Fundamental Biology
BI 1101

an interdisciplinary approach to introductory biology

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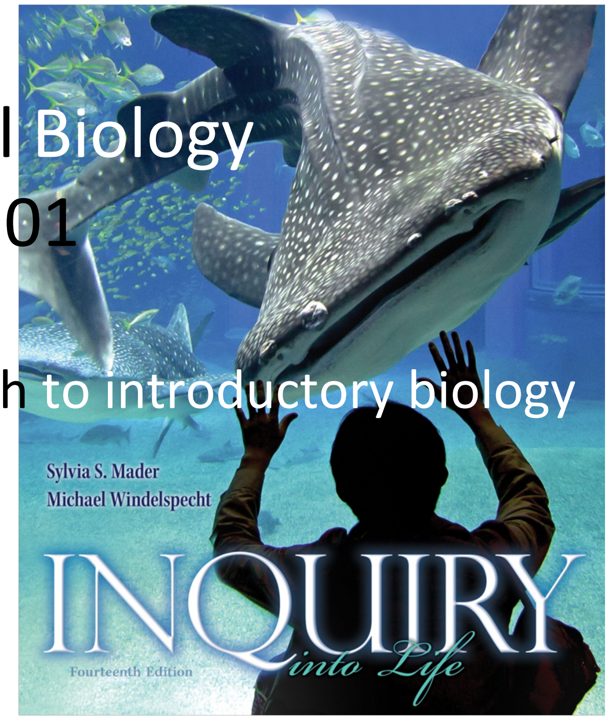
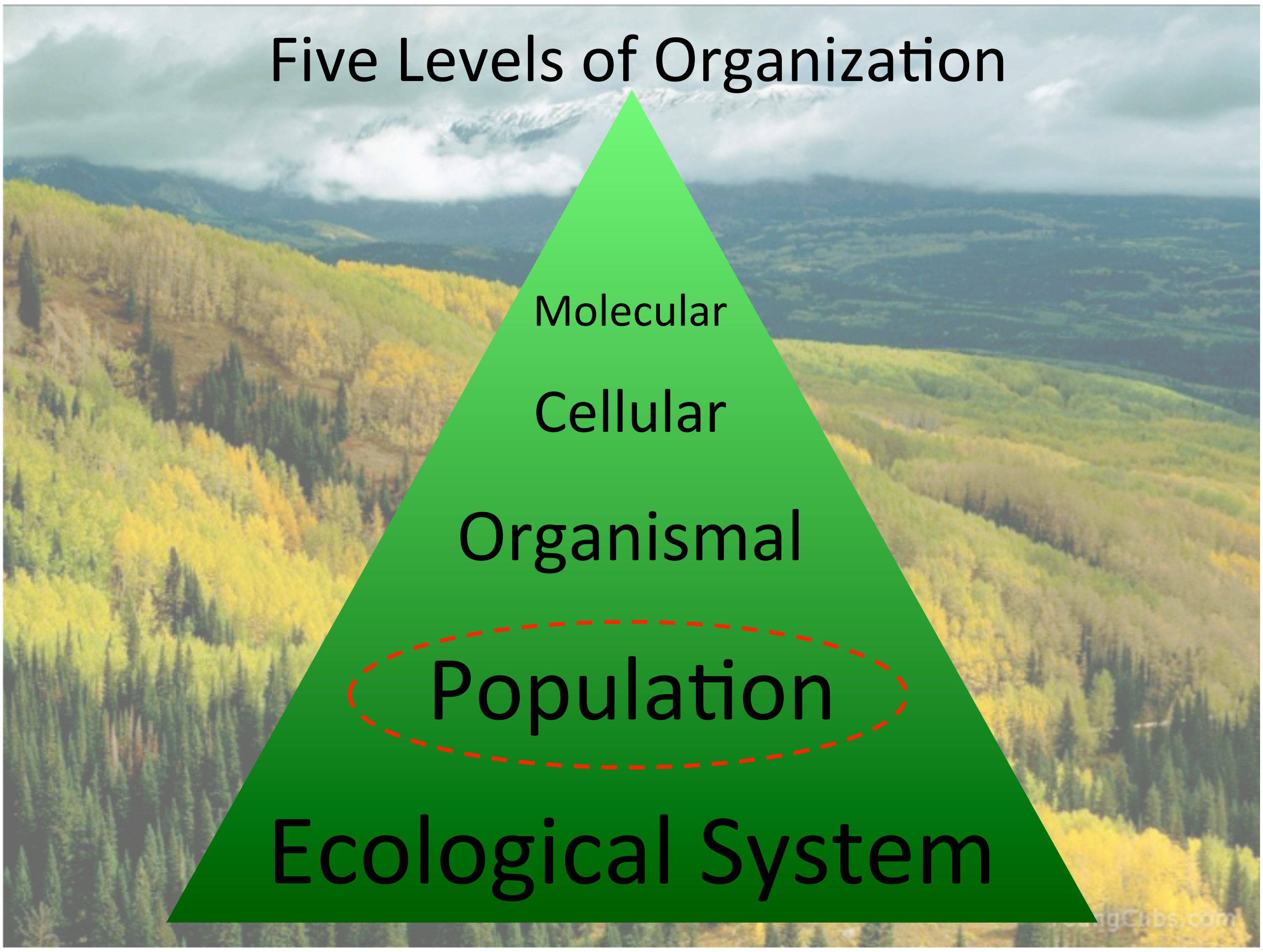




Learning outcome :

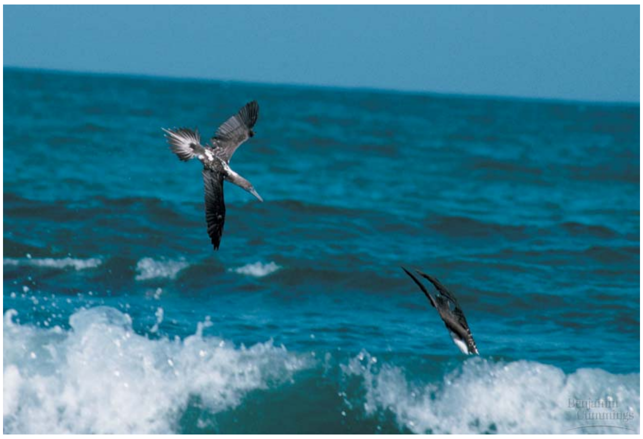
Students will be able to understand evolution by natural selection, and the fundamental asp aspects of population genetics.

Clown, Fool, or Simply Well Adapted?

- All organisms have evolutionary adaptations
  - Inherited characteristics that enhance their ability to survive and reproduce
- The blue-footed booby of the Galápagos Islands has features that help it succeed in its environment
  - Large, webbed feet help propel the bird through water at high speeds

– A streamlined shape, large tail, and nostrils that close are useful for diving

– Specialized salt-secreting glands manage salt intake while at sea



Clown, Fool, or Simply Well Adapted?

Living organisms are adapted to their environment

What is an adaptation?

- Behavioral adaptations
- Structural adaptations
- Biochemical adaptations
- Physiological adaptations

DARWIN'S THEORY OF EVOLUTION

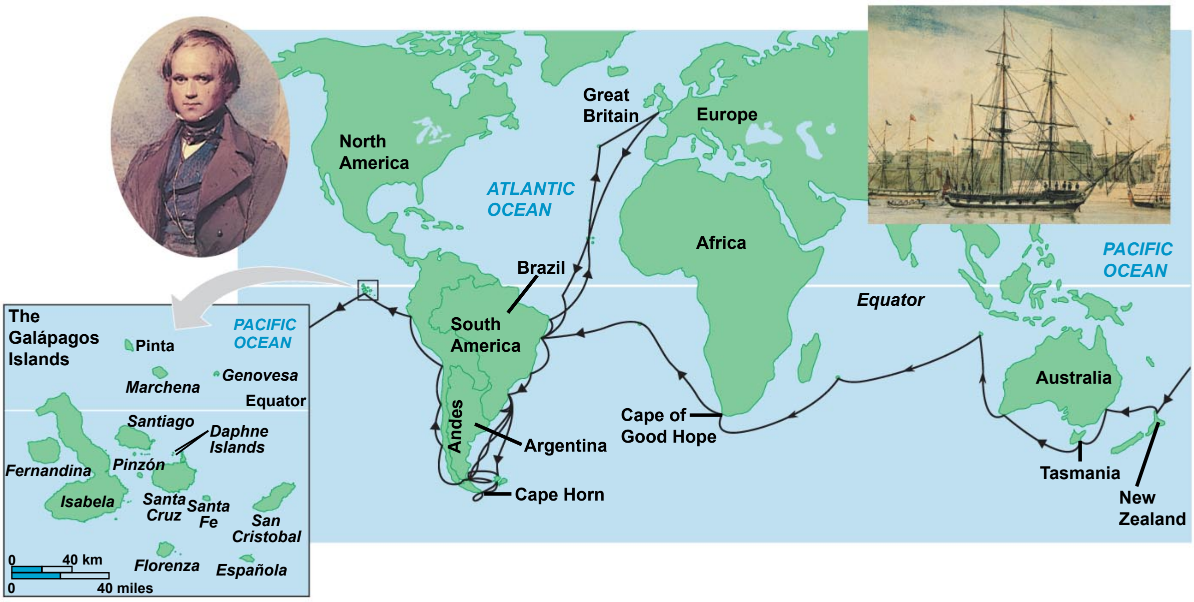
A sea voyage helped Darwin frame his theory of evolution

- The primary mechanism of evolutionary change producing adaptation of organisms to their environment is natural selection, the differential survival and reproduction of individuals within a population
- The Greek philosopher Aristotle viewed species as perfect and unchanging
- In the century prior to Darwin, the study of fossils suggested that species had changed over time

A sea voyage helped Darwin frame his theory of evolution

- Jean Baptiste Lamarck suggested that life on Earth evolves
  - His proposed mechanisms: – Use and disuse
  - Inheritance of acquired characteristics

- While on the voyage of the HMS *Beagle* in the 1830s, Charles Darwin observed
  – similarities between living and fossil organisms
  – the diversity of life on the Galápagos Islands, such as blue-footed boobies and giant tortoises



A sea voyage helped Darwin frame his theory of evolution

- Darwin was influenced by Lyell's *Principles of Geology*
- He came to realize that the Earth was very old and that, over time, present day species have arisen from ancestral species by natural processes
- In 1859, Darwin published *On the Origin of Species by Means of Natural Selection*, presenting a strong, logical explanation of *descent with modification,* evolution by the mechanism of natural selection

Darwin proposed natural selection as the mechanism of evolution

- **Note these important points**
  - Individuals do not evolve: populations evolve
  - Natural selection can amplify or diminish only heritable traits; acquired characteristics cannot be passed on to offspring
  - Evolution is not goal directed and does not lead to perfection; favorable traits vary as environments change

Darwin proposed natural selection as the mechanism of evolution

- Darwin observed that
  - Organisms produce more offspring than the environment can support
  - Organisms vary in many traits, that can be inherited
- Darwin concluded that individuals best suited for a particular environment are more likely to survive and reproduce than those less well adapted

Darwin saw natural selection as the basic mechanism of evolution

- As a result, the proportion of individuals with favorable characteristics increases ➔ chance of surviving and reproducing in their environment tend to leave more offspring than others
- Populations gradually change in response to the environment ➔ favorable traits accumulate in a population over generations

Darwin proposed natural selection as the mechanism of evolution

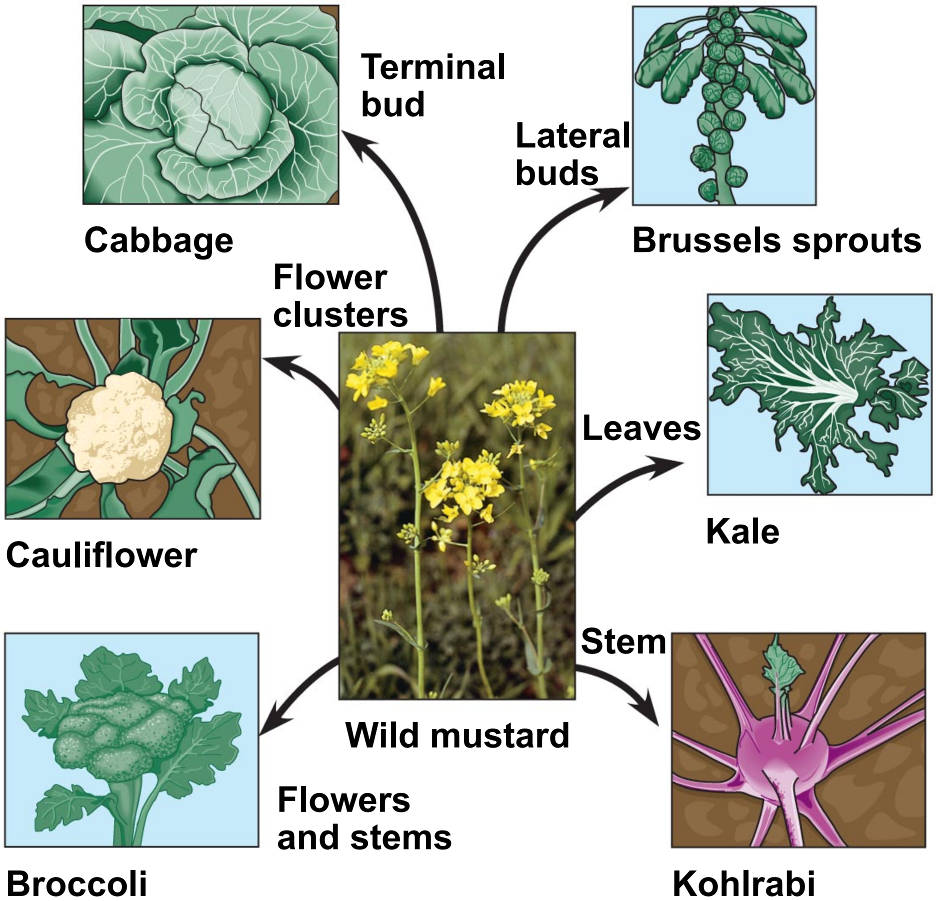
– Darwin found convincing evidence for his ideas in the results of artificial selection, the selective breeding of domesticated plants and animals

- humans choose organisms with specific characteristics as breeding stock, they are performing the role of the environment

– This is called artificial selection

– Example of artificial selection in plants: five vegetables derived from wild mustard

Figure 13.4A



– Example of artificial selection in animals: dog breeding

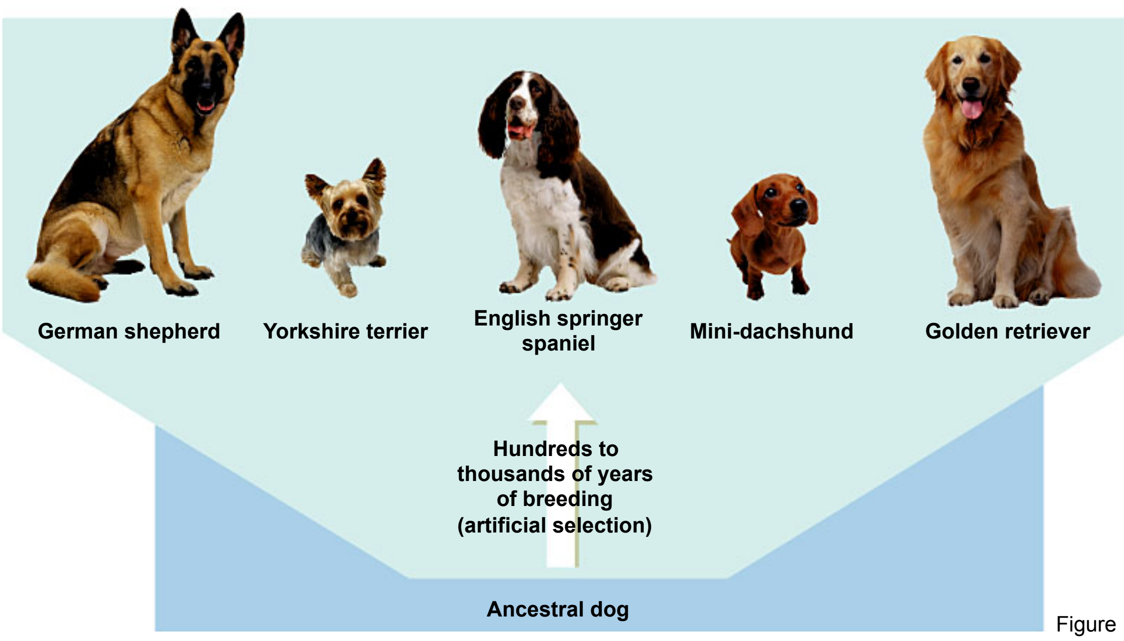


Figure 13.4B

- These five canine species evolved from a common ancestor through natural selection

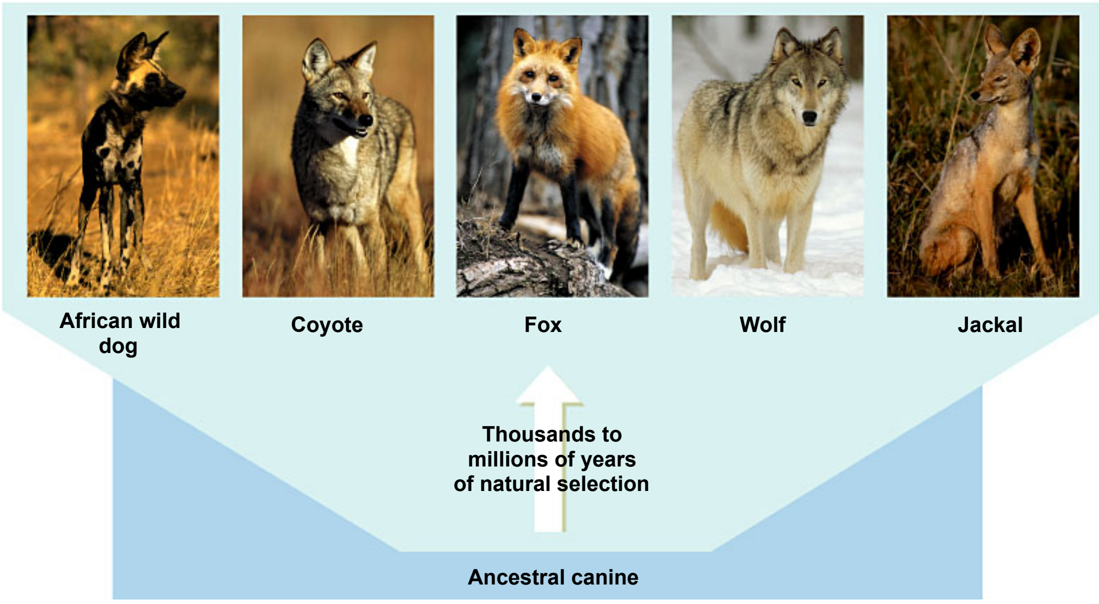


Figure 13.4C

Scientists can observe natural selection in action

– Rosemary and Peter Grant have worked on Darwin's finches in the Galápagos for over 20 years
  – In wet years, small seeds are more abundant and small beaks are favored
  – In dry years, large strong beaks are favored because large seeds remain

Scientists can observe natural selection in action

- Evolutionary adaptations have been observed in populations of birds, insects, and many other organisms
  - Example: camouflage adaptations of mantids that live in different environments

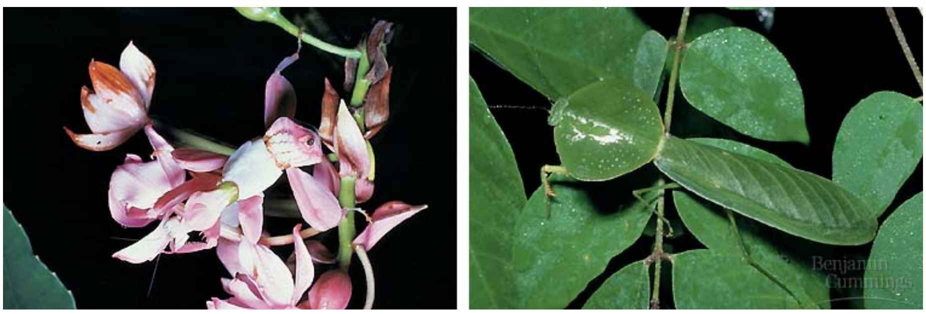
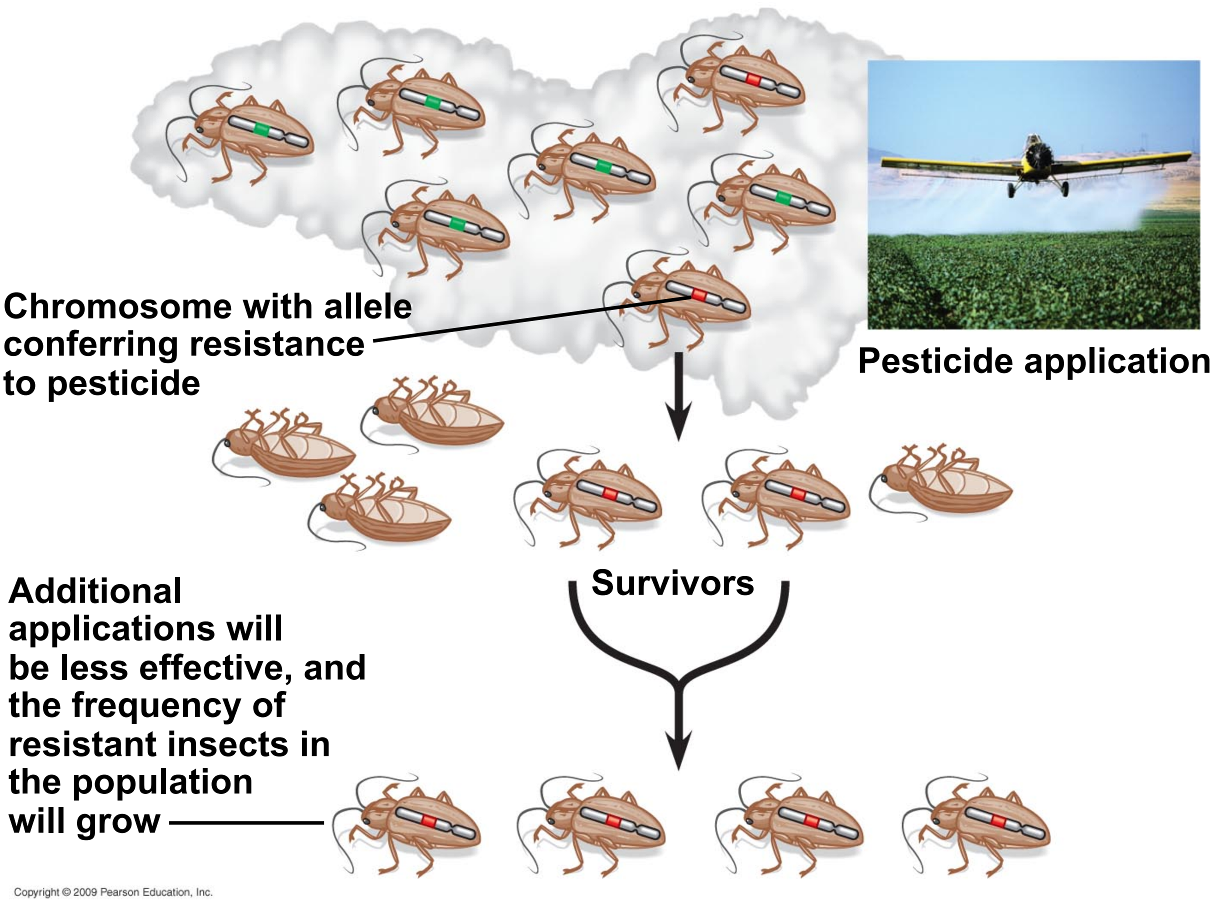


Figure 13.5A

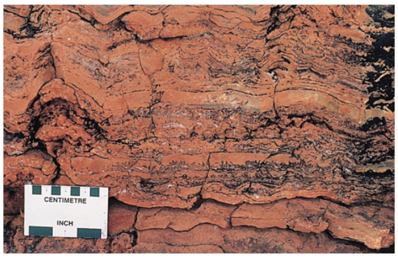
Scientists can observe natural selection in action

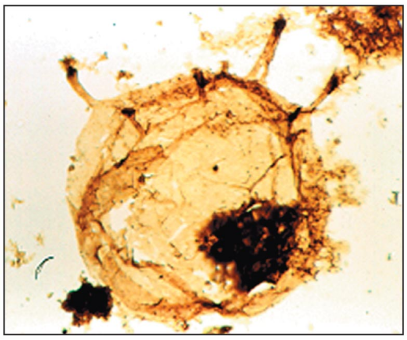
- Development of pesticide resistance in insects
  - Initial use of pesticides favors those few insects that have genes for pesticide resistance
  - With continued use of pesticides, resistant insects flourish and vulnerable insects die
  - Proportion of resistant insects increases over time



The study of fossils provides strong evidence for evolution

– The fossil record shows that organisms have evolved in a historical sequence
  – The oldest known fossils are prokaryote cells
  – The oldest eukaryotic fossils are a billion years younger
  – Multicellular fossils are even more recent





***Tappania*, a unicellular eukaryote**

Dickinsonia costata

2.5 cm

– Ammonite casts

– Fossilized organic matter in a leaf

Figure 13.2C, D

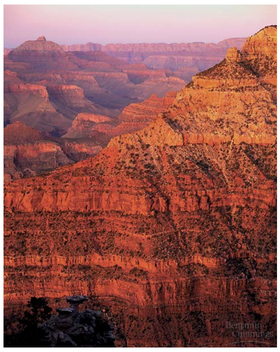
– Scorpion in amber

– "Ice Man"

Figure 13.2E, F

C Dinosaur tracks

- The fossil record shows that organisms have appeared in a historical sequence



- Many fossils link early extinct species with species living today
  - These fossilized hind leg bones link living whales with their land-dwelling ancestors

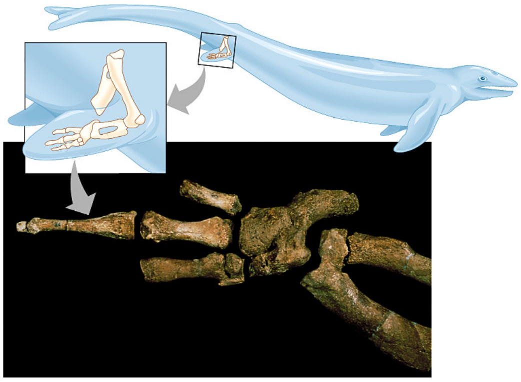


Figure 13.2G, H

A mass of other evidence reinforces the evolutionary view of life

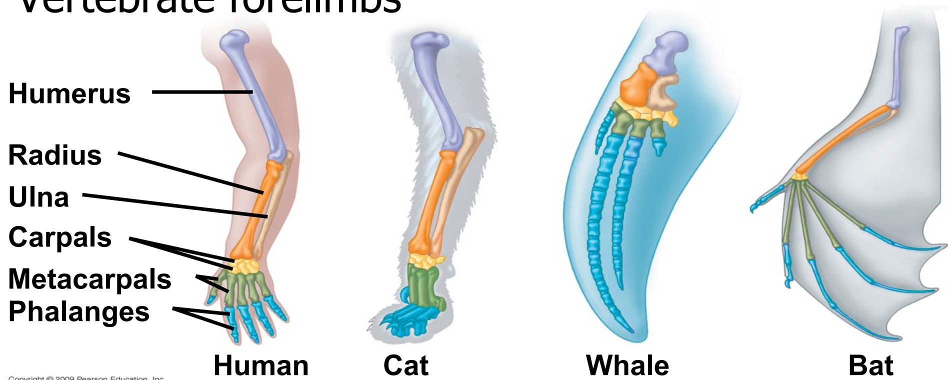
- **Biogeography**, the geographic distribution of species, suggested to Darwin that organisms evolve from common ancestors
  - Darwin noted that animals on islands resemble species on nearby mainland more closely than they resemble animals on similar islands close to other continents

A mass of other evidence reinforces the evolutionary view of life

– **Comparative anatomy** is the comparison of body structures in different species

– **Homology** is the similarity in characteristics that result from common ancestry

  – Vertebrate forelimbs



A mass of other evidence reinforces the evolutionary view of life

– Which of the following pairs are homologous structures?

  – Human limb and whale flipper

  – Insect wing and bat wing

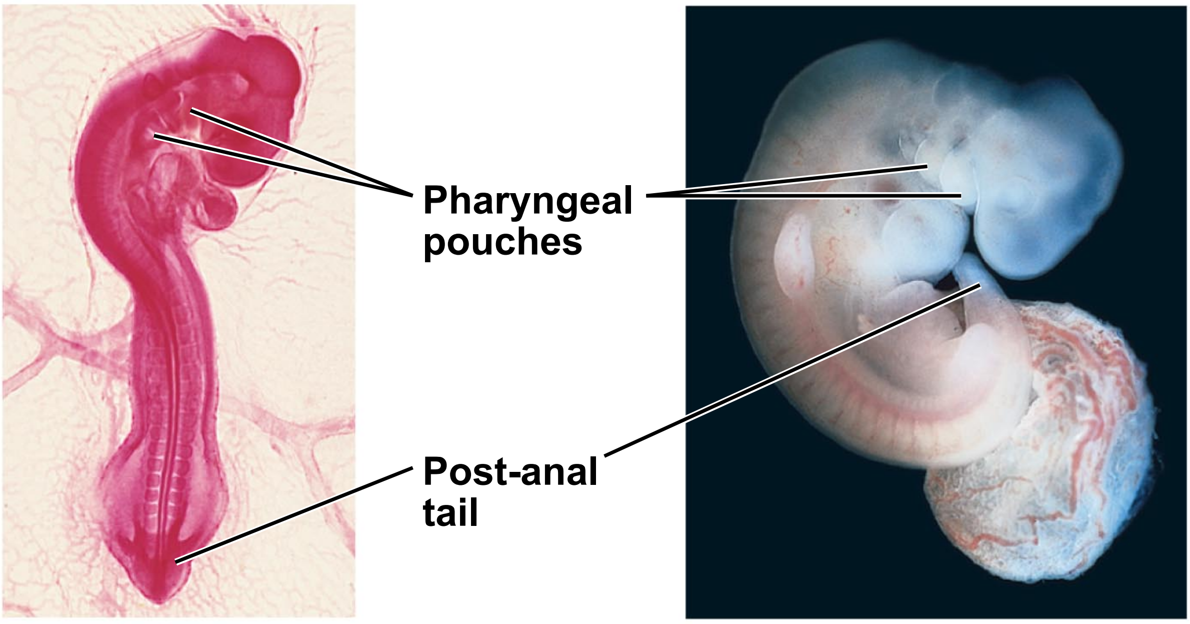
  – Human thumb and chimpanzee thumb

A mass of other evidence reinforces the evolutionary view of life

- Which of the following are homologous structures?
  - Oak leaf and oak root
  - Oak leaf and lichen
  - Oak leaf and maple leaf
  - There are no homologous plant structures

A mass of other evidence reinforces the evolutionary view of life

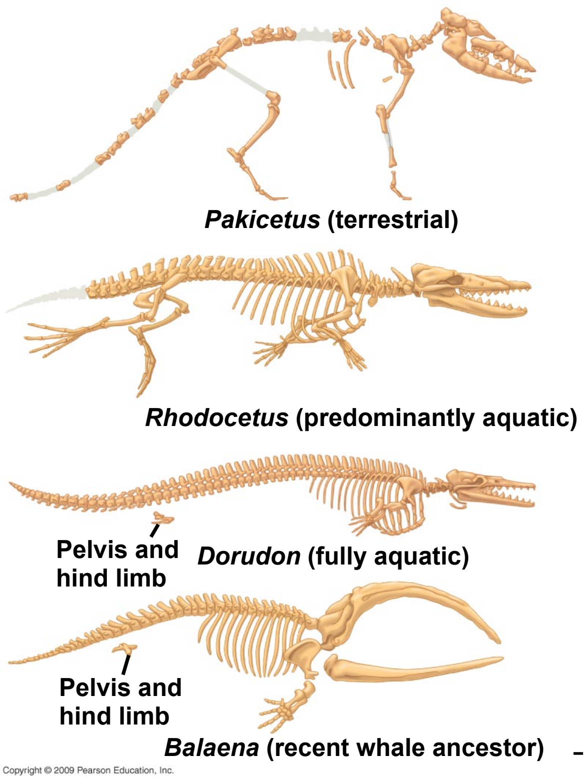
- *Comparative embryology* is the comparison of early stages of development among different organisms
  - Many vertebrates have common embryonic structures, revealing homologies
  - When you were an embryo, you had a tail and pharyngeal pouches (just like an embryonic fish)



Chick embryo **Human embryo**

A mass of other evidence reinforces the evolutionary view of life

- Some homologous structures are vestigial organs
  - For example, the pelvic and hind-leg bones of some modern whales



A mass of other evidence reinforces the evolutionary view of life

- **Molecular biology**: Comparisons of DNA and amino acid sequences between different organisms reveal evolutionary relationships
  - All living things share a common DNA code for the proteins found in living cells
  - We share genes with bacteria, yeast, and fruit flies

– Molecular biology

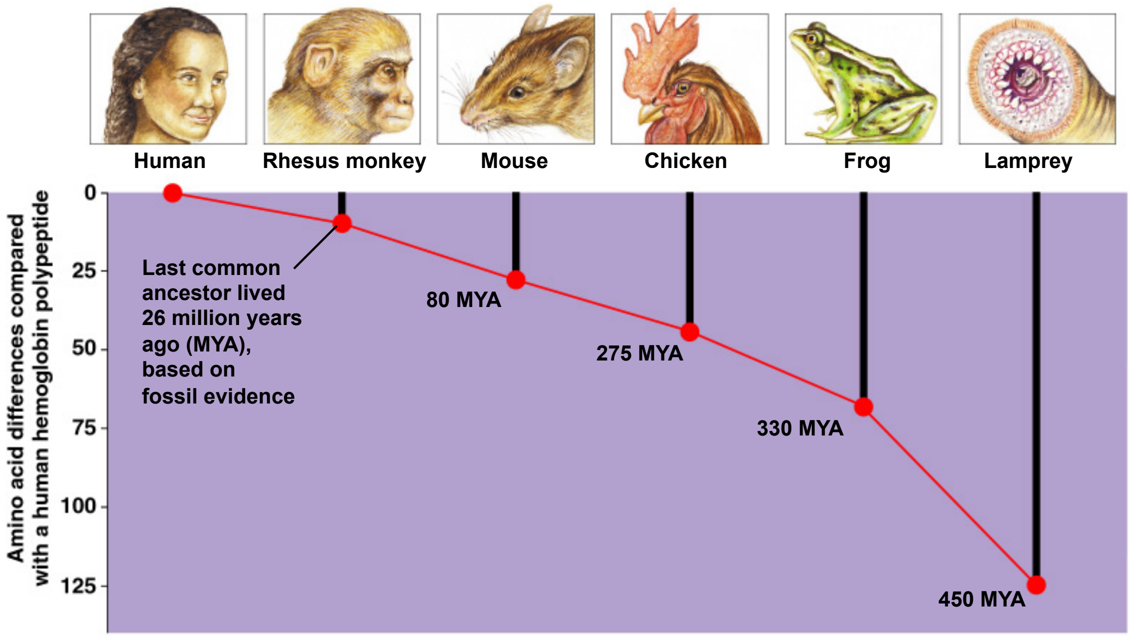
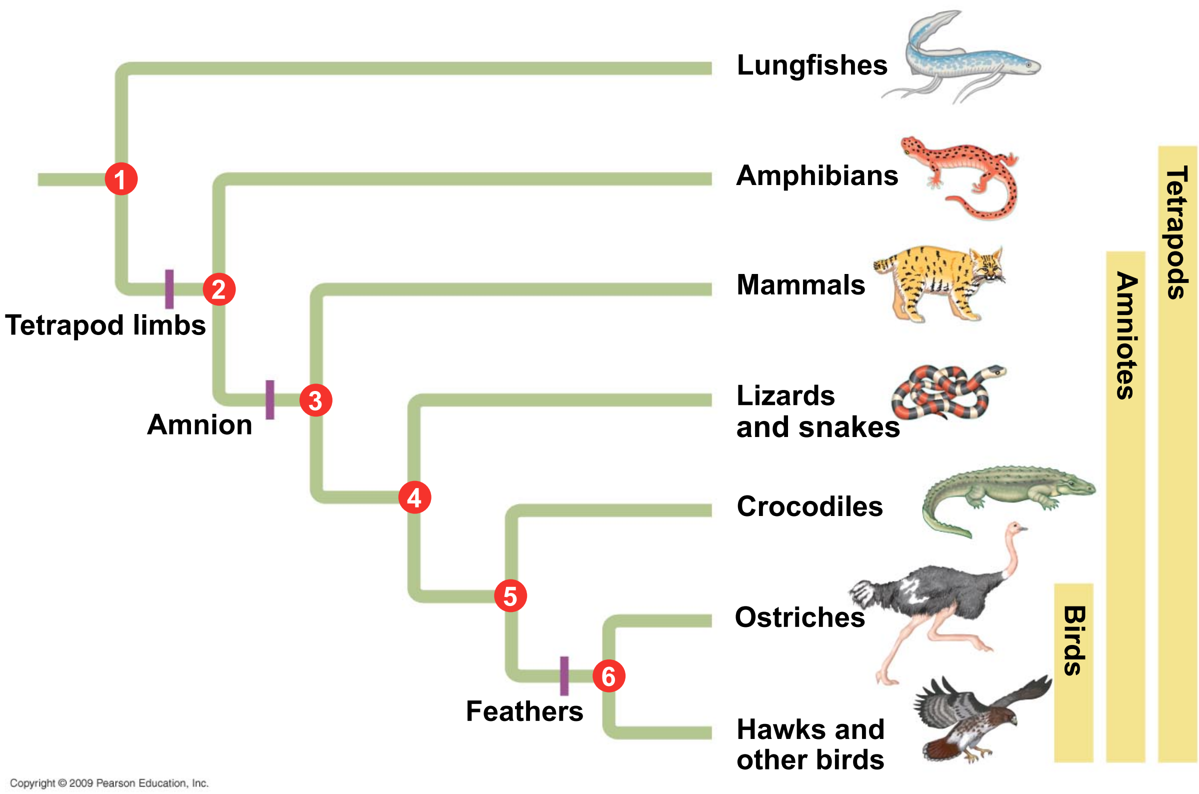


Figure 13.3B

Homologies indicate patterns of descent that can be shown on an evolutionary tree

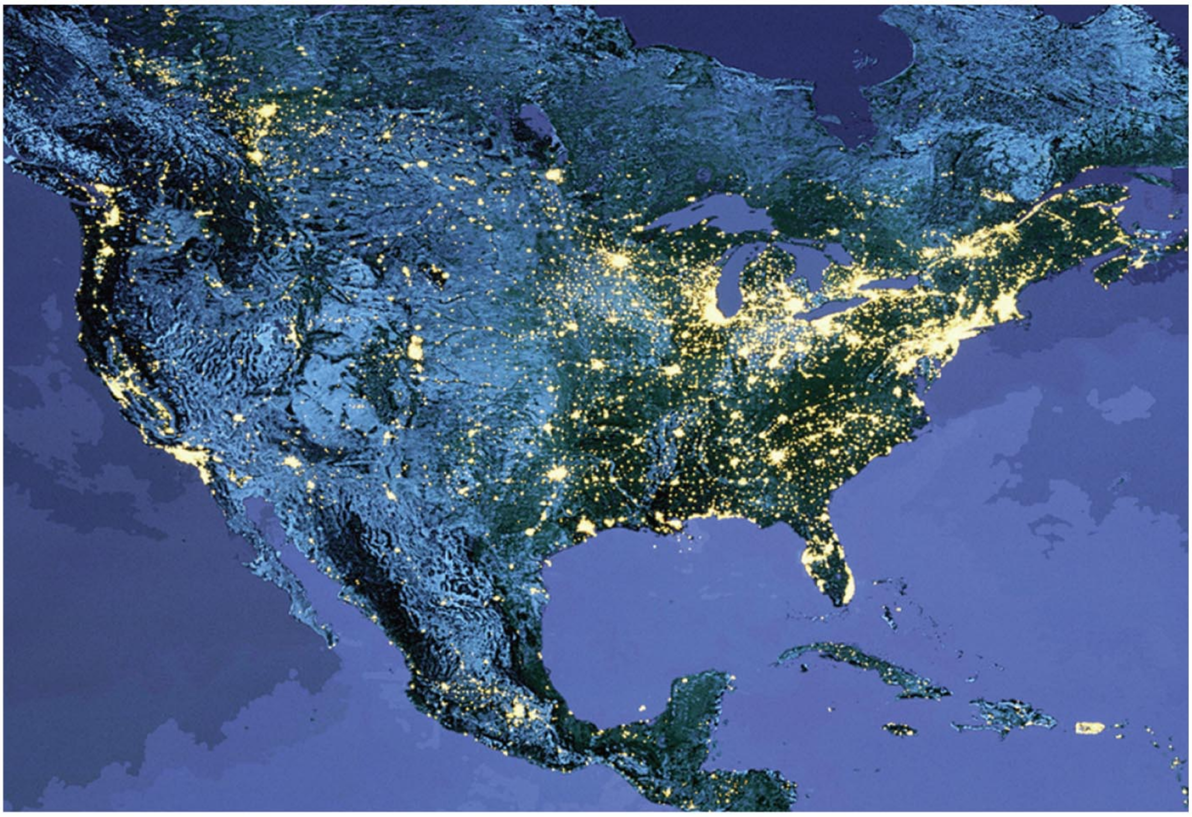
- Darwin was the first to represent the history of life as a tree
- Homologous structures and genes can be used to determine the branching sequence of an evolutionary tree



THE EVOLUTION OF POPULATIONS

13.7 Populations are the units of evolution

- A **population** is a group of individuals of the same species living in the same place at the same time
- **Evolution** is the change in heritable traits in a population over generations
- Populations may be isolated from one another (with little interbreeding), or individuals within populations may interbreed



Populations are the units of evolution

- A **gene pool** is the total collection of genes in a population at any one time
- **Microevolution** is a change in the relative frequencies of alleles in a gene pool over time
- **Population genetics** studies how populations change genetically over time
- The **modern synthesis** connects Darwin's theory with population genetics

Mutation and sexual reproduction produce genetic variation, making evolution possible

– **Mutation**, or changes in the nucleotide sequence of DNA, is the ultimate source of new alleles

  – Occasionally, mutant alleles improve the adaptation of an individual to its environment and increase its survival and reproductive success (for example, DDT resistance in insects)

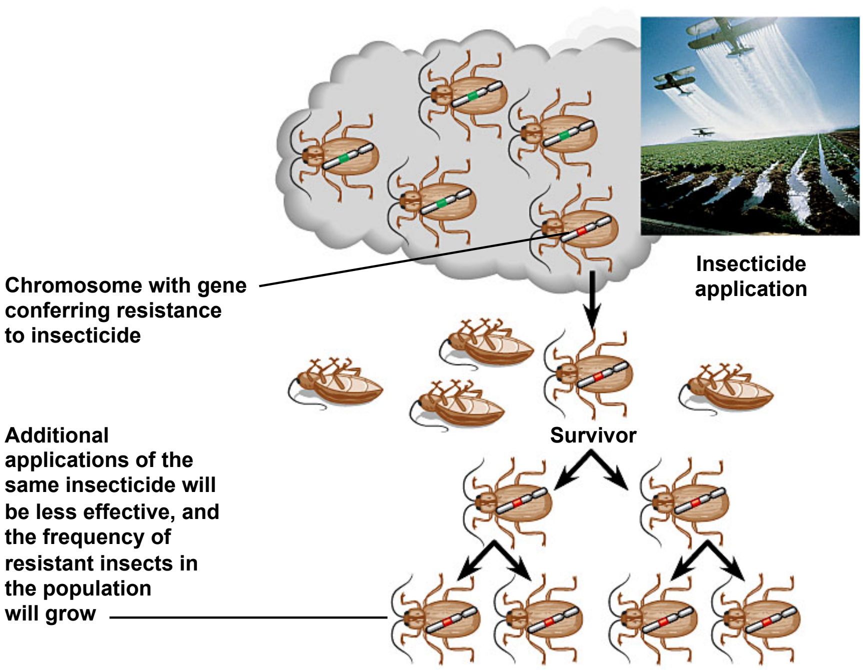


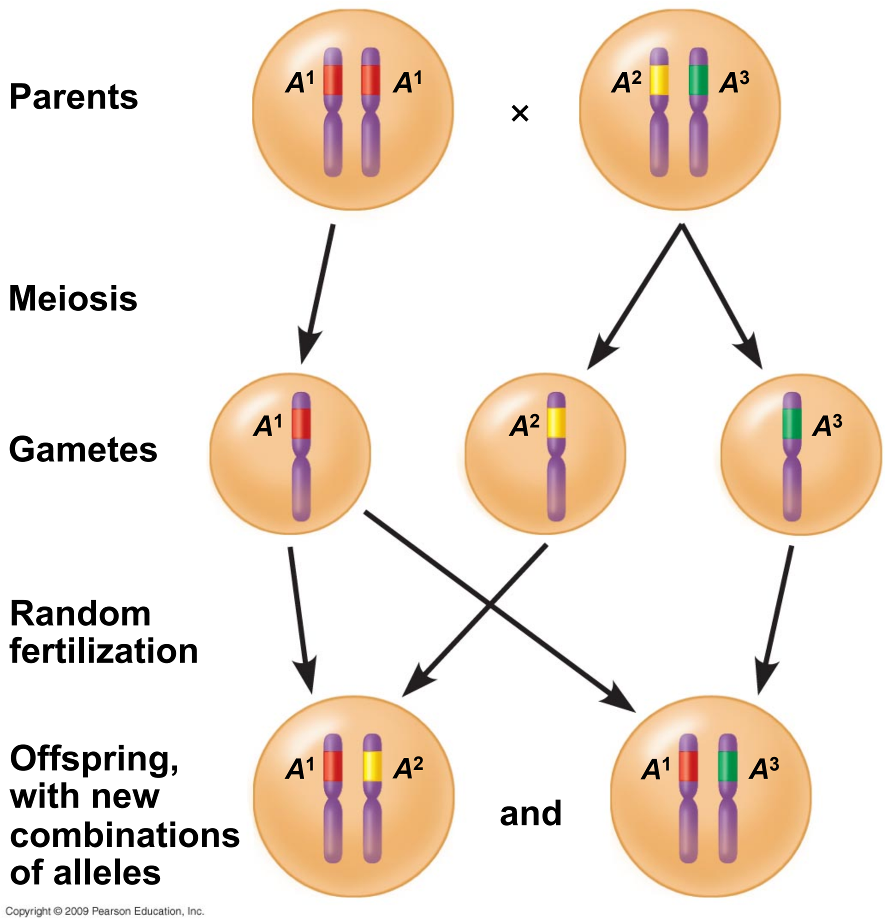
Figure 13.5B

Mutation and sexual reproduction produce genetic variation, making evolution possible

- Chromosomal duplication is an important source of genetic variation
  - If a gene is duplicated, the new copy can undergo mutation without affecting the function of the original copy
  - For example, an early ancestor of mammals had a single gene for an olfactory receptor
  - The gene has been duplicated many times, and humans now have 1,000 different olfactory receptor genes

Mutation and sexual reproduction produce genetic variation, making evolution possible

- Sexual reproduction shuffles alleles to produce new combinations
  - Homologous chromosomes sort independently as they separate during anaphase I of meiosis
  - During prophase I of meiosis, pairs of homologous chromosomes cross over and exchange genes
  - Further variation arises when sperm randomly unite with eggs in fertilization



Mutation and sexual reproduction produce genetic variation, making evolution possible

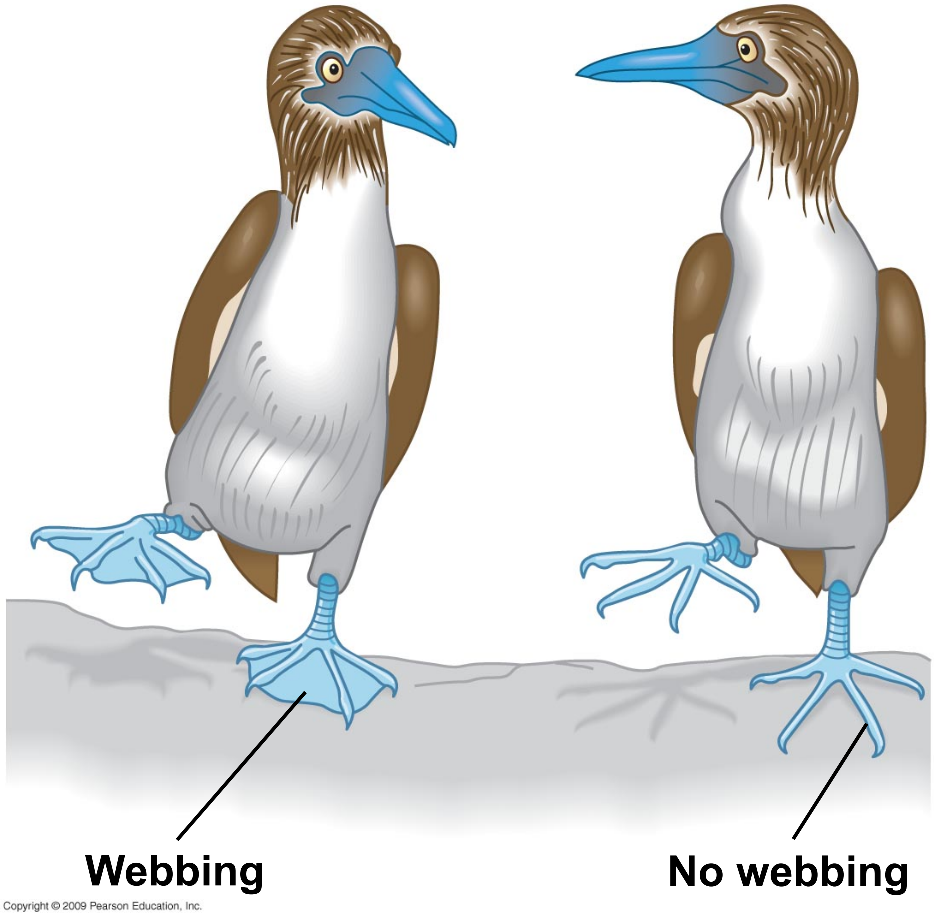
- How many possible combinations of chromosomes are possible in a human sperm or egg due to independent assortment during meiosis?
  - 23 combinations
  - 46 combinations
  - 23^2 = 529 combinations
  - 2^{23} = ~ 8 million combinations

The Hardy-Weinberg equation can be used to test whether a population is evolving

- Sexual reproduction alone does not lead to evolutionary change in a population
  - Although alleles are shuffled, the frequency of alleles and genotypes in the population does not change
  - Similarly, if you shuffle a pack of cards, you'll deal out different hands, but the cards and suits in the deck do not change

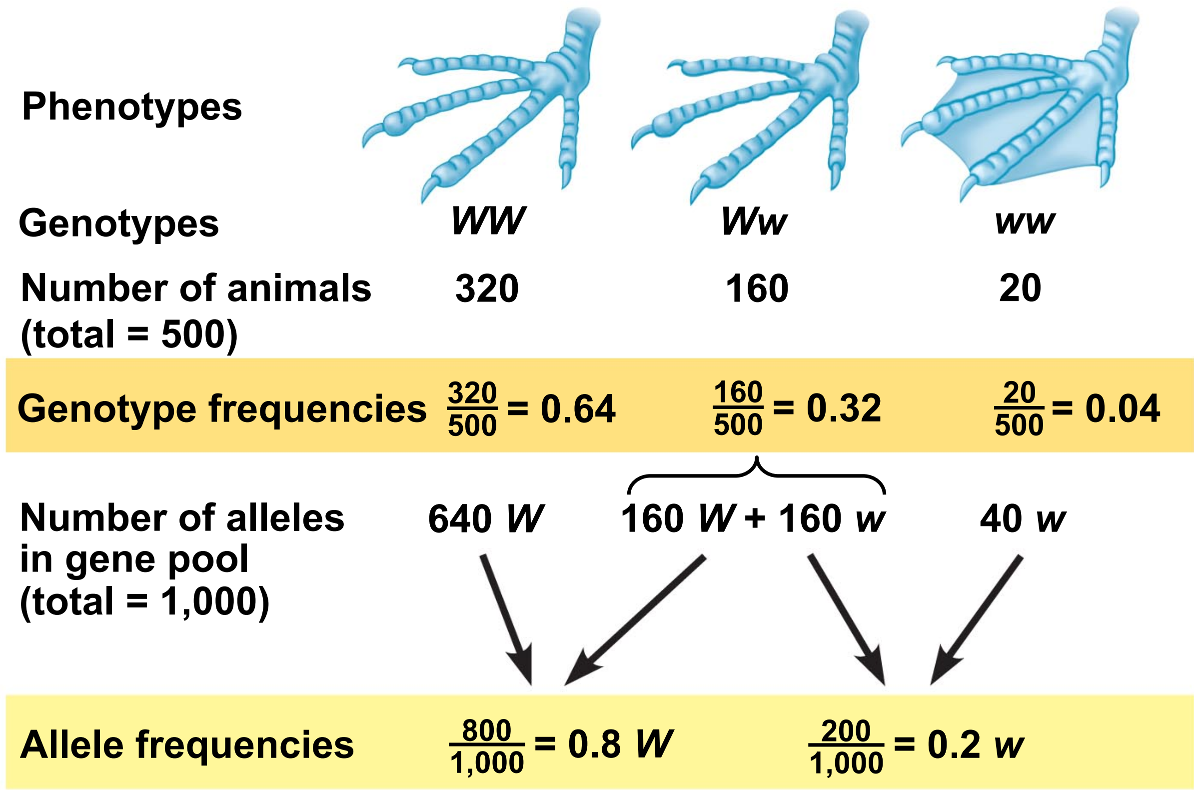
The Hardy-Weinberg equation can be used to test whether a population is evolving

- The **Hardy Weinberg principle** states that allele and genotype frequencies within a sexually reproducing, diploid population will remain in equilibrium unless outside forces act to change those frequencies
- Imagine that there are two alleles in a blue-footed booby population: *W* and *w*
  - *W* is a dominant allele for a non webbed booby foot
  - *w* is a recessive allele for a webbed booby foot



The Hardy-Weinberg equation can be used to test whether a population is evolving

- Consider the gene pool of a population of 500 boobies
  - 320 (64%) are homozygous dominant (*WW*)
  - 160 (32%) are heterozygous (*Ww*)
  - 20 (4%) are homozygous recessive (*ww*)



The Hardy-Weinberg equation can be used to test whether a population is evolving

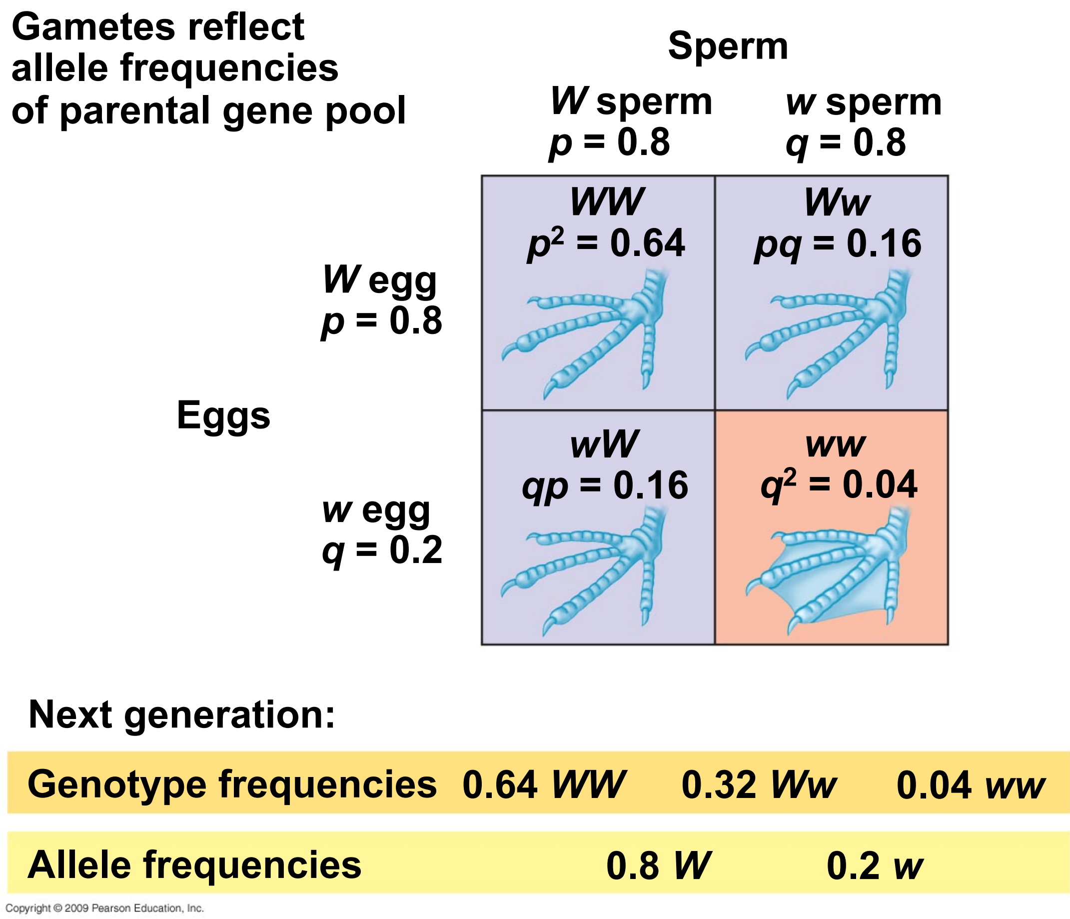
- Frequency of dominant allele (*W*) = 80% = *p*
  - 80% of alleles in the booby population are *W*
- Frequency of recessive allele (*w*) = 20% = *q*
  - 20% of alleles in the booby population are *w*

The Hardy-Weinberg equation can be used to test whether a population is evolving

- Frequency of all three genotypes must be 100% or 1.0
  - $p^2 + 2pq + q^2 = 100\% = 1.0$
  - homozygous dominant + heterozygous + homozygous recessive = 100%

The Hardy-Weinberg equation can be used to test whether a population is evolving

- What about the next generation of boobies?
  - Probability that a booby sperm or egg carries W = 0.8 or 80%
  - Probability that a sperm or egg carries w = 0.2 or 20%



The Hardy-Weinberg equation can be used to test whether a population is evolving

- What is the probability of a booby chick with a homozygous dominant genotype (*WW*)?
- What is the probability of a booby chick with a homozygous recessive genotype (*ww*)?
- What is the probability of a booby chick with a heterozygous genotype (*Ww*)?

The Hardy-Weinberg equation can be used to test whether a population is evolving

- If a population is in Hardy-Weinberg equilibrium, allele and genotype frequencies will not change unless something acts to change the gene pool

The Hardy-Weinberg equation can be used to test whether a population is evolving

– For a population to remain in Hardy-Weinberg equilibrium for a specific trait, it must satisfy five conditions:

1. Very large population
2. No gene flow between populations
3. No mutations
4. Random mating
5. No natural selection

CONNECTION: The Hardy-Weinberg equation is useful in public health science

- Public health scientists use the Hardy-Weinberg equation to estimate frequencies of disease-causing alleles in the human population
- One out of 3,300 Caucasian newborns in the United States have cystic fibrosis
  - This disease, which causes digestive and respiratory problems, is caused by a recessive allele

13.10 CONNECTION: The Hardy-Weinberg equation is useful in public health science

- The frequency of individuals with this disease is approximately $q^2 = 1/3300 = 0.0003$
  - The frequency of the recessive allele is $q = .0174$ or 1.7%
- The frequency of heterozygous carriers of cystic fibrosis is $2pq = 2 \times 0.983 \times 0.017 = 0.034$
- Around 3.4% of Caucasian Americans are carriers for cystic fibrosis

MECHANISMS OF MICROEVOLUTION

Natural selection, genetic drift, and gene flow can alter allele frequencies in a population

- If the five conditions for the Hardy-Weinberg equilibrium are not met in a population, the population's gene pool may change
  - **Mutations** are rare and random and have little effect on the gene pool
  - If **mating is nonrandom**, allele frequencies won't change much (although genotype frequencies may)

Natural selection, genetic drift, and gene flow can alter allele frequencies in a population

- The three main causes of evolutionary change are
  - Natural selection
  - Genetic drift
  - Gene flow

Natural selection, genetic drift, and gene flow can alter allele frequencies in a population

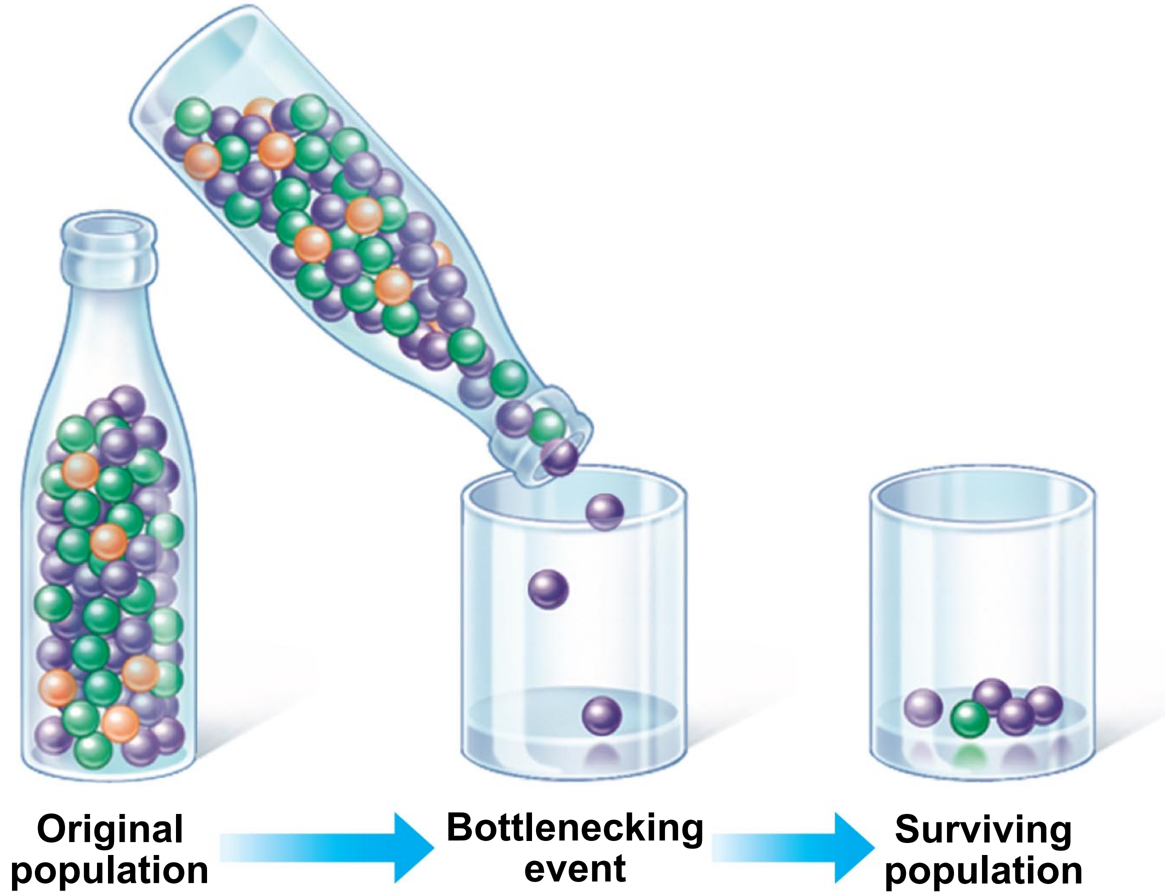
- **Natural selection**
  - If individuals differ in their survival and reproductive success, natural selection will alter allele frequencies
  - Consider the boobies: Would webbed or nonwebbed boobies be more successful at swimming and capturing fish?

Natural selection, genetic drift, and gene flow can alter allele frequencies in a population

- Genetic drift
  - **Genetic drift** is a change in the gene pool of a population due to chance
  - In a small population, chance events may lead to the loss of genetic diversity

Natural selection, genetic drift, and gene flow can alter allele frequencies in a population

- Genetic drift
  - The **bottleneck effect** leads to a loss of genetic diversity when a population is greatly reduced
    - For example, the northern elephant seal was hunted to near extinction in the 1700s and 1800s
    - A remnant population of fewer than 100 seals was discovered and protected; the current population of 175,000 descended from those few seals and has virtually no genetic diversity


Original population
Bottlenecking event
Surviving population

Natural selection, genetic drift, and gene flow can alter allele frequencies in a population

- **Genetic drift**
  - Genetic drift produces the **founder effect** when a few individuals colonize a new habitat
    - The smaller the group, the more different the gene pool of the new population will be from the gene pool of the original population

Natural selection, genetic drift, and gene flow can alter allele frequencies in a population

- **Gene flow**
  - **Gene flow** is the movement of individuals or gametes/spores between populations and can alter allele frequencies in a population

Natural selection, genetic drift, and gene flow can alter allele frequencies in a population

- Four moose were taken from the Canadian mainland to Newfoundland in 1904. These two males and two females rapidly formed a large population of moose that now flourishes in Newfoundland. Which mechanism is most likely to have contributed to the genetic differences between the mainland and Newfoundland moose?
  - Gene flow
  - Founder effect
  - Novel mutations

Natural selection, genetic drift, and gene flow can alter allele frequencies in a population

- The fossil remains of pygmy (or dwarf) mammoths (1.5 m to 2 m tall) have been found on Santa Rosa and San Miguel Islands off the coast of California. This population of pygmy mammoths is descended from a population of mammoths of normal size (4 m tall). Dwarfing is common in island populations and **is not the result of chance events**. What mechanism do you think best accounts for the decrease in mammoth size on these islands?
  - Gene flow
  - Genetic drift
  - Natural selection

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Natural selection is the only mechanism that consistently leads to adaptive evolution

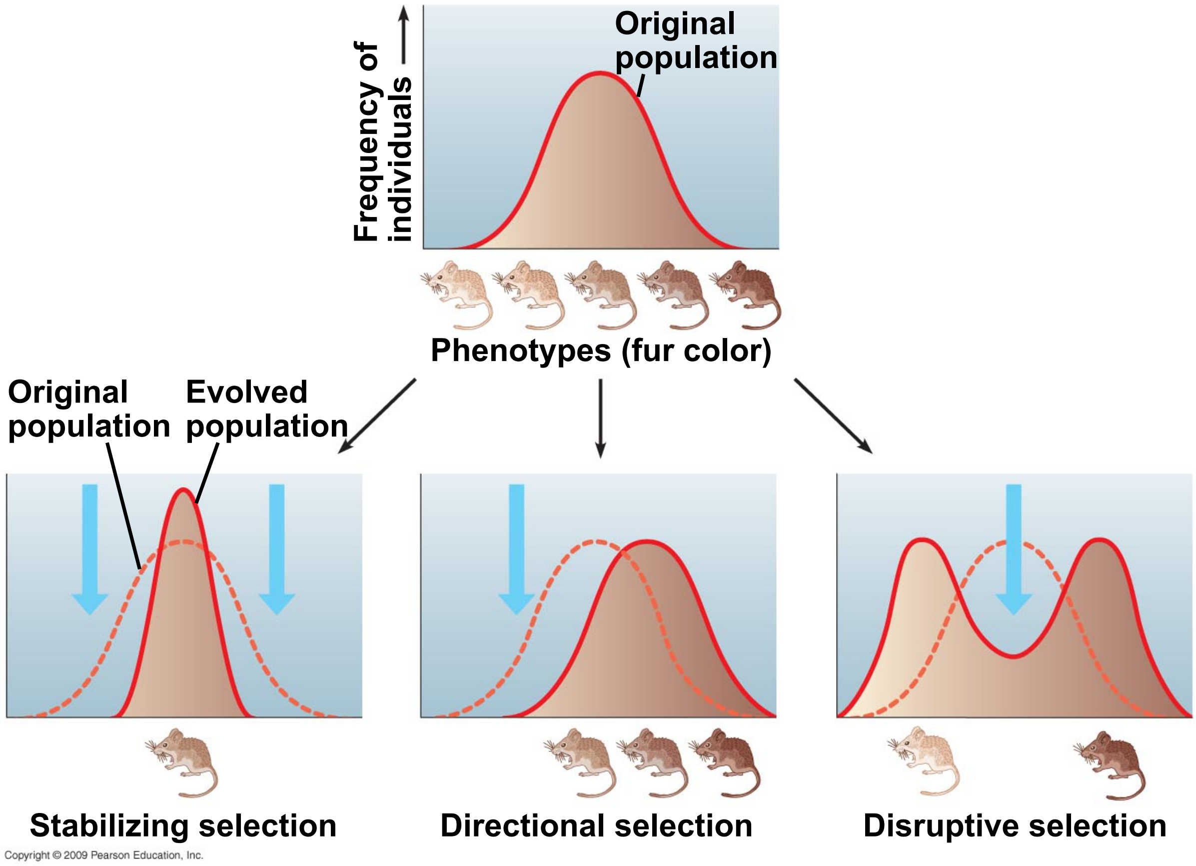
– An individual's fitness is the contribution it makes to the gene pool of the next and subsequent generations

– The fittest individuals are those that pass on the most genes to the next generation

Natural selection can alter variation in a population in three ways

– **Stabilizing selection** favors intermediate phenotypes, acting against extreme phenotypes

– Stabilizing selection is very common, especially when environments are stable



Natural selection can alter variation in a population in three ways

– **Directional selection** acts against individuals at one of the phenotypic extremes

– Directional selection is common during periods of environmental change, or when a population migrates to a new and different habitat

Natural selection can alter variation in a population in three ways

- **Disruptive selection** favors individuals at both extremes of the phenotypic range
  - This form of selection may occur in patchy habitats

Sexual selection may lead to phenotypic differences between males and females

- In many animal species, males and females show distinctly different appearance, called **sexual dimorphism**
- **Intrasexual competition** involves competition for mates, usually by males

Sexual selection may lead to phenotypic differences between males and females

– In **intersexual competition** (or mate choice), individuals of one sex (usually females) are choosy in picking their mates, often selecting flashy or colorful mates

Diploidy and balancing selection preserve genetic variation

– Why doesn't natural selection act to eliminate genetic variation in populations, retaining only the most favorable alleles?

– Diploidy preserves variation by "hiding" recessive alleles

  – A recessive allele is only subject to natural selection when it influences the phenotype in homozygous recessive individuals

  – For example, cystic fibrosis

Diploidy and balancing selection preserve genetic variation

- **Balancing selection** maintains stable frequencies of two or more phenotypes in a population
- In **heterozygote advantage**, heterozygotes have greater reproductive success than homozygous
  - For example, sickle-cell anemia

Diploidy and balancing selection preserve genetic variation

- In **frequency-dependent selection**, two different phenotypes are maintained in a population
  - For example, Indonesian silverside fishes
- Some variations may be **neutral**, providing no apparent advantage or disadvantages
  - For example, human variation in fingerprints

Natural selection cannot fashion perfect organisms

1. Selection can only act on existing variation
   - Natural selection cannot conjure up new beneficial alleles
2. Evolution is limited by historical constraints
   - Birds arose as the forelimb of a small dinosaur evolved into a wing

Natural selection cannot fashion perfect organisms

- There are at least four reasons why natural selection cannot produce perfection
  - Organisms are limited by historical constraints
  - Adaptations are often compromises
  - Chance and natural selection interact
  - Selection can only edit existing variations