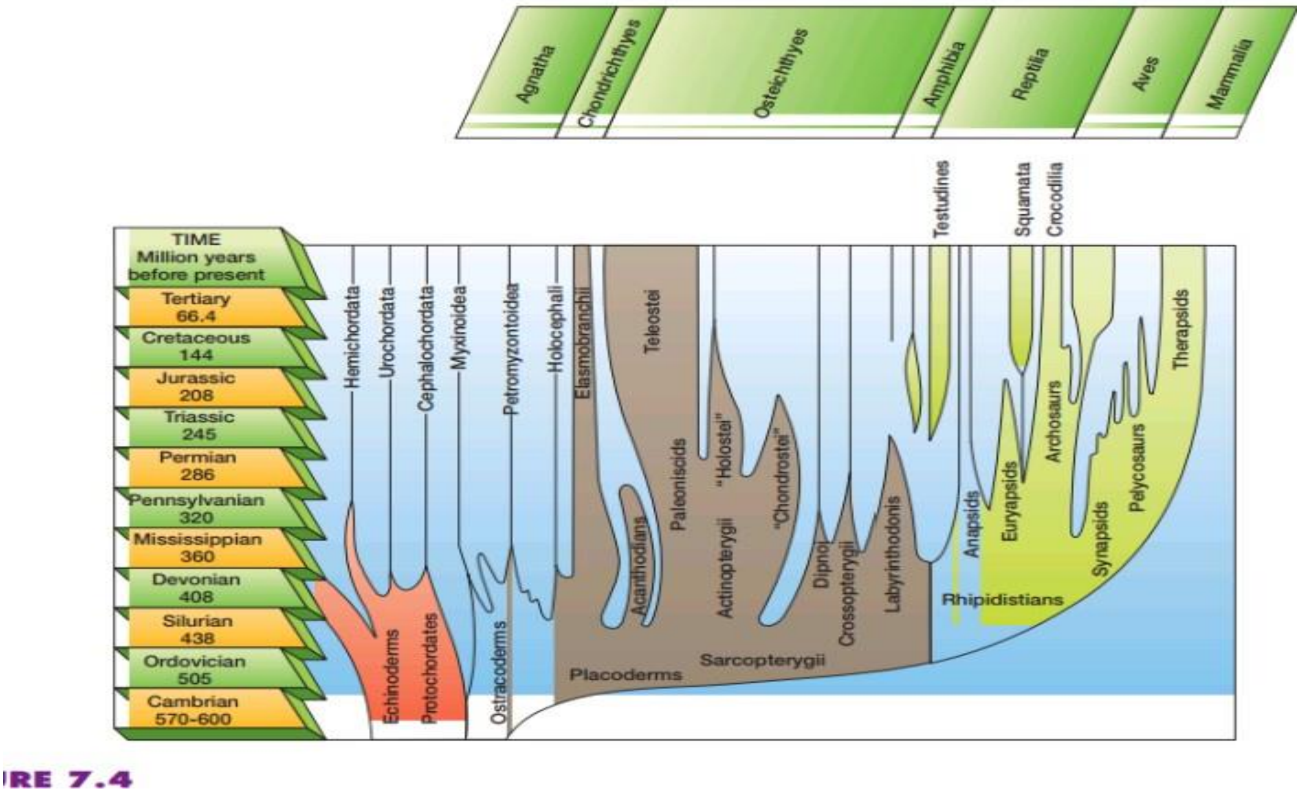


Fig. phylogenic tree

Lecture #`110

Cladogram

The hypothetical lineage shown in figure 7.5 is called a cladogram. Cladograms depict a sequence in the origin of derived characters. A cladogram is interpreted as a family tree depicting a hypothesis regarding monophyletic lineages. New data in the form of newly investigated characters or reinterpretations of old data are used to test the hypothesis the cladogram describes. cladogram depicting the evolutionary relationships among the vertebrates. The tunicates and cephalochordates are an out group for the entire vertebrate lineage. Derived characters are listed on the right side of the cladogram. Notice that extra embryonic membranes is a synapomorphy used to define the clade containing the reptiles, birds, and mammals. These extra embryonic membranes are a shared character for these groups and are not present in any of the fish taxa or the amphibians. Distinguishing between reptiles, birds, and mammals requires looking at characters that are even more recently derived than extraembryonic membranes. A derived character, the shell, distinguishes turtles from all other members of the clade; skull characters distinguish the lizard/crocodile/bird lineage from the mammal lineage; and hair, mammary glands, and endothermy is a unique mammalian character combination. Note that a synapomorphy at one level of taxonomy may be a symplesiomorphy at a different level of taxonomy. Extraembryonic membranes are a synapomorphic character within the vertebrates that distinguishes the reptile/bird/mammal clade.

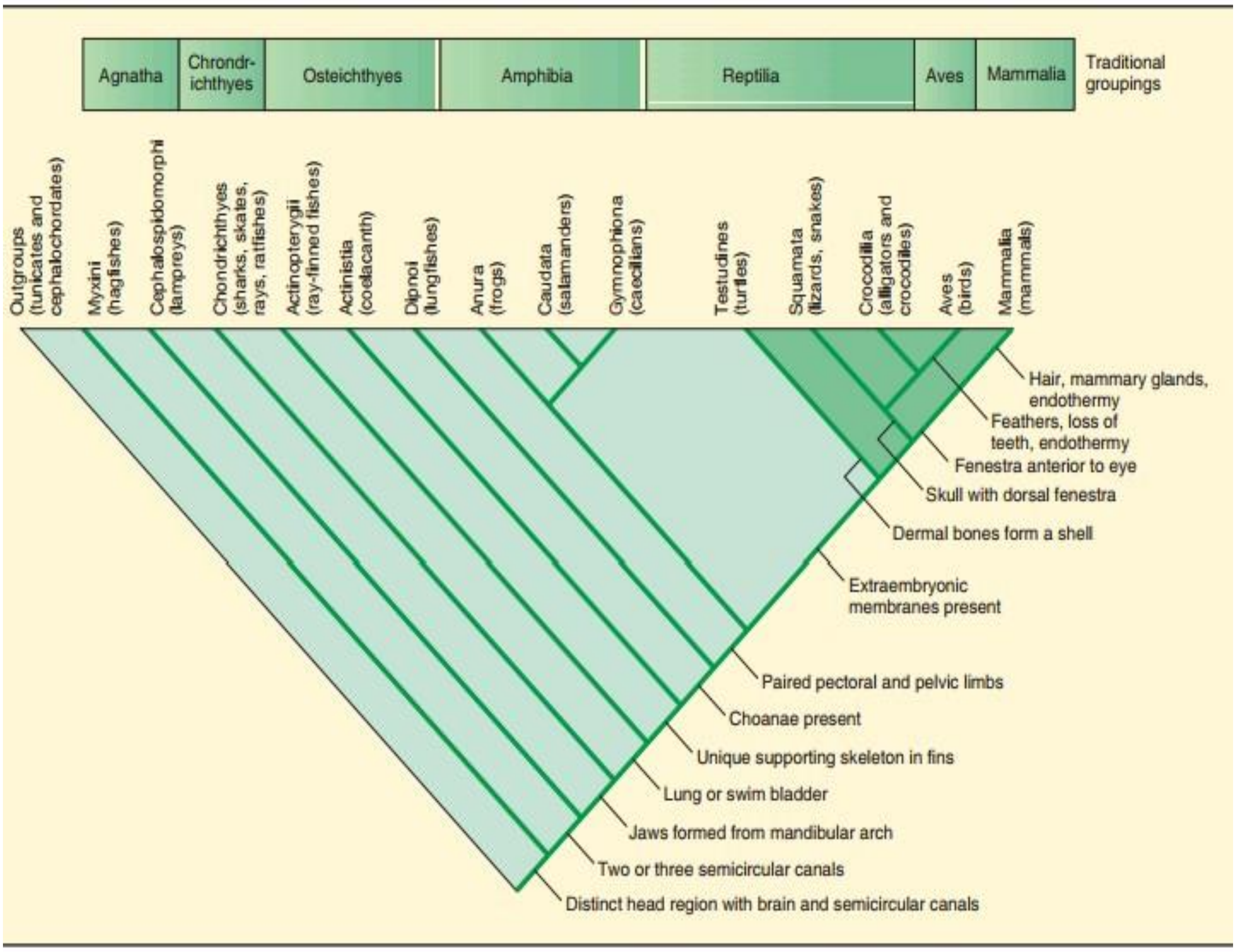


Fig. cladogram

Lecture #`111

Archaean characteristics

Although they are a diverse group, all archae share certain key characteristics (table 26.1). Their cell walls lack peptidoglycan (an important component of the cell walls of bacteria); the lipids in the cell membranes of archaea have a different structure from those in all other organisms; and archaea have distinctive ribosomal RNA sequences. Some of their genes possess introns, unlike those of bacteria. Both archaea and eukaryotes lack the peptidoglycan cell wall found in bacteria.

The archaea are grouped into three general categories— methanogens, extremophiles, and no extreme archaea—based primarily on the environments in which they live or on their specialized metabolic pathways. The word extreme refers to our current environment. When archaea first appeared on the scene their now extreme habitats may have been typical. Methanogens obtain their energy by using hydrogen gas (H2) to reduce carbon dioxide (CO2) to methane gas (CH4). They are strict anaerobes, poisoned by even traces of oxygen. They live in swamps, marshes, and the intestines of mammals. Methanogens release about 2 billion tons of methane gas into the atmosphere each year.

Extremophiles are able to grow under conditions that seem extreme to us. There are several types of extremophiles

Thermophiles, which live in temperatures ranging from 60° to 80°C. Many of these are autotrophs with a sulfur based metabolism.

Cold-adapted, which live in glacier ice and alpine lakes.

Halophiles, which live in very salty environments including the Great Salt Lake and the Dead Sea. These organisms require water with a salinity of 15 to 20%. pH-tolerant archaea, growing in highly acidic (pH = 0.7) or highly basic (pH = 11) environments.

Pressure-tolerant archaea found in the ocean depths. These archaea require at least 300 atmospheres (atm) of pressure to survive and tolerate up to 800 atm. To experience a pressure of 300 atm (300 times the pressure of our atmosphere) you would need to dive 3000 m below the surface of the ocean (not a good idea unless you were in a deep-sea submersible). The deepest recorded skin dive is 127 m and a 145-m record is reported for SCUBA diving. No extreme archaea grow in the same environments bacteria do. As the genomes of archaea have become better known, microbiologists have been able to identify signature sequences of DNA present only in archaea. The newly discovered microbe Nanoarchaeum equitens was identified as an Archaean based on a signature sequence. This odd Icelandic microbe may have the smallest known genome, only 500 Bp.

Lecture #`113

Prokaryotic Cells

When cells were visualized with microscopes, two basic cellular architectures were recognized: eukaryotic and prokaryotic. These terms refer to the presence or absence, respectively, of a membrane-bounded nucleus that contains genetic material. We have already mentioned that in addition to lacking a nucleus, prokaryotic cells do not have an internal membrane system or numerous membrane bounded organelles. Prokaryotes are the simplest organisms. Prokaryotic cells are small.

They consist of cytoplasm surrounded by a plasma mem cyanobacterium Prochloron, have an extensively folded plasma membrane, with the folds extending into the cell's interior. These membrane folds contain the bacterial pigments connected with photosynthesis.

In eukaryotic plant cells, photosynthetic pigments are found in the inner membrane of the chloroplast. Because a prokaryotic cell contains no membrane-bounded organelles, the DNA, enzymes, and other cytoplasmic constituents have access to all parts of the cell. Reactions are not compartmentalized as they are in eukaryotic cells, and the whole prokaryote operates as a single unit. Bacterial cell walls consist of peptidoglycan

Lecture #`113

Maintaining homeostasis within single cell

Process of maintaining a relatively constant internal environment (of whole organism) = homeostasis. d. Cells are specialized. Maintenance of homeostasis requires co-operation of many different cell types, not just circuits within a single cell.
the tendency of biological systems to maintain relatively constant conditions in the internal envi ronment while continuously interacting with and adjusting to changes originating within or outs ide the system. See also **BALANCE** and **EQUILIBRIUM**. adj., *adj* homeostat´ic. The term is consid ered by some to be misleading in that the word element.
STASIS implies a static or fixed and unmoving state, whereas homeostasis actually involves cont inuous motion, adaptation, and change in response to environmental factors.It is through homeo static mechanisms that body temperature is kept within normal range, the osmotic pressure of th e blood and its hydrogen ion concentration (pH) is kept within strict limits, nutrients are supplie d to cells as needed, and waste products are removed before they accumulate and reach toxic le vels of concentration. These are but a few examples of the thousands of homeostatic control sys tems within the body. Some of these systems operate within the cell and others operate within a n aggregate of cells (organs) to control the complex interrelationships among the various organs

Lecture #`113, 114

Reproduction

Reproduction (or procreation or breeding) is the biological process by which new individual

organisms – "offspring" – are produced from their "parents". Reproduction is a fundamental feature of all known life; each individual organism exists as the result of reproduction.

Asexual reproduction involves a single parent. It results in offspring that are genetically identical to each other and to the parent. All prokaryotes and some eukaryotes reproduce this way. There are several different methods of asexual reproduction. They include binary fission, **fragmentation**, and **budding**.

- **Binary fission** occurs when a parent cell splits into two identical daughter cells of the same size.
- **Fragmentation** occurs when a parent organism breaks into fragments, or pieces, and each fragment develops into a new organism. reproduce this way. A new starfish can develop from a single ray, or arm. Starfish, however, are also capable of sexual reproduction.

- **Budding** occurs when a parent cell forms a bubble-like bud. The bud stays attached to the parent cell while it grows and develops. When the bud is fully developed, it breaks away from the parent cell and forms a new organism.

  Sexual reproduction involves two parents. As you can see from **Figure** below, in sexual reproduction, parents produce reproductive cells—called **gametes**—that unite to form an offspring. Gametes are **haploid** cells. This means they contain only half the number of chromosomes found in other cells of the organism. Gametes are produced by a type of cell division called **meiosis**, which is described in detail in a subsequent concept. The process in which two gametes unite is called **fertilization**. The fertilized cell that results is referred to as a **zygote**. A zygote is **diploid** cell, which means that it has twice the number of chromosomes as a **gamete**.

Lecture #`113, 114

Symbiotic lifestyles

Symbiosis is an intimate association between two organisms. There are following types of symbiosis in protozoans: 1. Parasitism: An association in which one organism lives in or on a second organism, host and causes disease in the host is called parasitism.

Symbiosis is a relationship between two or more organisms that live closely together. There are several types or classes of symbiosis:

Commensalism

One organism benefits and the other is neither harmed nor helped.

Mutualism

Both organisms benefit. An obligate mutualist cannot survive without its partner; a facultative mutualist can survive on its own.

Parasitism

One organism (the parasite) benefits and the other (the host) is harmed.

To be successful, a symbiotic relationship requires a great deal of balance. Even parasitism, where one partner is harmed, is balanced so that the host lives long enough to allow the parasite to spread and reproduce.

These delicate relationships are the product of long years of co-evolution. Bacteria were the first living things on the planet, and all of Earth's other creatures have been living and evolving with them for hundreds of millions of years. Today, microbes are essential for many organisms' basic functions, including nourishment, reproduction, and protection.

Lecture #`115

The four kingdoms of eukaryotes

The first eukaryotes were unicellular organisms. A wide variety of unicellular eukaryotes exist today, grouped together in the kingdom Protista (along with some multicellular descendants) on the basis that they do not fit into any of the other three kingdoms of eukaryotes. Fungi, plants, and animals are largely multicellular kingdoms, each a distinct evolutionary line from a single-celled ancestor that would be classified in the kingdom Protista. Because of the size and ecological dominance of plants, animals, and fungi, and because they are predominantly multi cellular, we recognize them as kingdoms distinct from Protista, even though the amount of diversity among the protists is much greater than that within or between the fungi, plants, and animals.

Animalia

Organisms in the animalia kingdom are multicellular and don’t have cell walls or photosynthetic pigments. The animalia kingdom contains more than 1,000,000 species, according to Palomar College. All organisms in the animalia kingdom has some type of skeletal support and have specialized cells. In addition, these organisms have cellular, tissue, organ and system organization. All organisms in the animalia kingdom reproduce sexually instead of asexually.

Plantae

The plantae kingdom has more than 250,000 species, according to Palomar College. All land plants such as ferns, conifers, flowering plants and mosses are found in the plantae kingdom. Organisms in the plantae kingdom produce energy via photosynthesis. In addition, organisms in the plantae kingdom have a cell wall and a pigment called chlorophyll that helps capture light energy. The captured light energy is converted to sugars, starches and other types of carbohydrates.

Fungi

The fungi kingdom is responsible for breaking down dead organic material and helps recycle nutrients through ecosystems, according to the University of California Museum of Paleontology. In addition, the majority of vascular plants rely on symbiotic fungi to grow. Symbiotic fungi are found in the roots of all vascular plants and provide them with important nutrients. Fungi provide many types of medications such as antibiotics and penicillin, but also cause many diseases in the animalia kingdom. Fungal diseases are extremely difficult to treat because fungi are extremely similar genetically and chemically to organisms in the animalia kingdom.

Protista

The protista kingdom includes unicellular and multicellular organisms, according to Clermont College. Organisms in the protista kingdom need to live in some type of water environment to survive. This may include fresh water, marine water, damp soil and even the wet hair of an animal like a polar bear. The three types of organisms in the protista kingdom are protozoa, algae, and fungus-like protists. Protozoa obtain their food with phagocytosis, which involves engulfing their prey with mouth-like structures. Algae contain chlorophyll and obtain their food through photosynthesis just like organisms in the plantae kingdom. Fungus-like protists absorb nutrients from their environment directly into their cytoplasm. Slime molds are an example of fungus-like protists and commonly live in decayed wood.

Lecture #`115

Key characteristics of the eukaryotes

The characteristics of the six kingdoms are outlined in table 26.2 ; note that the archaea and bacteria are grouped in the same column. Although eukaryotic organisms are extraordinarily diverse, they share three characteristics that distinguish them from prokaryotes: compartmentalization; multi cellularity in many, but not all, eukaryotes; and sexual reproduction.

Compartmentalization

Discrete compartments provide evolutionary opportunities for increased specialization within the cell, as we see with chloroplasts and mitochondria. The evolution of a nuclear membrane, not found in prokaryotes, also accounts for increased complexity in eukaryotes. In eukaryotes, RNA transcripts from nuclear DNA are processed and transported across the nuclear membrane into the cytosol, where translation occurs. The physical separation of transcription and translation in eukaryotes adds additional levels of control to the process of gene expression.

Multicellularity. The unicellular body plan has been tremendously successful, with unicellular prokaryotes and eukaryotes constituting about half of the biomass on Earth. But a single cell has limits. The evolution of multicellularity allowed organisms to deal with their environments in novel ways through differentiation of cell types into tissues and organs. True multicellularity, in which the activities of individual cells are coordinated and the cells themselves are in contact, occurs only in eukaryotes and is one of their major characteristics. Bacteria and many protists form colonial aggregates of many cells, but the cells in the aggregates have little differentiation or integration of function. Other protists—the red, brown, and green algae, for example—have independently attained multicellularity. One lineage of multicellular green algae was the ancestor of the plants , and most taxonomists now place its members in the green plant kingdom, the Viridi plantae.

The multiple origins of multicellularity are also seen in the fungi and the animals, which arose from unicellular protist ancestors with different characteristics. As you will see in subsequent chapters, the groups that seem to have given rise to each of these kingdoms are still in existence.

Sexual Reproduction. Another major characteristic of eukaryotic species as a group is sexual reproduction. Although some interchange of genetic material occurs in bacteria, it is certainly not a regular, predictable mechanism in the same sense that sex is in eukaryotes. Sexual reproduction allows greater genetic diversity through the processes of meiosis and crossing over, as you learned in chapter 13 . In many of the unicellular phyla of protists, sexual reproduction occurs only occasionally. The first eukaryotes were probably haploid; diploids seem to have arisen on a number of separate occasions by the fusion of haploid cells, which then eventually divided by mitosis.

TABLE 26.2 Characteristics of the Six Kingdoms and Three Domains

	Archaea and Bacteria	Protista	Plantae	Fungi	Animalia
Cell Type	Prokaryotic	Eukaryotic	Eukaryotic	Eukaryotic	Eukaryotic
Nuclear Envelope	Absent	Present	Present	Present	Present
Transcription and Translation	Occur in same compartment	Occur in different compartments	Occur in different compartments	Occur in different compartments	Occur in different compartments
Histone Proteins Associated with DNA	Absent	Present	Present	Present	Present
Cytoskeleton	Absent	Present	Present	Present	Present
Mitochondria	Absent	Present (or absent)	Present	Present	Present
Chloroplasts	None (photosynthetic membranes in some types)	Present (some forms)	Present	Absent	Absent
Cell Wall	Noncellulose (polysaccharide plus amino acids)	Present in some forms, various types	Cellulose and other polysaccharides	Chitin and other noncellulose polysaccharides	Absent
Means of Genetic Recombination, if Present	Conjugation, transduction, transformation	Fertilization and meiosis	Fertilization and meiosis	Fertilization and meiosis	Fertilization and meiosis
Mode of Nutrition	Autotrophic (chemosynthetic, photosynthetic) or heterotrophic	Photosynthetic or heterotrophic, or combination of both	Photosynthetic, chlorophylls *a* and *b*	Absorption	Ingestion
Motility	Bacterial flagella, gliding or nonmotile	9 + 2 cilia and flagella; amoeboid, contractile fibrils	None in most forms; 9 + 2 cilia and flagella in gametes of some forms	Both motile and nonmotile	9 + 2 cilia and flagella, contractile fibrils
Multicellularity	Absent	Absent in most forms	Present in all forms	Present in most forms	Present in all forms
Nervous System	None	Primitive mechanisms for conducting stimuli in some forms	A few have primitive mechanisms for conducting stimuli	None	Present (except sponges), often complex

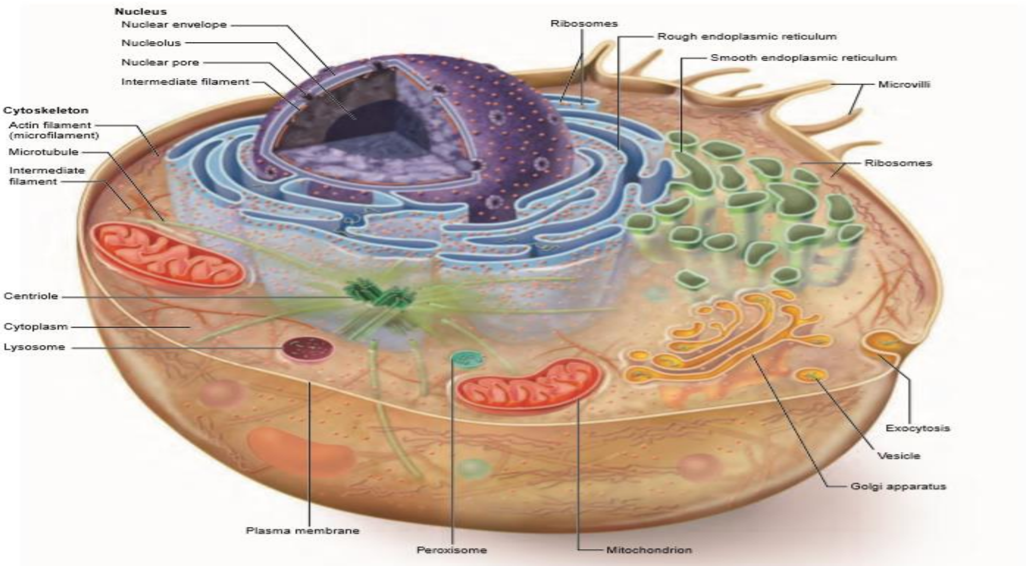
Lecture #`115

Eukaryotic Cells

Eukaryotic cells are far more complex than prokaryotic cells. The hallmark of the eukaryotic cell is compartmentalization. This is achieved through a combination of an extensive endomembrane system that weaves through the cell interior and by numerous organelles. These organelles include membrane-bounded structures that form compartments within which multiple biochemical processes can proceed simultaneously and independently. Plant cells often have a large, membrane-bounded sac called a central vacuole, which stores proteins, pigments, and waste materials.

Both plant and animal cells contain vesicles— smaller sacs that store and transport a variety of materials. Inside the nucleus, the DNA is wound tightly around proteins and packaged into compact units called chromosomes. All eukaryotic cells are supported by an internal protein scaffold, the cytoskeleton. Although the cells of animals and some protists lack cell walls, the cells of fungi, plants, and many protists have strong cell walls composed of cellulose or chitin fibers embedded in a matrix of other polysaccharides and proteins. Through the rest of this chapter, we will examine the internal components of eukaryotic cells in more detail.

Figure 4.6 Structure of an animal cell. In this generalized diagram of an animal cell, the plasma membrane encases the cell, which contains the cytoskeleton and various cell organelles and interior structures suspended in a semifluid matrix called the cytoplasm. Some kinds of animal cells possess finger-like projections called microvilli. Other types of eukaryotic cells—for example, many protist cells—may possess flagella, which aid in movement, or cilia, which can have many different functions.



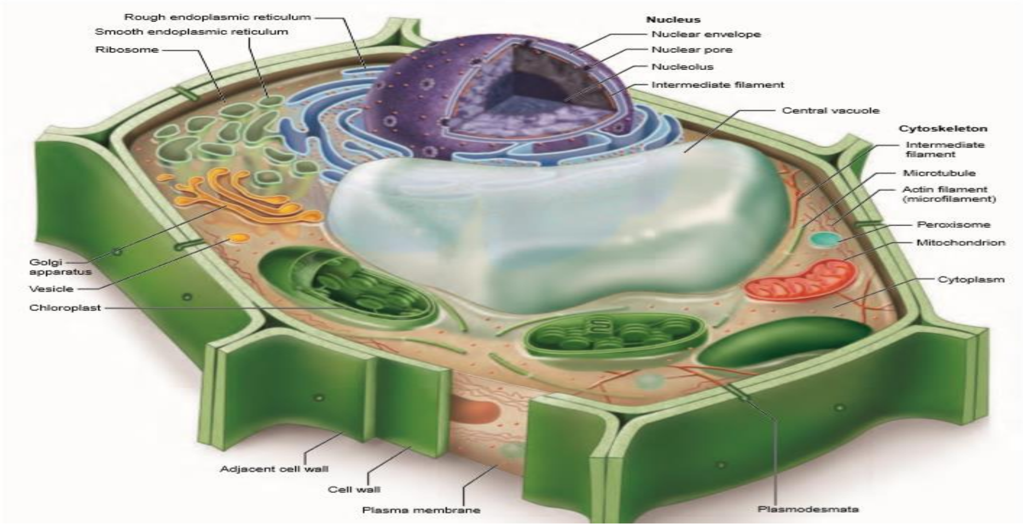


Figure 4.7 Structure of a plant cell. Most mature plant cells contain a large central vacuole, which occupies a major portion of the internal volume of the cell, and organelles called chloroplasts, within which photosynthesis takes place. The cells of plants, fungi, and some protists have cell walls, although the composition of the walls varies among the groups. Plant cells have cytoplasmic connections to one another through openings in the cell wall called plasmodesmata. Flagella occur in sperm of a few plant species, but are otherwise absent from plant and fungal cells. Centrioles are also usually absent.

Lecture #`111,112,115

The three domains probably are monophyletic

It has become increasingly clear that this group is very different from all other organisms. When the full genomic DNA sequences of an Archaean and a bacterium were first compared in 1996, the differences proved striking. Archaea are as different from bacteria as bacteria are from eukaryotes. Recognizing this, biologists are increasingly adopting a classification of living organisms that recognizes three domains, a taxonomic level higher than kingdom.

Archaea are in one domain (Domain Archaea), bacteria in a second (Domain Bacteria), and eukaryotes in the third (Domain Eukarya). Phylogenetically each of these domains forms a clade. In the remainder of this section, we preview the major characteristics of the three domains and viruses. The oldest divergences represent the deepest-rooted branches in the tree. The archaea and eukaryotes are more closely related to each other than to bacteria and are on a separate evolutionary branch of the tree.

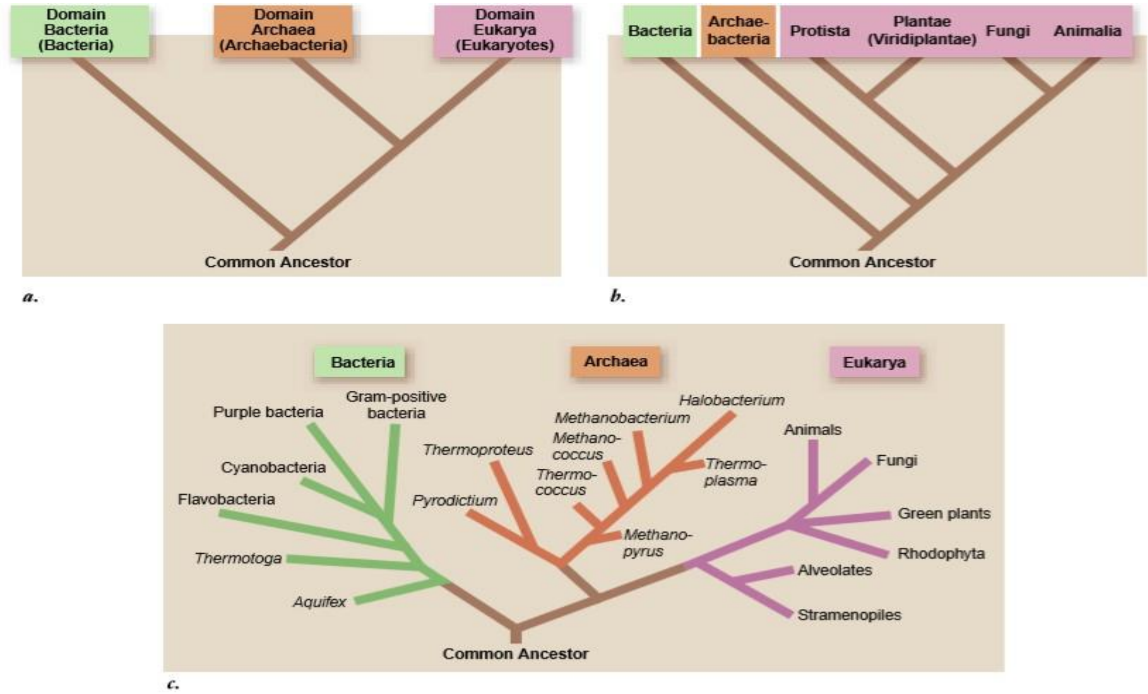


Figure 26.7 Different approaches to classifying living organisms. ***a.*** Bacteria and Archaea are so distinct that they have been assigned to separate domains distinct from the Eukarya. Members of the domain Bacteria are thought to have diverged early from the evolutionary line that gave rise to the archaea and eukaryotes. ***b.*** Eukarya are grouped into four kingdoms, but these, especially the protists, are not necessarily monophyletic groups. ***c.*** This phylogeny is prepared from rRNA analyses. The base of the tree was determined by examining genes that are duplicated in all three domains, the duplication presumably having occurred in the common ancestor. Archaea and eukaryotes diverged later than bacteria and are more closely related to each other than either is to bacteria. Bases of trees constructed with other traits are often less clear because of horizontal gene transfer (see chapter 24).

Lecture #`116

The nucleus acts as the information center

The largest and most easily seen organelle within a eukaryotic cell is the nucleus (Latin, “kernel” or “nut”), first described by the botanist Robert Brown in 1831. Nuclei are roughly spherical in shape, and in animal cells, they are typically located in the central region of the cell. In some cells, a network of fine cytoplasmic filaments seems to cradle the nucleus in this position. The nucleus is the repository of the genetic information that enables the synthesis of nearly all proteins of a living eukaryotic cell. Most eukaryotic cells possess a single nucleus, although the cells of fungi and some other groups may have several to many nuclei. Mammalian erythrocytes (red blood cells) lose their nuclei when they mature. Many nuclei exhibit a dark-staining zone called the nucleolus, which is a region where intensive synthesis of ribosomal RNA is taking place.

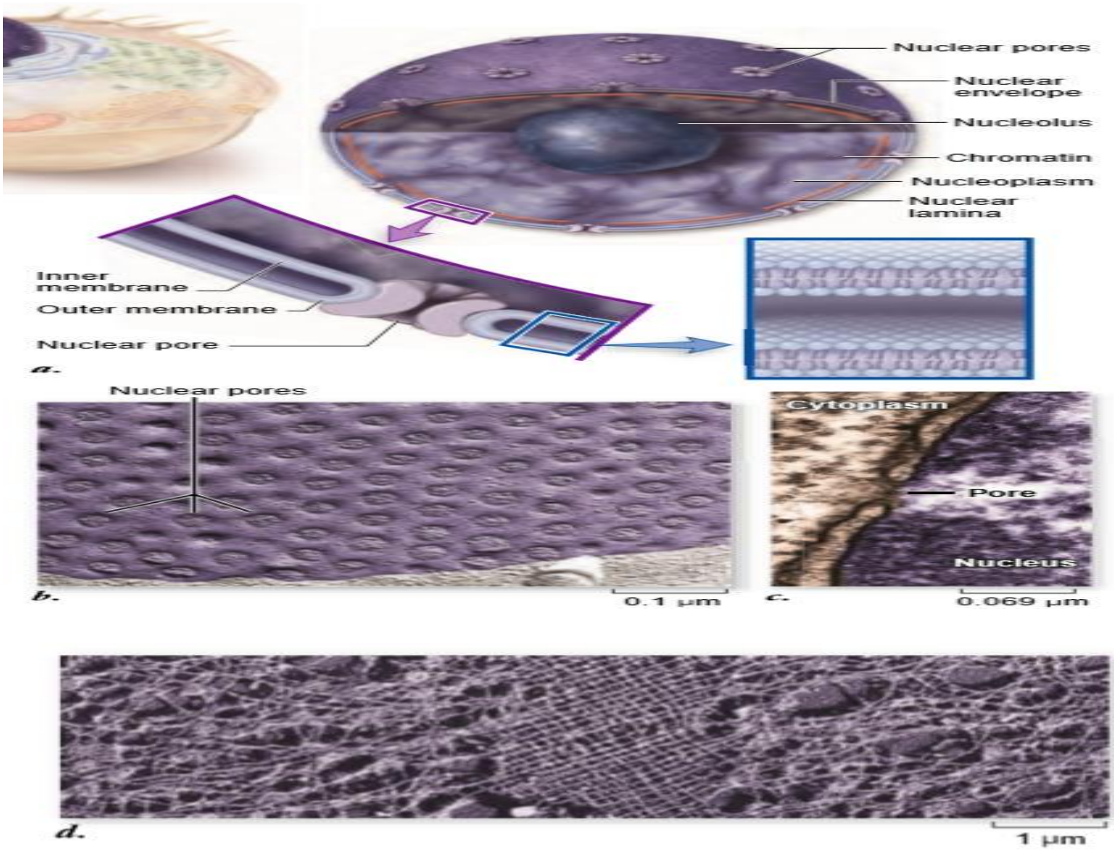


Figure 4.8 The nucleus. *a.* The nucleus is composed of a double membrane called the nuclear envelope, enclosing a fluid-filled interior containing chromatin. The individual nuclear pores extend through the two membrane layers of the envelope. *b.* A freeze-fracture electron micrograph (see figure 5.3) of a cell nucleus, showing many nuclear pores. *c.* A transmission electron micrograph of the nuclear membrane showing a single nuclear pore. The dark material within the pore is protein, which acts to control access through the pore. *d.* The nuclear lamina is visible as a dense network of fibers made of intermediate filaments. The nucleus has been colored purple in the micrographs.
(b): © Dr. Richard Kessel & Dr. Gene Shih/Visuals Unlimited

The nuclear envelope

The surface of the nucleus is bounded by two phospholipid bilayer membranes, which together make up the nuclear envelope. The outer membrane of the nuclear envelope is continuous with the cytoplasm's interior membrane system, called the endoplasmic reticulum (described later). Scattered over the surface of the nuclear envelope are what appear as shallow depressions in the electron micrograph but are in fact structures called nuclear pores. These pores form 50 to 80 nm apart at locations where the two membrane layers of the nuclear envelope pinch together.

They have a complex structure with a cytoplasmic face, a nuclear face, and a central ring embedded in the membrane. The proteins that make up this nuclear pore complex are arranged in a circle with a large central hole. The complex allows small molecules to diffuse freely between nucleoplasm and cytoplasm while controlling the passage of proteins and RNA– protein complexes. Passage is restricted primarily to two kinds of molecules: (1) proteins moving into the nucleus to be incorporated into nuclear structures or to catalyze nuclear activities and (2) RNA and R NA–protein complexes formed in the nucleus and exported to the cytoplasm. The inner surface of the nuclear envelope is covered with a network of fibers that make up the nuclear lamina. This is composed of intermediate filament fibers called nuclear lamins. This structure gives the nucleus its shape and is also involved in the deconstruction and reconstruction of the nuclear envelope that accompanies cell division.

Chromatin: DNA packaging

In both prokaryotes and eukaryotes, DNA contains the hereditary information specifying cell structure and function. In most prokaryotes, the DNA is organized into a single circular chromosome. In eukaryotes, the DNA is divided into multiple linear chromosomes. The DNA in these chromosomes is organized with proteins into a complex structure called chromatin. Chromatin is usually in a more extended form that allows regulatory proteins to attach to specific nucleotide sequences along the DNA and regulate gene expression. Without this access, DNA could not direct the day-to-day activities of the cell. When cells divide, the chromatin must be further compacted into a more highly condensed form.

The nucleolus: Ribosomal subunit manufacturing

Before cells can synthesize proteins in large quantity, they must first construct a large number of ribosomes to carry out this synthesis. Hundreds of copies of the genes encoding the ribosomal RNAs are clustered together on the chromosome, facilitating ribsosome construction. By transcribing RNA molecules from this cluster, the cell rapidly generates large numbers of the molecules needed to produce ribosomes.

The clusters of ribosomal RNA genes, the RNAs they produce, and the ribosomal proteins all come together within the nucleus during ribosome production. These ribosomal assembly areas are easily visible within the nucleus as one or more dark-staining regions called nucleoli singular, nucleolus). Nucleoli can be seen under the light microscope even when the chromosomes are uncoiled.

Lecture #`117

Ribosomes are the cell’s protein synthesis machinery

Although the DNA in a cell’s nucleus encodes the amino acid sequence of each protein in the cell, the proteins are not assembled there. A simple experiment demonstrates this: If a brief pulse of radioactive amino acid is administered to a cell, the radioactivity shows up associated with newly made protein in the cytoplasm, not in the nucleus. When investigators first carried out these experiments, they found that protein synthesis is associated with large RNA–protein complexes (called ribosomes) outside the nucleus.

Ribosomes are among the most complex molecular assemblies found in cells. Each ribosome is composed of two subunits, and each subunit is composed of a combination of RNA, called ribosomal RNA (rRNA), and proteins. The subunits join to form a functional ribosome only when they are actively synthesizing proteins. This complicated process requires the two other main forms of RNA: messenger RNA (mRNA), which carries coding information from DNA, and transfer RNA (tRNA), which carries amino acids. Ribosomes use the information in mRNA to direct the synthesis of a protein.

Ribosomes are found either free in the cytoplasm or associated with internal membranes, as described in the following section. Free ribosomes synthesize proteins that are found in the cytoplasm, nuclear proteins, mitochondrial proteins, and proteins found in other organelles not derived from the endomembrane system. Membrane-associated ribosomes synthesize membrane proteins, proteins found in the endomembrane system, and proteins destined for export from the cell. Ribosomes can be thought of as "universal organelles" because they are found in all cell types from all three domains of life. As we build a picture of the minimal essential functions for cellular life, ribosomes will be on the short list. Life is protein-based, and ribosomes are the factories that make proteins.

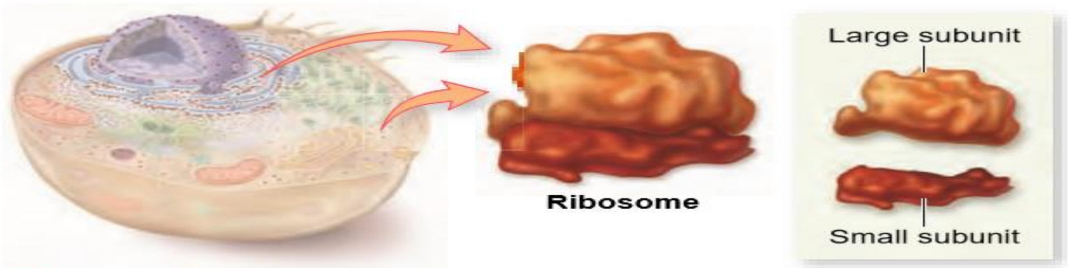


Figure 4.9 A ribosome. Ribosomes consist of a large and a small subunit composed of rRNA and protein. The individual subunits are synthesized in the nucleolus and then move through the nuclear pores to the cytoplasm, where they assemble to translate mRNA. Ribosomes serve as sites of protein synthesis.

Lecture #`118

The Endomembrane System

The interior of a eukaryotic cell is packed with membranes so thin that they are invisible under the low resolving power of light microscopes. This endomembrane system fills the cell, dividing it into compartments, channeling the passage of molecules through the interior of the cell, and providing surfaces for the synthesis of lipids and some proteins. The presence of these membranes in eukaryotic cells marks one of the fundamental distinctions between eukaryotes and prokaryotes. The largest of the internal membranes is called the **endoplasmic reticulum** (ER). Endoplasmic means "within the cytoplasm," and reticulum is Latin for "a little net." Like the plasma membrane, the ER is composed of a phospholipid bilayer embedded with proteins. It weaves in sheets through the interior of the cell, creating a series of channels between its folds. Of the many compartments in eukaryotic cells, the two largest are the inner region of the ER, called the cisternal space or lumen, and the region exterior to it, the cytosol, which is the fluid component of the cytoplasm containing dissolved organic molecules such as proteins and ions.

The rough ER is a site of protein synthesis

The rough ER (RER) gets its name from its surface appearance, which is pebbly due to the presence of ribosomes. The RER is not easily visible with a light microscope, but it can be seen using the electron microscope. It appears to be composed of flattened sacs, the surfaces of which are bumpy with ribosomes. The proteins synthesized on the surface of the RER are destined to be exported from the cell, sent to lysosomes or vacuoles (described in a later section), or embedded in the plasma membrane. These proteins enter the cisternal space as a first step in the pathway that will sort proteins to their eventual destinations. This pathway also involves vesicles and the Golgi apparatus, described later. The sequence of the protein being synthesized determines whether the ribosome will become associated with the ER or remain a cytoplasmic ribosome. In the ER, newly synthesized proteins can be modified by the addition of short-chain carbohydrates to form glycoproteins. Those proteins destined for secretion are separated from other products and later packaged into vesicles. The ER also manufactures membranes by producing membrane. Proteins and phospholipid molecules. The membrane proteins are inserted into the ER’s own membrane, which can then expand and pinch off in the form of vesicles to be transferred to other locations.

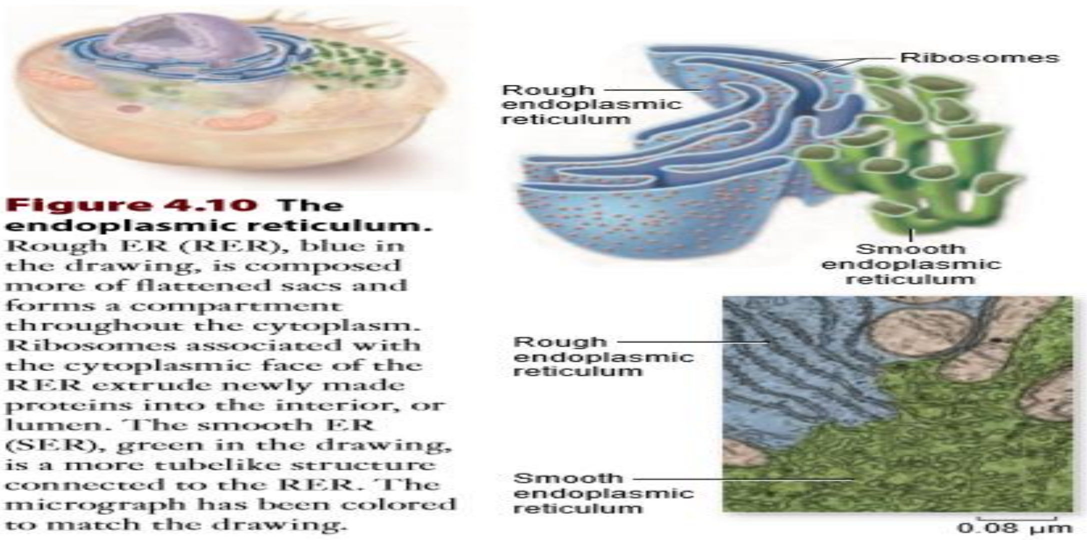


Figure 4.10 The endoplasmic reticulum. Rough ER (RER), blue in the drawing, is composed more of flattened sacs and forms a compartment throughout the cytoplasm. Ribosomes associated with the cytoplasmic face of the RER extrude newly made proteins into the interior, or lumen. The smooth ER (SER), green in the drawing, is a more tubelike structure connected to the RER. The micrograph has been colored to match the drawing.

The smooth ER has multiple roles

Regions of the ER with relatively few bound ribosomes are referred to as smooth ER (SER). The SER appears more like a network of tubules than the flattened sacs of the RER. The membranes of the SER contain many embedded enzymes. Enzymes anchored within the ER, for example, catalyze the synthesis of a variety of carbohydrates and lipids. Steroid hormones are synthesized in the SER as well. Most membrane lipids are assembled in the SER and then sent to whatever parts of the cell need membrane components.

The SER is used to store Ca2+ in cells. This keeps the cytoplasmic level low, allowing Ca2+ to be used as a signaling molecule. In muscle cells, for example, Ca2+ is used to trigger muscle contraction. In other cells, Ca2+ release from SER stores is involved in diverse signaling pathways. The ratio of SER to RER depends on a cell's function. In multicellular animals such as ourselves, great variation exists in this ratio. Cells that carry out extensive lipid synthesis, such as those in the testes, intestine, and brain, have abundant SER.

Cells that synthesize proteins that are secreted, such as antibodies, have much more extensive RER. Another role of the SER is the modification of foreign substances to make them less toxic. In the liver, the enzymes of the SER carry out this detoxification. This action can include neutralizing substances that we have taken for a therapeutic reason, such as penicillin. Thus, relatively high doses are prescribed for some drugs to offset our body's efforts to remove them. Liver cells have extensive SER as well as enzymes that can process a variety of substances by chemically modifying them.

Lecture #`119

The Golgi apparatus sorts and packages proteins

Flattened stacks of membranes, often interconnected with one another, form a complex called the Golgi body. These structures are named for Camillo Golgi, the 19th-century physician who first identified them. The number of stacked membranes within the Golgi body ranges from 1 or a few in protists, to 20 or more in animal cells and to several hundred in plant cells. They are especially abundant in glandular cells, which manufacture and secrete substances. The Golgi body is often referred to as the Golgi apparatus. The Golgi apparatus functions in the collection, packaging, and distribution of molecules synthesized at one location and used at another within the cell or even outside of it.

A Golgi body has a front and a back, with distinctly different membrane compositions at these opposite ends. The front, or receiving end, is called the cis face and is usually located near ER. Materials move to the cis face in transport vesicles that bud off the ER. These vesicles fuse with the cis face, emptying their contents into the interior, or lumen, of the Golgi apparatus. The ER synthesized molecules then pass through the channels of the Golgi apparatus until they reach the back, or discharging end, called the trans face, where they are discharged in secretory vesicles. Proteins and lipids manufactured on the rough and smooth ER membranes are transported into the Golgi apparatus and modified as they pass through it.

The most common alteration is the addition or modification of short sugar chains, forming glycoproteins and glycolipids. In many instances, enzymes in the Golgi apparatus modify existing glycoproteins and glycolipids made in the ER by cleaving a sugar from a chain or by modifying one or more of the sugars. The newly formed or altered glycoproteins and glycolipids collect at the ends of the Golgi bodies in flattened, stacked membrane folds called cisternae (Latin, “collecting vessels”). Periodically, the membranes of the cisternae push together, pinching off small, membrane-bounded secretory vesicles containing the glycoprotein and glycolipid molecules. These vesicles then diffuse to other locations in the cell, distributing the newly synthesized molecules to their appropriate destinations.

Another function of the Golgi apparatus is the synthesis of cell wall components. Noncellulose polysaccharides that form part of the cell wall of plants are synthesized in the Golgi apparatus and sent to the plasma membrane where they can be added to the cellulose that is assembled on the exterior of the cell. Other polysaccharides secreted by plants are also synthesized in the Golgi apparatus.

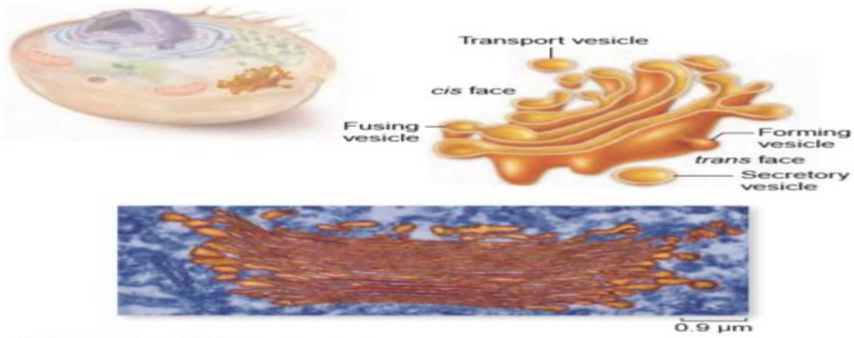


Figure 4.11 The Golgi apparatus. The Golgi apparatus is a smooth, concave, membranous structure. It receives material for processing in transport vesicles on the *cis* face and sends the material packaged in transport or secretory vesicles off the *trans* face. The substance in a vesicle could be for export out of the cell or for distribution to another region within the same cell.

Lecture #`120

Lysosomes contain digestive enzymes

Membrane-bounded digestive vesicles, called lysosomes, are also components of the endomembrane system. They arise from the Golgi apparatus. They contain high levels of degrading enzymes, which catalyze the rapid breakdown of proteins, nucleic acids, lipids, and carbohydrates. Throughout the lives of eukaryotic cells, lysosomal enzymes break down old organelles and recycle their component molecules. This makes room for newly formed organelles. For example, mitochondria are replaced in some tissues every 10 days. The digestive enzymes in the lysosome are optimally active at acid pH. Lysosomes are activated by fusing with a food vesicle produced by or by fusing with an old or worn-out organelle. The fusion event activates proton pumps in the lysosomal membrane, resulting in a lower internal pH.

As the interior pH falls, the arsenal of digestive enzymes contained in the lysosome is activated. This leads to the degradation of macromolecules in the food vesicle or the destruction of the old organelle. Several human genetic disorders, collectively called lysosomal storage disorders, affect lysosomes. For example, the genetic abnormality called Tay–Sachs disease is caused by the loss of function of a single lysosomal enzyme. This enzyme is necessary to break down a membrane glycolipid found in nerve cells. Accumulation of glycolipid in lysosomes affects nerve cell function, leading to a variety of clinical symptoms such as seizures and muscle rigidity. In addition to breaking down organelles and other structures within cells, lysosomes eliminate other cells that the cell has engulfed by phagocytosis. When a white blood cell, for example, phagocytizes a passing pathogen, lysosomes fuse with the resulting “food vesicle,” releasing their enzymes into the vesicle and degrading the material within.

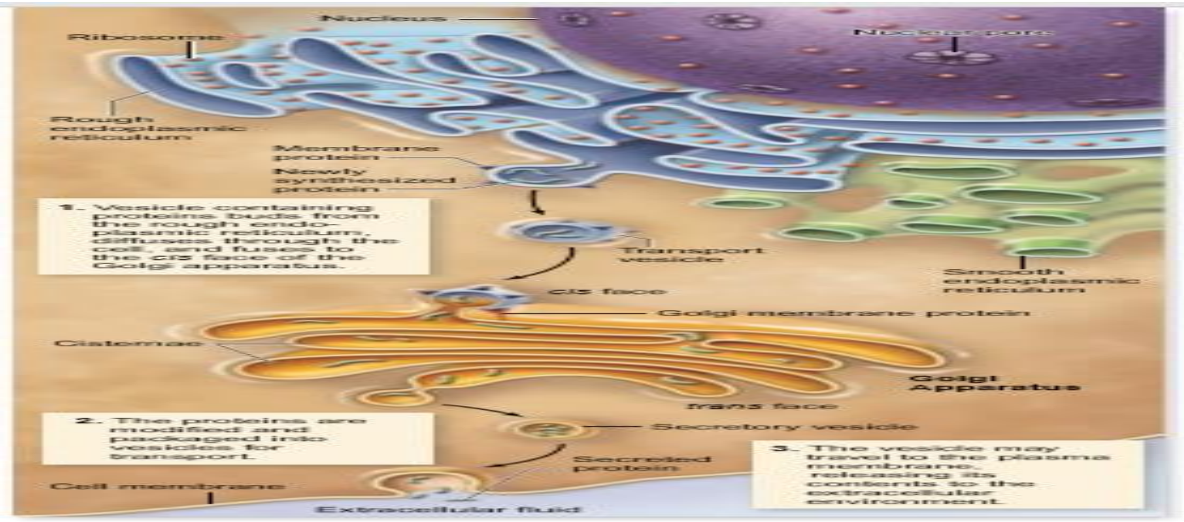


Figure 4.12 Protein transport through the endomembrane system. Proteins synthesized by ribosomes on the RER are translocated into the internal compartment of the ER. These proteins may be used at a distant location within the cell or secreted from the cell. They are transported within vesicles that bud off the rough ER. These transport vesicles travel to the *cis* face of the Golgi apparatus. There they can be modified and packaged into vesicles that bud off the *trans* face of the Golgi apparatus. Vesicles leaving the *trans* face transport proteins to other locations in the cell, or fuse with the plasma membrane, releasing their contents to the extracellular environment.

Microbodies are a diverse category of organelles

Eukaryotic cells contain a variety of enzyme-bearing, membrane enclosed vesicles called microbodies. These are found in the cells of plants, animals, fungi, and protists. The distribution of enzymes into microbodies is one of the principal ways eukaryotic cells organize their metabolism.

Peroxisomes

Peroxide utilization an important type of microbody is the peroxisome, which contains enzymes involved in the oxidation of fatty acids. If these oxidative enzymes were not isolated within microbodies, they would tend to short-circuit the metabolism of the cytoplasm, which often involves adding hydrogen atoms to oxygen. Because many peroxisomal proteins are synthesized by cytoplasmic ribosomes, the organelles themselves were long thought to form by the addition of lipids and proteins, leading to growth. As they grow larger, they divide to produce new peroxisomes.

Although division of peroxisomes still appears to occur, it is now clear that peroxisomes can form from the fusion of ER-derived vesicles. These vesicles then import peroxisomal proteins to form a mature peroxisome. Genetic screens have isolated some 32 genes that encode proteins involved in biogenesis and maintenance of peroxisomes. The human genetic diseases called peroxisome biogenesis disorders (PBDs) appear to be caused by mutations in some of these genes. Peroxisomes get their name from the hydrogen peroxide produced as a by-product of the activities of oxidative enzymes. Hydrogen peroxide is dangerous to cells because of its violent chemical reactivity. However, peroxisomes also contain the enzyme catalase, which breaks down hydrogen peroxide into its harmless constituents—water and oxygen.

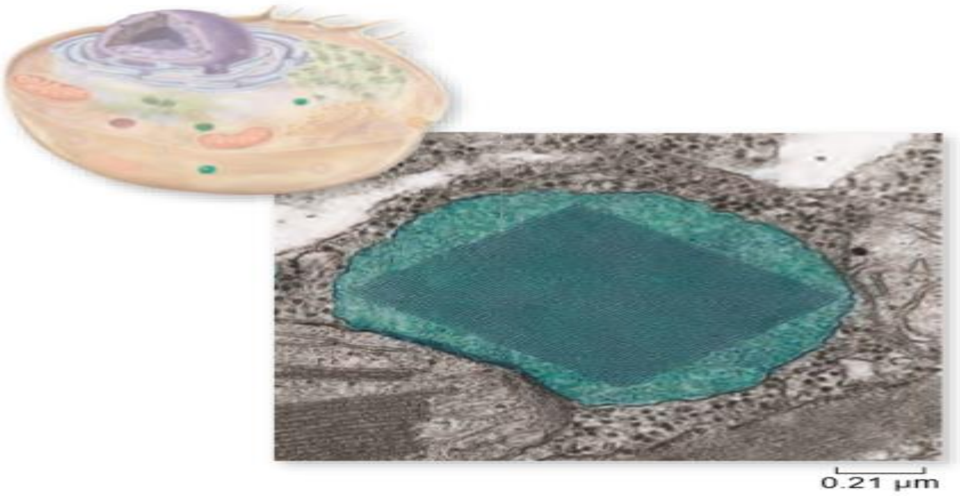


Figure 4.14 A peroxisome. Peroxisomes are spherical organelles that may contain a large crystal structure composed of protein. Peroxisomes contain digestive and detoxifying enzymes that produce hydrogen peroxide as a by-product. A peroxisome has been colored green in the electron micrograph.

Lecture #

Plants use vacuoles for storage and water balance

Plant cells have specialized membrane-bounded structures called vacuoles. The most conspicuous example is the large central vacuole seen in most plant cells. In fact, vacuole means blank space, referring to its appearance in the light microscope. The membrane surrounding this vacuole is called the tonoplast because it contains channels for water that are used to help the cell maintain its tonicity, or osmotic balance. For many years' biologists assumed that only one type of vacuole existed and that it served multiple functions. The functions assigned to this vacuole included water balance and storage of both useful molecules (such as sugars, ions and pigments) and waste products.

The vacuole was also thought to store enzymes involved in the breakdown of macromolecules and those used in detoxifying foreign substances. Old textbooks of plant physiology referred to vacuoles as the attic of the cell for the variety of substances thought to be stored there. Studies of tonoplast transporters and the isolation of vacuoles from a variety of cell types have led to a more complex view of vacuoles. These studies have made it clear that different vacuolar types can be found in different cells. These vacuoles are specialized, depending on the function of the cell. The central vacuole is clearly important for several roles in all plant cells. The central vacuole and the water

Channels of the tonoplast maintain the tonicity of the cell, allowing the cell to expand and contract depending on conditions. The central vacuole is also involved in cell growth by occupying most of the volume of the cell. Plant cells grow by expanding the vacuole, rather than by increasing cytoplasmic volume. Vacuoles with a variety of functions are also found in some types of fungi and protists. One form is the contractile vacuole, found in some protists, which can pump water and is used to maintain water balance in the cell. Other vacuoles are used for storage or to segregate toxic materials from the rest of the cytoplasm. The number and kind of vacuoles found in a cell depends on the needs of the cell type.

Lecture #`121

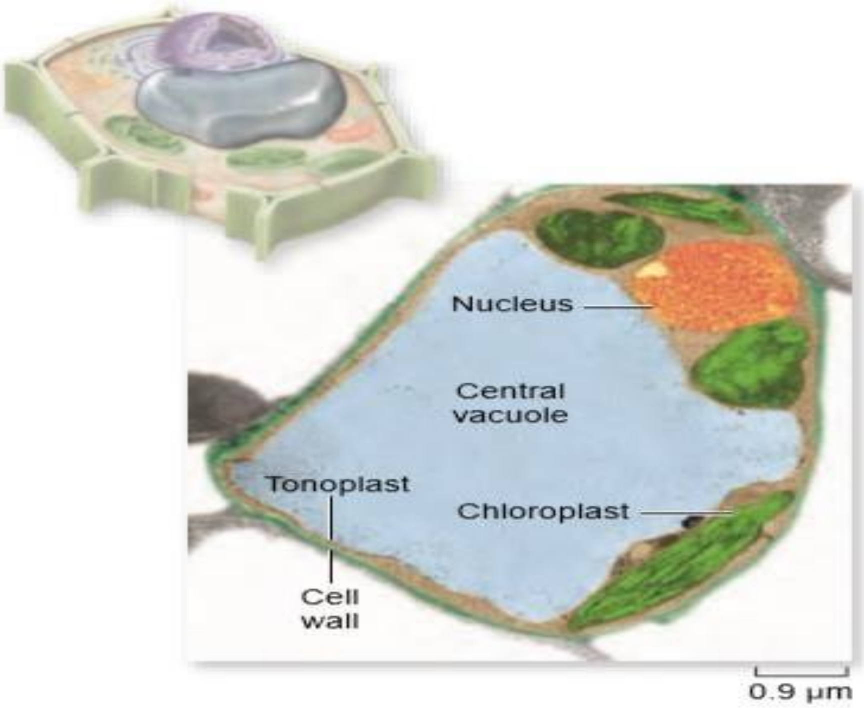


Figure 4.15 The central vacuole. A plant's central vacuole stores dissolved substances and can expand in size to increase the tonicity of a plant cell. Micrograph shown with false color.

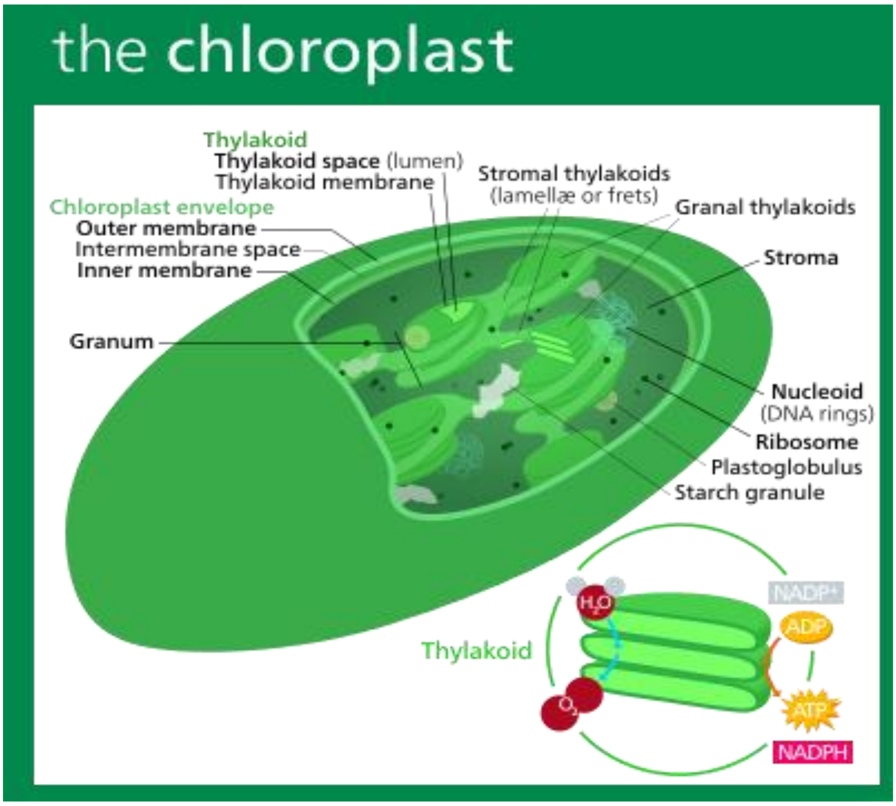
Mitochondria and Chloroplasts: Cellular Generators

Mitochondria and chloroplasts share structural and functional similarities. Structurally, they are both surrounded by a double membrane, and both contain their own DNA and protein synthesis machinery. Functionally, they are both involved in energy metabolism, as we will explore in detail in later chapters on energy metabolism and photosynthesis.

Chloroplasts are major organelles. They contain green pigments that make plants green. They are often called plastids, though plastids and chloroplasts are not exactly the same thing—a chloroplast is a special kind of plastid that photosynthesizes. Chloroplasts do lots of things, but their main function is photosynthesis.Plant cells, and some protists have chloroplasts, though animal and fungal cells lack them. Prokaryotes do not have chloroplasts (or any other organelles); though some can carry out photosynthesis, its cell acting like one big chloroplast.

Chloroplasts are mainly green in color since it absorbs red and blue light via their green pigment chlorophyll that is present in the thylakoid membranes.Chloroplasts are cellular generators.

They take in carbon dioxide and water, and release sugar and oxygen. This process is called photosynthesis. Mitochondria then use the sugar and oxygen to carry out cellular respiration, producing energy.



Mitochondria are essential parts of many eukaryotes, but they are useless without oxygen. Therefore, chloroplasts are extremely important. They produce breathable air for life.

Root hairs are seen to not have chloroplasts as their job is to collect water and nutrients. They do not carry out photosynthesis. Like mitochondria, chloroplasts have their own DNA. Scientists also think chloroplasts are descended from a kind of bacteria, called cyanobacteria. Cyanobacteria are the photosynthetic bacteria we mentioned earlier. In early stages of Earth, cyanobacteria produced oxygen for their friends, the aerobic bacteria aerobic means they use oxygen). Some of these aerobic bacteria later migrated into a eukaryotic cell, becoming mitochondria. The cyanobacteria followed, becoming chloroplasts. All eukaryotic cells contain mitochondria, but only plants and algae contain chloroplasts, so scientists think mitochondria came first.

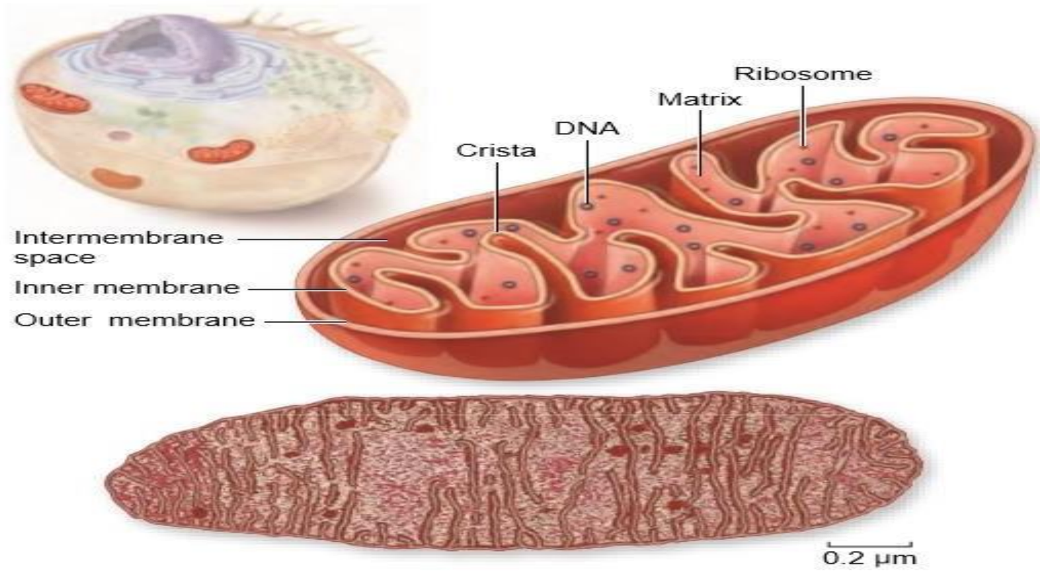


Figure 4.16 Mitochondria. The inner membrane of a mitochondrion is shaped into folds called cristae that greatly increase the surface area for oxidative metabolism. A mitochondrion in cross section and cut lengthwise is shown colored red in the micrograph.

<u>Mitochondria metabolize sugar to generate ATP</u>

Mitochondria (singular, mitochondrion) are typically tubular or sausage-shaped organelles about the size of bacteria that are found in all types of eukaryotic cells. Mitochondria are bounded by two membranes: a smooth outer membrane, and an inner folded membrane with numerous contiguous layers called cristae (singular, crista). The cristae partition the mitochondrion into two compartments: a matrix, lying inside the inner membrane; and an outer compartment, or inter-membrane space, lying between the two mitochondrial membranes. On the surface of the inner membrane, and embedded within it, are proteins that carry out oxidative metabolism, the oxygen-requiring process by which energy in macromolecules is used to produce ATP.

Mitochondria have their own DNA; this DNA contains several genes that produce proteins essential to the mitochondrion's role in oxidative metabolism. Thus, the mitochondrion, in many respects, acts as a cell within a cell, containing its own genetic information specifying proteins for its unique functions. The mitochondria are not fully autonomous, however, because most of the genes that encode the enzymes used in oxidative metabolism are in the cell nucleus. A eukaryotic cell does not produce brand-new mitochondria each time the cell divides. Instead, the mitochondria themselves divide in two, doubling in number, and these are partitioned between the new cells. Most of the components required for mitochondrial division are encoded by genes in the nucleus and are translated into proteins by cytoplasmic ribosomes.

Mitochondrial replication is, therefore, impossible without nuclear participation, and mitochondria thus cannot be grown in a cell-free culture.

Lecture #`124

Chloroplasts use light to generate ATP and sugars

Plant cells and cells of other eukaryotic organisms that carry out photosynthesis typically contain from one to several hundred chloroplasts. Chloroplasts bestow an obvious advantage on the organisms that possess them: They can manufacture their own food. Chloroplasts contain the photosynthetic pigment chlorophyll that gives most plants their green color. The chloroplast, like the mitochondrion, is surrounded by two membranes. However, chloroplasts are larger and more complex than mitochondria. In addition to the outer and inner membranes, which lie in close association with each other, chloroplasts have closed compartments of stacked membranes called grana (singular, granum), which lie inside the inner membrane. A chloroplast may contain a hundred or more grana, and each granum may contain from a few to several dozen disk shaped structures called thylakoids.

On the surface of the thylakoids are the light-capturing photosynthetic pigments, to be discussed in depth in chapter 8. Surrounding the thylakoid is a fluid matrix called the stroma. The enzymes used to synthesize glucose during photosynthesis are found in the stroma. Like mitochondria, chloroplasts contain DNA, but many of the genes that specify chloroplast components are also located in the nucleus. Some of the elements used in photosynthesis, including the specific protein components necessary to accomplish the reaction, are synthesized entirely within the chloroplast.

Other DNA containing organelles in plants, called leucoplasts, lack pigment and a complex internal structure. In root cells and some other plant cells, leucoplasts may serve as starch storage sites. A leucoplast that stores starch (amylose) is sometimes termed an amyloplast. These organelles—chloroplasts, leucoplasts, and amyloplasts—are collectively called plastids. All plastids are produced by the division of existing plastids.

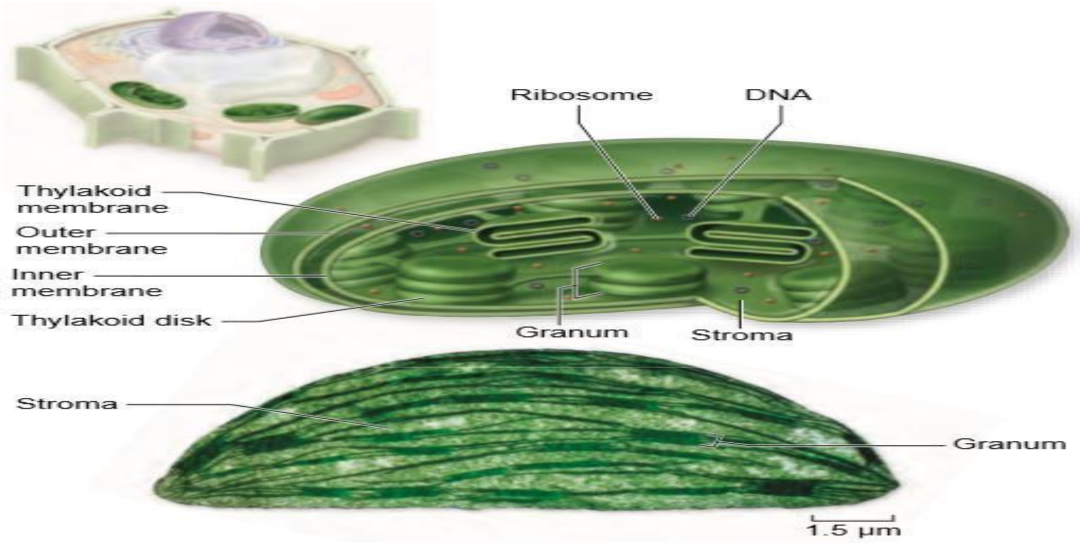


Figure 4.17 Chloroplast structure. The inner membrane of a chloroplast surrounds a membrane system of stacks of closed chlorophyll–containing vesicles called thylakoids, within which photosynthesis occurs. Thylakoids are typically stacked one on top of the other in columns called grana. The chloroplast has been colored green in the micrograph.

Mitochondria and chloroplasts arose by endosymbiosis

Symbiosis is a close relationship between organisms of different species that live together. As noted in chapter 29, the theory of endosymbiosis proposes that some of today's eukaryotic organelles evolved by a symbiosis arising between two cells that

were each free-living. One cell, a prokaryote, was engulfed by and became part of another cell, which was the precursor of modern eukaryotes. According to the endosymbiont theory, the engulfed prokaryotes provided their hosts with certain advantages associated with their special metabolic abilities. Two key eukaryotic organelles are believed to be the descendants of these endosymbiotic prokaryotes: mitochondria, which are thought to have originated as bacteria capable of carrying out oxidative metabolism, and chloroplasts, which apparently arose from photosynthetic bacteria.

Lecture#`125

Cytoskeleton

The cytoplasm of all eukaryotic cells is crisscrossed by a network of protein fibers that supports the shape of the cell and anchors organelles to fixed locations. This network, called the cytoskeleton, is a dynamic system, constantly assembling and disassembling. Individual fibers consist of polymers of identical protein subunits that attract one another and spontaneously assemble into long chains. Fibers disassemble in the same way, as one subunit after another breaks away from one end of the chain.

Three types of fibers compose the cytoskeleton

Eukaryotic cells may contain the following three types of cytoskeletal fibers, each formed from a different kind of subunit: (1) actin filaments, sometimes called microfilaments, (2) microtubules, and (3) intermediate filaments.

Actin filaments (microfilaments)

Actin filaments are long fibers about 7 nm in diameter. Each filament is composed of two protein chains loosely twined together like two strands of pearls. Each “pearl,” or subunit, on the chain is the globular protein actin. Actin filaments exhibit polarity, that is, they have plus (+) and minus (–) ends. These designate the direction of growth of the filaments. Actin molecules spontaneously form these filaments, even in a test tube. Cells regulate the rate of actin polymerization through other proteins that act as switches, turning on polymerization when appropriate. Actin filaments are responsible for cellular movements such as contraction, crawling, “pinching” during division, and formation of cellular extensions.

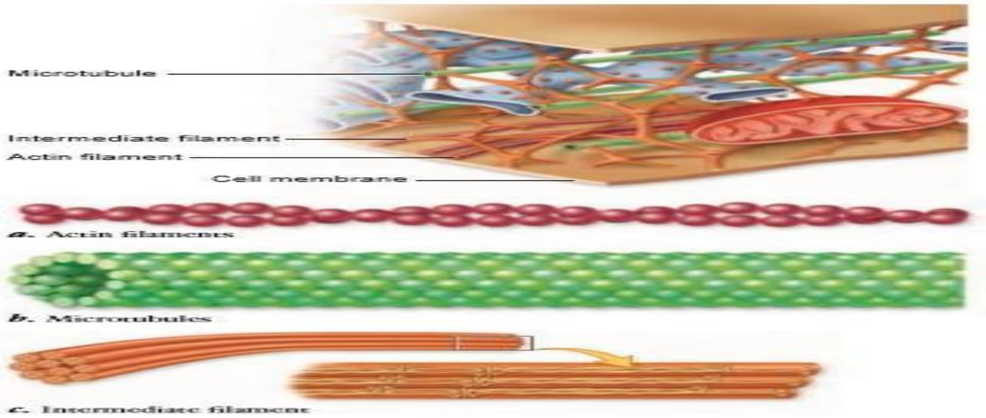


Figure 4.19 Molecules that make up the cytoskeleton. *a. Actin filaments:* Actin filaments, also called *microfilaments*, are made of two strands of the globular protein actin twisted together. They are often found in bundles or in a branching network. Actin filaments in many cells are concentrated below the plasma membrane in bundles known as stress fibers, which may have a contractile function. *b. Microtubules:* Microtubules are composed of α– and β–tubulin protein subunits arranged side by side to form a tube. Microtubules are comparatively stiff cytoskeletal elements and have many functions in the cell including intracellular transport and the separation of chromosomes during mitosis. *c. Intermediate filaments:* Intermediate filaments are composed of overlapping staggered tetramers of protein. These tetramers are then bundled into cables. This molecular arrangement allows for a ropelike structure that imparts tremendous mechanical strength to the cell.

Microtubule

Microtubules, the largest of the cytoskeletal elements, are hollow tubes about 25 nm in diameter, each composed of a ring of 13 protein protofilaments. Globular proteins consisting of dimers of α- and β-tubulin subunits polymerize to form the 13 protofilaments. The protofilaments are arrayed side by side around a central core, giving the microtubule its characteristic tube shape. In many cells, microtubules form from nucleation centers near the center of the cell and radiate toward the periphery. They are in a constant state of flux, continually polymerizing and depolymerizing. The average half-life of a microtubule ranges from as long as 10 minutes in a non-dividing animal cell to as short as 20 seconds in a dividing animal cell. The ends of the microtubule are designated as plus (+) (away from the nucleation center) or minus (–) (toward the nucleation center). Along with facilitating cellular movement, microtubules organize the cytoplasm and are responsible for moving materials within the cell itself, as described shortly.

Intermediate filaments

The most durable element of the cytoskeleton in animal cells is a system of tough, fibrous protein molecules twined together in an overlapping arrangement. These intermediate filaments are characteristically 8 to 10 nm in diameter—between the size of actin filaments and microtubules. Once formed, intermediate filaments are stable and usually do not break down. Intermediate filaments constitute a mixed group of cytoskeletal fibers. The most common type, composed of protein subunits called vimentin, provides structural stability for many kinds of cells. Keratin, another class of intermediate filament, is found in epithelial cells (cells that line organs and body cavities) and associated structures such as hair and fingernails. The intermediate filaments of nerve cells are called neurofilaments.

Extracellular Structures and Cell Movement

Essentially all cell motion is tied to the movement of actin filaments, microtubules, or both. Intermediate filaments act as intracellular tendons, preventing excessive stretching of cells. Actin filaments play a major role in determining the shape of cells. Because actin filaments can form and dissolve so readily, they enable some cells to change shape quickly.

Some cells crawl

The arrangement of actin filaments within the cell cytoplasm allows cells to crawl, literally! Crawling is a significant cellular phenomenon, essential to such diverse processes as inflammation, clotting, wound healing, and the spread of cancer. White blood cells exhibit this ability. Produced in the bone marrow, these cells are released into the circulatory system and then eventually crawl out of venules and into the tissues to destroy potential pathogens. At the leading edge of a crawling cell, actin filaments rapidly polymerize, and their extension forces the edge of the cell forward. This extended region is stabilized when microtubules polymerize into the newly formed region. Overall forward movement of the cell is then achieved through the action of the protein myosin, which is best known for its role in muscle contraction. Myosin motors along the actin filaments contract, pulling the contents of the cell toward the newly extended front edge. Cells crawl when these steps occur continuously, with a leading edge extending and stabilizing, and then motors contracting to pull the remaining cell contents along. Receptors on the cell surface can detect molecules outside the cell and stimulate extension in specific directions, allowing cells to move toward targets.

Flagella and cilia aid movement

Earlier in this chapter, we described the structure of prokaryotic flagella. Eukaryotic cells have a completely different kind of flagellum, consisting of a circle of nine microtubule pairs surrounding two central microtubules. This arrangement is referred to as the 9 + 2 structure. As pairs of microtubules move past each other using arms composed of the motor protein dynein, the eukaryotic flagellum undulates, rather than rotates. When examined carefully, each flagellum proves to be an outward projection of the cell's interior, containing cytoplasm and enclosed by the plasma membrane.

The microtubules of the flagellum are derived from a basal body, situated just below the point where the flagellum protrudes from the surface of the cell. The flagellum's complex microtubular apparatus evolved early in the history of eukaryotes. Today the cells of many multicellular and some unicellular eukaryotes no longer r possess flagella and are nonmotile. Other structures, called cilia (singular, cilium), with an organization like the 9 + 2 arrangement of microtubules can still be found within them. Cilia are short cellular projections that are often organized in rows. They are more numerous than flagella on the cell surface but have the same internal structure. In many multicellular organisms, cilia carry out tasks far removed from their original function of propelling cells through water. In several kinds of vertebrate tissues, for example, the beating of rows of cilia moves water over the tissue surface.

The sensory cells of the vertebrate ear also contain conventional cilia surrounded by actin- based stereocilia; sound waves bend these structures and provide the initial sensory input for hearing. Thus, the 9 + 2 structure of flagella and cilia appears to be a fundamental component of eukaryotic cells.

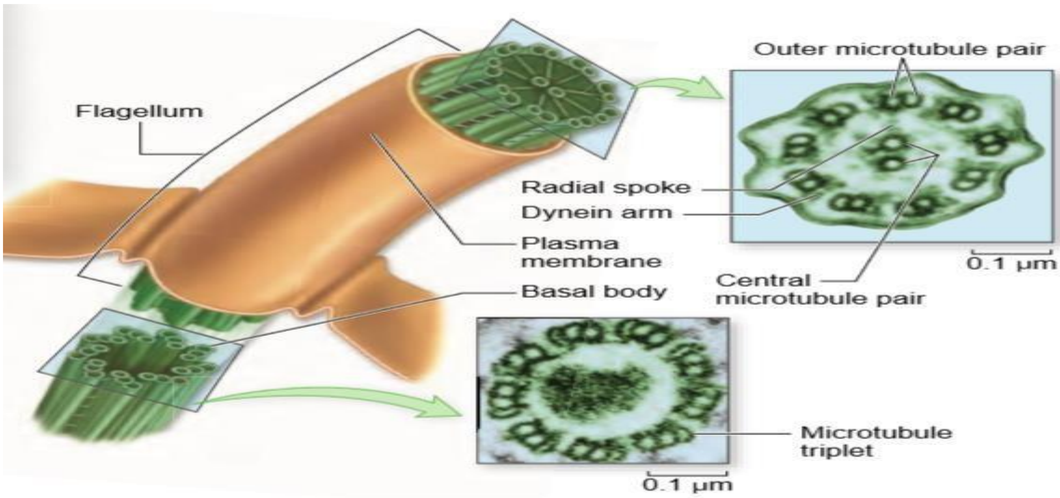


Figure 4.23 Flagella and cilia. A eukaryotic flagellum originates directly from a basal body. The flagellum has two microtubules in its core connected by radial spokes to an outer ring of nine paired microtubules with dynein arms (9 + 2 structure). The basal body consists of nine microtubule triplets connected by short protein segments. The structure of cilia is similar to that of flagella, but cilia are usually shorter.

Lecture #`127

Making Sense of the Protists

The kingdom Protista illustrates well the source of this tension. This kingdom is the weakest area of the six-kingdom classification system. Eukaryotes diverged rapidly in a world that was shifting from anaerobic to aerobic conditions. We may never be able to completely sort out the relationships among different lineages during this major evolutionary transition. Molecular systematics, however, clearly shows that the protists are a para phyletic group.

A although biologists continue to use the term protist as a catchall for any eukaryote that is not a plant, fungus, or animal, this grouping is not based on evolutionary relationships. The six main branching's of protists. Choanoflagellates are most closely related to sponges, and indeed, to all animals. The green algae can be split into two monophyletic groups, one of which gave rise to land plants. Many systematists are calling for a new kingdom called Viridiplantae, or the green plant kingdom, which would include all the green algae (not red or brown algae) and the land plants. Thus, the definition of a plant has been expanded beyond those species that made it onto land. Although the kingdom Protista is in ruins, our understanding of the evolutionary relationships among these early eukaryotes is growing exponentially.

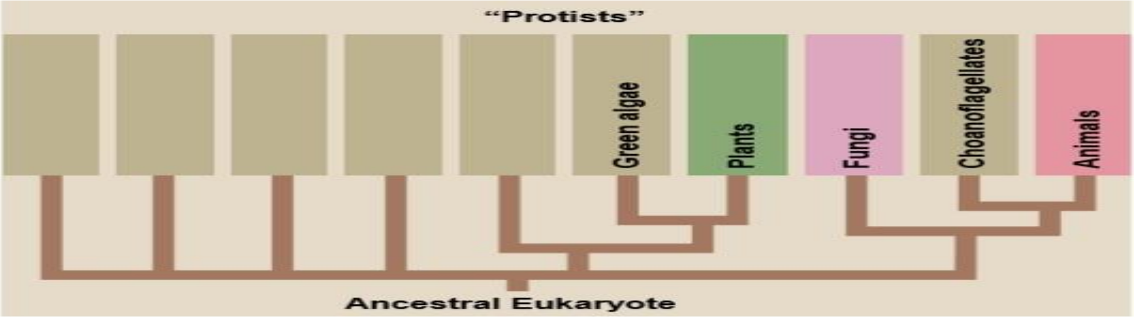


Figure 26.11 The fall of kingdom Protista. Systematists have shown that protists as a group are not monophyletic. Note how some lineages are actually more closely related to plants or animals than they are to other protists.

monophyletic groups, one of which gave rise to land plants. Many systematists are calling for a new kingdom called Virid-iplantae, or the green plant kingdom, which would include all the green algae (not red or brown algae) and the land plants. Thus, the definition of a plant has been expanded beyond those species that made it onto land. Although the kingdom Protista

Lecture #`128

Class Phytomastigophorea

The subphylum Mastigophora has two classes. Members of the class Phytomastigophorea (Gr. phytos, plant) possess chlorophyll and one or two flagella. Phytomastigophoreans produce a large portion of the food in marine food webs. Much of the oxygen used in aquatic habitats comes from photosynthesis by these marine organisms. Marine phytomastigophoreans include the dinoflagellates. Dinoflagellates have one flagellum that wraps around the organism in a transverse groove. The primary action of this flagellum causes the organism to spin on its axis. A second flagellum is a trailing flagellum that pushes the organism forward. In addition to chlorophyll, many dinoflagellates contain xanthophyll pigments, which give them a golden-brown color. At times, dinoflagellates become so numerous that they color the water. Several genera, such as Gymnodinium, have representatives that produce toxins. Periodic "blooms" of these organisms are called "red tides" and result in fish kills along the continental shelves. Humans who consume tainted molluscs or fish may die.

The Bible reports that the first plague Moses visited upon the Egyptians was a blood-red tide that killed fish and fouled water. Indeed, the Red Sea is probably named after these toxic dinoflagellate blooms. Euglena is a freshwater phyto mastigophorean. Each chloroplast has a pyrenoid, which synthesizes and stores polysaccharides. If cultured in the dark, euglenoids feed by absorption and lose their green color. Some euglenoids

(Peranema) lack chloroplasts and are always heterotrophic. Euglena orients toward light of certain intensities. A pigment shield (stigma) covers a photoreceptor at the base of the flagellum. The stigma permits light to strike the photoreceptor from only one direction, allowing Euglena to orient and move in relation to a light source.

Euglenoid flagellates are haploid and reproduce by longitudinal binary fission. Sexual reproduction in these species is unknown. Volvoxis a colonial flagellate consisting of up to 50,000 cells embedded in a spherical, gelatinous matrix (figure 8.8a). Individual cells possess two flagella, which cause the colony to roll and turn gracefully through the water (figure 8.8b). Although most Volvox cells are relatively unspecialized, reproduction depends on certain specialized cells. Asexual reproduction occurs in the spring and summer when certain cells withdraw to the watery interior of the parental colony and form daughter colonies. When the parental colony dies, it ruptures and releases daughter colonies. Sexual reproduction in Volvox occurs during autumn. Some species are dioecious (having separate sexes); other species are monoecious (having both sexes in the same colony).

In autumn, specialized cells differentiate into macrogametes or microgametes. Macrogametes are large, filled with nutrient reserves, and nonmotile. Microgametes form as a packet of flagellated cells that leaves the parental colony and swims to a colony containing macrogametes. The packet then breaks apart, and syngamy occurs between macro- and microgametes. The zygote, an overwintering stage, secretes a resistant wall around itself and is released when the parental colony dies. Because the parental colony consists of haploid cells, the zygote must undergo meiosis to reduce the chromosome number from the diploid zygotic condition. One of the products of meiosis then undergoes repeated mitotic divisions to form a colony consisting of just a few cells. The other products of meiosis degenerate. This colony is released from the protective zygotic capsule in the spring.

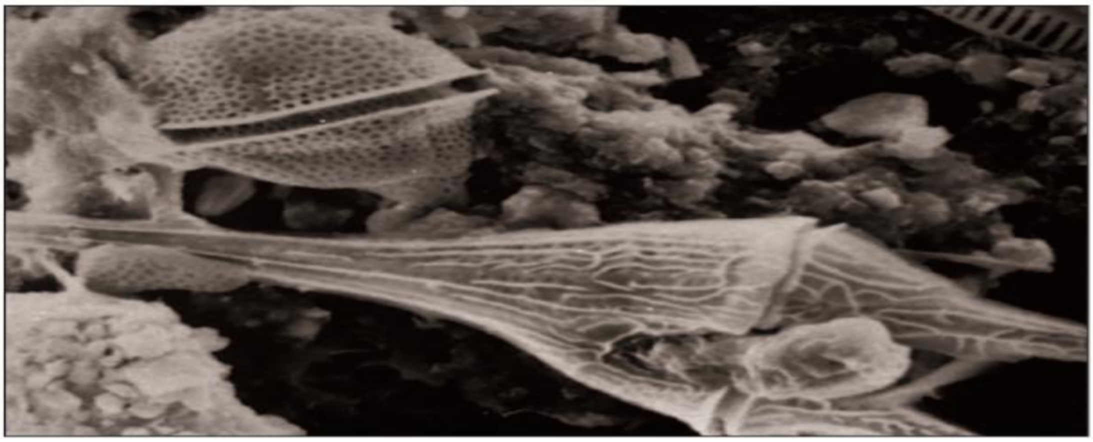


FIGURE 8.6

Class Phytomastigophorea: Dinoflagellates. Two species of dinoflagellates—*Peridinium* in the upper left and *Ceratium* in the lower half. The transverse groove in the center of each dinoflagellate is the location for one of the two flagella (SEM ×800).

Lecture #`129

Class Zoo-mastigophorea

Members of the class Zoomastigophorea (zoo-mas-ti-go-for-eeah) (Gr. zoion, animal) lack chloroplasts and are heterotrophic. Some members of this class are important parasites of humans. One of the most important species of zoomastigophoreans is Trypanosoma brucei. This species is divided into three subspecies: T. b. brucei, T. b. ambience, and T. b. rhodesiense, often referred to as the Trypanosoma brucei complex. The first of these three subspecies is a parasite of nonhuman mammals of Africa. The latter two cause sleeping sickness in humans. Tsetse flies (Glossina spp.) are intermediate hosts and vectors of all three subspecies. When a tsetse fly bites an infected human or mammal, it picks up parasites in addition to its meal of blood. Trypanosomes multiply asexually in the gut of the fly for about 10 days, then migrate to the salivary glands. While in the fly, trypanosomes transform, in 15 to 35 days, through several body forms.

When the infected tsetse fly bites another vertebrate host, the parasites travel with salivary secretions into the blood of a new definitive host. The parasites multiply asexually in the new host and again transform through several body forms. Parasites may live in the blood, lymph, spleen, central nervous system, and cerebrospinal fluid. When trypanosomes enter the central nervous system, they cause general apathy, mental dullness, and lack of coordination. “Sleepiness” develops, and the infected individual may fall asleep during normal daytime activities. Death results from any combination of the previous symptoms, as well as from heart failure, malnutrition, and other weakened conditions. If detected early, sleeping sickness is curable. However, if an infection has advanced to the central nervous system, recovery is unlikely.

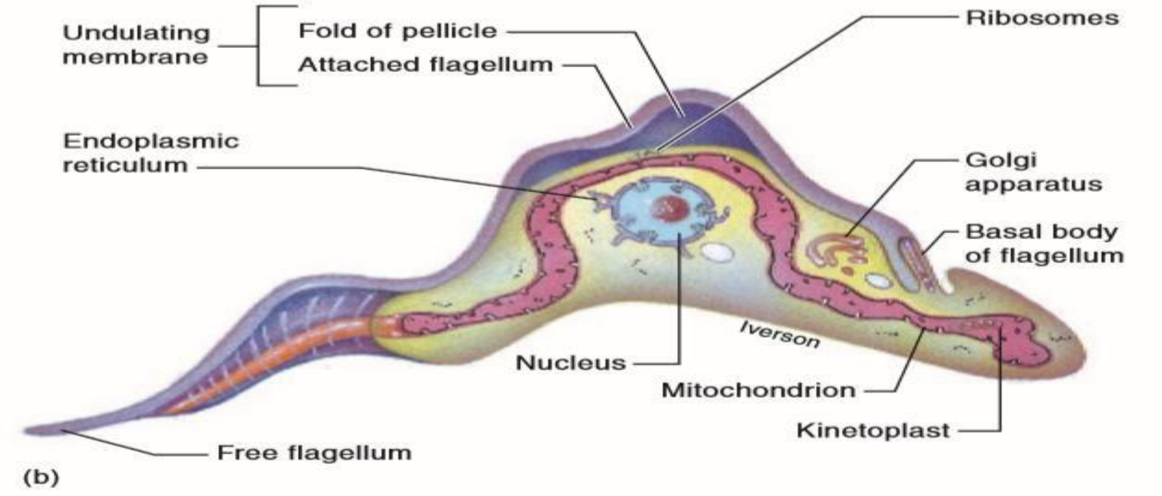


FIGURE 8.9
Class Zoomastigophorea: The Life Cycle of *Trypanosoma brucei*. *(a)* When a tsetse fly feeds on a vertebrate host, trypanosomes enter the vertebrate's circulatory system (first arrow on right) with the fly's saliva. Trypanosomes multiply in the vertebrate's circulatory and lymphatic systems by binary fission. When another tsetse fly bites this vertebrate host again, trypanosomes move into the gut of the fly and undergo binary fission. Trypanosomes then migrate to the fly's salivary glands, where they are available to infect a new host. *(b)* Structure of the flagellate, *Trypanosoma brucei rhodesiense*. This flagellate is about 25 µm long.

Lecture #`130

Sub phylum Sarcodina: Pseudopodia and Amoeboid Locomotion

Members of the subphylum Sarcodina (sarko-dinah) are the amoebae (sing., amoeba). When feeding and moving, they form temporary cell extensions called pseudopodia (sing., pseudo Podium) (Gr. pseudes, false podion, little foot). Pseudopodia exist in a variety of forms. Lobopodia (sing., lobopodium) (Gr. lobos, lobe) are broad cell processes containing ectoplasm and endoplasm and are used for locomotion and engulfing food .Filopodia (sing., filopodium) (L. filum, thread) contain ectoplasm only and provide a constant two-way streaming that delivers food in a conveyor-belt fashion. Reticulopodia (sing., reticulopodium) (L. reticulatus, netlike) are like filopodia, except that they branch and rejoin to form a netlike series of cell extensions. Axopodia (sing., axopodium) (L. axis, axle) are thin, filamentous, and supported by a central axis of microtubules. The cytoplasm

Covering the central axis is adhesive and movable. Food caught on axopodia can be delivered to the central cytoplasm of the amoeba.

Lecture #`131

Super class Rhizopoda, Class Lobosea

The most familiar amoebae belong to the superclass Rhizopoda (ri-zopo-dah), class Lobosea (lo-bosah) (Gr. lobos, lobe), and the genus Amoeba. These amoebae are naked (they have no test or shell) and are normally found on shallow-water substrates of freshwater ponds, lakes, and slow-moving streams, where they feed on other protists and bacteria. They engulf food by phagocytosis, a process that involves the cytoplasmic changes described earlier for amoeboid locomotion.

In the process, food is incorporated into food vacuoles. Binary fission occurs when an amoeba reaches a certain size limit. As with other amoebae, no sexual reproduction is known to occur. Other members of the super class Rhizopoda possess a test or shell. Tests are protective structures that the cytoplasm secretes. They may be calcareous (made of calcium carbonate), proteinaceous (made of protein), siliceous (made of silica [SiO2]), or chitinous (made of chitin—a polysaccharide). Other tests may be composed of sand or other debris cemented into a secreted matrix.

Usually, one or more openings in the test allow pseudopodia to be extruded. Marcella's a common freshwater, shelled amoeba. It has a brown, proteinaceous test that is flattened on one side and domed on the other. Pseudopodia project from an opening on the flattened side. Difflugia is another common freshwater, shelled amoeba. Its test is vase shaped and is composed of mineral particles embedded in a secreted matrix. All free-living amoebae are particle feeders, using their pseudopodia to capture food; a few are pathogenic.

For example, Entamoeba histolytica causes one form of dysentery in humans. Inflammation and ulceration of the lower intestinal tract and a debilitating diarrhea that includes blood and mucus characterize dysentery. Amoebic dysentery is a worldwide problem that plagues humans in crowded, unsanitary conditions. A significant problem in the control of Entamoeba histolytica is that an individual can be infected and contagious without experiencing symptoms of the disease. Amoebae live in the folds of the intestinal wall, feeding on starch and mucoid secretions. They pass from one host to another in the form of cysts transmitted by fecal contamination of food or water. After ingestion by a new host, amoebae leave their cysts and take up residence in the host's intestinal wall.

Lecture #`132

Subphylum Actinopoda: Foraminiferans, Heliozoans, and Radiolarians

Foraminifera's (commonly called forams) are primarily a marine group of amoebae. Foraminiferans possess reticulopodia and secrete a test that is primarily calcium carbonate. As foraminiferans grow, they secrete new, larger chambers that remain attached to the older chambers. Test enlargement follows a symmetrical pattern that may result in a straight chain of chambers or a spiral arrangement that resembles a snail shell. Many of these tests become relatively large; for example, "Mermaid's pennies," found in Australia, may be several centimeters in diameter.

Foram tests are abundant in the fossil record since the Cambrian period. They make up a large component of marine sediments, and their accumulation on the floor of primeval oceans resulted in limestone and chalk deposits. The white cliffs of Dover in England are one example of a foraminiferan-chalk deposit. Oil geologists use fossilized forams to identify geologic strata when taking exploratory cores. Heliozoans are aquatic amoebae that are either planktonic or live attached by a stalk to some substrate. (The plankton of a body of water consists of those organisms that float freely in the water.) Heliozoans are either naked or enclosed within a test that contains openings for axopodia. Radiolarians are planktonic marine and freshwater amoebae. They are relatively large; some colonial forms may reach several centimeters in diameter. They possess a test (usually siliceous) of long, movable spines and needles or of a highly sculptured and ornamented lattice (figure 8.14b). When radiolarians die, them tests drift to the ocean floor. Some of the oldest known fossils of eukaryotic organisms are radiolarians.

Phylum Labyrinthomorpha

The very small phylum Labyrinthomorpha (labrinth-o-morfa) consists of protozoa with spindle-shaped, nonamoeboid, vegetative cells. In some genera, amoeboid cells use a typical gliding motion to move within a network of mucous tracks. Most members are marine, and either saprozoic or parasitic on algae or seagrass. Several years ago, Labyrinthula killed most of the "eel grass" (a grass like marine flowering plant) on the Atlantic coast, starving many ducks that feed on the grass.

Lecture# 133

Phylum Apicomplexa

Members of the phylum Apicomplexa (api-kom-plexah) (L. apex, point com, together, plexus, interweaving) are all parasites. Characteristics of the phylum include: 1. apical complex for penetrating host cells 2.Single type of nucleus 3. No cilia and flagella, except in certain reproductive stages 4. Life cycles that typically include asexual (schizogony, sporogony) and sexual (gametogony) phases

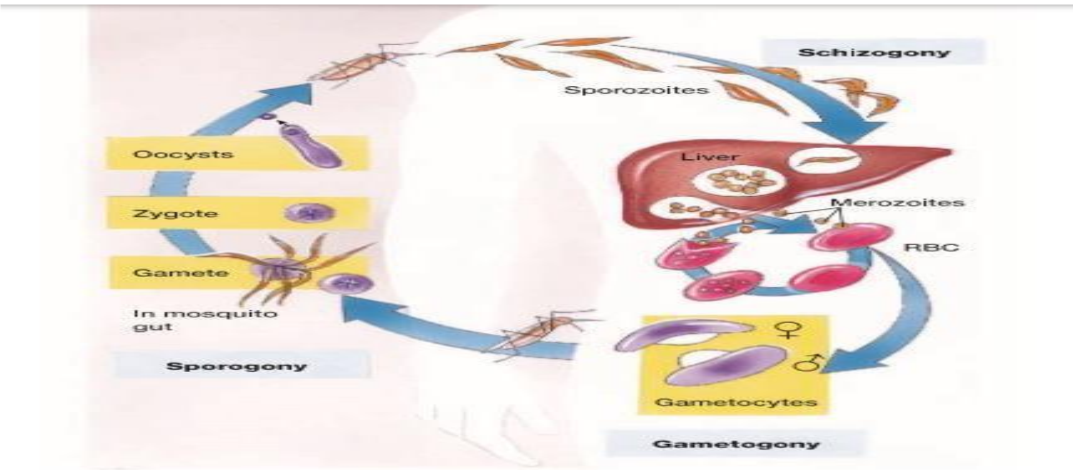


FIGURE 8.15
Phylum Apicomplexa: The Life Cycle of *Plasmodium*. Schizogony (merogony) occurs in liver cells and, later, in the red blood cells (RBCs) of humans. Gametogony occurs in RBCs. During a blood meal, the mosquito takes in micro- and macrogametes, which fuse to form zygotes. Zygotes penetrate the gut of the mosquito and form oocysts. Meiosis and sporogony form many haploid sporozoites that may enter a new host when the mosquito bites the host.

Class Sporozoea

The most important species in the phylum Apicomplexa are members of the class Sporozoea. The class name derives from most sporozoeans producing a resistant spore or oocyst following sexual reproduction. Some members of this class, including Plasmodium and coccidian’s, cause a variety of diseases in domestic animals and humans. Although the life cycles of sporozoeans vary considerably, certain generalizations are possible. Many are intracellular parasites, and their life cycles have three phases. Schizogony is multiple fission of an asexual stage in host cells to form many more (usually asexual) individuals, called merozoites, that leave the host cell and infect many other cells. (Schizogony to produce merozoites is also called merogony.

Some of the merozoites undergo gametogony, which begins the sexual phase of the life cycle. The parasite forms either microgametocytes or macrogametocytes. Microgametocytes undergo multiple fission to produce biflagellate microgametes that emerge from the infected host cell. The macrogametocyte develops directly into a single macrogamete. A microgamete fertilizes a macrogamete to produce a zygote that becomes enclosed and is called an oocyst. The zygote undergoes meiosis, and the resulting cells divide repeatedly by mitosis. This process, called sporogony, produces many rods like sporozoites in the oocyst. Sporozoites infect the cells of a new host after the new host ingests and digests the oocyst, or sporozoites are otherwise introduced (e.g., by a mosquito bite).

One sporozoeans genus, Plasmodium, causes malaria and has a long history. Accounts of the disease go back as far as 1550 B.C. Malaria contributed significantly to the failure of the Crusades during the medieval era, and along with typhus, has devastated more armies than has actual combat. Recently (since the early 1970s), malaria has resurged throughout the world. Over 100 million humans are estimated to annually contract the disease. The Plasmodium life cycle involves vertebrate and mosquito hosts. Schizogony occurs first in liver cells and later in red blood cells, and gametogony also occurs in red blood cells. A mosquito takes in gametocytes during a meal of blood, and the gametocytes subsequently fuse. The zygote penetrates the gut of the mosquito and transforms into an oocyst.

Sporogony forms haploid sporozoites that may enter a new host when the mosquito bites the host. The symptoms of malaria recur periodically and are called paroxysms.

Chills and fever correlate with the maturation of parasites, the rupture of red blood cells, and the release of toxic metabolites. Four species of Plasmodium are the most important human malarial species. P. vivax causes malaria in which the paroxysms recur every 48 hours. This species occurs in temperate regions and has been nearly eradicated in many parts of the world.

P. falciparum causes the most virulent form of malaria in humans. Paroxysms are more irregular than in the other species. P. falciparum was once worldwide but is now mainly tropical and subtropical in distribution. It remains one of the greatest killers of humanity, especially in Africa. P. malariae is worldwide in distribution and causes malaria with paroxysms that recur every 72 hours. P. ovaleis the rarest of the four human malarial species and is primarily tropical in distribution. Other members of the class Sporozoea also cause important diseases. Coccidiosis is primarily a disease of poultry, sheep, cattle, and rabbits. Two genera, Isospora and Eimeria, are particularly important parasites of poultry. Yearly losses to the U.S. poultry industry from coccidiosis have approached $35 million. Another coccidian, Cryptosporidium, has become more well-known with the advent of AIDS since it causes chronic diarrhea in AIDS patients, is the only known protozoan to resist chlorination, and is most virulent in immunosuppressed individuals. Toxoplasmosis is a disease of mammals, including humans, and birds. Sexual reproduction of Toxoplasma occurs primarily in cats.

Infections occur when oocysts are ingested with food contaminated by cat feces, or when meat containing encysted merozoites is eaten raw or poorly cooked. Most infections in humans are asymptomatic, and once infection occurs, an effective immunity develops. However, if a woman is infected near the time of pregnancy, or during pregnancy, congenital toxoplasmosis may develop in a fetus. Congenital toxoplasmosis is a major cause of stillbirths and spontaneous abortions. Fetuses that survive frequently show signs of mental retardation and epileptic seizures. Congenital toxoplasmosis has no cure. Toxoplasmosis also ranks high among the opportunistic diseases afflicting AIDS patients. Steps to avoid infections by toxoplasma include keeping stray and pet cats away from children's sandboxes; using sandbox covers; and awareness, on the part of couples considering having children, of the potential dangers of eating raw or very rare pork, lamb, and beef.

Lecture#`136

Phylum Microspora

Members of the phylum Microspore (micommonly called microsporidia, are small, obligatory intracellular parasites. Included in this phylum are several species that parasitize beneficial insects. Nosema bombicus parasitizes silkworms, causing the disease pebrine, and N. apis causes serious dysentery (foul brood) in honeybees. These parasites have a possible role as biological control agents for insect pests. For example, the U.S. Environmental Protection Agency has approved and registered N. locustae for use in residual control of rangeland grasshoppers. Recently, four micro sporidian genera have been implicated in secondary infections of immunosuppressed and AIDS patients.

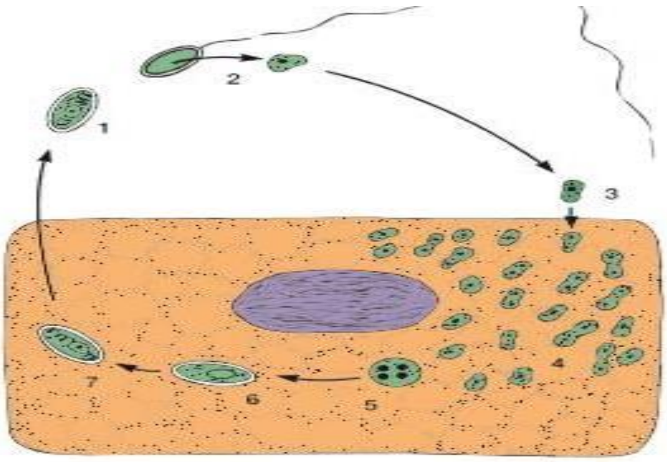


FIGURE 8.16

Phylum Microspora: The Microsporean *Nosema bombicus*, Which Is Fatal to Silkworms. The cell of a silkworm infected with *N. bombicus* is shown here. *(1)* A typical spore with one coiled filament. *(2)* When ingested, the spore extrudes the filament, which is used in locomotion. *(3)* The parasite enters an epithelial cell in the silkworm intensine and *(4)* divides many times to form small amoebae that eventually fill the cell and kill it. *(5–7)* During this phase, some of the amoebae with four nuclei become spores. Silkworms are infected by eating leaves contaminated with the feces of infected worms.

Lecture#`137

Phylum Acetospora

The **Ascetosporea** are a group of eukaryotes that are parasites of animals, especially marine invertebrates. The two groups, the haplosporids and paramyxids, are not particularly similar morphologically, but consistently group together on molecular trees, which place them near the base of the Cercozoa. Both produce spores without the complex structures found in similar groups (such as polar filaments or tubules).

Haplosporid spores have a single nucleus and an opening at one end, covered with an internal diaphragm or a distinctive hinged lid. After emerging, it develops within the cells of its host, usually a marine mollusc or annelid, although some infect other groups or freshwater species. The trophic cell is generally multinucleated. Paramyxids develop within the digestive system of marine invertebrates, and undergo internal budding to produce multicellular spores. A 2009 study concluded that *Haplosporidium* species form a paraphyletic group and that the taxonomy of the haplosporidians needs a thorough revision. Acetospora is a relatively small phylum that consists exclusively of obligatory extracellular parasites characterized by spores lacking polar caps or polar filaments. acetosporeans (e.g., Haplosporidium) primarily are parasitic in the cells, tissues, and body cavities of mollusk.

Phylum Myxozoa

The phylum Myxozoa commonly called myxosporeans, are all obligatory extracellular parasites in freshwater and marine fish. They have a resistant spore with one to six coiled polar filaments. The most economically important myxosporean is Myxosoma cerebralis, which infects the nervous system and auditory organs of trout and salmon, causing whirling or tumbling disease.

Myxozoa is a class of aquatic, obligately parasitic cnidarian animals. Over 1300 species have been described and many have a two-host lifecycle, involving a fish and an annelid worm or a bryozoan. The average size of a myxosporean spore usually ranges from 10 μm to 20 μm, whereas that of a malacosporean (a subclade of the Myxozoa) spore can be up to 2 mm. Myxozoans can live in both freshwater and marine habitats.

While the evolutionary history of myxozoans is still an active area of research, it is now understood that myxozoans are highly modified cnidarians that have undergone dramatic evolution from a free swimming, self-sufficient jellyfish-like creature into their current form of obligate parasites composed of a mere handful of cells. As myxozoans evolved into microscopic parasites, they lost many genes responsible for multicellular development, coordination, and cell-cell communication. The genomes of some myxozoans are now among the smallest genomes of any known animal species.

Phylogenetics

Myxozoans were originally considered protozoan, and were included among other non-motile forms in the group Sporozoa. As their distinct nature became clear through 18S ribosomal DNA (rDNA) sequencing, they were relocated in the metazoa. Detailed classification within the metazoa was however long hindered by conflicting rDNA evidence: although 18S rDNA suggested an affinity with Cnidaria, other rDNA sampled, and the HOX genes of two species, were more similar to those of the Bilateria.

The discovery that *Buddenbrockia plumatellae*, a worm-like parasite of bryozoans up to 2 mm in length, is a myxozoan initially appeared to strengthen the case for a bilaterian origin, as the body plan is superficially similar. Nevertheless, closer examination reveals that *Buddenbrockia*'s longitudinal symmetry is not twofold, but fourfold, casting doubt on this hypothesis.

Further testing resolved the genetic conundrum by sourcing the first three previously identified discrepant HOX genes (*Myx1-3*) to the bryozoan *Cristatella mucedo* and the fourth (*Myx4*) to Northern pike, the respective hosts of the two corresponding Myxozoa samples. This explained the confusion: the original experiments had used samples contaminated by tissue from host organisms, leading to false positives for a position among the Bilateria. More careful cloning of 50 coding genes from *Buddenbrockia* firmly established the clade as severely modified members of the phylum Cnidaria, with medusozoans as their closest relatives. Similarities between myxozoan polar capsules and cnidarian nematocysts had been drawn for a long time, but were generally assumed to be the result of convergent evolution.

Taxonomists now recognize the outdated subgroup Actinosporea as a life-cycle phase of Myxosporea

Lecture#`138

Phylum Ciliophora

The phylum Ciliophora includes some of the most complex protozoa. Ciliates are widely distributed in freshwater and marine environments. A few ciliates are symbiotic. Characteristics of the phylum Ciliophora include:

1. Cilia for locomotion and for the generation of feeding currents in water

2. Relatively rigid pellicle and fixed shape

3. Distinct cytostome

Cilia and Other Pellicular Structures

Cilia are generally like flagella, except that they are much shorter, more numerous, and widely distributed over the surface of the protozoan. Ciliary movements are coordinated so that ciliary waves pass over the surface of the ciliate. Many ciliates can reverse the direction of ciliary beating and the direction of cell movement. Basal bodies (kinetosomes) of adjacent cilia are interconnected with an elaborate network of fibers that are believed to anchor the cilia and give shape to the organism. Some ciliates have evolved specialized cilia. Cilia may cover the outer surface of the protozoan. They may join to form cirri, which are used in movement. Alternatively, cilia may be lost from large regions of a ciliate. Trichocysts are pellicular structures primarily used for protection. They are rodlike or oval organelles oriented perpendicular to the plasma membrane. In Paramecium, they have a “golf tee” appearance. The pellicle can discharge Trichocysts, which then remain connected to the body by a sticky thread

Nutrition

Some ciliates, such as Paramecium, have a ciliated oral groove along one side of the body.

Cilia of the oral groove sweep small food particles toward the cytopharynx, where

a food vacuole forms. When the food vacuole reaches an upper size limit, it breaks free and circulates through the endoplasm. Some free-living ciliates prey upon other protists or small animals. Prey capture is usually a case of fortuitous contact. The ciliate Didinium feeds principally on Paramecium, a prey that is bigger than itself. Didinium forms a temporary opening that can greatly enlarge to consume its prey (figure 8.19).

Suctorians are ciliates that live attached to their substrate. They possess tentacles whose secretions paralyze prey, often ciliates or amoebae. The tentacles digest an opening in the pellicle of the prey, and prey cytoplasm is drawn into the suctorian through tiny channels in the tentacle. The mechanism for this probably involves tentacular microtubules (figure 8.20).

Genetic Control and Reproduction

Ciliates have two kinds of nuclei. A large, polyploid macronucleus regulates daily metabolic activities. One or more smaller micronuclei are the genetic reserve of the cell.

Ciliates reproduce asexually by transverse binary fission and, occasionally, by budding. Budding occurs in Suctorians and results in the formation of ciliated, free-swimming organisms that attach to the substrate and take the form of the adult. Ciliates reproduce sexually by conjugation. The partners involved are called conjugants. Many species of ciliates have numerous mating types, not all of which are mutually compatible.

Initial contact between individuals is apparently random, and sticky secretions of the pellicle facilitate adhesion. Ciliate plasma membranes then fuse and remain that way for several hours. The macronucleus does not participate in the genetic exchange that follows. Instead, the macronucleus breaks up during or after micronuclear events, and reforms from micronuclei of the daughter ciliates. After separation, the exconjugants undergo a series of nuclear divisions to restore the nuclear characteristics of the species, including the formation of a macronucleus from one or more micronuclei. Cytoplasmic divisions that form daughter cells accompany these events.

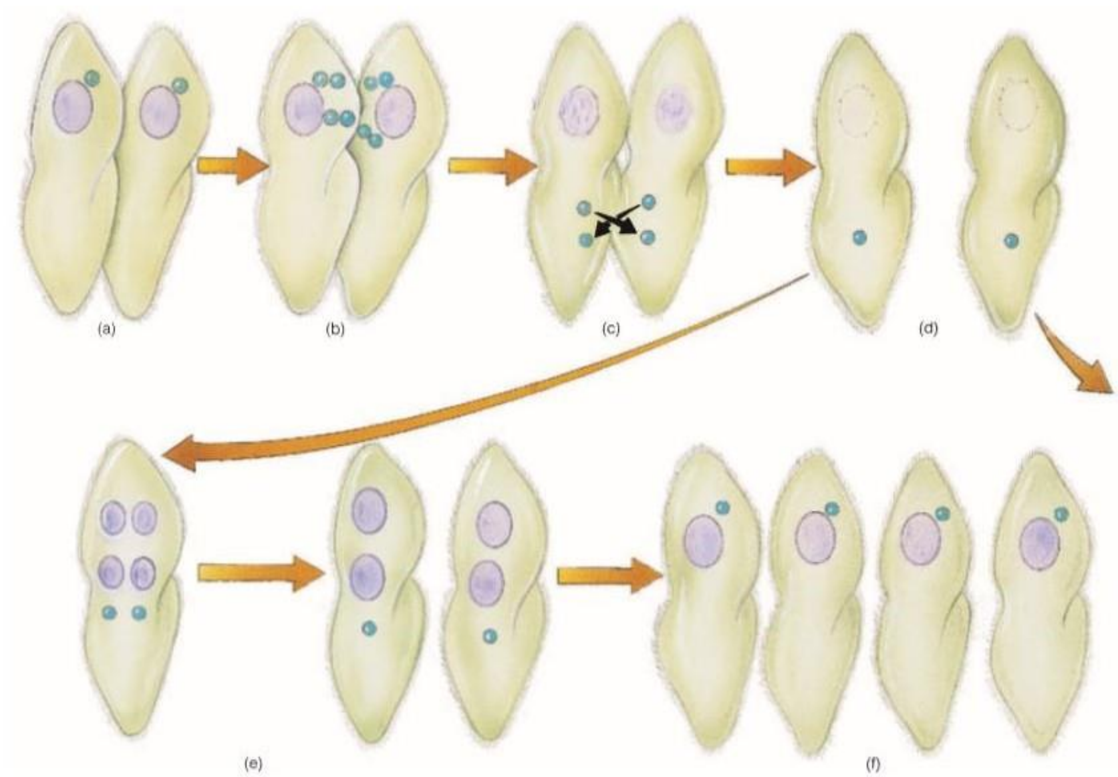


FIGURE 8.21

Conjugation in *Paramecium*. *(a)* Random contact brings individuals of opposite mating types together. *(b)* Meiosis results in four haploid pronuclei. *(c)* Three pronuclei and the macronucleus degenerate. Mitosis and mutual exchange of pronuclei is followed by fusion of pronuclei. *(d–f)* Conjugants separate. Nuclear divisions that restore nuclear characteristics of the species follow. Cytoplasmic divisions may accompany these events.

Symbiotic ciliates

Most ciliates are free living; however, some are commensalistic or mutualistic, and a few are parasitic. Balantidium coli is an important parasitic ciliate that lives in the large intestines of humans, pigs, and other mammals. At times, it is a ciliary feeder; at other times, it produces proteolytic enzymes that digest host epithelium, causing a flask-shaped ulcer. (Its pathology resembles that of Entamoeba histolytica.) B. coli is passed from one host to another in cysts that form as feces begin to dehydrate in the large intestine. Fecal contamination of food or water is the most common form of transmission. Its distribution is potentially worldwide, but it is most common in the Philippines. Large numbers of different species of ciliates also inhabit the rumen of many ungulates (hoofed animals). These ciliates contribute to the digestive processes of their hosts.

Lecture #140

Kingdom Animala

Molecular systematics is leading to a revision of our understanding of evolutionary history in all kingdoms, including the animals. Some phylogenies are changing, and others, including mammalian phylogenies, are being written for the first time. In this section, we explore three examples: the relationship between annelids and arthropods, relationships within the arthropods, and the discovery of phylogenetic relationships among mammals.

The origins of segmentation are puzzling

The arthropod phylum is a group of over one million described invertebrates that includes the insects and crustaceans; the annelid phylum, another invertebrate group, contains the segmented worms such as the earthworm. Morphological traits such as segmentation have been used in the past to group arthropods and annelids close together, but comparisons of rRNA sequences are raising questions about their relationship. As rRNA sequences are obtained, it is becoming increasingly clear that annelids and arthropods are more distantly related than taxonomists previously believed.

Evolutionary occurrences of segmentation Distinctions can be made among eukaryote animals based on timing of embryonic development of the mouth and anus. Annelids and arthropods belong to the protostome group, in which the mouth develops before the anus. Chordates, including humans, fall into the deuterostome group, in which the anus forms first. (You will learn more about these divisions in chapter 33.) With the addition of newly available molecular traits, annelids and arthropods fell into two distinct protostome branches ;lophotrochozoans and ecdysozoans.

These two branches have been evolving independently since ancient times. Lophotrochozoans include flatworms, mollusks, and annelids. Two ecdysozoan phyla have been particularly successful: roundworms (nematodes) and arthropods. In the new protostome phylogeny, annelids and arthropods do not constitute a monophyletic group, as they had in the past. The implication is that segmentation arose twice, not once, in the protostomes, as had been believed originally. Segmentation then arose independently once again in the deuterostomes, specifically in the chordates.

Molecular details of segmentation

The most likely explanation for the independent appearance of segmentation is that members of the same family of genes were co-opted at least three times. Segmentation is regulated by the Hox gene family that contains a homeod omain region. The Hox ancestral genes predate the ecdysozoans and lophotrochozoans. The ancient ancestor of the lophotrochozoans ecdysozoans, and deuterostomes most likely already had seven Hox genes. Some of these genes appear to have evolved a role in segmentation.

Insects and crustaceans are sister groups

Arthropods are the most diverse of all the animal phyla, composed of 80% of all described animal species. Within the arthropods, insects have traditionally been set apart from the crustaceans (such as shrimp, crabs, and lobsters), and grouped instead with the myriapods (centipedes and millipedes). This phylogeny, still widely employed, dates to benchmark work by Robert Snodgrass in the 1930s.

He pointed out that insects, centipedes, and millipedes are united by several seemingly powerful attributes, including uniramous (single branched) appendages. All crustacean appendages, by contrast, are basically biramous, or "two-branched", although some of these appendages have become single-branched by reduction in the course of their evolution. Taxonomists have traditionally assumed a character such as two-branched appendages to be a fundamental one, conserved over the course of evolution, and thus suitable for making taxonomic distinctions. As molecular methods have been developed, however, this assumption has become questionable.

Figure 26.16 Branched and single appendages. Development of a biramous leg in a crustacean (crayfish) and a uniramous leg in an insect are both initiated by the *Distal-less* gene even though their adult morphologies are distinct.

How genes and appendages

The patterning of appendages among arthropods is orchestrated by Hox genes. One of these Hox genes, called Distal-less, has been shown to initiate development of unbranched limbs insects and branched limbs in crustaceans. The same Distal-less gene is found in many animal phyla, including the vertebrates. Distal-less appears to be necessary to initiate limb development, and it turns on genes that are more directly involved in the development of the limb itself. Evolutionary changes in the genes that Distal-less acts on most likely account for differences in limb morphology.

A change in taxonomic relationship

In recent years, a mass of accumulating morphological and molecular data has led many taxonomists to suggest new arthropod phylogenies. Hexapods (insects) with their six legs and terrestrial habitat are the closest relatives of crustaceans, not the myriopods. Hexapods and crustaceans form a clade called pan crustacea. But hexapods likely are not monophyletic, indicating that crustacean ancestors moved onto land multiple times. The relationships among the pan crustacea suggest that hexapods are "flying crustaceans." These conclusions engender lively discussion since they conflict with 150 years of morphology-based phylogenetic inference.

The mammalian family tree is emerging

In the preceding arthropod examples, our interpretation of evolutionary history has been rewritten. In mammals, however, parts of the phylogeny are just emerging, based on molecular data.

The four groups of placental mammals

Among the vertebrate classes, mammals are unique because they have mammary glands to feed their young. Most mammals—over 90%—are eutherians, or placental mammals. There are at least 18 extant orders of eutherians, which are now divided into four major groups. The first major split occurred between the African clade and the other placental mammals when South America and Africa separated about 100 mya. Aardvarks and elephants are part of this African lineage, called the Afrotheria, a clade we did not even recognize a decade ago. In South America, anteaters and armadillos soon appeared. Then two other branches arose—one includes ungulates with an even number of toes (camels, llamas, and other artiodactyls), odd- toed ungulates (perissodactyls such as horses and rhinoceros), and carnivores, and the other, primates and rodents. Sorting out the relationships within these branches is an ongoing challenge.

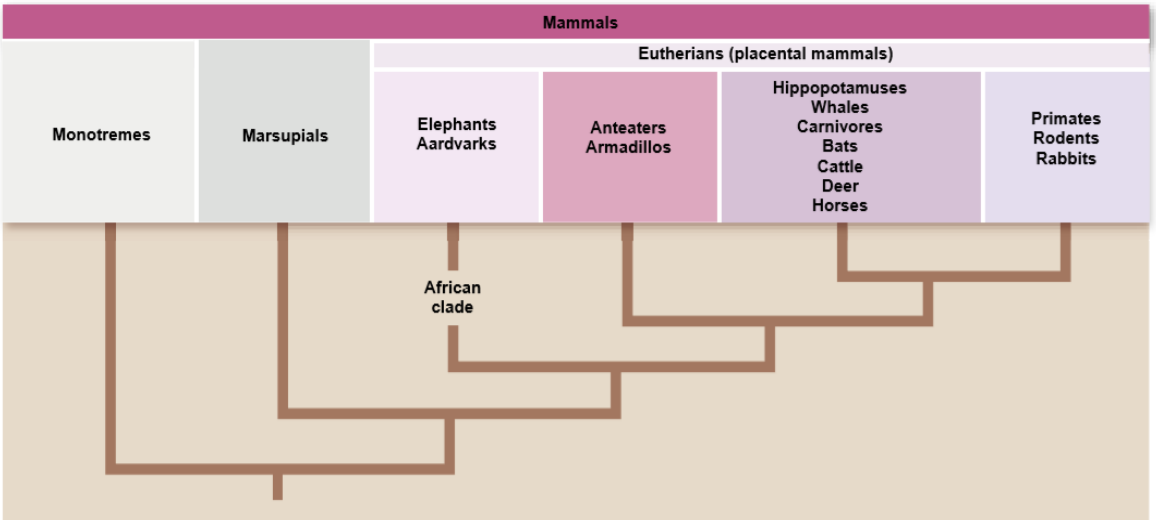


Figure 26.17 Major groups of mammals.

Whales and hippos

The origin and relationships of whales has been debated for over 200 years. Whales were initially thought to be relatives of pigs based on morphological information from fossils and extant animals, primarily the bones of the skull and shape of the teeth. DNA sequence data, however, revealed a particularly close relationship between whales and hippopotamuses, suggesting that whales were derived from within the group Artiodactyla. Whales and hippopotamuses appear to be much more closely related than, for example, hippopotamuses and cows. With this new phylogenetic information, the possibility arises that some adaptations to aquatic environments in both species had a common origin.

Recent finds of fossil whales with hind limbs have confirmed the artiodactyl origin of whales. Prior to these recent discoveries, no fossil whales with hind limbs had been found, so the key character uniting whales and artiodactyls, the shape of a bone in the ankle, was not known. A careful analysis of 80 traits in fossil whales and hippos indicated a common, water-loving ancestor existed 50 to 60 mya belonging to the anthracotheres. The anthracotheres split into two groups. One moved back to an aquatic environment.

The other gave rise to at least 37 genera that left a single descendent, the hippopotamus. In this case, molecular data provided insight into whale origins that was later confirmed by fossil evidence. Understanding evolutionary relationships among organisms does more than provide biologists with a sense of order and a logical way to name organisms. A phylogenetically based taxonomy allows researchers to ask important questions about physiology, behavior, and development using information already known about a related species. This information not only enriches our understanding of how biological complexity evolved, but also provides novel insights that lead to progress in our understanding of the history and origins of important features and functions.

Lecture #`142

Phylum Porifera

The Porifera (po-rifer-ah) (L. porus, pore fera, to bear), or sponges, are primarily marine animals consisting of loosely organized cells (figure 9.4; table 9.1). The approximately nine thousand species of sponges vary in size from less than a centimeter to a mass that would more than fill your arms. Characteristics of the phylum Porifera include: 1. Asymmetrical or radially symmetrical 2. Three cell types: pinacocytes, mesenchyme cells, and choanocytes 3. Central cavity, or a series of branching chambers, through which water circulates during filter feeding

4. No tissues or organs.

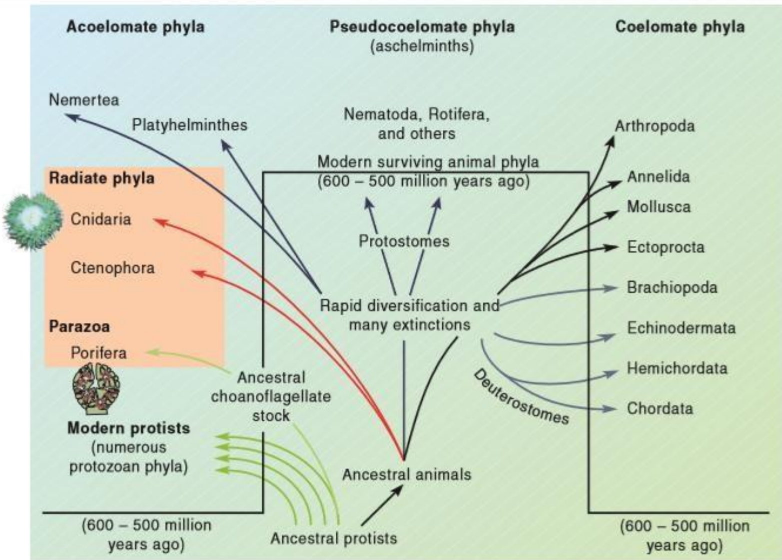


FIGURE 9.2

Evolutionary Relationships of the Poriferans and the Radiate Phyla. Members of the phylum Porifera are derived from ancestral protozoan stocks independently of other animal phyla. The radiate animals include members of the phyla Cnidaria and Ctenophora. This figure shows a diphyletic origin of the animal kingdom in which sponges arise from the protists separate from other animals. Other interpretations of sponge origins are discussed in the text.

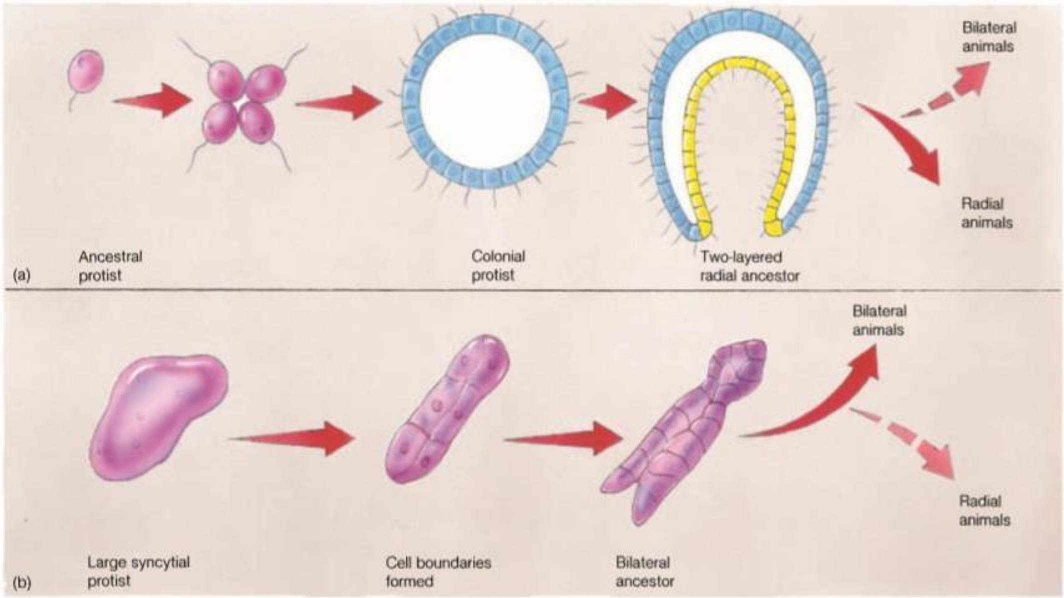


FIGURE 9.3

Two Hypotheses Regarding the Origin of Multicellularity. *(a)* The colonial hypothesis. Multicellularity may have arisen when cells that a dividing protist produced remained together. Cell invagination could have formed a second cell layer. This hypothesis is supported by the colonial organization of some Sarcomastigophora. (The colonial protist and the two-layered radial ancestor are shown in sectional views.) *(b)* The syncytial hypothesis. Multicellularity could have arisen when plasma membranes formed within the cytoplasm of a large, multinucleate protist. Multinucleate, bilateral ciliates support this hypothesis.

Cell Types, Body Wall, and Skeletons

Despite their relative simplicity, sponges are more than colonies of independent cells. As in all animals, sponge cells are specialized for functions. This organization is often referred to as division of labor.

Thin, flat cells, called pinacocytes, line the outer surface of a sponge. Pinacocytes may be mildly contractile, and their contraction may change the shape of some sponges. In several sponges, some pinacocytes are specialized into tube like, contractile porocytes, which can regulate water circulation.

Openings through porocytes are pathways for water moving through the body wall. Just below the pinacocyte layer of a sponge is a jellylike layer called the mesophyll (Gr. meso, middle hyl, matter). Amoeboid cells called mesenchyme cells move about in the mesophyll and are specialized for reproduction, secreting skeletal elements, transporting and storing food, and forming contractile rings around openings in the sponge wall.

Below the mesohyl and lining the inner chamber(s) are choanocytes, or collar cells. Choanocytes (Gr. choane, funnel cyte, cell) are flagellated cells that have a collar like ring of microvilli surrounding a flagellum. Microfilaments connect the microvilli, forming a netlike mesh within the collar.

The flagellum creates water currents through the sponge, and the collar filters microscopic food particles from the water. The presence of choanocytes in sponges suggests an evolutionary link between the sponges and a group of protists called choanoflagellates. Sponges are supported by a skeleton that may consist of microscopic needlelike spikes called spicules. Spicules are formed by amoeboid cells, are made of calcium carbonate or silica, and may take on a variety of shapes (figure 9.6). Alternatively, the skeleton may be made of spongin (a fibrous protein made of collagen), which is dried, beaten, and washed until all cells are removed to produce a commercial sponge. The nature of the skeleton is an important characteristic in sponge taxonomy.

Water Currents and Body Forms

The life of a sponge depends on the water currents that choanocytes create. Water currents bring food and oxygen to a sponge and carry away metabolic and digestive wastes. Methods of food filtration and circulation reflect the body forms in the phylum. Zoologists have described three sponge body forms.

The simplest and least common sponge body form is the ascon. Ascon sponges are vase like. Ostia are the outer openings of porocytes and lead directly to a chamber called the spongocoel. Choanocytes line the spongocoel, and their flagellar movements draw water into the spongocoel through the ostia. Water exits the sponge through the osculum, which is a single, large opening at the top of the sponge. In the sycon body form, the sponge wall appears folded (figure 9.7b). Water enters a sycon sponge through openings called dermal pores.

Dermal pores are the openings of invaginations of the body wall, called incurrent canals. Pores in the body wall connect incurrent canals to radial canals, and the radial canals lead to the spongocoel. Choanocytes line radial canals (rather than the spongocoel), and the beating of choanocyte flagella moves water from the ostia, through incurrent and radial canals, to the spongocoel, and out the osculum. Leucon sponges have an extensively branched canal system

.Water enters the sponge through ostia and moves through branched incurrent canals, which lead to choanocyte-lined chambers. Canals leading away from the chambers are called excurrent canals. Proliferation of chambers and canals has resulted in the absence of a spongocoel, and often, multiple exit points (oscula) for water leaving the sponge. In complex sponges, an increased surface area for choanocytes results in large volumes of water being moved through the sponge and greater filtering capabilities. Although the evolutionary pathways in the phylum are complex and incompletely described, most pathways have resulted in the leucon body form.

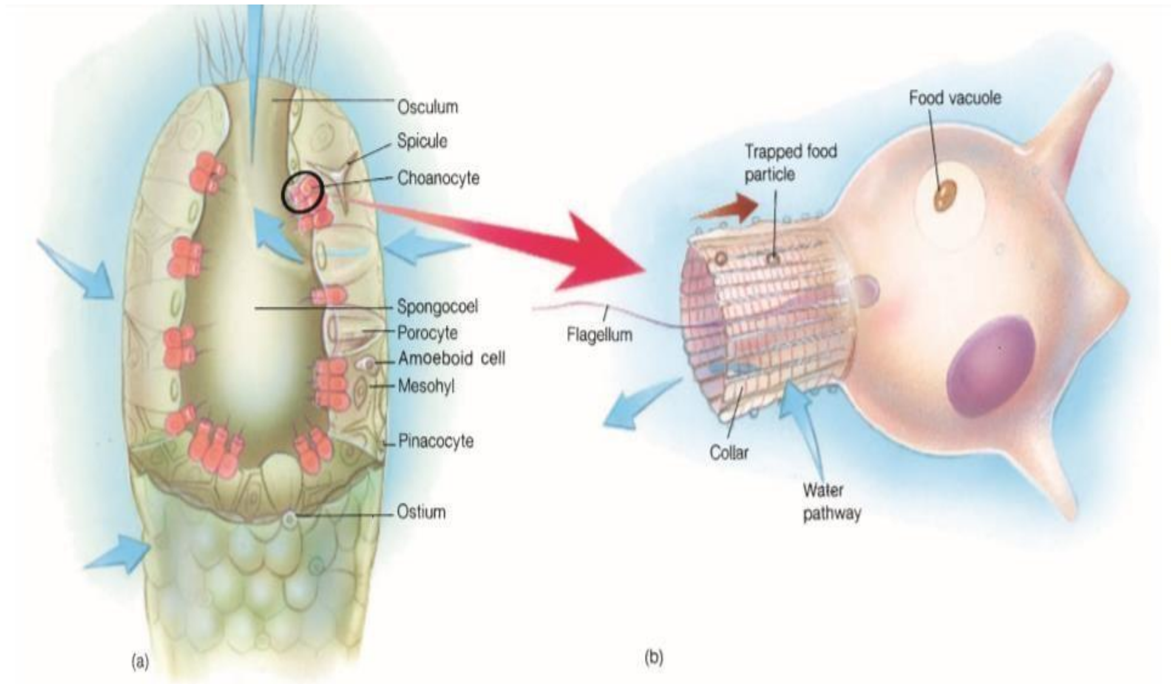


FIGURE 9.5

Morphology of a Simple Sponge. (*a*) In this example, pinacocytes form the outer body wall, and mesenchyme cells and spicules are in the mesohyl. Porocytes that extend through the body wall form ostia. (*b*) Choanocytes are cells with a flagellum surrounded by a collar of microvilli that traps food particles. Food moves toward the base of the cell, where it is incorporated into a food vacuole and passed to amoeboid mesenchyme cells, where digestion takes place. Blue arrows show water flow patterns. The brown arrow shows the direction of movement of trapped food particles.

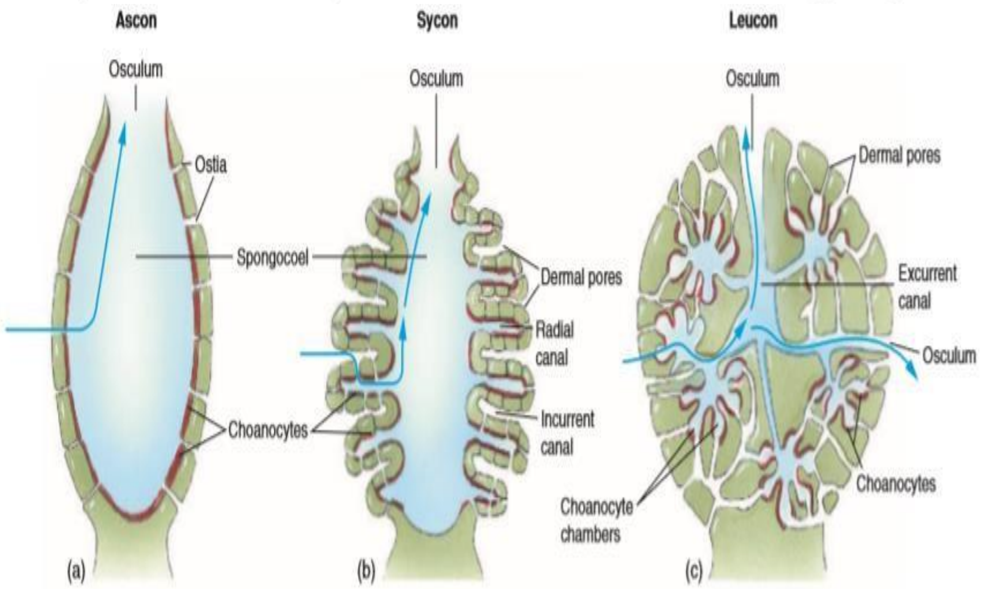


FIGURE 9.7

Sponge Body Forms. (*a*) An ascon sponge. Choanocytes line the spongocoel in ascon sponges. (*b*) A sycon sponge. The body wall of sycon sponges appears folded. Choanocytes line radial canals that open into the spongocoel. (*c*) A leucon sponge. The proliferation of canals and chambers results in the loss of the spongocoel as a distinct chamber. Multiple oscula are frequently present. Blue arrows show the direction of water flow.

Maintenance Functions

Sponges feed on particles that range in size from 0.1 to 50 µm. Their food consists of bacteria, microscopic algae, protists, and other suspended organic matter. The prey is slowly drawn into the sponge and consumed. Large populations of sponges play an important role in reducing the turbidity of coastal waters. A single leucon sponge, 1 cm in diameter and 10 cm high, can filter in excess of 20 liters of water every day! Recent investigations have discovered that a few sponges are carnivorous. These deep-water sponges (Asbestopluma) can capture small crustaceans using spicule-covered filaments.

Choanocytes filter small, suspended food particles. Water passes through their collar near the base of the cell and then moves into a sponge chamber at the open end of the collar. Suspended food is trapped on the collar and moved along microvilli to the base of the collar, where it is incorporated into a food vacuole. Digestion begins in the food vacuole by lysosomal enzymes and pH changes. Partially digested food is passed to amoeboid cells, which distribute it to other cells. Filtration is not the only way that sponges feed. Pinacocytes lining in current canals may phagocytize larger food particles (up to 50 µm). Sponges also may absorb by active transport nutrients dissolved in seawater.

Because of extensive canal systems and the circulation of large volumes of water through sponges, all sponge cells are in close contact with water. Thus, nitrogenous waste (principally ammonia) removal and gas exchange occur by diffusion. Sponges do not have nerve cells to coordinate body functions. Most reactions result from individual cells responding to a stimulus. For example, water circulation through some sponges is at a minimum at sunrise and at a maximum just before sunset because light inhibits the constriction of porocytes and other cells surrounding ostia, keeping incurrent canals open. Other reactions, however, suggest some communication among cells. For example, the rate of water circulation through a sponge can drop suddenly without any apparent external cause. This reaction can be due only to choanocytes ceasing activities simultaneously, and this implies some form of internal communication. The nature of this communication is unknown. Amoeboid cells transmitting chemical messages and ion movement over cell surfaces are possible control mechanisms.

Reproduction

Most sponges are monoecious (both sexes occur in the same individual) but do not usually self-fertilize because individual sponges produce eggs and sperm at different times. Certain choanocytes lose their collars and flagella and undergo meiosis to form flagellated sperm. Other choanocytes (and amoeboid cells in some sponges) probably undergo meiosis to form eggs. Eggs are retained in the mesohyl of the parent. Sperm cells exit one sponge through the osculum and enter another sponge with the incurrent water. Sperm are trapped by choanocytes and incorporated into a vacuole. The choanocytes lose their collar and flagellum, become amoeboid, and transport sperm to the eggs.

In most sponges, early development occurs in the mesohyl. Cleavage of a zygote results in the formation of a flagellated larval stage. (A larva is an immature stage that may undergo a dramatic change in structure before attaining the adult body form.) The larva breaks free, and water currents carry the larva out of the parent sponge. After no more than two days of a free-swimming existence, the larva settles to the substrate and begins to develop into the adult body form (figure 9.8a, b). Asexual reproduction of freshwater and some marine sponges involves the formation of resistant capsules, called gemmules, containing masses of amoeboid cells. When the parent sponge dies in the winter, it releases gemmules, which can survive both freezing and drying (figure 9.8c, d). When favorable conditions return in the spring, amoeboid cells stream out of a tiny opening, called the micropyle, and organize into a sponge. Some sponges possess remarkable powers of regeneration. Portions of a sponge that are cut or broken from one individual regenerate new individuals.

Lecture #`143

Phylum Cnidaria (Coelenterata)

Members of the phylum Cnidaria (ni-dare-ah) (Gr. knide, nettle) possess radial or biradial symmetry. Biradial symmetry is a modification of radial symmetry in which a single plane, passing through a central axis, divides the animal into mirror images. It results from the presence of a single or paired structure in a basically radial animal and differs from bilateral symmetry in that dorsal and ventral surfaces are not differentiated. Radially symmetrical animals have no anterior or posterior ends.

Thus, terms of direction are based on the position of the mouth opening. The end of the animal that contains the mouth is the oral end, and the opposite end is the aboral end. Radial symmetry is advantageous for sedentary animals because sensory receptors are evenly distributed around the body. These organisms can respond to stimuli from all directions. The Cnidaria include over nine thousand species, are mostly marine, and are important in coral reef ecosystems (table 9.2). Characteristics of the phylum Cnidaria include: 1. Radial or biradial symmetry 2. Diploblastic, tissue-level organization 3. Gelatinous mesoglea between the epidermal and gastrodermal tissue layers 4. Gastrovascular cavity 5. Nervous system in the form of a nerve net 6. Specialized cells, called cnidocytes, used in defense, feeding, and attachment

The Body Wall and Nematocysts

Cnidarians possess diploblastic, tissue-level organization. Cells organize into tissues that carry out specific functions, and all cells are derived from two embryological layers. The ectoderm of the embryo gives rise to an outer layer of the body wall, called the epidermis, and the inner layer of the body wall, called the gastrodermis, is derived from endoderm (figure 9.9). Cells of the epidermis and gastrodermis differentiate into several cell types for protection, food gathering, coordination, movement, digestion, and absorption. Between the epidermis and gastrodermis is a jellylike layer called mesoglea. Cells are present in the middle layer of some cnidarians, but they have their origin in either the epidermis or the gastrodermis. One kind of cell is characteristic of the phylum.

Epidermal and/or gastrodermal cells called cnidocytes produce structures called nematocysts, which are used for attachment, defense, and feeding. A nematocyst is a fluid-filled, intracellular capsule enclosing a coiled, hollow tube (figure 9.10). A lid like operculum caps the capsule at one end. The cnidocyte has a modified cilium, called a cnidocil. Stimulation of the cnidocil forces open the operculum, discharging the coiled tube—as you would evert a sweater sleeve that had been turned inside out. Zoologists have described nearly 30 kinds of nematocysts. Nematocysts used in food gathering and defense may discharge a long tube armed with spines that penetrates the prey. The spines have hollow tips that deliver paralyzing toxins. Other nematocysts contain unarmed tubes that wrap around prey or a substrate. Still other nematocysts have sticky secretions that help the animal anchor itself. Six or more kinds of nematocysts may be present in one individual.

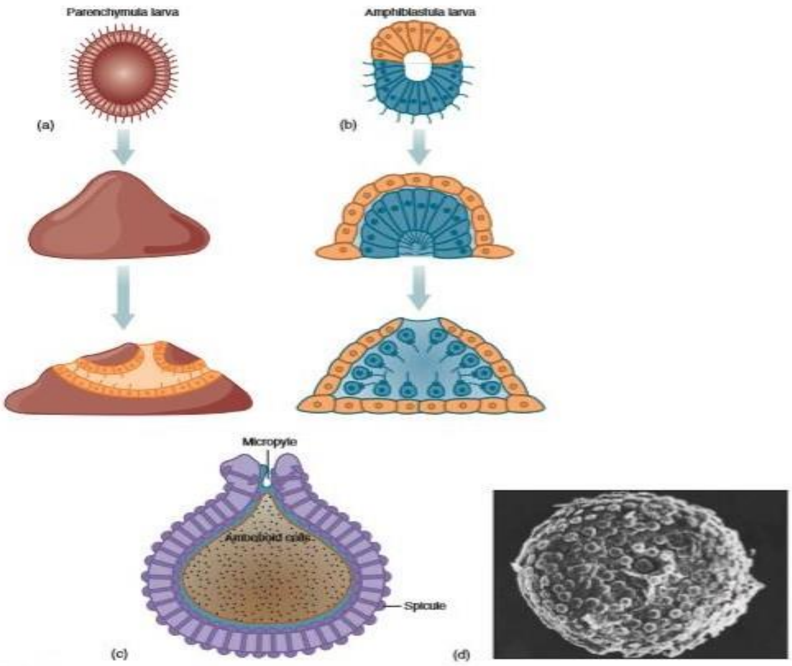


FIGURE 9.8
Development of Sponge Larval Stages. *(a)* Most sponges have a parenchymula larva (0.2 mm). Flagellated cells cover most of the larva's outer surface. After the larva settles and attaches, the outer cells lose their flagella, move to the interior, and form choanocytes. Interior cells move to the periphery and form pinacocytes. *(b)* Some sponges have an amphiblastula larva (0.2 mm), which is hollow and has half of the larva composed of flagellated cells. On settling, the flagellated cells invaginate into the interior of the embryo and form choanocytes. Nonflagellated cells overgrow the choanocytes and form the pinacocytes. *(c)* Gemmules (0.9 mm) are resistant capsules containing masses of amoeboid cells. Gemmules are released when a parent sponge dies (e.g., in the winter), and amoeboid cells form a new sponge when favorable conditions return. *(d)* Scanning electron micrograph of a gemmule of the freshwater sponge (*Dosilia brouni*). It is 0.5 mm in diameter and covered with a shell of spicules and spongin.

Alternation of Generations

Most cnidarians possess two body forms in their life histories (figure 9.11). The polyp is usually asexual and sessile. It attaches to a substrate at the aboral end, and has a cylindrical body, called the column, and a mouth surrounded by food-gathering tentacles. The medusa (pl., medusae) is dioecious and free swimming. It is shaped like an inverted bowl, and tentacles dangle from its margins. The mouth opening is centrally located facing downward, and the medusa swims by gentle pulsations of the body wall. The mesoglea is more abundant in a medusa than in a polyp, giving the former a jellylike consistency.

Maintained Function

The gastrodermis of all cnidarians lines a blind-ending gastrovascular cavity. This cavity functions in digestion, the exchange of respiratory gases and metabolic wastes, and the discharge of gametes. Food, digestive wastes, and reproductive stages enter and leave the gastrovascular cavity through the mouth. The food of most cnidarians consists of very small crustaceans, although some cnidarians feed on small fish. Nematocysts entangle and paralyze prey, and contractile cells in the tentackles cause the tentacles to shorten, which draws food toward the mouth.

As food enters the gastrovascular cavity, gastrodermal gland cells secrete lubricating mucus and enzymes, which reduce food to a soupy broth. Certain gastrodermal cells, called nutritive-muscular cells, phagocytize partially digested food and incorporate it into food vacuoles, where digestion is completed. Nutritive-muscular cells also have circularly oriented contractile fibers that help move materials into or out of the gastrovascular cavity by peristaltic contractions. During peristalsis, ring like contractions move along the body wall, pushing contents of the gastrovascular cavity ahead of them, expelling undigested material through the mouth. Cnidarians derive most of their support from the buoyancy of water around them. In addition, a hydrostatic skeleton aid in support and movement.

A hydrostatic skeleton is water or body fluids confined in a cavity of the body and against which contractile elements of the body wall act. In the Cnidaria, the water-filled gastrovascular cavity acts as a hydrostatic skeleton. Certain cells of the body wall, called epitheliomuscular cells, are contractile and aid in movement. When a polyp closes its mouth (to prevent water from escaping) and contracts longitudinal epitheliomuscular cells on one side of the body, the polyp bends toward that side. If these cells contract while the mouth is open, water escapes from the gastrovascular cavity, and the polyp collapses.

Contraction of circular epitheliomuscular cells causes constriction of a part of the body and, if the mouth is closed, water in the gastro vascular cavity is compressed, and the polyp elongates. Polyps use a variety of forms of locomotion. They may move by somersaulting from base to tentacles and from tentacles to base again, or move in an inchworm fashion, using their base and tentacles as points of attachment. Polyps may also glide very slowly along a substrate while attached at their base or walk on their tentacles. Medusa move by swimming and floating. Water currents and wind are responsible for most horizontal movements.

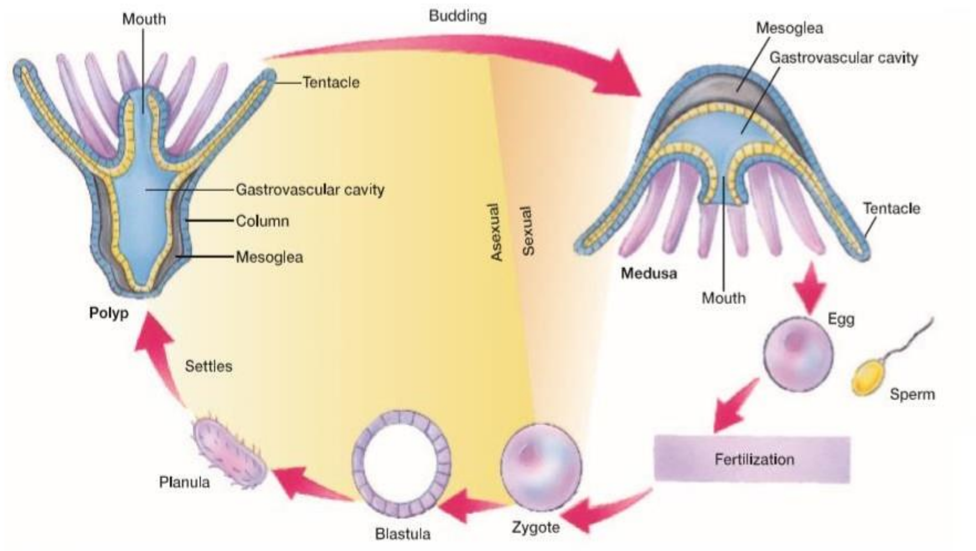


FIGURE 9.11

Generalized Cnidarian Life Cycle. This figure shows alternation between medusa and polyp body forms. Dioecious medusae produce gametes that may be shed into the water for fertilization. Early in development, a ciliated planula larva forms. After a brief free-swimming existence, the planula settles to the substrate and forms a polyp. Budding of the polyp produces additional polyps and medusa buds. Medusae break free of the polyp and swim away. The polyp or medusa stage of many species is either lost or reduced, and the sexual and asexual stages have been incorporated into one body form.

Vertical movements are the result of swimming. Contractions of circular and radial epitheliomuscular cells cause rhythmic pulsations of the bell and drive water from beneath the bell, propelling the medusa through the water. Cnidarian nerve cells have been of interest to zoologists for many years because they may be the most primitive nervous elements in the animal kingdom. By studying these cells, zoologists may gain insight into the evolution of animal nervous systems. Nerve cells are located below the epidermis, near the mesoglea, and interconnect to form a two-dimensional nerve net.

This net conduct nerve impulses around the body in response to a localized stimulus. The extent to which a nerve impulse spreads over the body depends on stimulus strength. For example, a weak stimulus applied to a polyp’s tentacle may cause the tentacle to be retracted. A strong stimulus at the same point may cause the entire polyp to withdraw. Sensory structures of cnidarians are distributed throughout the body and include receptors for perceiving touch and certain chemicals. More specialized receptors are located at specific sites on a polyp or medusa. Because cnidarians have large surface-area-to-volume ratios, all cells are a short distance from the body surface, and oxygen, carbon dioxide, and nitrogenous wastes exchange by diffusion.

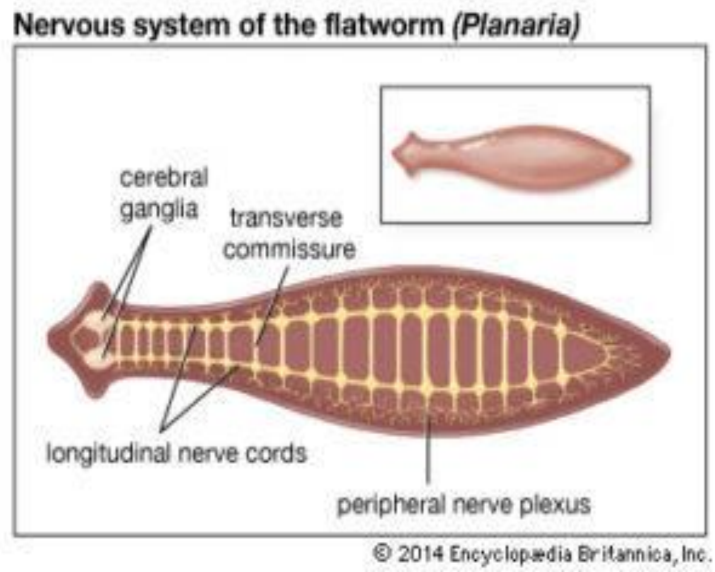
Reproduction

Most cnidarians are dioecious. Sperm and eggs may be released into the gastrovascular cavity or to the outside of the body. In some instances, eggs are retained in the parent until after fertilization. A blastula forms early in development, and migration of surface cells to the interior fills the embryo with cells that will eventually form the gastrodermis. The embryo elongates to form a ciliated, free-swimming larva, called a planula. The planula attaches to a substrate, interior cells split to form the gastrovascular cavity, and a young polyp develops. Medusae nearly always form by budding from the body wall of a polyp, and polyps may form other polyps by budding. Buds may detach from the polyp, or they may remain attached to the parent to contribute to a colony of individuals. Variations on this general pattern are discussed in the survey of cnidarian classes that follows.

Lecture #`145

Phylum Platyhelminthes

The phylum Platyhelminthes (plate-hel-minthez) (Gr. platys, flat helmins, worm) contains over 20,000 animal species. Flatworms range in adult size from 1 mm or less to 25 m (Taeniarhynchus saginatus) in length. Their mesodermally derived tissues include a loose tissue called parenchyma (Gr. patency, anything poured in beside) that fills spaces between other more specialized tissues, organs, and the body wall. Depending on the species, parenchyma may provide skeletal support, nutrient storage, motility, reserves of regenerative cells, transport of materials, structural interactions with other tissues, modifiable tissue for morphogenesis, oxygen storage, and perhaps other functions yet to be determined. This is the first phylum covered that has an organ-system level of organization—a significant evolutionary advancement over the tissue level of organization. The phylum is divided into four classes the Turbellaria consists of mostly free-living flatworms, whereas the (2) Monogenea, (3) Trematoda, and (4) Cestoidea contain solely parasitic species.



Characteristics of the phylum Platyhelminthes include:

- Usually flattened dorsoventrally, triploblastic, acoelomate, bilaterally symmetrical
- Unsegmented worms (members of the class Cestoidea are strobilated)
- Incomplete gut usually present; gut absent in Cestoidea
- Somewhat cephalized, with an anterior cerebral ganglion and usually longitudinal nerve cords
- Protonephridia as excretory/osmoregulatory structures 6. Hermaphroditic; complex reproductive systems
- The digestive system is incomplete or absent. There is a single opening which leads to a well-developed gastro-vascular cavity. The anus is absent. There is no true stomach structure. In a few species, the digestive system is completely absent.
- Respiratory and circulatory systems are absent. Respiration generally occurs through diffusion through the general body surface.
- The excretory system has protonephridia with the flame
- There is primitive nervous system present.
- These animals are hermaphrodites.
- Sexual reproduction happens through gametic fusion.
- Asexual reproduction also happens in a few species through regeneration and fission.
- Fertilization is internal.
- The life cycle of these organisms can be complex, especially if they are parasitic, as this may involve one or more host animals.

The different classes under this phylum are:

- Turbellaria
- Trematoda
- Cestoda

Examples

- Taenia (Tapeworm)
- Fasciola (Liver fluke)
- Taenia saginata (Beef tapeworm)

- Echinococcus granulosus – The dog tapeworm
- Planaria (freshwater flatworm)

Phylum Nematode

Nematodes (nema-todes) (Gr. nematos, thread) or roundworms are some of the most abundant animals on earth—some five billion may be in every acre (4,046 square meters) of fertile garden soil. Zoologists estimate that the number of roundworm species ranges from 16,000 to 500,000. Roundworms feed on every conceivable source of organic matter—from rotting substances to the living tissues of other invertebrates, vertebrates, and plants. They range in size from microscopic to several meters long. Many nematodes are parasites of plants or animals; most others are freeliving in marine, freshwater, or soil habitats.

Some nematodes play an important role in recycling nutrients in soils and bottom sediments. Except in their sensory structures, nematodes lack cilia, a characteristic they share with arthropods. Also, in common with some arthropods, the sperm of nematodes is amoeboid. Zoologists recognize two classes of nematodes

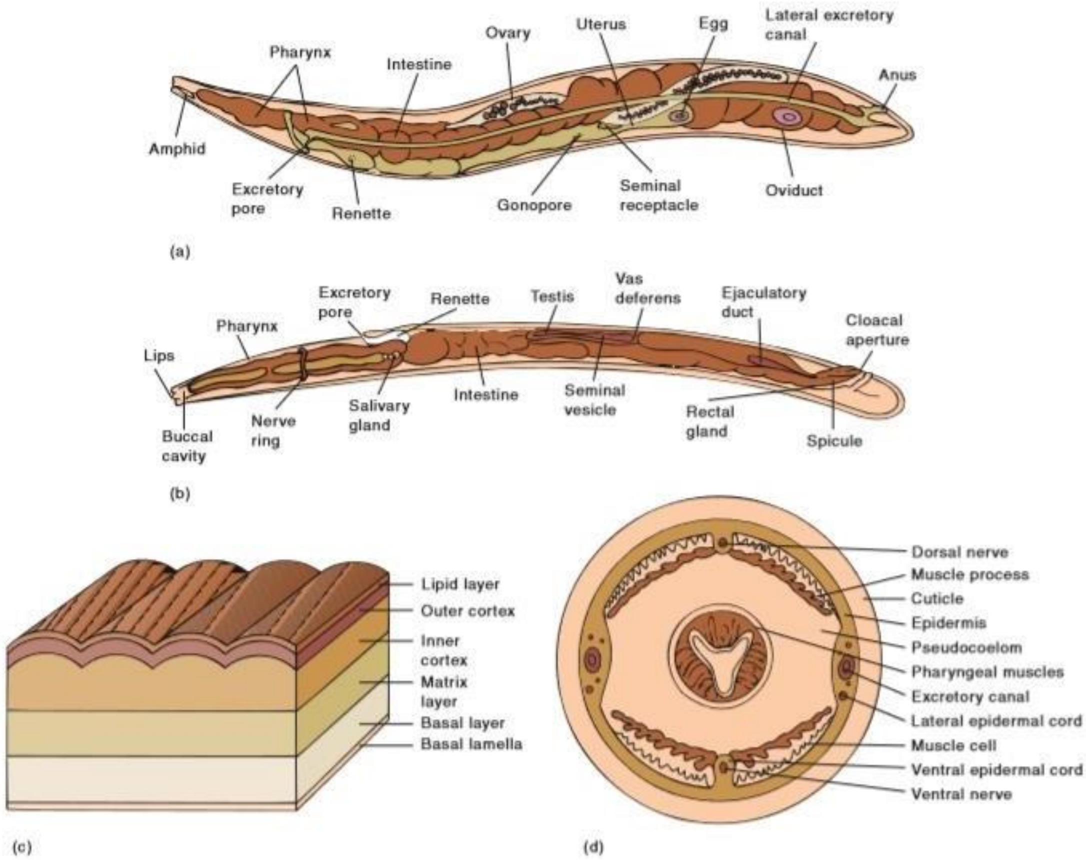


FIGURE 11.7

Phylum Nematoda. Internal anatomical features of an *(a)* female and *(b)* male *Rhabditis*. *(c)* Section through a nematode cuticle, showing the various layers. *(d)* Cross section through the region of the muscular pharynx of a nematode. The hydrostatic pressure in the pseudocoelom maintains the rounded body shape of a nematode and also collapses the intestine, which helps move food and waste material from the mouth to the anus.

Characteristics

Triploblastic, bilateral, vermiform (resembling a worm in shape; long and slender), unsegmented, pseudocoelomate

1. Body round in cross section and covered by a layered cuticle; molting usually accompanies growth in juveniles
2. Complete digestive tract; mouth usually surrounded by lips bearing sense organs
3. Most with unique excretory system comprised of one or two renette cells or a set of collecting tubules
4. Body wall has only longitudinal muscles

External Features

A typical nematode body is slender, elongate, cylindrical, and tapered at both ends. Much of the success of nematodes is due to their outer, noncellular, collagenous cuticle that is continuous with the foregut, hindgut, sense organs, and parts of the female reproductive system. The cuticle may be smooth, or it may contain spines, bristles, papillae (small, nipplelike projections), warts, or ridges, all of which are of taxonomic significance. Three primary layers make up the cuticle: cortex, matrix layer, and basal layer. The cuticle maintains internal hydrostatic pressure, provides mechanical protection, and in parasitic species of nematodes, resists digestion by the host. The cuticle is usually molted four times during maturation. Beneath the cuticle is the epidermis, or hypodermis, which surrounds the pseudocoelom.

The epidermis may be syncytial, and its nuclei are usually in the four epidermal cords (one dorsal, one ventral, and two lateral) that project inward. The longitudinal muscles are the principal means of locomotion in nematodes. Contraction of these muscles results in undulatory waves that pass from the anterior to posterior end of the animal, creating characteristic thrashing movements.

Nematodes lack circular muscles and therefore cannot crawl as do worms with more complex musculature. Some nematodes have lips surrounding the mouth, and some species bear spines or teeth on or near the lips. In others, the lips have disappeared. Some roundworms have head shields that afford protection. Sensory organs include amphids, phasmids, or ocelli. Amphids are anterior depressions in the cuticle that contain modified cilia and function in chemoreception. Phasmids are near the anus and function in chemoreception. The presence or absence of these organs determines the taxonomic class to which nematodes belong. Paired ocelli (eyes) are present in aquatic nematodes.

Internal Features

The nematode pseudocoelom is a spacious, fluid-filled cavity that contains the visceral organs and forms a hydrostatic skeleton. All nematodes are round because the body muscles contracting against the pseudo coelomic fluid generate an equal outward force in all directions

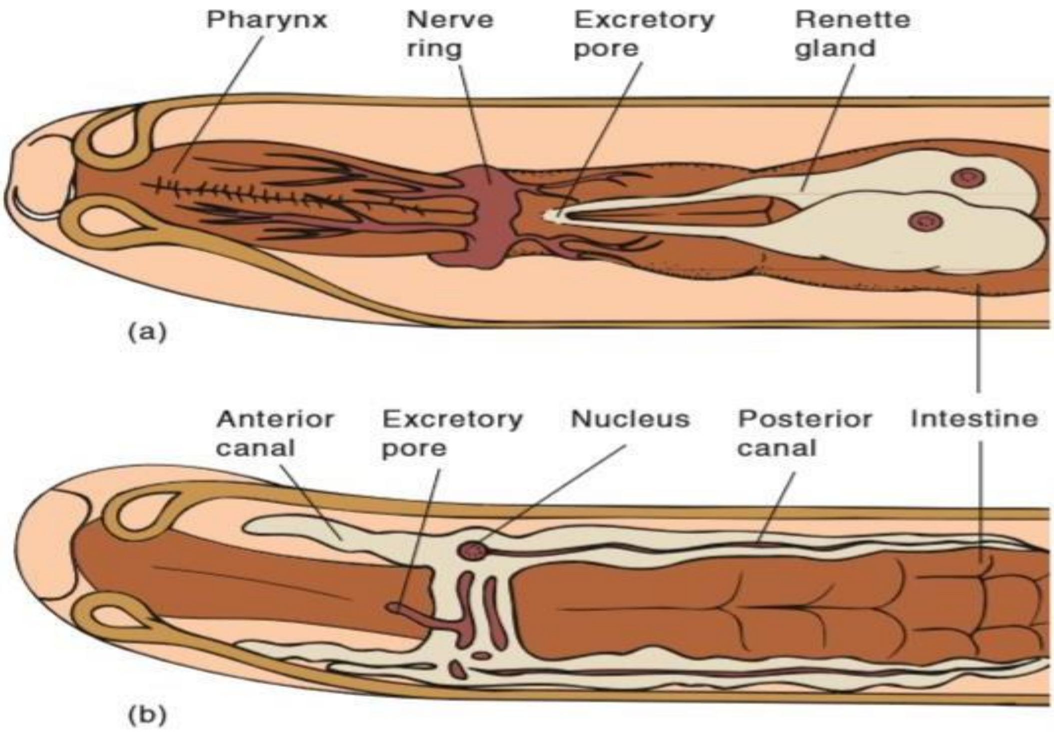


FIGURE 11.8
Nematode Excretory Systems. *(a)* Glandular, as in *Rhabditis*. *(b)* Tubular, as in *Ascaris*.

Feeding and The Digestive System

Depending on the environment, nematodes are capable of feeding on a wide variety of foods; they may be carnivores, herbivores, omnivores, or saprobes (saprotrophs) that consume decomposing organisms or parasitic species that feed on blood and tissue fluids of their hosts.

Nematodes have a complete digestive system consisting of a mouth, which may have teeth, jaws, or stylets (sharp, pointed structures); buccal cavity; muscular pharynx; long, tubular intestine where digestion and absorption occur; short rectum; and anus. Hydrostatic pressure in the pseudocoelom and the pumping action of the pharynx push food through the alimentary canal.

Other Organ Systems

Nematodes accomplish osmoregulation and excretion of nitrogenous waste products (ammonia, urea) with two unique systems. The glandular system is in aquatic species and consists of ventral gland cells, called renette, posterior to the pharynx (figure 11.8a). Each gland absorbs wastes from the pseudocoelom and empties them to the outside through an excretory pore. Parasitic nematodes have a more advanced system, called the tubular system, that develops from the renette system (figure 11.8b). In this system, the renette unite to form a large canal, which opens to the outside via an excretory pore. The nervous system consists of an anterior nerve ring. Nerves extend anteriorly and posteriorly; many connect to each other via commissures. Certain neuroendocrine secretions are involved in growth, molting, cuticle formation, and metamorphosis.

Reproduction and Development

Most nematodes are dioecious and dimorphic, with the males being smaller than the females. The long, coiled gonads lie free in the pseudocoelom. The female system consists of a pair of convoluted ovaries. Each ovary is continuous with an oviduct whose proximal end is swollen to form a seminal receptacle. Each oviduct becomes a tubular uterus; the two uteri unite to form a vagina that opens to the outside through a genital pore. The male system consists of a single testis, which is continuous with a vas deferens that eventually expands into a seminal vesicle. The seminal vesicle connects to the cloaca.

Males are commonly armed with a posterior flap of tissue called a bursa. The bursa aids the male in the transfer of sperm to the female genital pore during copulation. After copulation, hydrostatic forces in the pseudocoelom move each fertilized egg to the gonopore (genital pore). The number of eggs produced varies with the species; some nematodes produce only several hundred, whereas others may produce hundreds of thousands daily. Some nematodes give birth to larvae (ovoviviparity). External factors, such as temperature and moisture, influence the development and hatching of the eggs. Hatching produces a larva (some parasitologists refer to it as a juvenile) that has most adult structures. The larva (juvenile) undergoes four molts, although in some species, the first one or two molts may occur before the eggs hatch.

Lecture #`148

Phylum Annelida

Characteristics of the phylum Annelida include:

1. Body metameric, bilaterally symmetrical, and wormlike

2. Protostome characteristics include spiral cleavage, trochophore larvae (when larvae are present), and schizocoelous coelom formation

3. Paired, epidermal setae

4. Closed circulatory system

5. Dorsal suprapharyngeal ganglia and ventral nerve cord(s) with ganglia

6. Metanephridia (usually) or protonephridia

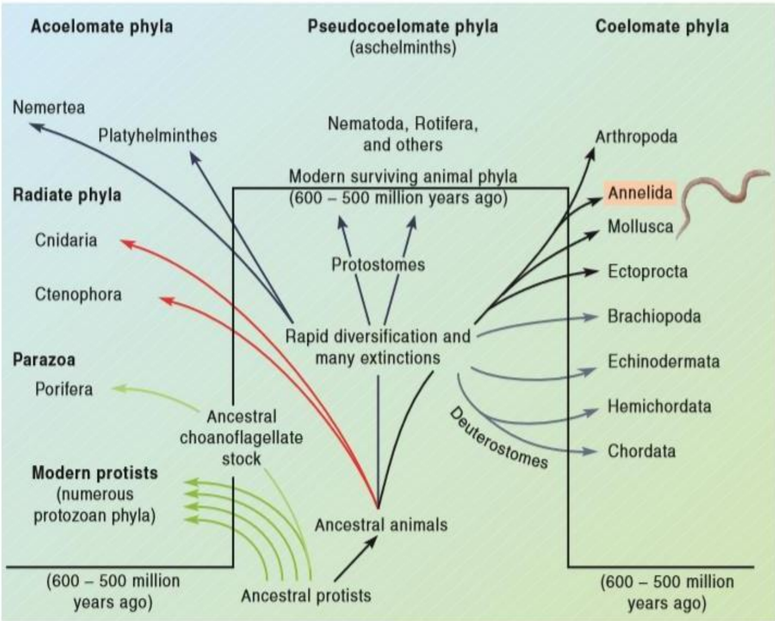


FIGURE 13.2

Evolutionary Relationships of the Annelida. Annelids (shaded in orange) are protostomes with close evolutionary ties to the arthropods.

Relationships to Other Animals

Annelids are protostomes. Protostome characteristics, such as spiral cleavage, a mouth derived from an embryonic blastopore, schizocoelous coelom formation, and trochophore

larvae are present in most members of the phylum. (Certain exceptions are discussed later.) This diverse phylum, like most other phyla, originated at least as early as Precambrian times, more than six hundred million years ago. Unfortunately, little evidence documents the evolutionary pathways that resulted in the first annelids. Several hypotheses account for annelid origins. These hypotheses are tied into hypotheses regarding the origin of the coelom. If a schizocoelous origin of the coelom is correct, as many zoologists believe, then the annelids evolved from ancient flatworm stock.

On the other hand, if an enterocoelous coelom origin is correct, then annelids evolved from ancient diploblastic animals, and the triploblastic, acoelomate body may have been derived from a triploblastic, coelomate ancestor. The recent discovery of a worm, Lobatocerebrum, that shares annelid and flatworm characteristics has lent support to the enterocoelous origin hypothesis. Lobatocerebrum is classified as an annelid based on the presence of certain segmentally arranged excretory organs, an annelid-like body covering, a complete digestive tract, and an annelid-like nervous system. However, it has a ciliated epidermis and is acoelomate like flatworms. Some zoologists believe that Lobatocerebrum illustrates how the triploblastic, acoelomate design could have been derived from the annelid lineage.

Metamerism and Tagmatization

Earthworm bodies are organized into a series of ring like segments. What is not externally obvious, however, is that the body is divided internally as well. Segmental arrangement of body parts in an animal is called metamerism (Gr. meta, after part). Metamerism profoundly influences virtually every aspect of annelid structure and function, such as the anatomical arrangement of organs that are coincidentally associated with metamerism. For example, the compartmentalization of the body has resulted in each segment having its own excretory, nervous, and circulatory structures. Two related functions are probably the primary adaptive features of metamerism: flexible support and efficient locomotion. These functions depend on the metameric arrangement of the coelom and can be understood by examining the development of the coelom and the arrangement of body-wall muscles.

During embryonic development, the body cavity of annelids arises by a segmental splitting of a solid mass of mesoderm that occupies the region between ectoderm and endoderm on either side of the embryonic gut tract. Enlargement of each cavity forms a double-membraned septum on the anterior and posterior margin of each coelomic space and dorsal and ventral mesenteries associated with the digestive tract. Muscles also develop from the mesodermal layers associated with each segment. A layer of circular muscles lies below the epidermis, and a layer of longitudinal muscles, just below the circular muscles, runs between the septa that separate each segment. In addition, some polychaetes have oblique muscles, and the leeches have dorsoventral muscles. One advantage of the segmental arrangement of coelomic spaces and muscles is the creation of hydrostatic compartments, which allow a variety of advantageous locomotor and supportive functions not possible in nonmetameric animals that utilize a hydrostatic skeleton. Each segment can be controlled independently of distant segments, and muscles can act as antagonistic pairs within a segment. The constant volume of coelomic fluid provides a hydrostatic skeleton against which muscles operate. Resultant localized changes in the shape of groups of segments provide the basis for swimming, crawling, and burrowing. A second advantage of metamerism is that it lessens the impact of injury. If one or a few segments are injured, adjacent segments, set off from injured segments by septa, may be able to maintain nearly normal functions, which increases the likelihood that the worm, or at least a part of it, will survive the trauma.

A third advantage of metamerism is that it permits the modification of certain regions of the body for specialized functions, such as feeding, locomotion, and reproduction. The specialization of body regions in a metameric animal is called tagmatization (Gr. tagma, arrangement). Although it is best developed in the arthropods, some annelids also display tagmatization. (The arthropods include animals such as insects, spiders, mites, ticks, and crayfish.) Because of similarities in the development of metamerism in the two groups, annelids and arthropods are thought to be closely related. Other common features include triploblastic coelomate organization, bilateral symmetry, a complete digestive tract, and a ventral nerve cord. As usual, fossil evidence documenting ancestral pathways that led from a common ancestor to the earliest representatives of these two phyla is scant. Annelids and arthropods may have evolved from a marine, wormlike, bilateral ancestor that possessed metameric design.

Phylum Arthropoda

Characteristics of the phylum Arthropoda include:

1. Metamerism modified by the specialization of body regions for specific functions (tagmatization)
2. Chitinous exoskeleton that provides support and protection and is modified to form sensory structures
3. Paired, jointed appendages
4. Growth accompanied by ecdysis or molting
5. Ventral nervous system
6. Coelom reduced to cavities surrounding gonads and sometimes excretory organs

7. Open circulatory system in which blood is released into tissue spaces (hemocoel) derived from the blastocoel

8. Complete digestive tract

9. Metamorphosis often present; reduces competition between immature and adult stages

Classification and Relationships to Other Animals

Arthropods and annelids are closely related. Shared protostome characteristics, such as schizocoelous coelom formation and the development of the mouth from the blastopore, as well as other common characteristics, such as the presence of a paired ventral nerve cord and metamerism, are evidence of a common ancestry. Zoologists, however, disagree about the evolutionary relationships among the arthropods. Many zoologists believe that it is not one phylum, but three. The arthropods are treated in this text as members of a single phylum. Living arthropods are divided into three subphyla: Chelicerata, Crustacea, and Uniramian. All members of a fourth subphylum, Trilobitomorpha, are extinct. This chapter examines Trilobitomorpha, Chelicerata, and Crustacea

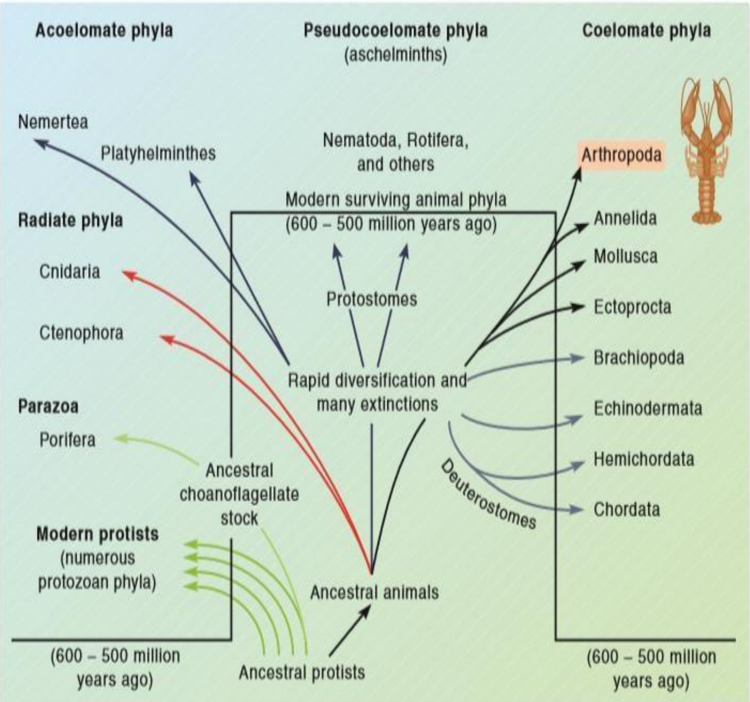


FIGURE 14.2

Evolutionary Relationships of the Arthropods. Arthropods (shaded in orange) are protostomes with close evolutionary ties to the annelids. A paired ventral nerve cord and metamerism in both groups are evidence of common ancestry.

Metamerism And Tagmatization

Three aspects of arthropod biology have contributed to their success. One of these is metamerism. Metamerism of arthropods is most evident externally because the arthropod body is often composed of a series of similar segments, each bearing a pair of appendages. Internally, however, septa do not divide the body cavity of an arthropod, and most organ systems are not metamerically arranged. The reason for the loss of internal metamerism is speculative; however, the presence of metamerically arranged hydrostatic compartments would be of little value in the support or locomotion of animals enclosed by an external skeleton (discussed under "The Exoskeleton"). As discussed in chapter 13, metamerism permits the specialization of regions of the body for specific functions. This regional specialization is called tagmatization. In arthropods, body regions, called tagmata (sing., tagma), are specialized for feeding and sensory perception, locomotion, and visceral functions.

The Exoskeleton

An external, jointed skeleton, called an exoskeleton or cuticle, encloses arthropods. The exoskeleton is often cited as the major reason for arthropod success. It provides structural support, protection, impermeable surfaces for the prevention of water loss, and a system of levers for muscle attachment and movement. The exoskeleton covers all body surfaces and invaginations of the body wall, such as the anterior and posterior portions of the gut tract. It is nonliving and is secreted by a single layer of epidermal cells (figure 14.3). The epidermal layer is sometimes called the hypodermis because, unlike other epidermal tissues, it is covered on the outside by exoskeleton, rather than being directly exposed to air or water.

The exoskeleton has two layers. The epicuticle is the outermost layer. Made of a waxy lipoprotein, it is impermeable to water and a barrier to microorganisms and pesticides. The bulk of the exoskeleton is below the epicuticle and is called the procuticle. (In crustaceans, the procuticle is sometimes called the endocuticle.) The procuticle is composed of chitin, a tough, leathery polysaccharide, and several kinds of proteins. The procuticle hardens through a process called sclerotization and sometimes by impregnation with calcium carbonate. Sclerotization is a tanning process in which layers of protein are chemically cross-linked with one another—hardening and darkening the exoskeleton.

In insects and most other arthropods, this bonding occurs in the outer portion of the procuticle. The exoskeleton of crustaceans hardens by sclerotization and by the deposition of calcium carbonate in the middle regions of the procuticle. Some proteins give the exoskeleton resiliency. Distortion of the exoskeleton stores energy for such activities as flapping wings and jumping. The inner portion of the procuticle does not harden. Hardening in the procuticle provides armorlike protection for arthropods, but it also necessitates a variety of adaptations to allow arthropods to live and grow within their confines. Invaginations of the exoskeleton form firm ridges and bars for muscle attachment. Another modification of the exoskeleton is the formation of joints. A flexible membrane, called an articular membrane, is present in regions where the procuticle is thinner and less hardened (figure 14.4). Other modifications of the exoskeleton in

clude sensory receptors, called sensilla, in the form of pegs, bristles, and lenses, and modifications of the exoskeleton that permit gas exchange. The growth of an arthropod would be virtually impossible unless the exoskeleton were periodically shed, such as in the molting process called ecdysis (Gr. ekdysis, getting out). Ecdysis is divided into four stages:

(1) Enzymes, secreted from hypodermal glands, begin digesting the old procuticle to separate the hypodermis and the exoskeleton

(2) new procuticle and epicuticle are secreted

(3) the old exoskeleton splits open along predetermined ecdysal lines when the animal stretches by air or water intake; pores in the procuticle secrete additional epicuticle

(4) finally, calcium carbonate deposits and/or sclerotization harden the new exoskeleton

During the few hours or days of the hardening process, the arthropod is vulnerable to predators and remains hidden. The nervous and endocrine systems control all these changes

Metamorphosis

A third characteristic that has contributed to arthropod success is a reduction of competition between adults and immature stages because of metamorphosis. Metamorphosis is a radical change in body form and physiology as an immature stage, usually called a larva, becomes an adult. The evolution of arthropods has resulted in an increasing divergence of body forms, behaviors, and habitats between immature and adult stages. Adult crabs, for example, usually prowl the sandy bottoms of their marine habitats for live prey or decaying organic matter, whereas larval crabs live and feed in the plankton. Similarly, the caterpillar that feeds on leafy vegetation eventually develops into a nectar-feeding adult butterfly or moth. Having different adult and immature stages means that the stages do not compete for food or living space. In some arthropod and other animal groups, larvae also serve as the dispersal stage.

Lecture #`150

Molluscan characteristics

Molluscs range in size and body form from the giant squid, measuring 18 m in length, to the smallest garden slug, less than 1 cm long. Despite this diversity, the phylum Mollusca (mol-luskah) (L. molluscus, soft) is not difficult to characterize (table 12.1). Characteristics of the phylum Mollusca include: 1. Body of two parts: head-foot and visceral mass 2. Mantle that secretes a calcareous shell and covers the visceral mass 3. Mantle cavity functions in excretion, gas exchange, elimination of digestive wastes, and release of reproductive products 4. Bilateral symmetry 5. Protostome characteristics, including trochophore larvae, spiral cleavage, and schizocoelous coelom formation 6. Coelom reduced to cavities surrounding the heart, nephridia, and gonads 7. Open circulatory system in all but one class (Cephalopoda) 8. Radula usually present and used in scraping food the body of a mollusc has three main regions—the head foot, the visceral mass, and the mantle (figure 12.3). The head foot is elongate with an anterior head, containing the mouth and certain nervous and sensory structures, and an elongate foot, used for attachment and locomotion. The visceral mass contains the organs of digestion, circulation, reproduction, and excretion and is positioned dorsal to the head-foot. The mantle of a mollusc usually attaches to the visceral mass, enfolds most of the body, and may secrete a shell that overlies the mantle. The shell of a mollusc is secreted in three layers (figure 12.4). The outer layer of the shell is called the periostracum.

Mantle cells at the mantle's outer margin secrete this protein layer. The middle layer of the shell, called the prismatic layer, is the thickest of the three layers and consists of calcium carbonate mixed with organic materials. Cells at the mantle's outer margin also secrete this layer. The inner layer of the shell, the nacreous layer, forms from thin sheets of calcium carbonate alternating with organic matter. Cells along the entire epithelial border of the mantle secrete the nacreous layer. Nacre secretion thickens the shell. Between the mantle and the foot is a space called the mantle cavity. The mantle cavity opens to the outside and functions in gas exchange, excretion, elimination of digestive wastes, and release of reproductive products.

The mouth of most molluscs possesses a rasping structure called a radula, which consists of a chitinous belt and rows of posteriorly curved teeth (figure 12.5). The radula overlies a fleshy, tongue like structure supported by a cartilaginous odontophore. Muscles associated with the odontophore permit the radula to be protruded from the mouth. Muscles associated with the radula move the radula back and forth over the odontophore. Food is scraped from a substrate and passed posteriorly to the digestive tract.

Lecture #`154

Echinoderm Characteristics

The approximately seven thousand species of living echinoderms are exclusively marine and occur at all depths in all oceans. Modern echinoderms have a form of radial symmetry, called pentaradial symmetry, in which body parts are arranged in fives, or a multiple of five, around an oral-aboral axis (figure 16.3a). Radial symmetry is adaptive for sedentary or slowly moving animals because it allows a uniform distribution of sensory, feeding, and other structures around the animal. Some modern mobile echinoderms, however, have secondarily returned to a basically bilateral form.

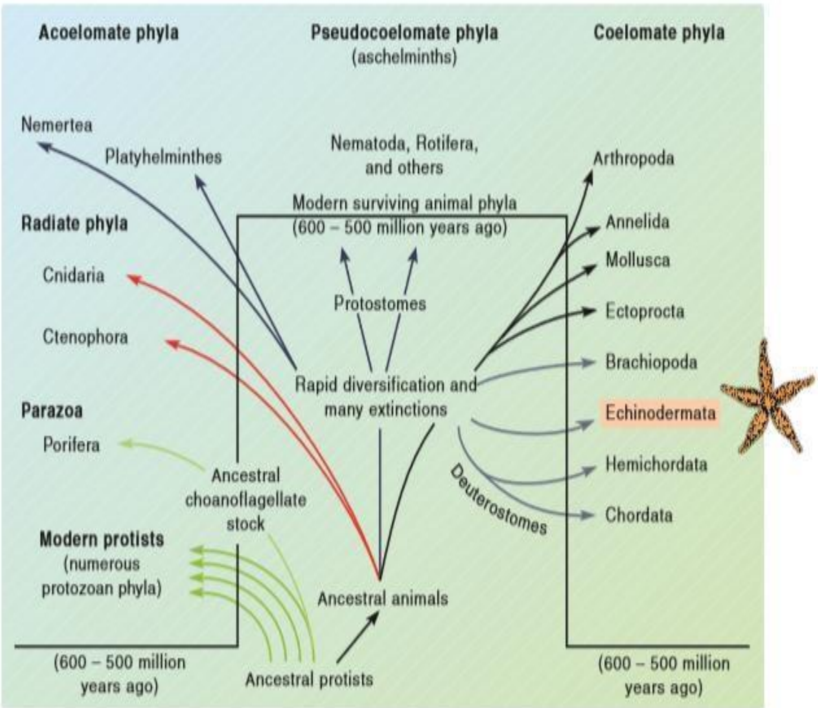


FIGURE 16.2
Evolutionary Relationships of the Echinoderms. The echinoderms (shaded in orange) diverged from the deuterostomate lineage at least 600 million years ago. Although modern echinoderms are pentaradially symmetrical, the earliest echinoderms were probably bilaterally symmetrical.

The echinoderm skeleton consists of a series of calcium carbonate plates called ossicles. These plates are derived from mesoderm, held in place by connective tissues, and covered by an epidermal layer. If the epidermal layer is abraded away, the skeleton may be exposed in some body regions. The skeleton is frequently modified into fixed or articulated spines that project from the body surface. The evolution of the skeleton may be responsible for the pentaradial body form of echinoderms. The joints between two skeletal plates represent a weak point in the skeleton (figure 16.3b). By not having weak joints directly opposite one another, the skeleton is made stronger than if the joints were arranged opposite each other. The water- vascular system of echinoderms is a series of water-filled canals, and their extensions are called tube feet. It originates embryologically as a modification of the coelom and is ciliated internally. The water-vascular system includes a ring canal that surrounds the mouth . The ring canal usually opens to the outside or to the body cavity through a stone canal and a sieve-like plate, called the madreporite.

The madreporite may serve as an inlet to replace water lost from the water-vascular system and may help equalize pressure differences between the water-vascular system and the outside. Tiedemann bodies are swellings often associated with the ring canal. They are believed to be sites to produce phagocytic cells, called coelomocytes, whose functions are described later in this chapter. Polian vesicles are sacs that are also associated with the ring canal and function in fluid storage for the water-vascular system. five (or a multiple of five) radial canals branch from the ring canal. Radial canals are associated with arms of star-shaped echinoderms. In other echinoderms, they may be associated with the body wall and arch toward the aboral pole. Many lateral canals branch off each radial canal and end at the tube feet. Tube feet are extensions of the canal system and usually emerge through openings in skeletal ossicles. Internally, tube feet usually terminate in a bulblike, muscular ampulla. When an ampulla contracts, it forces water into the tube foot, which then extends. Valves prevent the backflow of water from the tube foot into the lateral canal.

A tube foot often has a suction cup at its distal end. When the foot extends and contacts solid substrate, muscles of the suction cup contract and create a vacuum. In some taxa, tube feet have a pointed or blunt distal end. These echinoderms may extend their tube feet into a soft substrate to secure contact during locomotion or to sift sediment during feeding. The water-vascular system has other functions in addition to locomotion.

As is discussed at the end of this chapter, the original function of water-vascular systems was probably feeding, not locomotion. In addition, the soft membranes of the water-vascular system permit diffusion of respiratory gases and nitrogenous wastes across the body wall. A hemal system consists of strands of tissue that encircle an echinoderm near the ring canal of the water-vascular system and run into each arm near the radial canals. The hemal system has been likened to a vestigial circulatory system; however, its function is largely unknown. It may aid in the transport of large molecules, hormones, or coelomocytes, which are cells that engulf and transport waste particles within the body.

Lecture #`156

Phylum Hemichordata

The phylum Hemichordata (hemi-kor-datah) (Gr. hemi, half L. chorda, cord) includes the acorn worms (class Enteropneusta) and the pterobranchs (class Pterobranchia) (table 17.1). Members of both classes live in or on marine sediments. Characteristics of the phylum Hemichordata include:

- Marine, deuterostomate animals with a body divided into three regions: proboscis, collar, and trunk; coelom divided into three cavities
- Ciliated pharyngeal slits
- Open circulatory system
- Complete digestive tract
- Dorsal, sometimes tubular, nerve cord

Class Enteropneusta

Members of the class Enteropneusta (enter-op-nustah) (Gr. entero, intestine pneustikos, for breathing) are marine worms that usually range in size between 10 and 40 cm, although some can be as long as 2 m. Zoologists have described about 70 species, and most occupy U-shaped burrows in sandy and muddy substrates between the limits of high and low tides. The common name of the enteropneusts—acorn worms—is derived from the appearance of the proboscis, which is a short, conical projection at the worm's anterior end. A ring like collar is posterior to the proboscis, and an elongate trunk is the third division of the body (figure 17.3). A ciliated epidermis and gland cells cover acorn worms. The mouth is located ventrally between the proboscis and the collar. A variable number of pharyngeal slits, from a few to several hundred, are positioned laterally on the trunk. Pharyngeal slits are openings between the anterior region of the digestive tract, called the pharynx, and the outside of the body.

Maintenance Functions

Cilia and mucus assist acorn worms in feeding. Detritus and other particles adhere to the mucus-covered proboscis. Tracts of cilia transport food and mucus posteriorly and ventrally. Ciliary tracts converge near the mouth and form a mucoid string that enters the mouth. Acorn worms may reject some substances trapped in the mucoid string by pulling the proboscis against the collar. Ciliary tracts of the collar and trunk transport rejected material and discard it posteriorly. The digestive tract of enteropneusts is a simple tube. Food is digested as diverticula of the gut, called hepatic sacs, release enzymes.

The worm extends its posterior end out of the burrow during defecation. At low tide, coils of fecal material, called castings, lie on the substrate at burrow openings. The nervous system of enteropneusts is ectodermal in origin and lies at the base of the ciliated epidermis. It consists of dorsal and ventral nerve tracts and a network of epidermal nerve cells, called a nerve plexus. In some species, the dorsal nerve is tubular and usually contains giant nerve fibers that rapidly transmit impulses. There are no major ganglia. Sensory receptors are unspecialized and widely distributed over the body. Because acorn worms are small, respiratory gases and metabolic waste products (principally ammonia) probably are exchanged by diffusion across the body wall. In addition, respiratory gases are exchanged at the pharyngeal slits.

Cilia associated with pharyngeal slits circulate water into the mouth and out of the body through the pharyngeal slits. As water passes through the pharyngeal slits, gases are exchanged by diffusion between water and blood sinuses surrounding the pharynx. The circulatory system of acorn worms consists of one dorsal and one ventral contractile vessel. Blood moves anteriorly in the dorsal vessel and posteriorly in the ventral vessel. Branches from these vessels lead to open sinuses. All blood flowing anteriorly passes into a series of blood sinuses, called the glomerulus, at the base of the proboscis. Excretory wastes may be filtered through the glomerulus, into the coelom of the proboscis, and released to the outside through one or two pores in the wall of the proboscis. The blood of acorn worms is colorless, lacks cellular elements, and distributes nutrients and wastes.

Reproduction and Development

Enteropneusts are dioecious. Two rows of gonads lie in the body wall in the anterior region of the trunk, and each gonad opens separately to the outside. Fertilization is external. Spawning by one worm induces others in the area to spawn—behavior that suggests the presence of spawning pheromones. Ciliated larvae, called tornaria, swim in the plankton for several days to a few weeks. The larvae settle to the substrate and gradually transform into the adult form.

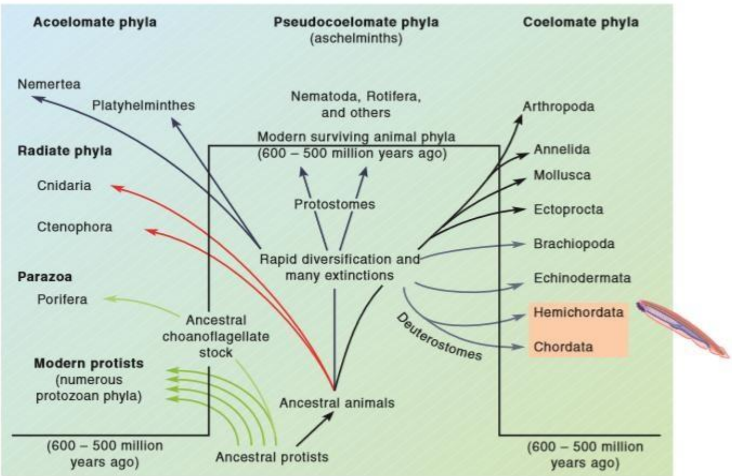


FIGURE 17.2
Phylogenetic Relationships among the Hemichordata and Chordata. Hemichordates and chordates (shaded in orange) are distantly related deuterostomes derived from a common, as yet undiscovered, diploblastic or triploblastic ancestor.

Lecture #`157

Characteristics of Phylum Chordata

Chordates (phylum Chordata) are deuterostome coelomates; their nearest relatives in the animal kingdom are the echinoderms, the only other major phylum of deuterostomes. There are some 56,000 species of chordates, a phylum that includes fishes, amphibians, reptiles, birds, and mammals. Four features characterize the chordates and have played an important role in the evolution of the phylum: A single, hollow

1. nerve cord runs just beneath the dorsal surface of the animal. In vertebrates, the dorsal nerve cord differentiates into the brain and spinal cord. A flexible rod, the

2. notochord, forms on the dorsal side of the primitive gut in the early embryo and is present at some developmental stage in all chordates. The notochord is located just below the nerve cord. The notochord may persist in some chordates; in others it is replaced during embryonic development by the vertebral column that forms around the nerve cord.

3. connect the pharynx, a muscular tube that links the mouth cavity and the esophagus, with the external environment. In terrestrial vertebrates, the slits do not actually connect to the outside and are better termed pharyngeal pouches. Pharyngeal pouches are present in the embryos of all vertebrates. They become slits, open to the outside in animals with gills, but leave no external trace in those lacking gills. The presence of these structures in all vertebrate embryos provides evidence of their aquatic ancestry.

Chordates have a post anal tail that extends beyond the anus, at least during their embryonic development. Nearly all other animals have a terminal anus. All chordates have all four of these characteristics at some time in their lives. For example, humans as embryos have pharyngeal pouches, a dorsal nerve cord, a postanal tail, and a notochord. As adults, the nerve cord remains, and the notochord is replaced by the vertebral column. All but one pair of pharyngeal pouches are lost; this remaining pair forms the Eustachian tubes that connect the throat to the middle ear. The postanal tail regresses, forming the tail bone (coccyx).

Several other characteristics also fundamentally distinguish the chordates from other animals. Chordate muscles are arranged in segmented blocks that affect the basic organization of the chordate body and can often be clearly seen in embryos of this phylum. Most chordates have an internal skeleton against which the muscles work. Either this internal skeleton or the notochord makes possible the extraordinary powers of locomotion characteristic of this group.

Lecture #157

Class Pisces

Over half of all vertebrates are fishes. The most diverse vertebrate group, fishes provided the evolutionary base for invasion of land by amphibians. In many ways, amphibians can be viewed as transitional— “fish out of water.” The story of vertebrate evolution started in the ancient seas of the Cambrian period (545 to 490 mya). Figure 35.8 shows the key vertebrate characteristics that evolved subsequently. Wriggling through the water, jawless and toothless, the first fishes sucked up small food particles from the ocean floor like miniature vacuum cleaners. Most were less than a foot long, respired with gills, and had no paired fins or vertebrae (although some had rudimentary vertebrae); they did have a head and a primitive tail to push them through the water. For 50 million years, during the Ordovician period (490 to 438 mya), these simple fishes were the only vertebrates. By the end of this period, fish had developed primitive fins to help them swim and massive shields of bone for protection. Jawed fishes first appeared during the Silurian period (438 to 408 mya), and along with them came a new mode of feeding.

Fishes exhibit five key characteristics from whale sharks 18 m long to tiny gobies no larger than your fingernail, fishes vary considerably in size, shape, color, and appearance. Some live in freezing arctic seas, others in warm, freshwater lakes, and still others spend a lot of time entirely out of water. However varied, all fishes have important characteristics in common: Vertebral column.

1. Fish have an internal skeleton with a bony or cartilaginous spine surrounding the dorsal nerve cord, and a bony or cartilaginous skull encasing the brain. Exceptions are the jawless hagfish and lampreys. In hagfish, a cartilaginous skull is present, but vertebrae are not; the notochord persists and provides support. In lampreys, a cartilaginous skeleton and notochord are present, but rudimentary cartilaginous vertebrae also surround the notochord in places. Jaws and paired appendages.

2. Fishes other than lampreys and hagfish all have jaws and paired appendages, features that are also seen in tetrapod's. Jaws allowed these fish to capture larger and more active prey. Most fishes have two pairs of fi ns: a pair of pectoral fins at the shoulder, and a pair of pelvic fi ns at the hip. In the lobe-finned fish, these pairs of fi ns became jointed. Internal gills.

3. Fishes are water-dwelling creatures and must extract oxygen dissolved in the water around them. They do this by directing a flow of water through their mouths and across their gills. The gills are composed of fi ne fi laments of tissue that are rich in blood vessels. Single-loop blood circulation.

4. Blood is pumped from the heart to the gills. From the gills, the oxygenated blood passes to the rest of the body, and then returns to the heart. The heart is a muscular tube-pump made of two chambers that contract in sequence. Nutritional deficiencies.

5. Fishes are unable to synthesize the aromatic amino acids (phenylalanine, tryptophan, and tyrosine), and they must consume them in their foods. This inability has been inherited by all their vertebrate descendants.

Lecture # 158

Class amphibians

Frogs, salamanders, and caecilians, the damp-skinned vertebrates, are direct descendants of fishes. They are the sole survivors of a very successful group, the amphibians (class Amphibia), the first vertebrates to walk on land. Most present-day amphibians are small and live largely unnoticed by humans, but they are among the most numerous of terrestrial vertebrates. Throughout the world, amphibians play key roles in terrestrial food chains. Living amphibians have five distinguishing features Biologists have classified living species of amphibians into three orders: 5000 species of frogs and toads in 22 families make up the order Anura ("without a tail"); 500 species of salamanders and newts in 9 families make up the order Caudata ("visible tail"); and 170 species (6 families) of wormlike, nearly blind organisms called caecilians that live in the tropics make up the order Apoda ("without legs").

These amphibians have several key characteristics in common:

1. Legs. Frogs and most salamanders have four legs and can move about on land quite well. Legs were one of the key adaptations to life on land. Caecilians have lost their legs during adapting to a burrowing existence.

2. Lungs. Most amphibians possess a pair of lungs, although the internal surfaces have much less surface area than do reptilian or mammalian lungs. Amphibians breathe by lowering the floor of the mouth to suck in air, and then raising it back to force the air down into the lungs. Cutaneous respiration.

3. Frogs, salamanders, and caecilians all supplement the use of lungs by respiring through their skin, which is kept moist and provides an extensive surface area. Pulmonary veins.

4. After blood is pumped through the lungs; two large veins called pulmonary veins return the aerated blood to the heart for repumping. In this way aerated blood is pumped to the tissues at a much higher pressure. Partially divided heart.

5. A dividing wall helps prevent aerated blood from the lungs from mixing with non-aerated blood being returned to the heart from the rest of the body. The blood circulation is thus divided into two separate paths: pulmonary and systemic. The separation is imperfect, however, because no dividing wall exists in one chamber of the heart, the ventricle. Several other specialized characteristics are shared by all present-day amphibians. In all three orders, there is a zone of weakness between the base and the crown of the teeth. They also have a peculiar type of sensory rod cell in the retina of the eye called a “green rod.” The function of this rod is unknown.

Lecture #`158

Amphibians overcame terrestrial challenges

The word amphibia means “double life,” and it nicely describes the essential quality of modern-day amphibians, reflecting their ability to live in two worlds—the aquatic world of their fish ancestors and the terrestrial world they first invaded. Here, we review the checkered history of this group, almost all whose members have been extinct for the last 200 million years. Then we examine in more detail what the few kinds of surviving amphibians are like. The successful invasion of land by vertebrates posed several major challenges:

- Because amphibian ancestors had relatively large bodies, supporting the body’s weight on land as well as enabling movement from place to place was a challenge. Legs evolved to meet this need.

- Even though far more oxygen is available to gills in air than in water, the delicate structure of fish gills requires the buoyancy of water to support them, and they will not function in air. Therefore, other methods of obtaining oxygen were required.

■ Delivering great amounts of oxygen to the larger muscles needed for movement on land required modifications to the heart and circulatory system.

■ Reproduction still had to be carried out in water so that eggs would not dry out.

■ Most importantly, the body itself had to be prevented from drying out.

Lecture #`159

Reptiles exhibit three key characteristics

All living reptiles share certain fundamental characteristics, features they retain from the time when they replaced amphibians as the dominant terrestrial vertebrates. Among the most important are: Amniotic eggs.

1. Amphibians' eggs must be laid in water or a moist setting to avoid drying out. Most reptiles lay watertight eggs that contain a food source (the yolk) and a series of four membranes: the yolk sac, the amnion, the allantois, and the chorion. Each membrane plays a role in making the egg an independent life support system. All modern reptiles, as well as birds and mammals, show exactly this same pattern of membranes within the egg. These three classes are called amniotes. The outermost membrane of the egg is the chorion, which lies just beneath the porous shell. It allows exchange of respiratory gases but retains water. The amnion encases the developing embryo within a fluid-filled cavity. The yolk sac provides food from the yolk for the embryo via blood vessels connecting to the embryo's gut. The allantois surrounds a cavity into which waste products from the embryo are excreted.

2. Most living amphibians have moist skin and must remain in moist places to avoid drying out. Reptiles have dry, watertight skin. A layer of scales covers their bodies, preventing water loss. These scales develop as surface cells fill with keratin, the same protein that forms claws, fingernails, hair, and bird feathers.

3. Amphibians breathe by squeezing their throat to pump air into their lungs; this limits their breathing capacity to the volume of their mouths. Reptiles developed pulmonary breathing, expanding and contracting the rib cage to suck air into the lungs and then force it out. The capacity of this system is limited only by the volume of the lungs.

Lecture #`160

Characteristics of Class Aves

Key characteristics of birds are feathers and a lightweight skeleton Modern birds lack tooth and have only vestigial tails, but they still retain many reptilian characteristics. For instance, birds lay amniotic eggs. Also, reptilian scales are present on the feet and lower legs of birds. Two primary characteristics distinguish birds from living reptiles: Feathers.

1. Feathers are modified reptilian scales made of keratin, just like hair and scales. Feathers serve two functions: providing lift for flight and conserving heat. The structure of feathers combines maximum flexibility and strength with minimum weight. Feathers develop from tiny pits in the skin called follicles. In a typical flight feather, a shaft emerges from the follicle, and pairs of vanes develop from its opposite sides. At maturity, each vane has many branches called barbs. The barbs, in turn, have many projections called barbules that are equipped with microscopic hooks. These hooks link the barbs to one another, giving the feather a continuous surface and a sturdy but flexible shape. Like scales, feathers can be replaced. Among living animals, feathers are unique to birds. Recent fossil finds suggest that some dinosaurs may have had feathers. Flight skeleton.

2. The bones of birds are thin and hollow. Many of the bones are fused, making the bird skeleton more rigid than a reptilian skeleton. The fused sections of backbone and of the shoulder and hip girdles form a sturdy frame that anchors muscles during flight. The power for active flight comes from large breast muscles that can make up 30% of a bird's total body weight. They stretch down from the wing and attach to the breastbone, which is greatly enlarged and bears a prominent keel for muscle attachment. Breast muscles also attach to the fused collarbones that form the so-called wishbone. No other living vertebrates have a fused collarbone or a keeled breastbone.

Lecture #`162

Characteristics of class mammals

Mammals have hair, mammary glands, and other characteristics Mammals are distinguished from all other classes of vertebrates by two fundamental characteristics—hair and mammary glands— and are marked by several other notable features:

1. Hair. All mammals have hair. Even apparently hairless whales and dolphins grow sensitive bristles on their snouts. The evolution of fur and the ability to regulate body temperature enabled mammals to invade colder climates that ectothermic reptiles do not inhabit. Mammals are endothermic animals, and typically maintain body temperatures higher than the temperature

of their surroundings. The dense undercoat of many mammals reduces the amount of body heat that escapes.

2.Another function of hair is camouflage age. The coloration and pattern of a mammal's coat usually matches its background. A little brown mouse is practically invisible against the brown leaf litter of a forest floor, and the orange and black stripes of a Bengal tiger disappear against the orange-brown color of the tall grass in which it hunts. Hairs also function as sensory structures. The whiskers of cats and dogs are stiff hairs that are very sensitive to touch. Mammals that are active at night or live underground often rely on their whiskers to locate prey or to avoid colliding with objects. Finally, hair can serve as a defensive weapon. Porcupines and hedgehogs protect themselves with long, sharp, stiff hairs called quills.

3. All female mammals possess mammary glands that can secrete milk. Newborn mammals, born without teeth, suckle this milk as their primary food. Even baby whales are nursed by their mother's milk. Milk is a very high-calorie food (human milk has 750 kcal per liter), important because of the high energy needs of a rapidly growing newborn mammal. About 50% of the energy in the milk comes from fat.

4. As stated previously, mammals are endothermic, a crucial adaptation that has allowed them to be active at any time of the day or night and to colonize severe environments, from deserts to ice fields. Also, more efficient blood circulation provided by the four chambered heart and more efficient respiration provided by the diaphragm (a special sheet of muscles below the rib cage that aids breathing) make possible the higher metabolic rate on which endothermy depends. Placenta.

5. In most mammal species, females carry their developing young internally in a uterus, nourishing them through the placenta, and give birth to live young. The placenta is a specialized organ that brings the bloodstream of the fetus into close contact with the bloodstream of the mother. Food, water, and oxygen can pass across from mother to child, and wastes can pass over to the mother's blood and be carried away.

Lecture#`164

Kingdom Plantae

The origin of land plants from a green algal ancestor has long been recognized as a major evolutionary event. Molecular phylogenetics reveals that land plants arose from an ancestral green alga, and that the evolution of land plants occurred only once, an indication of the incredible challenges involved in the move onto land.

Molecular phylogenetics has identified the closest living relatives of land plants

The phylogenetic relationships among the algae and the first land plants have been fuzzy and subject to long debate. Cell biology, biochemistry, and molecular systematics have provided surprising new evolutionary hypotheses. The green algae consist of two monophyletic groups, the Chlorophyta and the Streptophyta (chapter 30). Land plants are members of the Streptophyta, not a separate kingdom. This new phylogenetic information demoted the land plants from constituting a kingdom to be a branch within the algal group Streptophyta. The Streptophyta along with the sister green algal clade, Chlorophyta, are now considered by most to make up the kingdom Viridiplantae. The current phylogeny is shown in figure 26.12. What was the earliest streptophyte? Conflicting answers have been obtained with different phylogenetic analyses, but growing evidence supports the hypothesis that the scaly, unicellular flagellate Mesostigma (order Mesostigmatales) represents the earliest streptophyte branch.

Which of the Streptophyta clades contains the closest living relative of land plants? The two contenders have been the Charales, with about 300 species, and the Coleochaetales, with about 30 species. Both lineages are freshwater algae, but the Charales are huge compared with the microscopic Coleochaetales. Now, the Charales appear to be the sister clade to land plants, with the Coleochaetales the next closest relatives. Charales fossils dating back 420 mya indicate that the common ancestor of land plants was a relatively complex freshwater alga.

Horizontal gene transfer occurred in land plants

The shrub Amborella trichopoda is the closest living relative to the earliest flowering plants (angiosperms). Its clade is a sister clade to all other flowering plants, yet at least one copy of 20 out of 31 of its known mitochondrial protein genes hopped into the mitochondrial genome from other land plants through horizontal gene transfer (HGT). In addition, three different moss species contributed to the mix.

Amborella is not typical of most extant flowering plants. It is the only existing member of its genus and is native only to the tropical rain forests of New Caledonia, an island group east of Australia that has been isolated for some 70 million years and contains many ancient endemic species. Here parasitic plants called epiphytes (plants that derive nutrients from other plants) are common. Close contact with parasitic plants could increase the probability of HGT. An open question is whether the moss genes in Amborella has functions. About half the genes are intact and could be transcribed and translated into a protein. The protein would be like an existing protein in the plant, but its function, if any, remains to be determined.

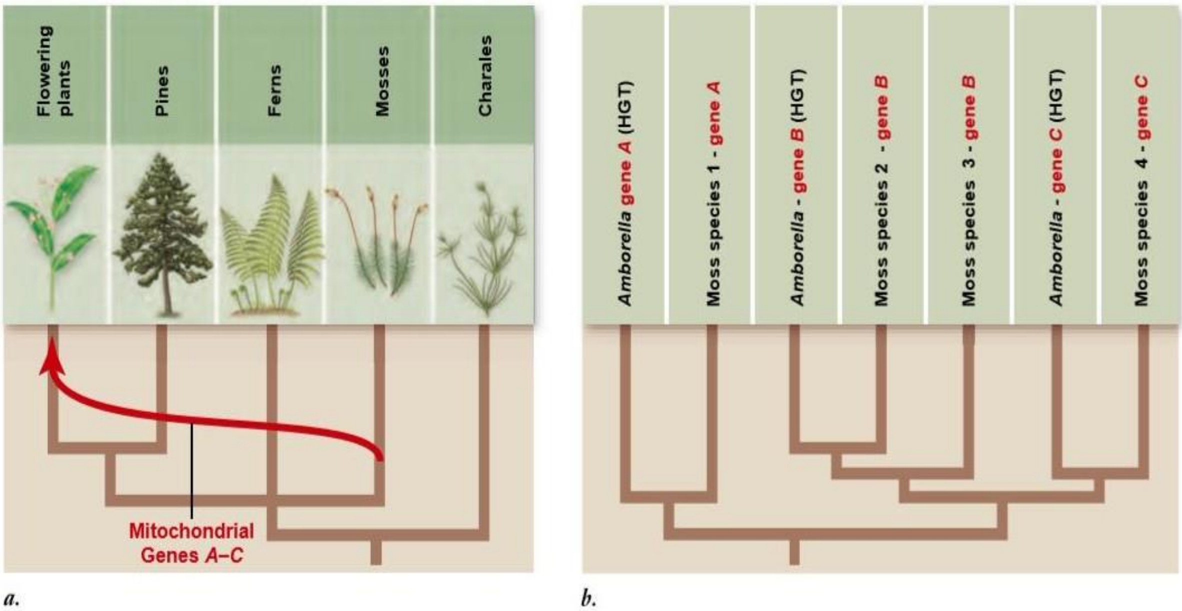


Figure 26.13 The flowering plant *Amborella* acquired three moss genes through horizontal gene transfer. *a.* Phylogenetic relationship of *Amborella* to other land plants. As shown by the arrow connecting moss and the flowering plants, HGT is the only plausible explanation for the presence of moss mitochondrial genes in *Amborella*. *b.* Phylogenetic relationships among the horizontally transferred gene.