13.1 How Did Evolutionary Thought Evolve?

- Fossil discoveries showed that life has changed over time.
  - Scientists discovered that fossil remains showed a discernable progression.
  - Fossils from the oldest rock layers were very different from modern organisms.
  - Fossil resemblance to modern organisms gradually increased in progressively younger rocks.
  - Conclusion: different types of organisms had lived at different times in the past
13.2 How Does Natural Selection Work?

- Darwin and Wallace proposed that life’s huge variety of excellent designs arose by a process of descent with modification, in which individuals in each generation differ slightly from the members of the preceding generation.

- Over long stretches of time, these small differences accumulate to produce major transformations.
13.2 How Does Natural Selection Work?

- Darwin and Wallace’s theory rests on four postulates.
  - **Postulate 1**: Individual members of a population differ from one another.
  - **Postulate 2**: Some differences among individuals are due to traits that may be passed from parent to offspring.
  - **Postulate 3**: Some individuals in each generation survive and reproduce successfully but others do not.
  - **Postulate 4**: The fate of individuals is not determined entirely by chance; an individual’s survival and reproduction depends upon its traits; advantageous traits lead to greater survival and more reproduction, a process known as natural selection.
13.2 How Does Natural Selection Work?

- Postulate 1: Individuals in a population vary.
  - People differ in size, eye color, skin color, and many other physical features; similar variability occur in other organisms.
  - These variations occur as a result of random mutations in DNA; differences among individuals extends to the molecular level.
13.2 How Does Natural Selection Work?

- Postulate 2: Traits are passed from parent to offspring.
  - Although observations of people, pets, and farm animals seemed to show that offspring generally resemble their parents, Darwin and Wallace did not have scientific evidence to support this postulate.
  - Mendel’s work on the principles of genetics was not published until far later, but confirmed postulate 2 through experimentation.
  - Modern genetics has refined that understanding.
Postulate 3: Some individuals fail to survive and reproduce.

- Darwin knew that organisms produce far more offspring than are required to replace the parents.
- However, the numbers of individuals in a population tend to remain constant; more individuals are born than survive long enough to reproduce.
- It is clear that in a population, some individuals have more offspring than others.
13.2 How Does Natural Selection Work?

- Postulate 4: Survival and reproduction are not determined by chance.
  - Reproductive success depends upon an individual’s characteristics.
  - For example, larger male elephant seals in a California population have more offspring than smaller males.
  - These results show that in the competition to survive and reproduce, winners are determined not by chance but by the traits they possess.
13.2 How Does Natural Selection Work?

- Natural selection modifies populations over time.
  - Observation and experimentation suggest that the four postulates of Darwin and Wallace are sound.
  - Natural selection acts on individuals within a population; over generations, the population changes as the percentage of individuals inheriting favorable traits increases; an individual cannot evolve, but a population can.
  - Although it is easier to understand how natural selection would cause changes within a species, under the right circumstances, the same principles produce entirely new species.
13.3 How Do We Know That Evolution Has Occurred?

- Fossils provide evidence of evolutionary change over time.
  - If it is true that many fossils are the remains of species ancestral to modern species, we ought to find a series of fossils that start with ancient, primitive organisms and culminate with modern species.
  - Such series has been found for ancestors of modern whales, fossil giraffes, elephants, horses, and mollusks.
  - These fossil series suggest that new species evolved from, and replaced, previous species.
13.3 How Do We Know That Evolution Has Occurred?

- Comparative anatomy gives evidence of descent with modification.
  - Comparing the bodies of organisms of different species can reveal similarities that can be explained only by shared ancestry, and differences that could result only from evolutionary change during descent from a common ancestor.
  - The study of comparative anatomy has supplied strong evidence that different species are linked by a common evolutionary heritage.
13.3 How Do We Know That Evolution Has Occurred?

- Homologous structures provide evidence of common ancestry.
  - The forelimbs of birds and mammals are variously used for flying, swimming, running, and grasping objects.
  - Despite this diversity of function, the internal anatomy of all bird and mammal forelimbs is remarkably similar.
  - This similarity is what would be expected if the forelimbs were derived from a common ancestor; each forelimb has been modified to perform a particular function.
  - Such internally similar structures are called homologous structures and have the same evolutionary origin.
13.3 How Do We Know That Evolution Has Occurred?

- Homologous structures

![Diagram showing homologous structures of different animals](image-url)
13.3 How Do We Know That Evolution Has Occurred?

- Functionless structures are inherited from ancestors.
  - Evolution by natural selection helps explain vestigial structures that serve no apparent purpose.
  - These are homologous structures to those found in, and used by, other vertebrates; ancestors of whales had four legs with well-developed pelvic bones.
  - During whale evolution, losing the hind legs provided a streamlining advantage; therefore, modern whales only have small, useless pelvic bones.
13.3 How Do We Know That Evolution Has Occurred?

- Vestigial structures

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Fig. 13-9

The bones of a salamander’s hindlimb function in support and locomotion.

These vestigial bones are similar in structure to those of the salamander but serve no function; all three animals inherited the bones from a common ancestor.

(a) Salamander

(b) Baleen whale

(c) Boa constrictor
13.3 How Do We Know That Evolution Has Occurred?

- Some anatomical similarities result from evolution in similar environments.
  - There are many anatomical similarities that do not stem from common ancestry.
  - Such similarities stem from convergent evolution, in which natural selection causes non-homologous structures that serve similar functions to resemble one another.
  - Both birds and insects have wings, but this similarity did not arise from evolutionary modification of a structure that both birds and insects inherited from a common ancestor.
  - Such outwardly similar, but non-homologous, structures are called analogous structures, and have very different internal anatomy.
13.3 How Do We Know That Evolution Has Occurred?

- Analogous structures

(a) Damselfly  
(b) Swallow
13.3 How Do We Know That Evolution Has Occurred?

- Embryological similarity suggests common ancestry.
  - All vertebrate embryos look quite similar to one another early in their development.

(a) Lemur  (b) Pig  (c) Human

Fig. 13-11
13.3 How Do We Know That Evolution Has Occurred?

• In early embryonic development, fish, turtles, chickens, mice, and humans all develop tails and gill slits.

• Only fish retain gills as adults, and only fish, turtles, and mice retain tails.

• Ancestral vertebrates possessed genes that directed the development of gills and tails; all their descendents still have these genes.

• In fish, these genes are active throughout development; in humans, these genes are active only during early development, and the structures are lost as adults.
13.3 How Do We Know That Evolution Has Occurred?

- Modern biochemical and genetic analyses reveal relatedness among diverse organisms.
  - Biochemical similarities among organisms provide perhaps the most striking evidence of their evolutionary relatedness.
  - The protein cytochrome c is present in all plants and animals, and performs the same function in all of them.
  - The DNA sequence of nucleotides is similar in all these diverse species; this provides evidence that a common ancestor of plants and animals had cytochrome c in its cells.
13.3 How Do We Know That Evolution Has Occurred?

- Other biochemical similarities also extend to all living cells.
  - All cells have DNA.
  - All cells use RNA, ribosomes, and the same genetic code.
  - All cells use the same 20 amino acids in proteins.
  - All cells use ATP as a cellular energy carrier.
  - The explanation for such widespread sharing of these complex and specific biochemical traits is that they are homologous, arising from a common ancestor.
13.4 What Is The Evidence That Populations Evolve By Natural Selection?

- Controlled breeding modifies organisms.
  - Humans produced radically different dogs in a few thousand years by repeatedly selecting individuals with desirable traits.
  - Therefore, it is plausible that natural selection by an analogous process acting over hundreds of millions of years produce the spectrum of living organisms.
13.4 What Is The Evidence That Populations Evolve By Natural Selection?

- Evolution by natural selection occurs today.
  - Brighter coloration can evolve when fewer predators are present.
  - In Trinidad, guppies live in streams with larger predators that eat them.
  - In the shallow upstream waters, the guppies are free of predators and are more brightly colored than the downstream guppies.
  - Thus, where predators are common, they act as agents of natural selection by eliminating the bright-colored guppies.
13.4 What Is The Evidence That Populations Evolve By Natural Selection?

- Natural selection can lead to pesticide resistance.
  - Insect pests can evolve resistance to pesticides through natural selection.
  - In Florida, a pesticide called Combat was used to control the number of roaches; roaches that liked it were killed.
  - Those that survived inherited a rare mutation that caused them to dislike the sugar that was used in the Combat bait.
  - Soon, all the roaches had this mutation and were immune to Combat.
13.4 What Is The Evidence That Populations Evolve By Natural Selection?

- Experiments can demonstrate natural selection.
  - *Anolis sagrei* lizards were released in small groups onto 14 small Bahamian islands that previously did not have the lizards.
  - The original lizards came from an island with tall vegetation and many trees; the island where they were transplanted had few or no trees, and were covered with small shrubs and other low-growing plants.
  - After 14 years, the released lizards were examined and displayed shorter and thinner legs than the original population.
13.4 What Is the Evidence That Populations Evolve by Natural Selection?

- Selection acts on random variation to favor the phenotypes that work best in particular environments.
  
  - The variations on which natural selection works are produced by chance variation.
  
  - The mutations that produced bright or dark colored Trinidadian guppies, a distaste for Combat poison in cockroaches, and shorter legs in Bahamian lizards were beneficial traits that arose spontaneously in each case.
What Is the Evidence That Populations Evolve by Natural Selection?

- Natural selection favors organisms that are best adapted to a particular environment.
  - Natural selection does not select the “best” in any absolute sense, but only for what is best in the context of a particular environment.
  - A trait that is advantageous under one set of conditions may become disadvantageous if conditions change.
14.1 How Are Populations, Genes, And Evolution Related?

- Evolutionary changes are those that occur from generation to generation and cause offspring to be different from their ancestors.
- Evolution is a property of populations, not individuals.
- A population is a group that includes all members of a species living in a given area.
14.1 How Are Populations, Genes, And Evolution Related?

- Genes and the environment interact to determine traits.
  - The specific alleles borne on an organism’s chromosomes (its genotype) interact with the environment to influence the development of its physical and behavior traits (its phenotype).
14.1 How Are Populations, Genes, And Evolution Related?

- The gene pool is the sum of the genes in a population.
  - Population genetics deals with the study of the frequency, distribution, and inheritance of alleles in a population.
  - Population genetics defines the gene pool as the sum of all genes in a population; that is, all the alleles of all the genes of all the individuals in a population.
14.1 How Are Populations, Genes, And Evolution Related?

- The gene pool is the sum of the genes in a population (continued).
  - Each gene can also be considered to have its own gene pool, made up of all the alleles of that specific gene in a population.
  - Adding up all the copies of each allele in a population, we could determine the relative proportion of each allele of the gene, a number called the allele frequency.
The gene pool is the sum of the genes in a population (continued).

• For example, a population of 25 hamsters has 50 alleles of the gene that controls coat color.
• 20 of the 50 alleles code for black coats, so the frequency of that allele in the population is 40%, because $20/50 = 0.40$, or 40%.
The gene pool for the coat-color gene contains 20 copies of allele $B$ and 30 copies for allele $b$.
14.1 How Are Populations, Genes, And Evolution Related?

- Evolution is the change of allele frequencies within a population.
  - A population geneticist defines evolution as the changes in allele frequency in a gene pool over time.
  - Evolution is a change in the genetic makeup of populations over generations.
14.1 How Are Populations, Genes, And Evolution Related?

- The equilibrium population is a hypothetical population in which evolution does not occur.
  - The Hardy-Weinberg Principle showed that under certain conditions, allele frequencies and genotype frequencies in a population will remain constant no matter how many generations pass; in other words, this population will not evolve.
  - This ideal, non-evolving population is called an equilibrium population.
14.1 How Are Populations, Genes, And Evolution Related?

- An equilibrium population will occur as long as the following conditions are met.
  - There must be no mutations.
  - There must be no gene flow between different populations.
  - The population has to be very large.
  - All mating must be random; there must be no selection of specific genotypes by other genotypes.
  - There must be no natural selection; all genotypes must reproduce with equal success.

- If one of these conditions is violated, then allele frequencies may change and the population will evolve.
14.2 What Causes Evolution?

- Mutations are the original source of genetic variability in a population.
  - An unrepaired mutation in a nucleotide sequence in DNA occurs rarely, but when it does, the change is passed on to the gametes and shows up in the offspring as an addition to the population gene pool diversity among organisms.
14.2 What Causes Evolution?

- Inherited mutations are rare but important.
  - Mutation by itself generally causes only very small changes in the frequency of any particular allele.
  - The cumulative effect of mutations is essential to evolution.
  - Without mutations, there would be no evolution and no diversity among organisms.
14.2 What Causes Evolution?

- Mutations are not goal directed.
  - Whether a change from a mutation is helpful or harmful or neutral depends on environmental conditions over which the organism has little or no control.
  - The mutation provides a potential for evolutionary change.
  - Other processes, especially natural selection, may act to spread the mutation through the population or to eliminate it from the population.
1. Start with bacterial colonies that have never been exposed to antibiotics.

2. Use velvet to transfer colonies to identical positions in three dishes containing the antibiotic streptomycin.

3. Incubate the dishes.

4. Only streptomycin-resistant colonies grow; the few colonies are in the exact same positions in each dish.
14.2 What Causes Evolution?

- Allele frequencies may drift in a small population.
  - If individuals in a population were eliminated from the gene pool before they reproduced, their alleles would not be passed to the next generation.
  - In a small population, this could affect the genetic outcome of the population, but in a large population, it would not.
  - The process by which chance events change allele frequencies in a small population is called genetic drift.
14.2 What Causes Evolution?

- Genetic drift, generation 1

In each generation, only two randomly chosen individuals breed; their offspring form the entire next generation.

Frequency of $B = 50\%$

Frequency of $b = 50\%$
14.2 What Causes Evolution?

- Genetic drift, generation 2

![Genetic drift, generation 2](image)

- Frequency of \( B \) = 25%
- Frequency of \( b \) = 75%

Fig. 14-4(2)
14.2 What Causes Evolution?

- Genetic drift, generation 3

**Fig. 14-14(3)**

<table>
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<tr>
<td>frequency of B = 0%</td>
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<tr>
<td>frequency of b = 100%</td>
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</tbody>
</table>
14.2 What Causes Evolution?

- Population size matters.
  - If a population is sufficiently large, chance events are unlikely to significantly alter its genetic composition.
  - In a small population, a particular allele may be carried by only a few organisms; chance events could eliminate most or all examples of such an allele from the population.
14.2 What Causes Evolution?

- Population size matters (*continued*).
  - Effects of population size on genetic drift can be seen with two populations of amoebas, in which each amoeba is either red or blue.
  - Color is controlled by two alleles (A and a) of a gene—half of the amoebas are red, and half are blue.
  - One population has four individuals, and the other has 10,000.
  - Half of the individuals in each population is allowed to reproduce by binary fission.
  - In a large population, 5,000 individuals reproduce, producing 10,000 individuals.
14.2 What Causes Evolution?

- The chances that all 10,000 offspring will be red is just about nil; there would not be a major change in the allele frequencies from generation to generation.

Fig. 14-5a

In the large population, allele frequencies remain relatively constant.
14.2 What Causes Evolution?

- Population size matters *(continued)*.
  - In a small population, the situation is different.
  - Only two amoebas reproduce, and there is a 25% chance that both reproducers will be red.
  - If only red amoebas reproduce, the next generation will consist entirely of red amoebas—a likely outcome.
14.2 What Causes Evolution?

Thus, it is possible that within a single generation, the allele for blue color may disappear from the population.
14.2 What Causes Evolution?

- A population bottleneck can cause genetic drift.
  - In a population bottleneck, a population is drastically reduced as a result of a natural catastrophe or overhunting.
  - Only a few individuals are then available to contribute genes to the next generation.
  - Population bottlenecks can rapidly change allele frequencies, and can reduce genetic variability by eliminating alleles.
14.2 What Causes Evolution?

- Population bottlenecks reduce variation.

The gene pool of a population contains equal numbers of red, blue, yellow, and green alleles.

A bottleneck event drastically reduces the size of the population.

By chance, the gene pool of the reduced population contains mostly blue and a few yellow alleles.

After the population grows and returns to its original size, blue alleles predominate; red and green alleles have disappeared.
14.2 What Causes Evolution?

- The founder effect
  - A special case of a population bottleneck is the founder effect, which occurs when isolated colonies are founded by a small number of organisms.
  - The founder group may have different allele frequencies than those of the main group from which they came.
14.2 What Causes Evolution?

- All genotypes are not equally beneficial.
  - In an equilibrium population, individuals of all genotypes survive and reproduce equally well; no genotype has any advantage over the others.
  - In real populations, however, not all alleles are neutral in all environments.
  - Any time an allele provides a small increase in survivability, natural selection favors the individuals who possess it, and those individuals have a higher reproductive success.
  - This phenomenon can be seen in an example concerning an antibiotic drug.
14.2 What Causes Evolution?

- Antibiotic resistance evolves by natural selection.
  - Penicillin was developed in World War II to combat infections.
  - A wounded soldier may be given an intravenous drip of penicillin to treat a bacterial infection.
  - Millions of the bacteria die, but a few bacteria have a mutation that codes for an enzyme that destroys any penicillin that comes into contact with the bacterial cell.
Antibiotic resistance evolves by natural selection (continued).

• The bacterium carrying this allele survives and reproduces, and its offspring inherits the penicillin-destroying allele.

• After a few generations, all the bacteria possess this allele through natural selection, and the penicillin is ineffective in treating the infection.
14.2 What Causes Evolution?

- Penicillin resistance illustrates key points about evolution.
  - Natural selection does not cause genetic change in individuals.
  - Natural selection acts on individuals, but it is populations that are changed by evolution.
  - Evolution is change in allele frequency of a population, owing to unequal success at reproduction among organisms bearing different alleles.
  - Evolution is not progressive; it does not make organisms “better”, it makes them better suited to a particular environment.
14.3 How Does Natural Selection Work?

- Natural selection stems from unequal reproduction.
  - Natural selection works on increasing the numbers of individuals in a population that are the most fit to survive in their particular environment.
  - Natural selection also works through those individuals in a population that leave the most offspring that carry their particular allele combinations.
14.3 How Does Natural Selection Work?

- Natural selection acts on phenotypes.
  - Natural selection does not act directly on the genotype of an organism but on its phenotype, the structures and behaviors displayed by members of a population.
  - This selection of phenotypes inevitably affects the genotypes because phenotypes and genotypes are closely tied.
14.3 How Does Natural Selection Work?

- Some phenotypes reproduce more successfully than others.
  - Anatomical and functional properties that help an organism to live better and reproduce in a given environment are adaptations.
  - These adaptations are passed on to their offspring and are maintained in the population.
14.3 How Does Natural Selection Work?

- An environment has nonliving and living components.
  - The nonliving component of the environment includes climate, availability of water, and minerals in the soil.
  - The abiotic environment plays a large role in determining the traits that help an organism to survive and reproduce.
  - For example, adaptations also arise because of interactions with other organisms.
  - Adaptations of buffalo grass have developed as a result of the interaction of the grass with the low water and mineral content of the soil, and of the predators that wish to eat it.
14.3 How Does Natural Selection Work?

- Competition acts as an agent of selection.
  - One of the major agents of natural selection in the biotic environment is competition with other organisms for scarce resources.
  - Competition is most intense among members of the same species.
  - No competing organism has such similar requirements for survival as does another member of the same species.
  - Different species may also compete for the same resources, but to a lesser extent than do individuals within a species.
14.3 How Does Natural Selection Work?

- Both predator and prey act as agents of selection.
  - When two species interact extensively and one evolves a new feature or modifies an old one, the other typically evolves new adaptations in response.
  - This mutual feedback between two species is called coevolution.
14.3 How Does Natural Selection Work?

- Both predator and prey act as agents of selection (*continued*).
  - Predation includes any situation in which one organism eats another.
  - In some instances, coevolution between predators and prey interact with each side, evolving new adaptations in response to “escalations” by the other.
14.3 How Does Natural Selection Work?

- Sexual selection favors traits that help an organism mate.
  - Sexual selection is the special kind of selection that acts on traits that help an animal acquire a mate.
  - Examples would be bright coloration in fish or birds, or elaborate courtship behavior or songs.
14.3 How Does Natural Selection Work?

- Female mate choice provides a second source of sexual selection.
  - In animal species where females actively choose their mates from among males, females often seem to prefer males with the most elaborate ornaments or the most extravagant displays.
  - Why? A popular hypothesis is that male structures and display provide a female with an outward sign of a male’s reproductive condition.
14.4 What Is A Species?

- Species are groups of interbreeding populations.
  - The most widely used standard defines species as “groups of actually or potentially interbreeding natural populations, which are reproductively isolated.”
  - This definition, known as the biological species concept, is based on the observation that reproductive isolation (inability to successfully breed outside the group) ensures evolutionary independence.
14.4 What Is A Species?

- This concept has at least two major limitations.
  - First, because the definition is based on patterns of sexual reproduction, it does not help us determine species boundaries among asexually reproducing organisms.
  - Second, it is not always practical or even possible to directly observe whether members of two different groups interbreed.
  - However, most biologists accept this concept for identifying species of sexually reproducing organisms.
14.5 How Is Reproductive Isolation Between Species Maintained?

What prevents different species from interbreeding?

- The traits that prevent interbreeding and maintain reproductive isolation are called isolating mechanisms.
- Mechanisms that prevent mating between species are called premating isolating mechanisms.
- Mechanisms that prevent the formation of vigorous, fertile hybrids between species are called postmating isolating mechanisms.
### 14.5 How Is Reproductive Isolation Between Species Maintained?

#### Table 14-1 Mechanisms of Reproductive Isolation

**Premating isolating mechanisms:** factors that prevent organisms of two populations from mating

- **Geographical isolation:** The populations cannot interbreed because a physical barrier separates them.
- **Ecological isolation:** The populations do not interbreed even if they are within the same area because they occupy different habitats.
- **Temporal isolation:** The populations cannot interbreed because they breed at different times.
- **Behavioral isolation:** The populations do not interbreed because they have different courtship and mating rituals.
- **Mechanical incompatibility:** The populations cannot interbreed because their reproductive structures are incompatible.

**Postmating isolating mechanisms:** factors that prevent organisms of two populations from producing vigorous, fertile offspring after mating

- **Gametic incompatibility:** Sperm from one population cannot fertilize the eggs of another population.
- **Hybrid inviability:** Hybrid offspring fail to survive to maturity.
- **Hybrid infertility:** Hybrid offspring are sterile or have low fertility.
14.6 How Do New Species Form?

- Isolation of populations: if individuals of two populations can interbreed, gene flow between the populations will prevent the individuals in the populations from becoming different; speciation depends on isolation.

- Genetic divergence: populations must be isolated from each other and evolve sufficiently large genetic differences that they cannot interbreed if brought back together.
Organisms may colonize isolated habitats.

- A small population can become isolated if it moves to a new location, such as an isolated island.
- Any bounded habitat, such as a lake, a mountaintop, or a parasite’s host, can isolate arriving colonists.
14.6 How Do New Species Form?

- Geological and climate changes may divide populations.
  - Isolation can also result from landscape changes that divide a population.
  - For example, rising sea levels might transform a coastal hilltop into an island, isolating the residents.
  - A river that changes course can divide populations.
  - Populations can be divided by continental drift.
14.6 How Do New Species Form?

- Natural selection and genetic drift may cause isolated populations to diverge.
  - When two populations become isolated, there is no gene flow between them; genetic differences will occur.
  - Large enough genetic differences will prevent interbreeding, and the populations become separate species.
14.6 How Do New Species Form?

- Under some conditions, many new species arise.
  - When many new species arise in a relatively short time, the process is called adaptive radiation.
  - This occurs when populations of one species invade a variety of new habitats and evolve in response to the differing environmental pressures in those habitats.
  - There are many examples of adaptive radiation.
14.6 How Do New Species Form?

- Adaptive radiation
  - Episodes of adaptive radiation include:
    - When some wayward finches colonized the Galapagos Islands.
    - When a population of cichlid fish reached isolated Lake Malawi in Africa.
    - When an ancestral tarweed plant species arrived at the Hawaiian Islands.
14.7 What Causes Extinction?

- The ultimate fate of any species is extinction, the death of the last of its members.
  - At least 99.9% of all the species that have ever existed are now extinct.
  - The natural course of evolution, as revealed by fossils, is continual turnover of species as new ones arise and old ones go extinct.
  - Two major environmental factors that may drive a species to extinction are competition among species and habitat destruction.
14.7 What Causes Extinction?

- Habitat change and destruction are the leading causes of extinction.
  - Habitat change, both contemporary and prehistoric, is the single greatest cause of extinction.
  - Many biologists believe that we are presently in the midst of the fastest-paced and most widespread episode of species extinction in the history of the Earth due to human habitat destruction.
28.1 Why Are Interactions in Ecological Communities Important?

- An ecological community consists of all the interacting populations in an ecosystem.
  - The populations in a community interact in the following ways:
    - Competition
    - Predation (including parasitism)
    - Symbiosis (excluding parasitism)
  - These distinctions are based on whether the interactions are help or harm each participant.
28.1 Why Are Interactions In Ecological Communities Important?

<table>
<thead>
<tr>
<th>Type of Interaction</th>
<th>Effect on Organism A</th>
<th>Effect on Organism B</th>
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<tr>
<td><strong>Competition</strong> between A and B</td>
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<tr>
<td><strong>Predation</strong>* by A on B</td>
<td>Benefits</td>
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<tr>
<td><strong>Commensalism</strong> of A with B</td>
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<td>No effect</td>
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<tr>
<td><strong>Mutualism</strong> between A and B</td>
<td>Benefits</td>
<td>Benefits</td>
</tr>
</tbody>
</table>

*Predation includes parasitism and herbivory.
28.1 Why Are Interactions In Ecological Communities Important?

- Community interactions help limit population size.
  - The interactions that form a community tend to maintain a balance between resources and the number of individuals consuming them.
  - This balance is susceptible to disruption, especially when foreign organisms are introduced into an ecosystem.
28.1 Why Are Interactions In Ecological Communities Important?

- Community interactions influence evolutionary change.
  - When members of different populations interact they may influence each other’s ability to survive and reproduce.
  - Community interactions, therefore, serve as agents of natural selection.
  - Predators tend to kill prey that are easiest to eat leaving behind individuals with better defenses against predation.
  - These individuals survive longer and leave more offspring.
28.1 Why Are Interactions In Ecological Communities Important?

- Community interactions influence evolutionary change (*continued*).
  
  - Simultaneously the increasingly effective defenses of prey favor the survival and reproduction of predators that are best able to overcome those defenses.
  
  - Thus, even as predator–prey interactions limit population size, they also shape the bodies and behaviors of the interacting populations.
  
  - This process, in which interacting species influence one another’s evolution, is called *coevolution*.
28.2 What Are The Effects Of Competition Among Species?

- When different species compete for a limited resource, the interaction is called **interspecific competition**.
  - In interspecific competition, each species is harmed, because access to resources is reduced for both.
  - The intensity of interspecific competition depends on how similar the requirements of the competing species are.
  - Ecologists express the degree of competition as the degree to which the ecological niches of the competing species overlap.
28.2 What Are The Effects Of Competition Among Species?

- Each species has a unique place in its ecosystem.
  - Each species occupies a unique ecological niche that encompasses all aspects of its way of life.
  - A species’ niche includes
    - the type of habitat in which it lives
    - the environmental factors necessary for its survival
    - the methods by which it acquires its nutrients.
28.2 What Are The Effects Of Competition Among Species?

- The ecological niches of coexisting species never overlap completely.
  - No two species ever occupy exactly the same ecological niche.
  - This concept is called the competitive exclusion principle (G. F. Gause 1934).
  - Gause ran an experiment with *Paramecium*: *P. aurelia, P. caudatum, and P. bursaria.*
28.2 What Are The Effects Of Competition Among Species?

- Grown separately, and provided with food, the two species flourished.

![Graph showing population density over days for P. aurelia and P. caudatum grown in separate flasks.](Fig. 28-1a)
28.2 What Are The Effects Of Competition Among Species?

- When Gause placed the two species together in a single flask, one species always died out because they used the same food source.
28.2 What Are The Effects Of Competition Among Species?

- Species evolve in ways that reduce niche overlap.
  - Robert MacArthur documented the effects of competitive exclusion by observing five warbler species in the wild.
  - All five species lived and built nests in the same spruce trees, so it appeared at first glance that their niches overlapped significantly.
28.2 What Are The Effects Of Competition Among Species?

- Species evolve in ways that reduce niche overlap *(continued)*.
  - MacArthur found that the different species nested at different times, and searched for food in different portions of the tree, employing different hunting tactics.
  - The five species in effect divided up the resources reducing niche overlap and limiting interspecific competition.
28.2 What Are The Effects Of Competition Among Species?

- Reducing niche overlap
28.2 What Are The Effects Of Competition Among Species?

- Species evolve in ways that reduce niche overlap (*continued*).
  - When two species with similar requirements coexist, they typically occupy a smaller niche than either would if it were by itself.
  - This is called **resource partitioning**.
28.2 What Are The Effects Of Competition Among Species?

- Species evolve in ways that reduce niche overlap (*continued*).
  - A dramatic example of resource partitioning is found among the 13 species of Darwin’s finches in the Galapagos Islands.
  - Each finch species have evolved a different bill size and shape, as well as different feeding behaviors that reduce competition among them.
28.3 What Are The Effects Of Predator–Prey Interactions?

- Predators and prey coevolve.
  - When a predator consumes its prey, one species benefits at the expense of another.
  - Parasites live on or inside their prey, or host, and feed on its body without necessarily killing it.
  - Herbivores are also predators that do not necessarily kill the prey on which they feed.
28.3 What Are The Effects Of Predator–Prey Interactions?

- Predators and prey coevolve *(continued)*.
  - Predator and prey exert intense natural selection pressure on one another.
  - As prey become more difficult to catch, predators must become more adept at hunting.
  - As predators become more adept at hunting, prey must get better at eluding them.
  - Coevolution has endowed the cheetah with speed and camouflage spots, and its zebra prey with speed and camouflage stripes.
28.3 What Are The Effects Of Predator–Prey Interactions?

- Predators and prey coevolve (*continued*).
  - Bats hunt at night using echolocation to locate their prey.
  - In response to this prey-detection system, some moth species evolved ears sensitive to the frequencies used for echolocation.
  - When a moth hears those sound frequencies, it takes evasive action, flying erratically or dropping to the ground.
28.3 What Are The Effects Of Predator–Prey Interactions?

- Camouflaged prey animals may resemble specific objects such as leaves, twigs, seaweed, thorns, or bird droppings.
28.3 What Are The Effects Of Predator–Prey Interactions?

- Predators may also be camouflaged..
28.3 What Are The Effects Of Predator–Prey Interactions?

- Bright colors often warn of danger.
  - In contrast to camouflaged animals, some animal species have evolved bright, conspicuous warning coloration.
  - Animals with warning coloration are usually distasteful and/or poisonous.
  - Predators can learn from their mistakes and unpleasant experiences teach predators to avoid similarly colored prey in the future.
28.3 What Are The Effects Of Predator–Prey Interactions?

- Some organisms gain protection through mimicry.
  - In mimicry, one species evolves to resemble another.
  - Mimics gain added protection from predators as a result of their appearance.
  - This benefit can be gained in various ways.
28.3 What Are The Effects Of Predator–Prey Interactions?

- Some animal species have evolved patterns of color that closely resemble the eyes of a much larger animal, which may startle the predator and allow the prey to escape.

Fig. 28-11
28.3 What Are The Effects Of Predator–Prey Interactions?

- Some animal predators and prey engage in chemical warfare.
  - Some predators and prey have evolved toxic chemicals for attack and defense.
28.3 What Are The Effects Of Predator–Prey Interactions?

- Plants have defenses against herbivores.
  - Plants have evolved chemical adaptations that deter their herbivorous predators.
  - Lupine plants produce chemicals that deter attack by the blue butterfly, whose larvae feed on the lupine’s buds.
  - Plants may also defend themselves by producing compounds that toughen their edible parts.
  - Some plants deter predation with structures such as thorns or thick bark.
28.3 What Are The Effects Of Predator–Prey Interactions?

- Herbivores have adaptations overcoming plant defenses.
  - Herbivorous predators have coevolved with the chemical defenses of plants.
  - Some insect species have evolved efficient ways to detoxify or even use the toxic chemicals present in many plant tissues.
28.4 What Is Symbiosis?

- Symbiosis is an intimate, prolonged interaction between organisms of different species.
  - In a symbiotic relationship, one species always benefits, but the second species may be unaffected, harmed, or helped by the relationship.

- In commensal interactions, one species benefits and the other is unaffected.
  - Barnacles attached to a whale benefit by getting a free ride through nutrient-rich water, and the whale does not seem to be affected.
28.4 What Is Symbiosis?

- In parasitic interactions, one species benefits and the other is harmed.
  - Parasites live in or on their hosts, usually harming or weakening them but not immediately killing them.
  - Symbiotic parasites include tapeworms, fleas, numerous disease-causing protists, fungi, bacteria, and viruses.
  - In parasitic symbiosis, one organism benefits by feeding on another.
  - Parasite-host interactions are a powerful source of coevolutionary change.
28.4 What Is Symbiosis?

- In parasitic interactions, one species benefits and the other is harmed (continued).
  - Effects of mutual selection are evident in the precision and complexity of the human immune system, and in the adaptations that help disease-causing parasites overcome the immune response.
  - The malaria protist parasite takes up residence inside human red blood cells and induces frequent changes in the protein coat of the cells, which the human immune system is then unable to recognize and destroy.
28.4 What Is Symbiosis?

- In mutualistic interactions, both species benefit.
  - A lichen is a mutualistic association between an algae and a fungus, which appears to be a single organism.
  - The fungal body in the lichen provides support and protection for the photosynthetic algae, which in turn provide sugars for the fungus.
28.4 What Is Symbiosis?

- Animals and plants may have symbiotic mutualistic associations with microorganisms.
  - Animals lack the enzymes required to digest cellulose; however, some animals—such as cows, horses, rabbits, and termites—have cellulose-digesting protists and bacteria in their digestive tracts that digest this plant material for them.
28.4 What Is Symbiosis?

- Animals and plants may have symbiotic mutualistic associations with microorganisms *(continued)*.
  - Plants and certain fungal species may associate to form mycorrhizae, in which the fungal bodies penetrate and become entwined with plant roots.
  - The fungi acquire sugars that the plant has produced by photosynthesis, and the plant acquires mineral nutrients that the fungi extract from the soil.
28.4 What Is Symbiosis?

- Not all mutualisms are symbiotic.
  - Many mutualistic interactions between species do not involve the prolonged intimacy of symbiosis.
  - Many flowering plants are pollinated by animals that visit only when the plant is in bloom.
  - In the mutualistic relationship between plant and pollinator, the plant gains transportation of its pollen, and the pollinator gains food.
28.5 What Are Keystone Species?

- In some communities, a keystone species plays a major role in determining community structure
  - This role is out of proportion to its biomass.
  - If a keystone species is eliminated the diversity of the community is drastically reduced.
  - Removal of the sea otter from its community caused the collapse of the kelp forest communities of the Western Americas.
28.5 What Are Keystone Species?

- Removal of the starfish *Pisaster* from its intertidal community caused mussels to overrun the community and displace other species.
28.6 How Does A Community Change Over Time?

- As time passes, the makeup of a community may change; this gradual process of change is called succession.
  - Freshwater ponds and lakes tend to undergo a series of changes that transform them first into marshes, and then into dry land.
  - Coastal sand dunes tend to be stabilized by creeping plants and undergo changes that eventually lead to a forest.
28.6 How Does A Community Change Over Time?

- Succession can be observed because events frequently disrupt existing communities.
  - Forest fires destroy an existing community, but at the same time, release nutrients and create conditions that favor rapid succession.
  - Most succession events begin with a few hardy invaders called pioneers, and if undisturbed, progress to a diverse and relatively stable climax community—the end point of succession.
28.6 How Does A Community Change Over Time?

- Volcanic eruptions may create new islands ripe for colonization, or leave behind a nutrient-rich environment that is rapidly invaded by new life.

(a) Mt. St. Helens shortly after eruption  
(b) Twenty years later
There are two types of succession: primary and secondary.

- Primary succession starts “from scratch” on bare rock, on sand, in a clear glacial pool, or at some other location where there is no trace of a previous community.
- Secondary succession begins only after an existing ecosystem is disturbed; for example, by a forest fire or abandonment of a farm field.
28.6 How Does A Community Change Over Time?

- Primary succession can begin on bare rock.
  - Primary succession begins on bare rock that is weathered over time by wind, rain, and cycles of freezing and thawing; this causes cracks and the release of minerals that serve as nutrients for plants.
  - Lichens settle on the weathered rocks, which in turn dissolves some of the rock through the acid they secrete; this liberates more nutrients, which mosses can then use to start to grow.
28.6 How Does A Community Change Over Time?

- Primary succession

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**Fig. 28-16**

- lichens and moss on bare rock
- bluebell, yarrow
- blueberry, juniper
- jack pine, black spruce, aspen
- fir-spruce-birch climax forest

0 - 1000 years
28.6 How Does A Community Change Over Time?

- Primary succession can begin on bare rock.
  - Within the moss mat that forms, seeds of larger plants, such as bluebell and yarrow, germinate.
  - Later, these plants die, and their bodies contribute to a growing layer of soil.
  - Shrubs grow and shade out the lichens and moss, which die away.
  - Eventually, trees take root and form a tall climax community.
Abandoned farmland may undergo secondary succession.

- In secondary succession, the pioneer species are fast-growing annual plants—such as crabgrass, ragweed, and sorrel—which sprout in the rich soil already present and thrive in the direct sunlight.
- A few years later, longer-lived perennial plants—such as asters, goldenrod, and broom sedge grass—invade, along with woody shrubs such as blackberry.
Abandoned farmland may undergo secondary succession (continued).

- These plants are replaced by pines and fast-growing deciduous trees, which become the dominate plants for about 25 years.
- Later, hardwood trees, such as oak and hickory, overtake the pines and shade them out.
- Eventually, a stable climax community of hardwood trees comes to dominate the landscape.
28.6 How Does A Community Change Over Time?

- Secondary succession

<table>
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<th>time (years)</th>
<th>plowed field</th>
<th>ragweed, crabgrass and other grasses</th>
<th>asters, goldenrod, broom sedge grass</th>
<th>blackberry</th>
<th>Virginia pine, tulip poplar, sweet gum</th>
<th>oak-hickory climax forest</th>
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</thead>
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</tbody>
</table>

Fig. 28-17
Succession culminates in the climax community.

- Succession ends with a relatively stable climax community that perpetuates itself as long as it is not disturbed by external forces.
- The species in a climax community have ecological niches that allow them to coexist without replacing one another.
- Climax communities have more species and more community interactions than do early stages of succession.
28.6 How Does A Community Change Over Time?

- Some ecosystems are maintained in a subclimax state.
  - The tallgrass prairie that covered northern Missouri and Illinois was a subclimax community whose climax would have been deciduous forest.
  - The prairie was maintained by periodic fires, some of which were set by Native Americans to increase grazing land for buffalo.
  - Forest now encroaches, and limited prairie preserves are maintained by carefully managed burning.
28.6 How Does A Community Change Over Time?

- Some ecosystems are maintained in a subclimax state (*continued*).
  - Agriculture also depends on the artificial maintenance of carefully selected subclimax communities.
  - A hayfield is a grass-dominated early stage of succession, maintained by people to feed their livestock.
  - A suburban lawn is a carefully maintained subclimax ecosystem where mowing destroys woody invaders and herbicides kill pioneers, such as crabgrass and dandelions.