Chapter 15

The Theory of Evolution

What You'll Learn

- You will analyze the theory of evolution.
- You will compare and contrast the processes of evolution.

Why It's Important

Evolution is the key concept for understanding biology. Evolution explains the diversity of species and predicts changes.

Understanding the Photo

This crayfish lives in dark caves and is blind. It has sighted relatives that live where there is light. Both the cave-dwelling species and their relatives are adapted to different environments. As populations adapt to new or changing environments, individuals in the population that are best adapted survive long enough to reproduce.

Biology Online

Visit bdol.glencoe.com to
- study the entire chapter online
- access Web Links for more information and activities on evolution
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Section 15.1

Natural Selection and the Evidence for Evolution

SECTION PREVIEW

Objectives

Summarize Darwin's theory of natural selection.

Explain how the structural and physiological adaptations of organisms relate to natural selection.

Distinguish among the types of evidence for evolution.

Review Vocabulary

evolution: the changes in populations over time (p. 10)

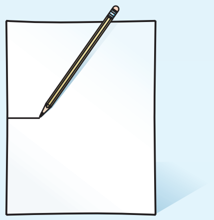
New Vocabulary

artificial selection
natural selection
mimicry
camouflage
homologous structure
analogous structure
vestigial structure
embryo

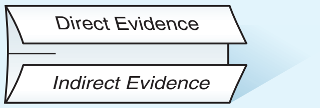
FOLDABLES Study Organizer

Evolution Make the following Foldable to help you analyze and critique evidence supporting the theory of evolution.

STEP 1 **Draw** a mark at the midpoint of a vertical sheet of paper along the side edge.



STEP 2 **Turn** the paper horizontally and **fold** the outside edges in to touch at the midpoint mark.



STEP 3 **Label** the tabs as shown.

Analyze and Critique As you read Chapter 15, summarize, analyze, and critique the direct and indirect evidence used to support the theory of evolution.

Charles Darwin and Natural Selection

The modern theory of evolution is the fundamental concept in biology. Recall that evolution is the change in populations over time. Learning the principles of evolution makes it easier to understand modern biology. One place to start is by learning about the ideas of English scientist Charles Darwin (1809–1882)—ideas supported by fossil evidence.

Fossils shape ideas about evolution

Biologists have used fossils in their work since the eighteenth century. In fact, fossil evidence formed the basis of early evolutionary concepts. Scientists wondered how fossils formed, why many fossil species were extinct, and what kinds of relationships might exist between the extinct and the modern species.

Before geologists provided evidence indicating that Earth was much older than many people had originally thought, biologists suspected that species change over time, or evolve. Many explanations about how species evolve have been proposed, but the ideas first published by Charles Darwin are the basis of modern evolutionary theory.

Darwin on HMS *Beagle*

It took Darwin years to develop his theory of evolution. He began in 1831 at age 22 when he took a job as a naturalist on the English ship HMS *Beagle*, which sailed around the world on a five-year scientific journey.

As the ship's naturalist, Darwin studied and collected biological and fossil specimens at every port along the route. As you might imagine, these specimens were quite diverse. Studying the specimens made Darwin curious about possible relationships among species. His studies provided the foundation for his theory of evolution by natural selection.

Darwin in the Galápagos

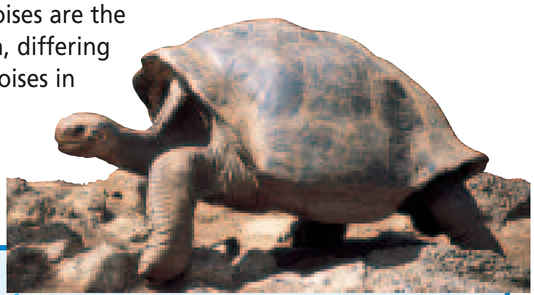
The Galápagos (guh LAH puh gus) Islands are a group of small islands near the equator, about 1000 km off the west coast of South America. The observations that Darwin made and the specimens that he collected there were especially important to him.

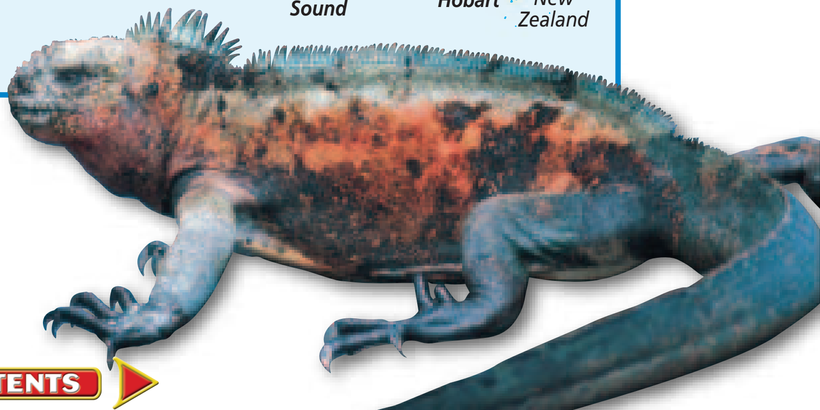
On the Galápagos Islands, Darwin studied many species of animals and plants, ***Figure 15.1***, that are unique to the islands but similar to species elsewhere. These observations led Darwin to consider the possibility that species can change over time. However, after returning to England, he could not at first explain how such changes occur.

Figure 15.1
The five-year voyage of HMS *Beagle* took Darwin around the world. Animal species in the Galápagos Islands have unique adaptations.

A The beak of this Galápagos finch is adapted to feed on cacti.

B Galápagos tortoises are the largest on Earth, differing from other tortoises in body size and shape.





C Galápagos marine iguanas eat algae from the ocean, an unusual food source for reptiles. Large claws help them cling to slippery rocks.

(tl)Frans Lanting/Photo Researchers (tr)Tom Brakefield/DRK Photo (b)Barbara Cushman Rowell/DRK Photo

Darwin continues his studies

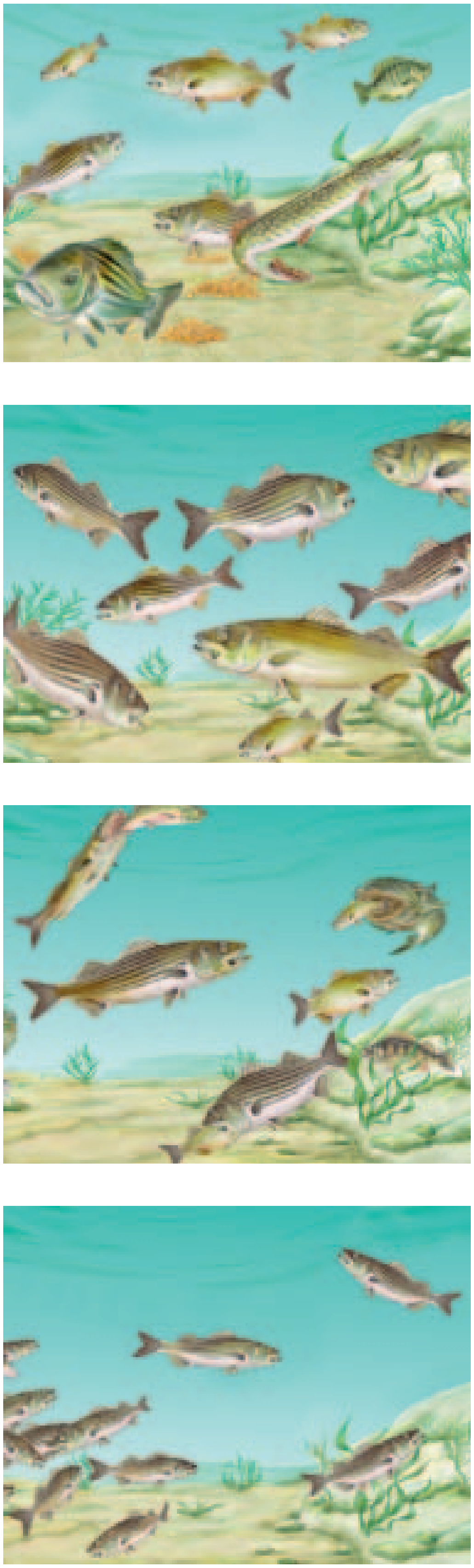
For the next two decades, Darwin worked to refine his explanation for how species change over time. He read, studied, collected specimens, and conducted experiments.

English economist Thomas Malthus had proposed an idea that Darwin modified and used in his explanation. Malthus's idea was that the human population grows faster than Earth's food supply. How did this help Darwin? He knew that many species produce large numbers of offspring. He also knew that such species had not overrun Earth. He realized that individuals struggle to compete in changing environmental conditions. There are many kinds of competition, such as competing for food and space, escaping from predators, finding mates, and locating shelter. Only some individuals survive the competition and produce offspring. Which individuals survive?

Darwin gained insight into the mechanism that determined which organisms survive in nature from his pigeon-breeding experiments. Darwin observed that the traits of individuals vary in populations. Variations are then inherited. By breeding pigeons with desirable variations, Darwin produced offspring with these variations. Breeding organisms with specific traits in order to produce offspring with identical traits is called **artificial selection.** Darwin hypothesized that there was a force in nature that worked like artificial selection.

Darwin explains natural selection

Using his collections and observations, Darwin identified the process of natural selection, the steps of which you can see summarized in ***Figure 15.2.*** **Natural selection** is a mechanism for change in populations. It occurs when organisms with favorable variations



A In nature, organisms produce more offspring than can survive. Fishes, for example, can sometimes lay millions of eggs.

B In any population, individuals have variations. Fishes, for example, may differ in color, size, and speed.

C Individuals with certain useful variations, such as speed, survive in their environment, passing those variations to the next generation.

D Over time, offspring with certain variations make up most of the population and may look entirely different from their ancestors.

Figure 15.2
Darwin proposed the idea of natural selection to explain how species change over time.

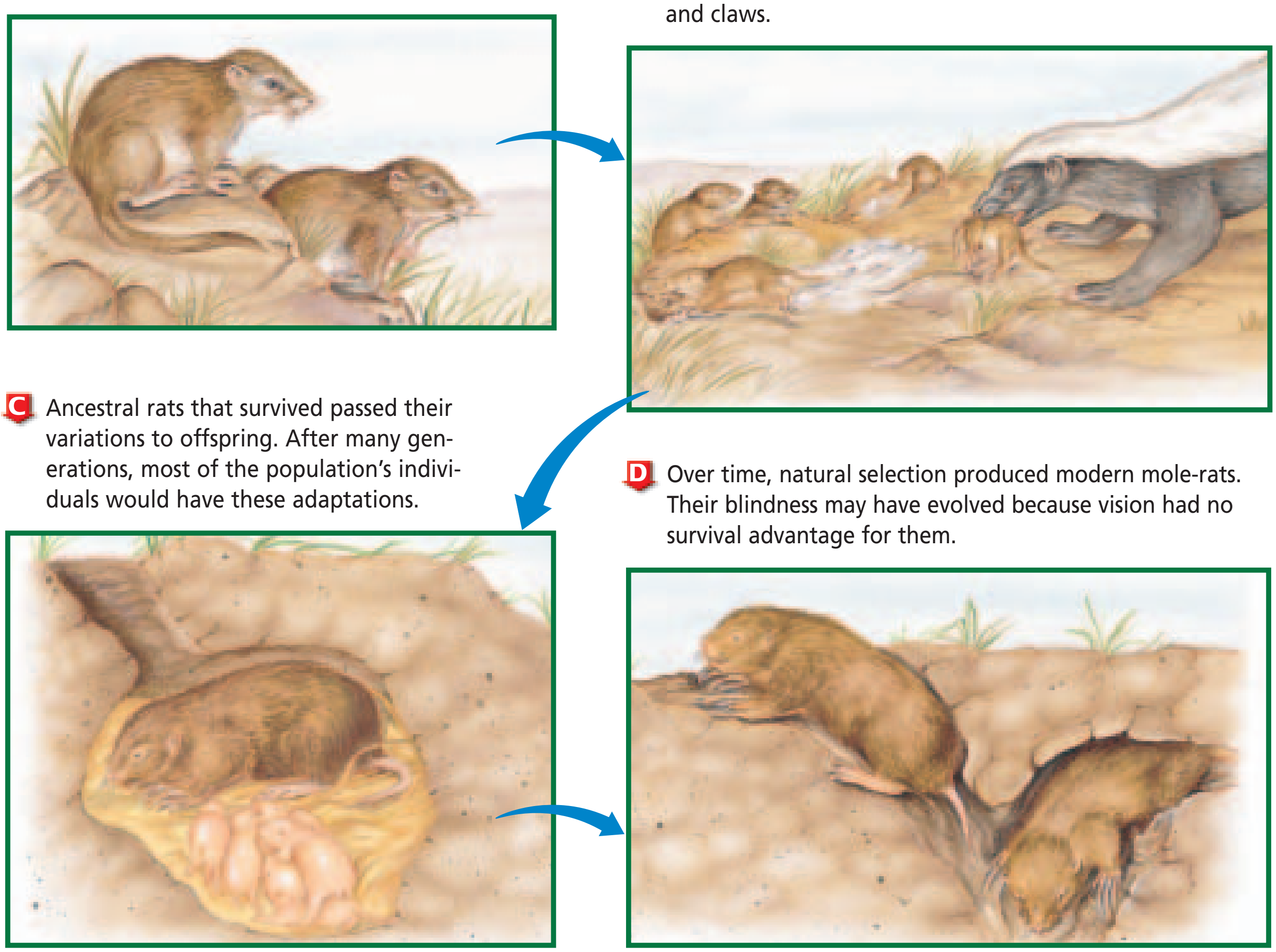
survive, reproduce, and pass their variations to the next generation. Organisms without these variations are less likely to survive and reproduce. As a result, each generation consists largely of offspring from parents with these variations that aid survival.

Darwin was not the only one to recognize the significance of natural selection for populations. As a result of his studies on islands near Indonesia in the Pacific Ocean, Alfred Russell Wallace, another British naturalist, reached a similar conclusion. After Wallace wrote Darwin to share his ideas about natural selection, Darwin and Wallace had their similar ideas jointly presented to the scientific community. Soon thereafter, Darwin published the first book about evolution called *On the Origin of Species by Means of Natural Selection* in 1859. The ideas detailed in Darwin's book are a basic unifying theme of biology today.

Interpreting evidence after Darwin

Volumes of scientific data have been gathered as evidence for evolution since Darwin's time. Much of this evidence is subject to interpretation by different scientists. One of the issues is that evolutionary processes are difficult for humans to observe directly. The short scale of human life spans makes it difficult to comprehend evolutionary processes

Figure 15.3
Darwin's ideas about natural selection can explain some adaptations of mole-rats.



A The ancestors of today's common mole-rats probably resembled African rock rats.

B Some ancestral rats may have avoided predators better than others because of variations such as the size of teeth and claws.

C Ancestral rats that survived passed their variations to offspring. After many generations, most of the population's individuals would have these adaptations.

D Over time, natural selection produced modern mole-rats. Their blindness may have evolved because vision had no survival advantage for them.

that occur over millions of years. Despite this, much data about the biological world has been gathered from many sources. These data are best explained by evolution. Almost all of today's biologists accept the theory of evolution by natural selection. The advent of genetics has added yet more data to our understanding of evolution. This means that the change in the gene pool of a population over time can be added to our modern definition of evolution. Use *Problem-Solving Lab 15.1* to analyze data from a study of peppered moths.

Reading Check **Summarize** the main ideas of natural selection.

Adaptations: Evidence for Evolution

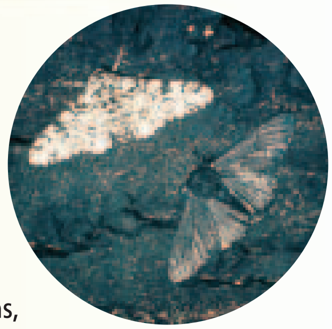
Have you noticed that some plants have thorns and some plants don't? Have you noticed that some animals have distinctive coloring but others don't? Have you ever wondered how such variations arose? Recall that an adaptation is any variation that aids an organism's chances of survival in its environment. Thorns are an adaptation of some plants and distinctive colorings are an adaptation of some animals. Darwin's theory of evolution explains how adaptations may develop in species.

Structural adaptations arise over time

According to Darwin's theory, adaptations in species develop over many generations. Learning about adaptations in mole-rats can help you understand how natural selection has affected them. Mole-rats that live underground in darkness are blind. These blind mole-rats have many adaptations that enable them to live successfully underground. Look at ***Figure 15.3*** to see how these modern mole-rat adaptations might have evolved over millions of years from characteristics of their ancestors.

Problem-Solving Lab 15.1

Interpret Data



Biston betularia

How can natural selection be observed? In some organisms that have a short life cycle, biologists have observed the evolution of adaptations to rapid environmental changes. Scientists studied camouflage adaptations in a population of light- and dark-colored peppered moths, *Biston betularia.* The moths sometimes rested on trees that grew in both the country and the city. Moths are usually speckled gray-brown, and dark moths, which occur occasionally, are black. Some birds eat peppered moths. Urban industrial pollution had blackened the bark of city trees with soot. In the photo, you see a city tree with dark bark similar to the color of one of the moths.

Solve the Problem

Scientists raised more than 3000 caterpillars to provide adult moths. They marked the wings of the moths these caterpillars produced so they would recapture only their moths. In a series of trials in the country and the city, they released and recaptured the moths. The number of moths recaptured in a trial indicates how well the moths survived in the environment. Examine the table below.

Comparison of Country and City Moths

Location		Numbers of Light Moths	Numbers of Dark Moths
Country	Released	496	488
	Recaptured	62	34
City	Released	137	493
	Recaptured	18	136

Thinking Critically

Interpret Data Calculate the percentage of moths recaptured in each experiment, and explain any differences in survival rates in the country and the city moths in terms of natural selection.

MiniLab 15.1

Formulate Models

Camouflage Provides an Adaptive Advantage Camouflage is a structural adaptation that allows organisms to blend with their surroundings. In this activity, you'll discover how natural selection can result in camouflage adaptations in organisms.

Procedure

1. Working with a partner, punch 100 dots from a sheet of white paper with a paper hole punch. Repeat with a sheet of black paper. These dots will represent black and white insects.
2. Scatter both white and black dots on a sheet of black paper.
3. Decide whether you or your partner will role-play a bird.
4. The "bird" looks away from the paper, then turns back, and immediately picks up the first dot he or she sees.
5. Repeat step 4 for one minute.

Analysis

1. **Observe** What color dots were most often collected?
2. **Infer** How does color affect the survival rate of insects?
3. **Hypothesize** What might happen over many generations to a similar population in nature?

The structural adaptations of common mole-rats include large teeth and claws. These are body parts that help mole-rats survive in their environment by, for example, enabling them to dig better tunnels. Structural adaptations such as the teeth and claws of mole-rats are often used to defend against predators. Some adaptations of other organisms that keep predators from approaching include a rose's thorns or a porcupine's quills.

Some other structural adaptations are subtle. **Mimicry** is a structural adaptation that enables one species to resemble another species. In one form of mimicry, a harmless species has adaptations that result in a physical resemblance to a harmful species. Predators that avoid the harmful species also avoid the similar-looking, harmless species. See if you can tell the difference between a harmless fly and the wasp it mimics when you look at ***Figures 15.4A*** and ***B.***

In another form of mimicry, two or more harmful species resemble each other. For example, yellow jacket hornets, honeybees, and many other

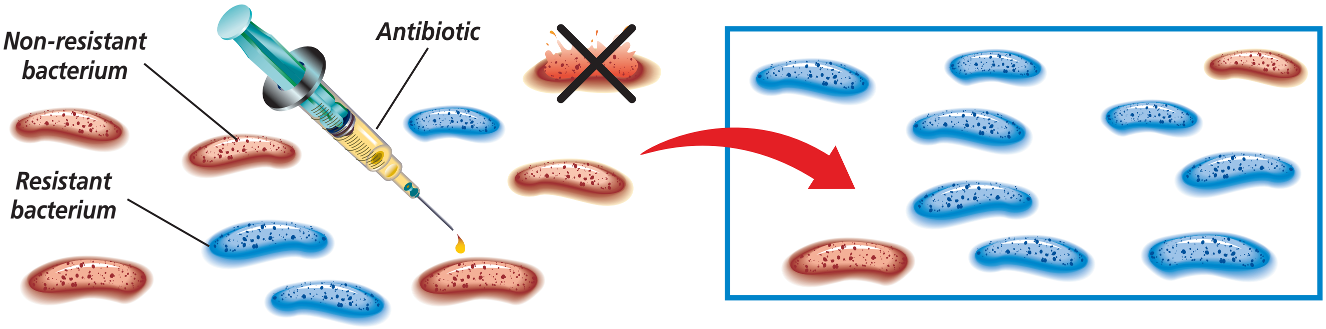
Figure 15.4
Mimicry and camouflage are protective adaptations of organisms. The colors and body shape of a yellow jacket wasp **(A)** and a harmless syrphid fly **(B)** are similar. Predators avoid both insects. Camouflage enables organisms, such as this leaf frog **(C),** to blend with their surroundings.

C


A


B


(l)R. Calentine/Visuals Unlimited (c)John Colwell/Grant Heilman Photography (r)S.L. & J.T. Collins/Photo Researchers



A The bacteria in a population vary in their ability to resist antibiotics.

B When the population is exposed to an antibiotic, only the resistant bacteria survive.

C The resistant bacteria live and produce more resistant bacteria.

Figure 15.5
The development of bacterial resistance to antibiotics is direct evidence for evolution.
Infer ***What problems can antibiotic-resistant bacteria cause?***

species of wasps all have harmful stings and similar coloration and behavior. Predators may learn quickly to avoid any organism with their general appearance.

Another subtle adaptation is **camouflage** (KA muh flahj), an adaptation that enables species to blend with their surroundings, as shown in ***Figure 15.4C.*** Because well-camouflaged organisms are not easily found by predators, they survive to reproduce. Try *MiniLab 15.1* to experience how camouflage can help an organism survive and adapt to it's environment.

Reading Check **Explain and illustrate** how mimicry and camouflage can cause populations to change over time.

Physiological adaptations can develop rapidly

In general, most structural adaptations develop over millions of years. However, there are some adaptations that evolve much more rapidly. For example, do you know that some of the medicines developed during the twentieth century to fight bacterial diseases are no longer effective? When the antibiotic drug penicillin was discovered about 50 years ago, it was called a wonder drug because it killed many types of disease-causing bacteria and saved many lives. Today, penicillin no longer affects as many species of bacteria because some species have evolved physiological (fih zee uh LAH jih kul) adaptations to prevent being killed by penicillin. Look at ***Figure 15.5*** to see how resistance develops in bacteria.

Physiological adaptations are changes in an organism's metabolic processes. In addition to species of bacteria, scientists have observed these adaptations in species of insects and weeds that are pests. After years of exposure to specific pesticides, many species of insects and weeds have become resistant to these chemicals that used to kill them.

Other Evidence for Evolution

The development of physiological resistance in species of bacteria, insects, and plants is direct evidence of evolution. However, most of the evidence for evolution is indirect, coming from sources such as fossils and studies of anatomy, embryology, and biochemistry.

Fossils

Fossils are an important source of evolutionary evidence because they provide a record of early life and evolutionary history. For example, paleontologists conclude from fossils that the ancestors of whales were probably land-dwelling, doglike animals.

Although the fossil record provides evidence that evolution occurred, the record is incomplete. Working with an incomplete fossil record is something like trying to put together a jigsaw puzzle with missing pieces. But, after the puzzle is together, even with missing pieces, you will probably still understand the overall picture. It's the same with fossils. Although paleontologists do not have fossils for all the changes that have occurred, they can still understand the overall picture of how most groups evolved.

Fossils are found throughout the world. As the fossil record becomes more complete, the sequences of evolution become clearer. For example, in ***Table 15.1*** you can see how paleontologists have charted the evolutionary path that led to today's camel after piecing together fossil skulls, teeth, and limb bones.

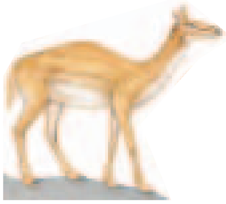
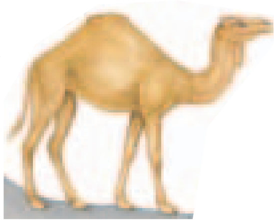
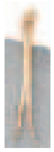
Anatomy

Look at the forelimb bones of the animals shown in ***Figure 15.6.*** Although the bones of each forelimb are modified for their function, the basic arrangement of the bones in each limb is similar. Evolutionary biologists view such structural similarities as evidence that organisms evolved from a common ancestor. It would be unlikely for so many animals to have similar structures if each species arose separately. Structural features with a common evolutionary origin are called **homologous structures.** Homologous structures can be similar in arrangement, in function, or in both.

The structural or functional similarity of a body feature doesn't always mean that two species are closely related. In ***Figure 15.7,*** you can compare the wing of a butterfly with the

Table 15.1
Fossils are used by scientists to understand how camels evolved.

Table 15.1 Camel Evolution

Age	Paleocene 65 million years ago	Eocene 54 million years ago	Oligocene 33 million years ago	Miocene 23 million years ago	Present
Organism					
Skull and teeth					
Limb bones					

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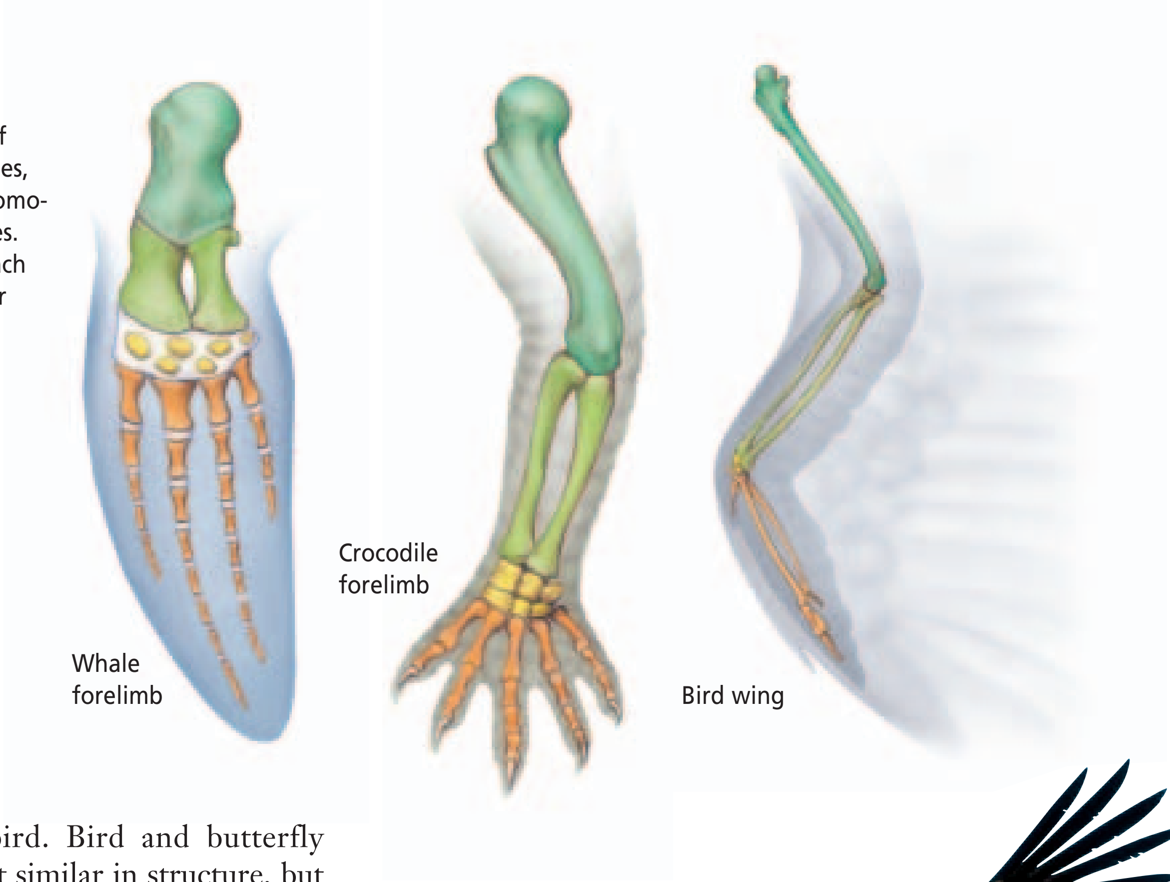


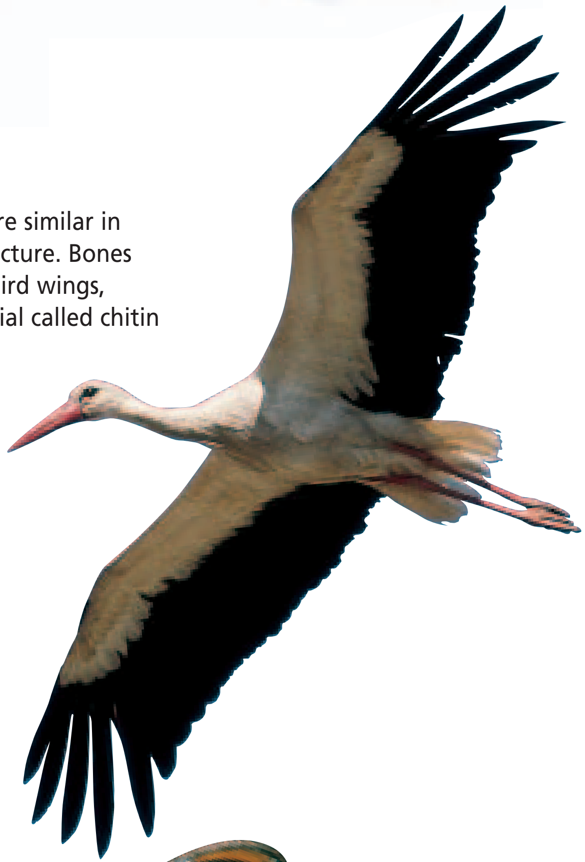
Figure 15.6
The forelimbs of crocodiles, whales, and birds are homologous structures. The bones of each are modified for their function.

wing of a bird. Bird and butterfly wings are not similar in structure, but they are similar in function. The wings of birds and insects evolved independently of each other in two distantly related groups of ancestors. The body parts of organisms that do not have a common evolutionary origin but are similar in function are called **analogous structures.**

Although analogous structures don't shed light on evolutionary relationships, they do provide evidence of evolution. For example, insect and bird wings probably evolved separately when their different ancestors adapted independently to similar ways of life.

Another type of body feature that suggests an evolutionary relationship is a **vestigial** (veh STIH jee ul) **structure**—a body structure in a present-day organism that no longer serves its original purpose, but was probably useful to an ancestor. A structure becomes vestigial when the species no longer needs the feature for its original function, yet it is still inherited as part of the body plan for the species.

Figure 15.7
Insect and bird wings are similar in function but not in structure. Bones are the framework of bird wings, whereas a tough material called chitin composes insect wings.



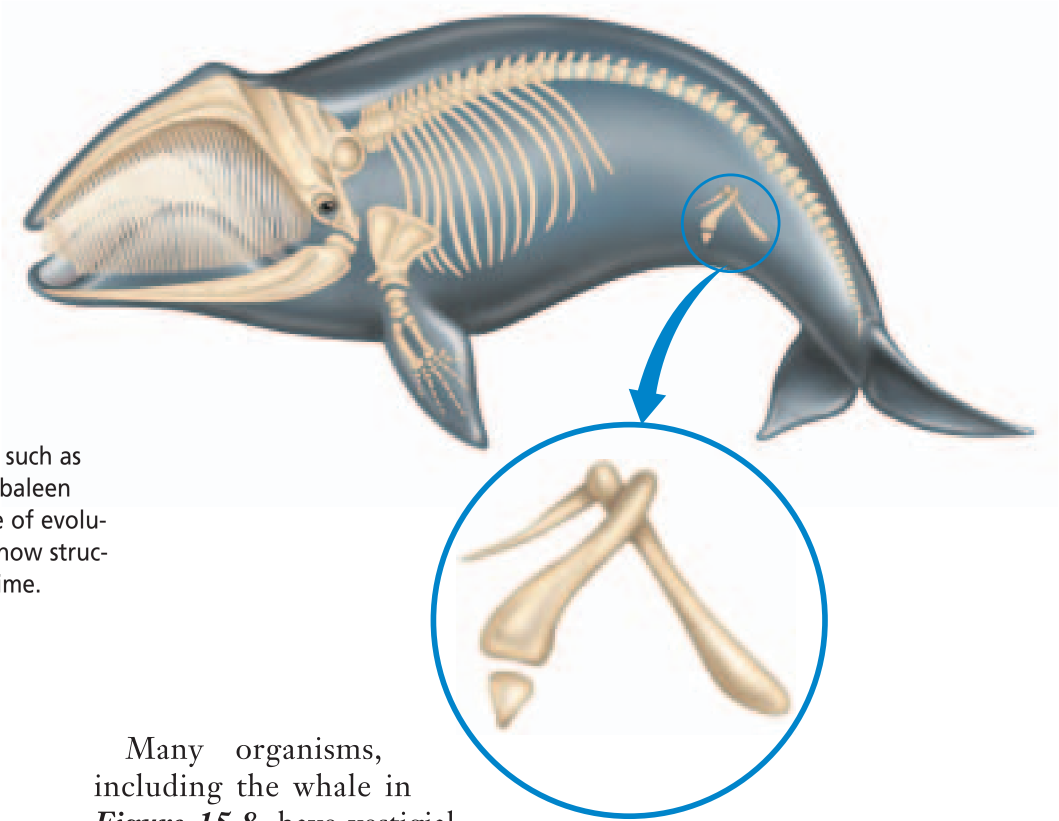


Figure 15.8
Vestigial structures, such as pelvic bones in the baleen whale, are evidence of evolution because they show structural change over time.

Many organisms, including the whale in *Figure 15.8*, have vestigial structures. The eyes of blind mole-rats and cave fish are vestigial structures because they are no longer used for sight. Two flightless birds—an extinct elephant bird and an African ostrich—have extremely reduced forelimbs. Their ancestors probably foraged on land for food and nested on the ground. As a result, over time, the ancestral birds became quite large and unable to fly, features evident in fossils of the elephant bird and present in the African ostrich.

Word Origin

vestigial from the Latin word *vestigium,* meaning "sign"; The forelimbs of ostriches are vestigial structures.

Embryology

It's very easy to see the difference between an adult bird and an adult mammal, but can you distinguish between them by looking at their embryos? An **embryo** is the earliest stage of growth and development of both plants and animals. The embryos of a fish, a reptile, a bird, and a mammal are shown in *Figure 15.9.* At this stage of development, all the embryos have a tail and pharyngeal pouches. In fish, these pouches develop into the supports for the gills, while in mammals, reptiles, and birds, they develop into parts of ears, jaws, and throat. It is the shared features in the young embryos that suggest evolution from a distant, common ancestor.

Biochemistry

Biochemistry also provides strong evidence for evolution. Nearly all

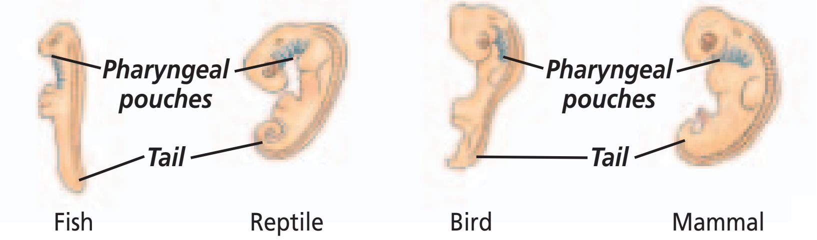


Figure 15.9
Comparing embryos can reveal their evolutionary relationships. **Identify** ***What evidence from the art indicates that these four organisms may share a common ancestor?***

Comparison of Organisms	Percent Substitutions of Amino Acids in Cytochrome c Residues
Two orders of mammals	5 and 10
Birds vs. mammals	8–12
Amphibians vs. birds	14–18
Fish vs. land vertebrates	18–22
Insects vs. vertebrates	27–34
Algae vs. animals	57

Table 15.2 Biochemical Similarities of Organisms

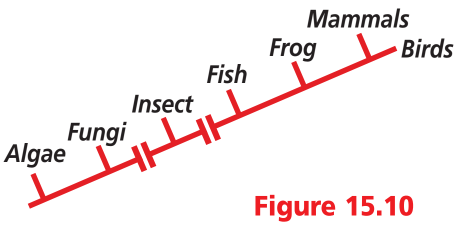


Figure 15.10
This drawing shows the evolutionary relationship of some of the groups in the table.

organisms share DNA, ATP, and many enzymes among their biochemical molecules. One enzyme, cytochrome c, occurs in organisms as diverse as bacteria and bison. Biologists compared the differences that exist among species in the amino acid sequence of cytochrome c. Data from these biochemical studies are shown in ***Table 15.2.*** The data show the number of amino acid substitutions in the amino acid sequences for the different organisms. Organisms that are biochemically similar have fewer differences in their amino acid sequences. Groups that share more similarities are interpreted as being more closely related or as sharing a closer ancestor. The evolutionary relationships of some of the groups in the table are shown in ***Figure 15.10.***

Since Darwin's time, scientists have constructed evolutionary diagrams that show levels of relationships among species. In the 1970s, some biologists began to use RNA and DNA nucleotide sequences to construct evolutionary diagrams. Today, scientists combine data from fossils, comparative anatomy, embryology, and biochemistry in order to interpret the evolutionary relationships among species.

Section Assessment

Understanding Main Ideas

1. Briefly review, analyze, and critique Darwin's ideas about natural selection.
2. Some snakes have vestigial legs. Why is this considered evidence for evolution?
3. Explain how mimicry and camouflage help species survive.
4. How do homologous structures provide evidence for evolution?

Thinking Critically

5. A parasite that lives in red blood cells causes the disease called malaria. In recent years, new strains of the parasite have appeared that are resistant to the drugs used to treat the disease. Explain how this could be an example of natural selection occurring.

Skill Review

6. **Get the Big Picture** Fossils indicate that whales evolved from ancestors that had legs. Using your knowledge of natural selection, sequence the steps that may have occurred during the evolution of whales from their terrestrial, doglike ancestors. For more help, refer to *Get the Big Picture* in the **Skill Handbook.**

Section
15.2

Mechanisms of Evolution

SECTION PREVIEW

Objectives

Summarize the effects of the different types of natural selection on gene pools.

Relate changes in genetic equilibrium to mechanisms of speciation.

Explain the role of natural selection in convergent and divergent evolution.

Review Vocabulary

gene: DNA segment that controls protein production and the cell cycle (p. 211)

New Vocabulary

gene pool
allelic frequency
genetic equilibrium
genetic drift
stabilizing selection
directional selection
disruptive selection
speciation
geographic isolation
reproductive isolation
polyploid
gradualism
punctuated equilibrium
adaptive radiation
divergent evolution
convergent evolution

Interspecies Competition

Using Prior Knowledge You may recognize the birds shown here as meadowlarks. These birds range throughout much of the United States. Meadowlarks look so similar that it's often difficult to tell them apart. Although they are closely related and occupy the same ranges in parts of the central United States, these different meadowlarks do not normally interbreed and are classified as distinct species.

Infer *Using your knowledge of birds and animal behavior, infer what prevents competition between two meadowlark species that occupy the same area.*

Western meadowlark—*Sturnella neglecta*

Eastern meadowlark—*Sturnella magna*

Population Genetics and Evolution

When Charles Darwin developed his theory of natural selection in the 1800s, he did so without knowing about genes. Since Darwin's time, scientists have learned a great deal about genes and modified Darwin's ideas accordingly. At first, genetic information was used to explain the variation among individuals of a population. Then, studies of the complex behavior of genes in populations of plants and animals developed into the field of study called population genetics. The principles of today's modern theory of evolution are rooted in population genetics and other related fields of study and are expressed in genetic terms.

Populations, not individuals, evolve

Can individuals evolve? That is, can an organism respond to natural selection by acquiring or losing characteristics? Recall that genes determine most of an individual's features, such as tooth shape or flower color. If an organism has a feature—called a phenotype in genetic terms—that is poorly adapted to its environment, the organism may be unable to survive and reproduce. However, within its lifetime, it cannot evolve a new phenotype by natural selection in response to its environment.

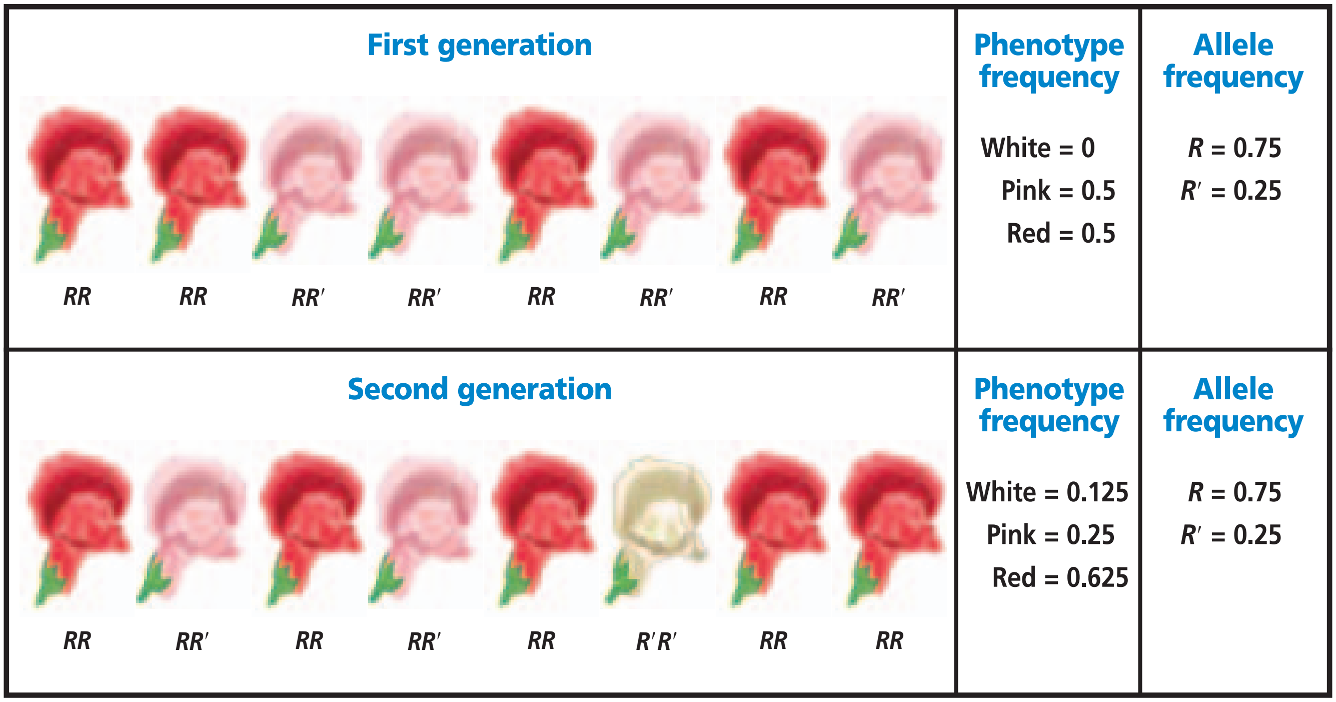


Figure 15.11
Incomplete dominance produces three phenotypes: red flowers *(RR)*, white flowers *(R'R')*, and pink flowers *(RR')*. Although the phenotype frequencies of the generations vary, the allelic frequencies for the *R* and *R'* alleles do not vary.

Rather, natural selection acts on the range of phenotypes in a population. Recall that a population consists of all the members of a species that live in an area. Each member has the genes that characterize the traits of the species, and these genes exist as pairs of alleles. Just as all of the individuals make up the population, all of the genes of the population's individuals make up the population's genes. Evolution occurs as a population's genes and their frequencies change over time.

How can a population's genes change over time? Picture all of the alleles of the population's genes as being together in a large pool called a **gene pool.** The percentage of any specific allele in the gene pool is called the **allelic frequency.** Scientists calculate the allelic frequency of an allele in the same way that a baseball player calculates a batting average. They refer to a population in which the frequency of alleles remains the same over generations as being in **genetic equilibrium.** In the *Connection to Math* at the end of the chapter, you can read about the mathematical description of genetic equilibrium. You can study the effect of natural selection on allelic frequencies in the *BioLab* at the end of the chapter.

Look at the population of snapdragons shown in ***Figure 15.11.*** A pattern of heredity called incomplete dominance, which you learned about earlier, governs flower color in snapdragons. If you know the flower-color genotypes of the snapdragons in a population, you can calculate the allelic frequency for the flower-color alleles. The population of snapdragons is in genetic equilibrium when the frequency of its alleles for flower color is the same in all its generations.

Changes in genetic equilibrium

A population that is in genetic equilibrium is not evolving. Because allelic frequencies remain the same, phenotypes remain the same, too. Any factor that affects the genes in the gene pool can change allelic frequencies, disrupting a population's genetic equilibrium, which results in the process of evolution.

Figure 15.12
Genetic drift can result in an increase of rare alleles in a small population. Notice the child has six fingers on each hand.

You have learned that one mechanism for genetic change is mutation. Environmental factors, such as radiation or chemicals, cause many mutations, but other mutations occur by chance. Of the mutations that affect organisms, many are lethal, and the organisms do not survive. Thus, lethal mutations are quickly eliminated. However, occasionally, a mutation results in a useful variation, and the new gene becomes part of the population's gene pool by the process of natural selection.

Another mechanism that disrupts a population's genetic equilibrium is **genetic drift**—the alteration of allelic frequencies by chance events. Genetic drift can greatly affect small populations that include the descendants of a small number of organisms. This is because the genes of the original ancestors represent only a small fraction of the gene pool of the entire species and are the only genes available to pass on to offspring. The distinctive forms of life that Darwin found in the Galápagos Islands may have resulted from genetic drift.

Genetic drift has been observed in some small human populations that have become isolated due to reasons such as religious practices and belief systems. For example, in Lancaster County, Pennsylvania, there is an Amish population of about 12 000 people who have a unique lifestyle and marry other members of their community. By chance, at least one of the original 30 Amish settlers in this community carried a recessive allele that results in short arms and legs and extra fingers and toes in offspring, ***Figure 15.12.*** Because of the small gene pool, many individuals inherited the recessive allele over time. Today, the frequency of this allele among the Amish is high—1 in 14 rather than 1 in 1000 in the larger population of the United States.

Genetic equilibrium is also disrupted by the movement of individuals in and out of a population. The transport of genes by migrating individuals

Figure 15.13
These swallowtail butterflies live in different areas of North America. Despite their slight variations, they can interbreed to produce fertile offspring.

Papilio ajax ajax

Papilio ajax ampliata

(t)CORBIS/Bettmann-UPI (b)Matt Meadows

is called gene flow. When an individual leaves a population, its genes are lost from the gene pool. When individuals enter a population, their genes are added to the pool.

Mutation, genetic drift, and gene flow may significantly affect the evolution of small and isolated gene pools, such as those on islands. However, their effect is often insignificant in larger, less isolated gene pools. Natural selection is usually the most significant factor that causes changes in established gene pools—small or large.

Natural selection acts on variations

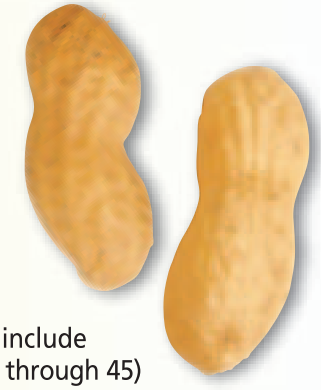
As you've learned, traits have variation, as shown in the butterflies pictured in ***Figure 15.13.*** Try measuring variations in *MiniLab 15.2.*

Recall that some variations increase or decrease an organism's chance of survival in an environment. These variations can be inherited and are controlled by alleles. Thus, the allelic frequencies in a population's gene pool will change over generations due to the natural selection of variations. There are three different types of natural selection that act on variation: stabilizing, directional, and disruptive.

Reading Check **Explain** why populations that are in genetic equilibrium are not evolving.

MiniLab 15.2

Collect Data



Detecting a Variation Pick almost any trait—height, eye color, leaf width, or seed size—and you can observe how the trait varies in a population. Some variations are an advantage to an organism and some are not.

Procedure

1. Copy the data table shown here, but include the lengths in millimeters (numbers 25 through 45) that are missing from this table.

Data Table

Length in mm	20	21	22	23	24	—	46	47	48	49	50
Checks											
My Data—Number of Shells											
Class Data—Number of Shells											

2. Use a millimeter ruler to measure a peanut shell's length. In the Checks row, check the length you measured.
3. Repeat step 2 for 29 more shells.
4. Count the checks under each length and enter the total in the row marked My Data.
5. Use class totals to complete the row marked Class Data.

Analysis

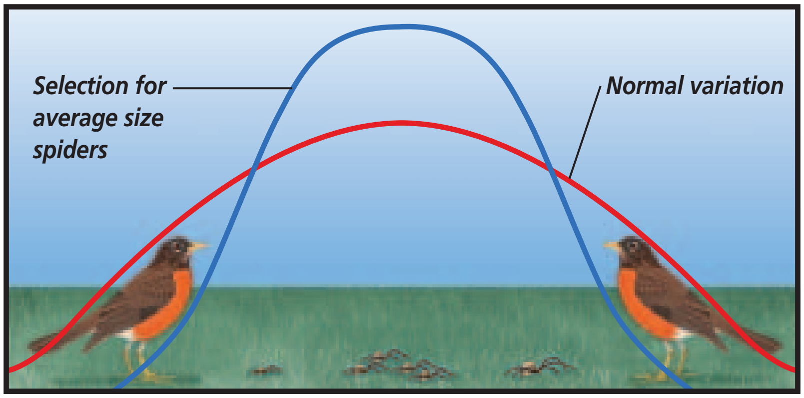
1. **Collect and Organize Data** Was there variation among the lengths of peanut shells? Use class data to support your answer.
2. **Draw Conclusions** If larger peanut shells were a selective advantage, would this be stabilizing, directional, or disruptive selection? Explain your answer.

Papilio ajax curvifascia

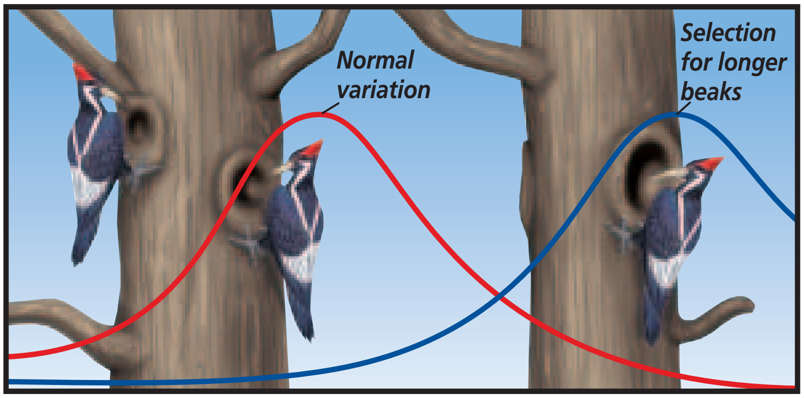
Papilio ajax ehrmann

(t)Elaine Shay (b)Matt Meadows

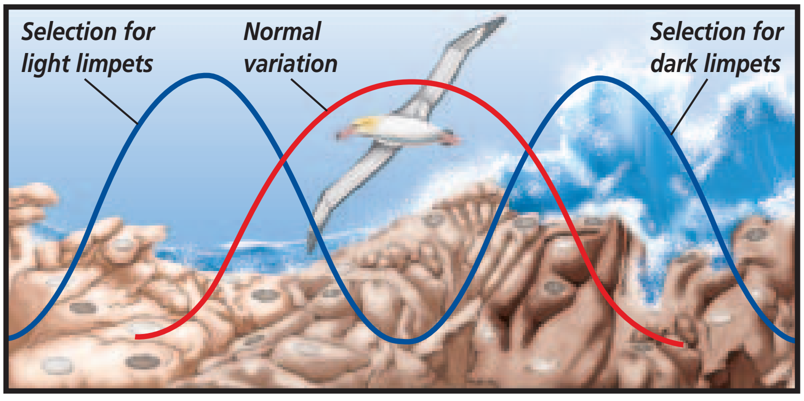
Figure 15.14
Different types of natural selection act over the range of a trait's variation. The red, bell-shaped curve indicates a trait's variation in a population. The blue, bell-shaped curve indicates the effect of a natural selection.



A **Stabilizing selection** favors average individuals. This type of selection reduces variation in a population.



B **Directional selection** favors one of the extreme variations of a trait and can lead to the rapid evolution of a population.



C **Disruptive selection** favors both extreme variations of a trait, resulting eventually in no intermediate forms of the trait and leading to the evolution of two new species.

Stabilizing selection is natural selection that favors average individuals in a population, as shown in ***Figure 15.14.*** Consider a population of spiders in which average size is a survival advantage. Predators in the area might easily see and capture spiders that are larger than average. However, small spiders may find it difficult to find food. Therefore, in this environment, average-sized spiders are more likely to survive—they have a selective advantage, or are "selected for."

Directional selection occurs when natural selection favors one of the extreme variations of a trait. For example, imagine a population of woodpeckers pecking holes in trees to feed on the insects living under the bark. Suppose that a species of insect that lives deep in tree tissues invades the trees in a woodpecker population's territory. Only woodpeckers with long beaks could feed on that insect. Therefore, the long-beaked woodpeckers in the population would have a selective advantage over woodpeckers with very short or average-sized beaks.

Finally, in **disruptive selection,** individuals with either extreme of a trait's variation are selected for. Consider, for example, a population of marine organisms called limpets. The shell color of limpets ranges from white, to tan, to dark brown. As adults, limpets live attached to rocks. On light-colored rocks, white-shelled limpets have an advantage because their bird predators cannot easily see them. On dark-colored rocks, dark-colored limpets have the advantage because they are camouflaged. On the other hand, birds easily see tan-colored limpets on either the light or dark backgrounds. Disruptive selection tends to eliminate the intermediate phenotypes.

Natural selection can significantly alter the genetic equilibrium of a population's gene pool over time. Significant changes in the gene pool could lead to the evolution of a new species over time.

The Evolution of Species

You've just read about how natural processes such as mutation, genetic drift, gene flow, and natural selection can change a population's gene pool over time. But how do the changes in the makeup of a gene pool result in the evolution of new species? Recall that a species is defined as a group of organisms that look alike and can interbreed to produce fertile offspring in nature. The evolution of new species, a process called **speciation** (spee shee AY shun), occurs when members of similar populations no longer interbreed to produce fertile offspring within their natural environment.

Physical barriers can prevent interbreeding

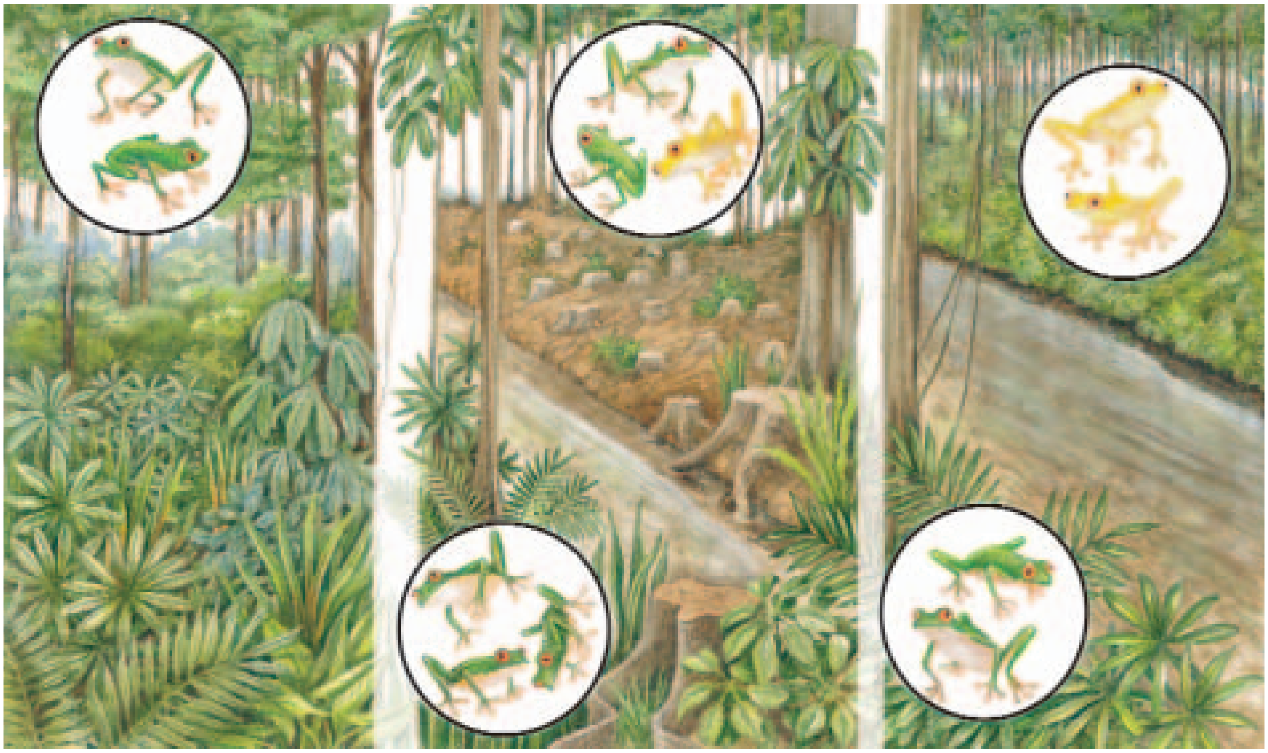
In nature, physical barriers can break large populations into smaller ones. Lava from volcanic eruptions can isolate populations. Sea-level changes along continental shelves can create islands. The water that surrounds an island isolates its populations. **Geographic isolation** occurs whenever a physical barrier divides a population.

A new species can evolve when a population has been geographically isolated. For example, imagine a population of tree frogs living in a rain forest, ***Figure 15.15***. If small populations of tree frogs were geographically isolated, they would no longer be able to interbreed and exchange genes. Over time, each small population might adapt to its environment through natural selection and develop its own gene pool. Eventually, the gene pools of each population might become so different

Word Origin

speciation from the Latin word *species,* meaning "kind"; Speciation is a process that produces two species from one.

Figure 15.15
When geographic isolation divides a population of tree frogs, the individuals no longer mate across populations. **Explain and Illustrate** ***How could geographic isolation result in natural selection and possibly new species?***



A Tree frogs are a single population.

B The formation of a river may divide the frogs into two populations. A new form may appear in one population.

C Over time, the divided populations may become two species that may no longer interbreed, even if reunited.

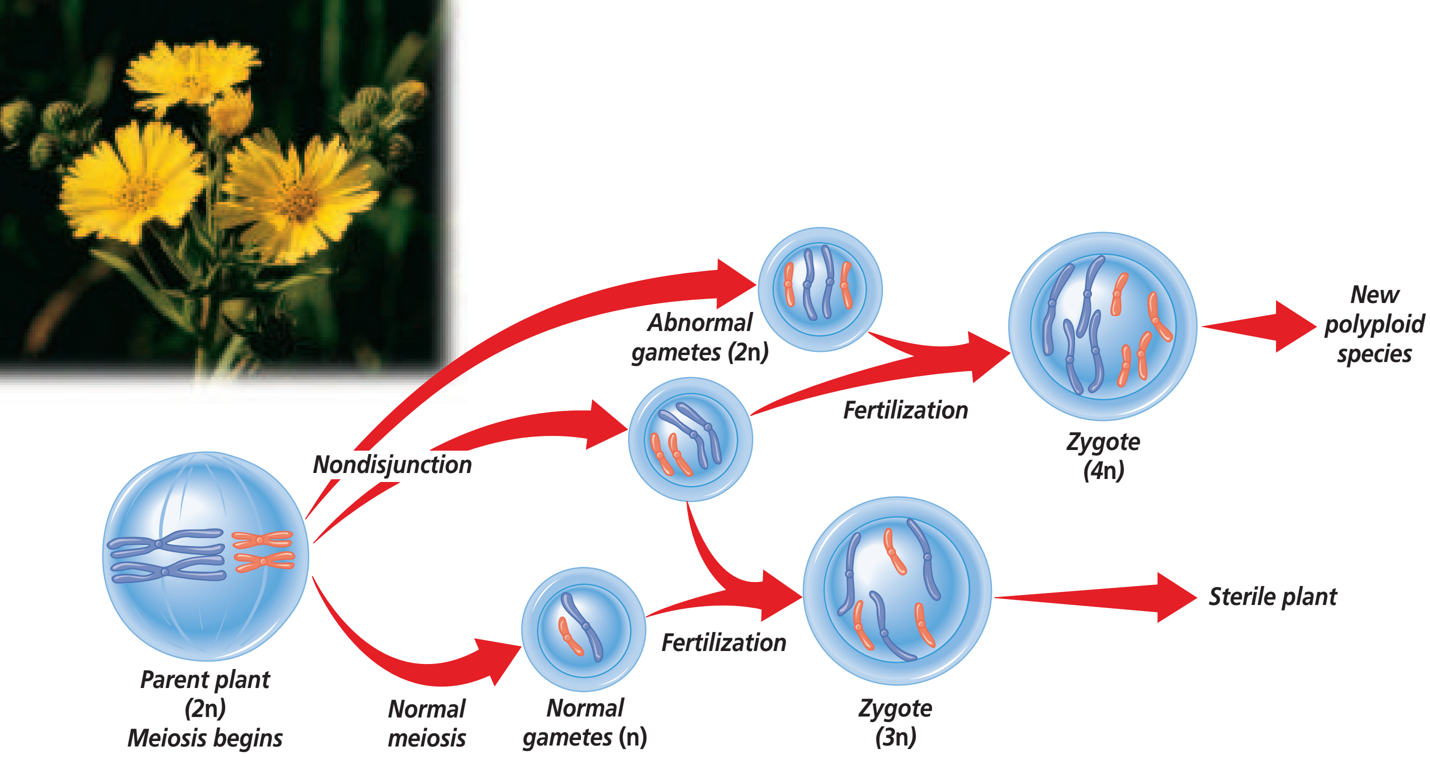


Figure 15.16
Many flowering plants, such as this California tarweed, are polyploids—individuals that result from mistakes made during meiosis.

that they could no longer interbreed with the other populations. In this way, natural selection results in new species.

Reproductive isolation can result in speciation

As populations become increasingly distinct, reproductive isolation can arise. **Reproductive isolation** occurs when formerly interbreeding organisms can no longer mate and produce fertile offspring.

There are different types of reproductive isolation. Two examples are given here. One type occurs when the genetic material of the populations becomes so different that fertilization cannot occur. Some geographically separated populations of salamanders in California have this type of reproductive isolation. Another type of reproductive isolation is behavioral. For example, if one population of tree frogs mates in the fall, and another mates in the summer, these two populations will not mate with each other and are reproductively isolated.

A change in chromosome numbers and speciation

Chromosomes can also play a role in speciation. Many new species of plants and some species of animals have evolved in the same geographic area as a result of polyploidy (PAH lih ploy dee), illustrated in ***Figure 15.16.*** Any individual or species with a multiple of the normal set of chromosomes is known as a **polyploid.**

Mistakes during mitosis or meiosis can result in polyploid individuals. For example, if chromosomes do not separate properly during the first meiotic division, diploid ($2n$) gametes can be produced instead of the normal haploid (n) gametes. Polyploidy may result in immediate reproductive isolation. When a polyploid mates with an individual of the normal species, the resulting zygotes may not develop normally because of the difference in chromosome numbers. In other cases, the zygotes develop into adults that probably cannot reproduce. However, polyploids within a population may interbreed and form a separate species.

Polyploids can arise from within a species or from hybridization between

Word Origin

polyploidy from the Greek word *polys,* meaning "many"; Polyploid plants contain multiple sets of chromosomes.

species. Many flowering plant species and many important crop plants, such as wheat, cotton, and apples, originated by polyploidy.

Speciation rates

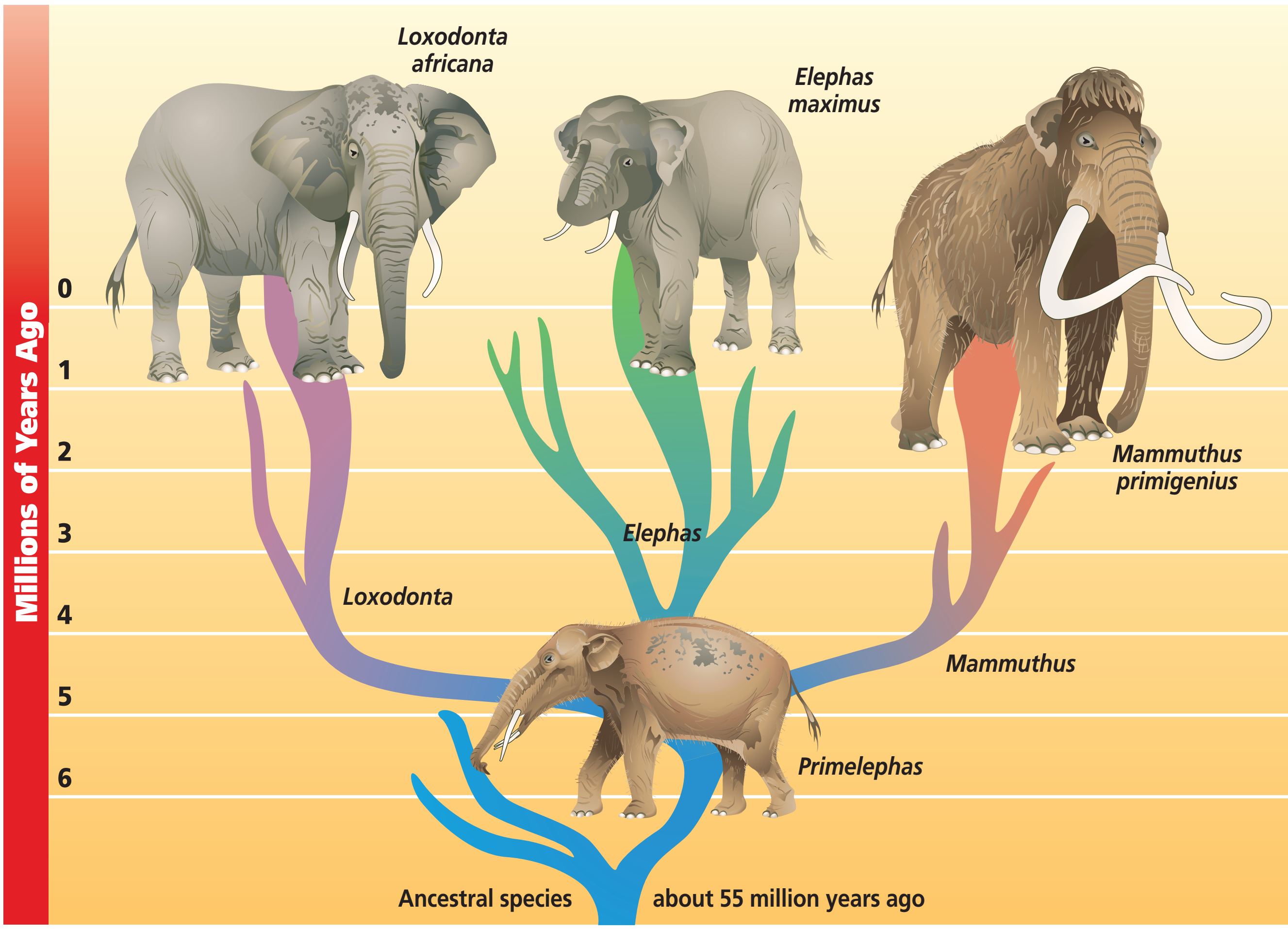
Although polyploid speciation takes only one generation, most other mechanisms of speciation do not occur as quickly. What is the usual rate of speciation?

Scientists once argued that evolution occurs at a slow, steady rate, with small, adaptive changes gradually accumulating over time in populations. **Gradualism** is the idea that species originate through a gradual change of adaptations. Some evidence from the fossil record supports gradualism. For example, fossil evidence shows that sea lilies evolved slowly and steadily over time.

In 1972, Niles Eldredge and Stephen J. Gould proposed a different hypothesis known as **punctuated equilibrium.** This hypothesis argues that speciation occurs relatively quickly, in rapid bursts, with long periods of genetic equilibrium in between. According to this hypothesis, environmental changes, such as higher temperatures or the introduction of a competitive species, lead to rapid changes in a small population's gene pool that is reproductively isolated from the main population. Speciation happens quickly—in about 10 000 years or less. Like gradualism, punctuated equilibrium is supported by fossil evidence as shown in ***Figure 15.17.***

Biologists generally agree that both gradualism and punctuated equilibrium can result in speciation, depending on the circumstances. It shouldn't

Figure 15.17
The fossil record of elephant evolution supports the view of punctuated equilibrium. Several elephant species may have evolved from an ancestral population in a short time.



surprise you to see scientists offer alternative hypotheses to explain observations. The nature of science is such that new evidence or new ideas can modify theories.

Patterns of Evolution

Biologists have observed different patterns of evolution that occur throughout the world in different natural environments. These patterns support the idea that natural selection is an important agent for evolution.

Diversity in new environments

An extraordinary diversity of unique plants and animals live or have lived on the Hawaiian Islands, among them a group of birds called Hawaiian honeycreepers. This group of birds is interesting because, although similar in body size and shape, they differ sharply in color and beak shape. Different species of honeycreepers evolved to occupy their own niches.

Despite their differences, scientists hypothesize that honeycreepers, as shown in ***Figure 15.18,*** evolved from a single ancestral species that lived on the Hawaiian Islands long ago. When an ancestral species evolves into an array of species to fit a number of diverse habitats, the result is called **adaptive radiation.**

Adaptive radiation in both plants and animals has occurred and continues to occur throughout the world and is common on islands. For example, the many species of finches that Darwin observed on the Galápagos Islands are a typical example of adaptive radiation.

Adaptive radiation is a type of **divergent evolution,** the pattern of evolution in which species that once were similar to an ancestral species diverge, or become increasingly

Figure 15.18
Evolutionary biologists have suggested that the ancestors of all Hawaiian Island honeycreepers migrated from North America about 5 million years ago. As this ancestral bird population settled in the diverse Hawaiian niches, adaptive radiation occurred.

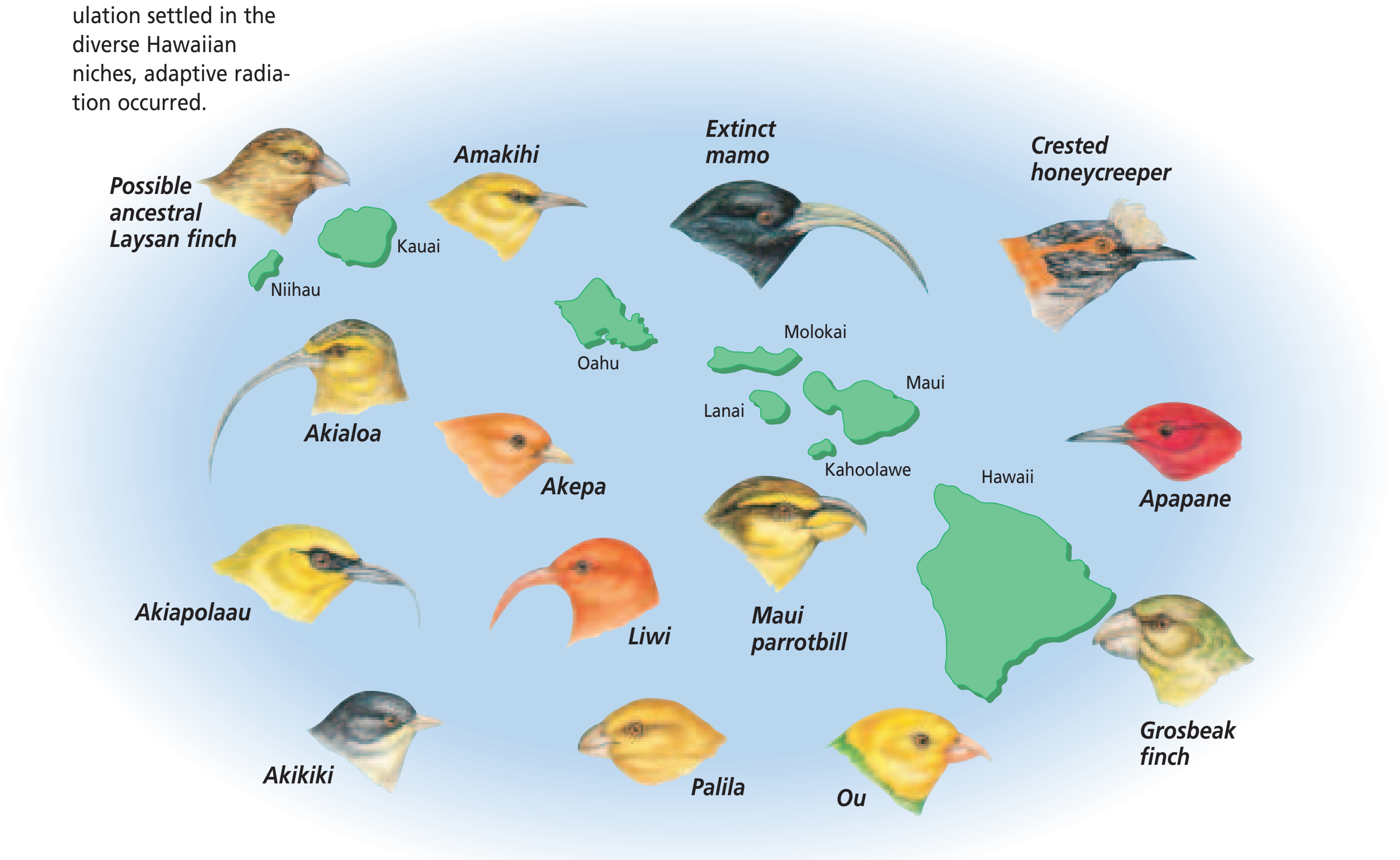
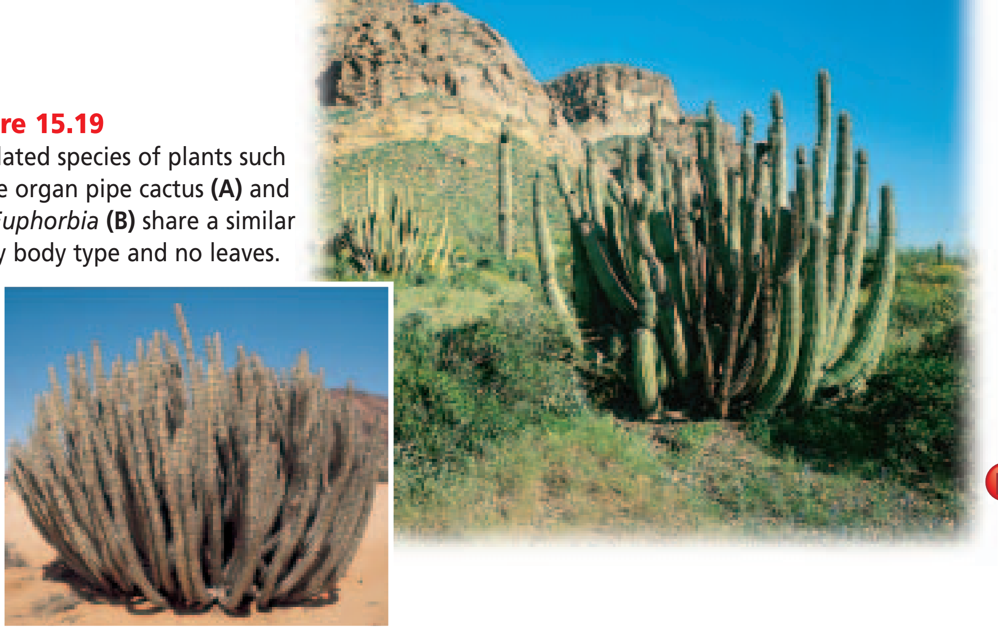


Figure 15.19
Unrelated species of plants such as the organ pipe cactus **(A)** and this *Euphorbia* **(B)** share a similar fleshy body type and no leaves.



distinct. Divergent evolution occurs when populations change as they adapt to different environmental conditions, eventually resulting in new species.

Different species can look alike

A pattern of evolution in which distantly related organisms evolve similar traits is called **convergent evolution.** Convergent evolution occurs when unrelated species occupy similar environments in different parts of the world. Because they share similar environmental pressures, they share similar pressures of natural selection.

For example, in ***Figure 15.19*** you see an organ pipe cactus (family Cactaceae) that grows in the deserts of North and South America and a plant of the family Euphorbiaceae that looks similar and lives in African deserts. Although these plants are unrelated species, their environments are similar. You can see that they both have fleshy bodies and no leaves. That convergent evolution has apparently occurred in unrelated species, is further evidence for natural selection.

✓Reading Check **Compare and contrast** convergent and divergent evolution.

Section Assessment

Understanding Main Ideas

1. Explain and illustrate why the evolution of resistance to antibiotics in bacteria is an example of directional natural selection.
2. How can geographic isolation change a population's gene pool?
3. Why is rapid evolutionary change more likely to occur in small populations?
4. How do gradualism and punctuated equilibrium differ? How are they similar? Include in your answer the patterns of extinction observed in both theories.

Thinking Critically

5. Hummingbird moths are night-flying insects whose behavior and appearance are similar to those of hummingbirds. Explain how these two organisms demonstrate convergent evolution.

Skill Review

6. **Experiment** Biologists discovered two squirrel species living on opposite sides of the Grand Canyon. They hypothesize that the species evolved from a common ancestor. What observations or experiments could provide evidence for this hypothesis? For more help, refer to *Experiment* in the **Skill Handbook.**

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(l)Stephen J. Krasemann/DRK Photo (r)Patti Murray/Earth Scenes

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INTERNET

BioLab

Before You Begin

Evolution can be described as the change in allelic frequencies of a gene pool over time. Natural selection can place pressure on specific phenotypes and cause a change in the frequency of the alleles that produce the phenotypes. In this activity, you will simulate the effects of eagle predation on a population of rabbits, where *GG* represents the homozygous condition for gray fur, *Gg* is the heterozygous condition for gray fur, and *gg* represents the homozygous condition for white fur.

Natural Selection and Allelic Frequency

Preparation

Problem

How does natural selection affect allelic frequency?

Objectives

In this BioLab, you will:

- **Simulate** natural selection by using beans of two different colors.
- **Calculate** allelic frequencies over five generations.
- **Demonstrate** how natural selection can affect allelic frequencies over time.
- **Use the Internet** to collect and compare data from other students.

Materials

colored pencils (2)
graph paper
white navy beans
paper bag
pinto beans

Safety Precautions

CAUTION: ***Clean up spilled beans immediately to prevent anyone from slipping.***

Skill Handbook

If you need help with this lab, refer to the **Skill Handbook.**

Procedure

1. Copy the data table shown on the next page.
2. Place 50 pinto beans and 50 white navy beans into the paper bag.
3. Shake the bag. Remove two beans. These represent one rabbit's genotype. Set the pair aside, and continue to remove 49 more pairs.
4. Arrange the beans on a flat surface in two columns representing the two possible rabbit phenotypes, gray (genotypes *GG* or *Gg*) and white (genotype *gg*).
5. Examine your columns. Remove 25 percent of the gray rabbits and 100 percent of the white rabbits. These numbers represent a random selection pressure on your rabbit population. If the number you calculate is a fraction, remove a whole rabbit to make whole numbers.

Matt Meadows

CONTENTS

6. Count the number of pinto and navy beans remaining. Record this number in your data table.
7. Calculate the allelic frequencies by dividing the number of beans of one type by 100. Record these data.
8. Begin the next generation by placing 100 beans into the bag. The proportions of pinto and navy beans should be the same as the percentages you calculated in step 7.
9. Repeat steps 3 through 8, collecting data for five generations.
10. Go to bdol.glencoe.com/internet_lab to **post your data.**
11. Graph the frequencies of each allele over five generations. Plot the frequency of the allele on the vertical axis and the number of the generation on the horizontal axis. Use a different colored pencil for each allele.
12. **CLEANUP AND DISPOSAL** Return all materials to their proper places for reuse.

Data Table

	Allele *G*			Allele *g*		
Generation	**Number**	**Percentage**	**Frequency**	**Number**	**Percentage**	**Frequency**
Start	50	50	0.50	50	50	0.50
1						
2						
3						
4						
5						

ANALYZE AND CONCLUDE

1. **Analyze Data** Did either allele disappear? Why or why not?
2. **Think Critically** What does your graph show about allelic frequencies and natural selection?
3. **Infer** What would happen to the allelic frequencies if the number of eagles declined?
4. **ERROR ANALYSIS** Explain any differences in allelic frequencies you observed between your data and the data from the Internet. What advantage is there to having a large amount of data? What problems might there be in using data from the Internet?

Share Your Data

Graph Find this BioLab using the link below, and post your data in the data table provided for this activity. Using the additional data from other students, analyze the combined data, and complete your graph.

bdol.glencoe.com/internet_lab

Photodisc

connection to Math

Mathematics and Evolution

In the early 1900s, G. H. Hardy, a British mathematician, and W. Weinberg, a German doctor, independently discovered how the frequency of a trait's alleles in a population could be described mathematically.

Suppose that in a population of pea plants, 36 plants are homozygous dominant for the tall trait *(TT)*, 48 plants are heterozygous tall *(Tt)*, and 16 plants are short plants *(tt)*. In the homozygous tall plants, there are (36) (2), or 72, *T* alleles and in the heterozygous plants there are 48 *T* alleles, for a total of 120 *T* alleles in the population. There are 48 *t* alleles in the heterozygous plants plus (16) (2), or 32, *t* alleles in the short plants, for a total of 80 *t* alleles in the population. The number of *T* and *t* alleles in the population is 200. The frequency of *T* alleles is 120/200 or 0.6, and the frequency of *t* alleles is 80/200, or 0.4.

The Hardy-Weinberg principle The Hardy-Weinberg principle states that the frequency of the alleles for a trait in a stable population will not vary. This statement is expressed as the equation $p + q = 1$, where p is the frequency of one allele for the trait, and q is the frequency of the other allele. The sum of the frequencies of the alleles always includes 100 percent of the alleles, and is therefore stated as 1.

Squaring both sides of the equation produces the equation $p^2 + 2pq + q^2 = 1$. You can use this equation to determine the frequency of genotypes in a population: homozygous dominant individuals (p^2), heterozygous individuals ($2pq$), and recessive individuals (q^2). For example, in the pea plant population described above, the frequency of the genotypes would be

$$(0.6)\,(0.6) + 2(0.6)\,(0.4) + (0.4)\,(0.4) = 1$$

A population of penquins

The frequency of the homozygous tall genotype is 0.36, the heterozygous genotype is 0.48, and the short genotype is 0.16.

In any sexually reproducing, large population, genotype frequencies will remain constant if no mutations occur, random mating occurs, no natural selection occurs, and no genes enter or leave the population.

Implications of the principle The Hardy-Weinberg principle is useful for several reasons. First, it explains that the genotypes in populations tend to remain the same. Second, because a recessive allele may be masked by its dominant allele, the equation is useful for determining the recessive allele's frequency in the population. Finally, the Hardy-Weinberg principle is useful in studying natural populations to determine how much natural selection may be occurring in the population.

Math in Biology

Draw Conclusions The general population of the United States is getting taller. Assuming that height is a genetic trait, does this observation violate the Hardy-Weinberg principle? Explain your answer.

To find out more about the Hardy-Weinberg principle, visit bdol.glencoe.com/math

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Chapter 15 Assessment

Study Guide

Section 15.1

Natural Selection and the Evidence for Evolution

Key Concepts

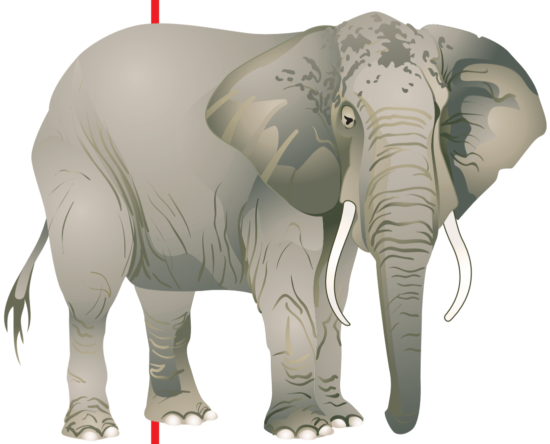
- After many years of experimentation and observation, Charles Darwin proposed the idea that species originated through the process of natural selection.
- Natural selection is a mechanism of change in populations. In a specific environment, individuals with certain variations are likely to survive, reproduce, and pass these variations to future generations.
- Evolution has been observed in the lab and field, but much of the evidence for evolution has come from studies of fossils, anatomy, and biochemistry.

Vocabulary

analogous structure (p. 401)
artificial selection (p. 395)
camouflage (p. 399)
embryo (p. 402)
homologous structure (p. 400)
mimicry (p. 398)
natural selection (p. 395)
vestigial structure (p. 401)

Section 15.2

Mechanisms of Evolution



Key Concepts

- Evolution can occur only when a population's genetic equilibrium changes. Mutation, genetic drift, and gene flow can change a population's genetic equilibrium, especially in a small, isolated population. Natural selection is usually a factor that causes change in established gene pools—both large and small.
- The separation of populations by physical barriers can lead to speciation.
- There are many patterns of evolution in nature. These patterns support the idea that natural selection is an important mechanism of evolution.
- Gradualism is the hypothesis that species originate through a gradual change in adaptations. The alternative hypothesis, punctuated equilibrium, argues that speciation occurs in relatively rapid bursts, followed by long periods of genetic equilibrium. Evidence for both evolutionary rates can be found in the fossil record.

Vocabulary

adaptive radiation (p. 412)
allelic frequency (p. 405)
convergent evolution (p. 413)
directional selection (p. 408)
disruptive selection (p. 408)
divergent evolution (p. 412)
gene pool (p. 405)
genetic drift (p. 406)
genetic equilibrium (p. 405)
geographic isolation (p. 409)
gradualism (p. 411)
polyploid (p. 410)
punctuated equilibrium (p. 411)
reproductive isolation (p. 410)
speciation (p. 409)
stabilizing selection (p. 408)

Foldables

To help you review the evidence for evolution, use the Organizational Study Fold on page 393.

bdol.glencoe.com/vocabulary_puzzlemaker

Chapter 15 Assessment

Vocabulary Review

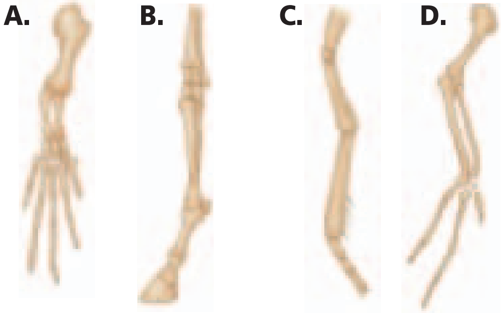
Review the Chapter 15 vocabulary words listed in the Study Guide on page 417. Match the words with the definitions below.

1. adaptation that enables an individual to blend with its surroundings
2. mechanism for change in a population
3. process of evolution of a new species
4. hypothesis that speciation occurs, in rapid bursts

Understanding Key Concepts

5. Which of the structures shown below is NOT homologous with the others?

A. **B.** **C.** **D.**



6. Which type of natural selection favors average individuals in a population?
   - **A.** directional
   - **B.** disruptive
   - **C.** stabilizing
   - **D.** divergent
7. Which of the following pairs of terms is NOT related?
   - **A.** analogous structures—butterfly and bird wings
   - **B.** evolution—natural selection
   - **C.** vestigial structure—eyes in blind fish
   - **D.** adaptive radiation—convergent evolution
8. The fish and whale shown here are not closely related. Their structural similarities appear to be the result of ________.

   - **A.** adaptive radiation
   - **B.** convergent evolution
   - **C.** divergent evolution
   - **D.** punctuated equilibrium
9. Which of the following is a true statement about evolution?
   - **A.** Individuals evolve more slowly than populations.
   - **B.** Individuals evolve; populations don't.
   - **C.** Individuals evolve by changing the gene pool.
   - **D.** Populations evolve; individuals don't.

Constructed Response

10. **Open Ended** How might the bright colors of poisonous species aid in their survival?
11. **Open Ended** Explain the different ways in which a new species can evolve as a result of natural selection. Give examples of species that illustrate and support your conclusions.
12. **Open Ended** Explain why the forelimbs of a cat, a bat, and a whale would be homologous structures.

Thinking Critically

13. **REAL WORLD BIOCHALLENGE** Examples of divergent evolution are especially evident in island archipelagoes. Visit **bdol.glencoe.com** to find out about some examples of divergent evolution. Chose an island group, such as the Galápagos Islands or the Hawaiian Islands. Make a map of the islands and drawings of a group of organisms that shows divergent evolution. Your drawings should show at least three species that are closely related. Explain you findings to the class.
14. **Draw Conclusions** What can be concluded from the observation that many organisms have the same chemical enzymes that work in exactly the same way?
15. **Observe and Infer** Describe adaptive radiation as a form of divergent evolution.

Chapter 15 Assessment

16. Explain In terms of natural selection, why do many municipalities no longer routinely spray insecticides to kill mosquitoes during the summer months?

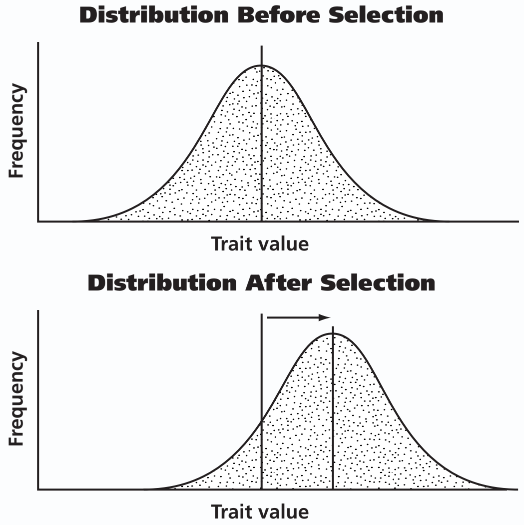
17. Infer The structural characteristics of many species, such as sharks, have changed little over time. What evolutionary factors might be affecting their stability?

Standardized Test Practice

All questions aligned and verified by The Princeton Review

Part 1 Multiple Choice

Use the graph below to answer question 18.

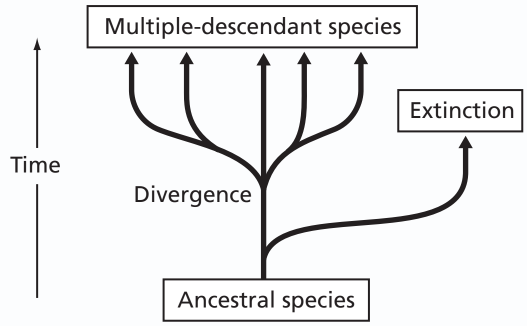


18. Which pattern of natural selection is illustrated above?
A. disruptive selection
B. stabilizing selection
C. directional selection
D. random selection

19. Which of the following provides for instant reproductive isolation?
A. polyploidy
B. most geographic barriers such as rivers and mountain belts
C. climate changes
D. behavior changes in females of the species

20. Which type of adaptation develops quickly in bacteria that are antibiotic resistant?
A. structural adaptation
B. physical adaptation
C. physiological adaptation
D. phenotypic adaptation

Use the illustration below to answer questions 21 and 22.



21. The pattern of evolution shown above indicates ________.
A. convergent evolution
B. divergent evolution
C. stabilizing selection
D. geographic isolation

22. The pattern of evolution shown above most closely resembles that of ________.
A. Hawaiian honeycreepers and Galápagos finches
B. organ pipe cactus and *Euphorbia*
C. bat wings and butterfly wings
D. forelimbs of whales and crocodiles

Part 2 Constructed Response/Grid In

Record your answers on your answer document.

23. Open Ended Give an example of two species that evolved due to geographic isolation.

24. Open Ended How is it possible for both Darwin's idea of gradualism and Eldredge and Gould's idea of punctuated equilibrium to be valid?