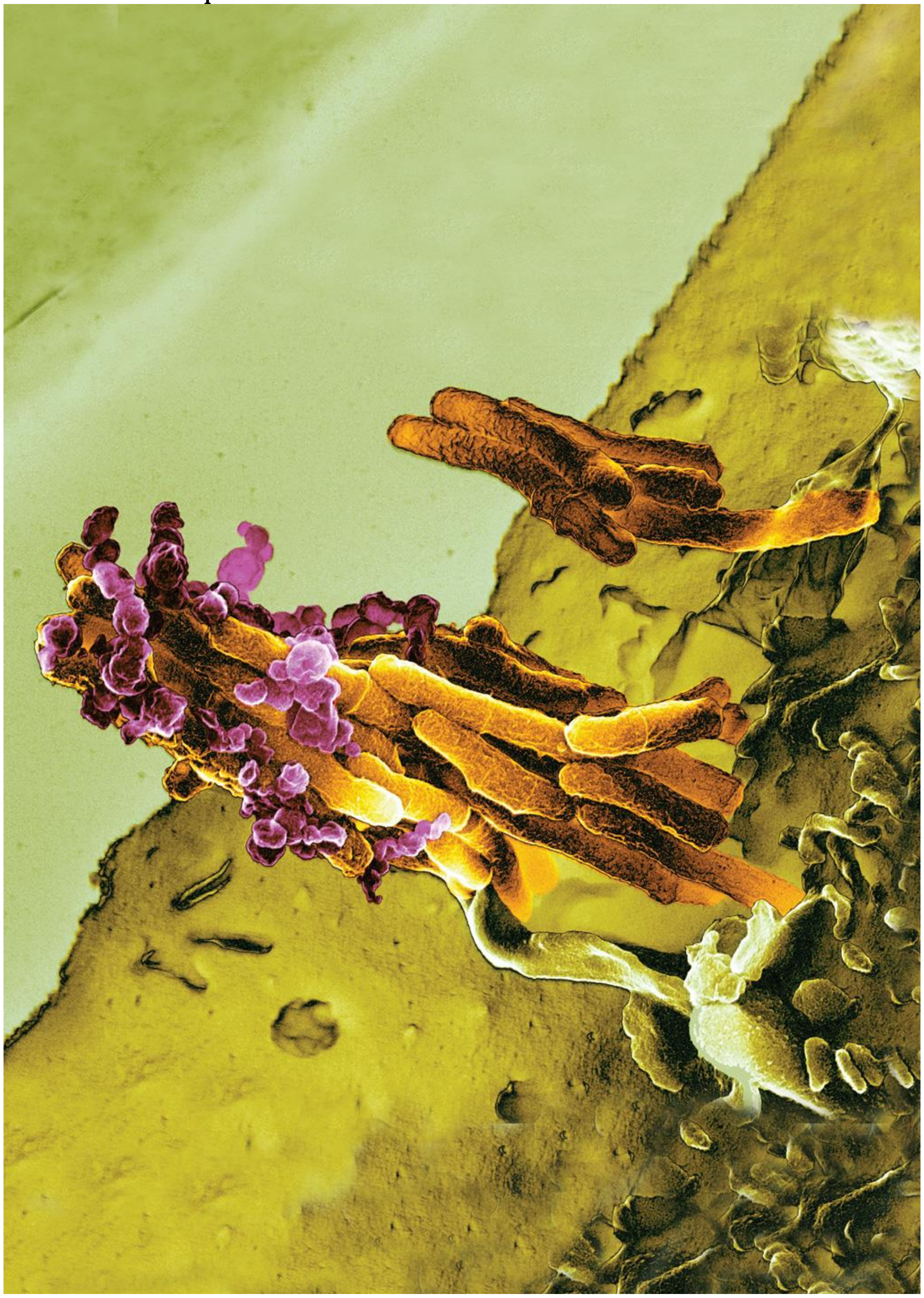
CHAPTER 18

Evolution of Populations



CHAPTER 18

Case Study

This content is unavailable when printing.

How can antibiotics keep up with drug-resistant bacteria?

“When I woke up just after dawn …” biologist Alexander Fleming once said, “ I certainly didn’t plan to revolutionize all medicine by discovering the world’s first antibiotic ...” Yet that’s precisely what Fleming did that day. Returning to his laboratory after a vacation, he noticed that one of his bacterial cultures had been contaminated by a mold. Another scientist might have thought the culture was ruined. But Fleming observed something happening in that dish that got him thinking.

Fleming noticed that bacteria near the mold were dying. “That’s funny,” he remarked. But instead of just tossing the dish away, he did what scientists do. He proposed a hypothesis to explain his observation, and gathered data to test that hypothesis.

Fleming hypothesized that the mold produced something that killed bacteria. He identified the mold as *Penicillium*, grew it in culture, and isolated that “something,” which he called penicillin.

Years later, researchers learned to mass-produce a form of penicillin that could be used to treat bacterial infections. Antibiotics saved thousands of lives during World War II by controlling bacterial infections among wounded soldiers. Soon, many bacterial diseases, such as pneumonia, posed much less of a threat. That’s why antibiotics were called “magic bullets” and “wonder drugs.”

Doctors began prescribing antibiotics widely. Farmers started giving antibiotics to farm animals such as cattle to prevent infections so they could fatten them up quickly. As a result, antibiotics are now a regular part of the environment for bacteria.

But the magic is fading as bacteria evolve. Today, the original form of penicillin is no longer effective. Newer antibiotics are failing too. The Centers for Disease Control (CDC) estimates that 2 million Americans each year become infected with antibiotic-resistant bacteria, and as many as 23,000 die from those infections.

Bacterial populations have always contained a few individuals with mutations that enabled them to destroy, inactivate, or eliminate antibiotics. But those individuals didn't have higher fitness, so those mutant alleles didn't become common.

What's happening? Evolution! In this new environment, individuals with resistance alleles have higher fitness, so the resistance alleles increase in frequency. Also, resistance alleles can be transferred from one bacterial species to another species on their plasmids. Thus, disease-causing bacteria can pick up resistance from harmless strains.

Many bacteria, including those that cause tuberculosis and certain forms of staph infections, are evolving resistance to not just one type of antibiotic, but to almost all medicines known. This prospect terrifies doctors. They fear the loss of one of the vital weapons against bacterial disease and the impact that could have.

Just how do populations evolve over time? How do new traits, such as antibiotic resistance, appear and become more common in a population, while other traits become less common, or disappear? Is it possible for new genes to appear, and if so, how?

Throughout this chapter, look for connections to the CASE STUDY to help you answer these questions.

LESSON 18.1

Standards

This content is unavailable when printing.

Key Questions

Vocabulary

- gene pool
- allele frequency
- single-gene trait
- polygenic trait

Use the section headings to help you understand the information.

Fill in the outline in the **Foundations Reading and Study Guide Workbook** on your digital course.

These ladybugs show some of the genetic variation typically present in their populations. Darwin knew that in order for traits to evolve, they had to be heritable. He also knew that to change over time, those traits had to vary among individuals. But he had no idea how heritable traits pass from one generation to the next, or where that all-important variation came from. Mendel's studies of inheritance were published during Darwin's lifetime, but no one, including Darwin, realized how important that work was. After Mendel's work was rediscovered around 1900, genetics took off like a rocket. One discovery after another tested evolutionary theory. Would new data support or refute Darwin's work?

Genetics Joins Evolutionary Theory

Twentieth-century geneticists discovered that heritable traits are controlled by genes carried on chromosomes. They also learned that changes in genes and chromosomes generate variation. Molecular genetic techniques can now test hypotheses about variation and selection, and help us understand evolutionary change better than Darwin ever could. Studies in population genetics reinforce Darwin's understanding that populations—not individual organisms—evolve over time. All these discoveries give biologists a deeper understanding of how evolution works. To discuss that understanding properly, we need genetically based definitions of some important concepts.

Genes, Populations, and Species

With insights from modern genetics, we can refine our definitions of important evolutionary terms. The genetic definition of a *species* is a population (or group of populations) of physically similar, interbreeding organisms that do not interbreed with other such groups. And in genetic terms, a *population* is a group of individuals of the same species that mate and produce offspring.

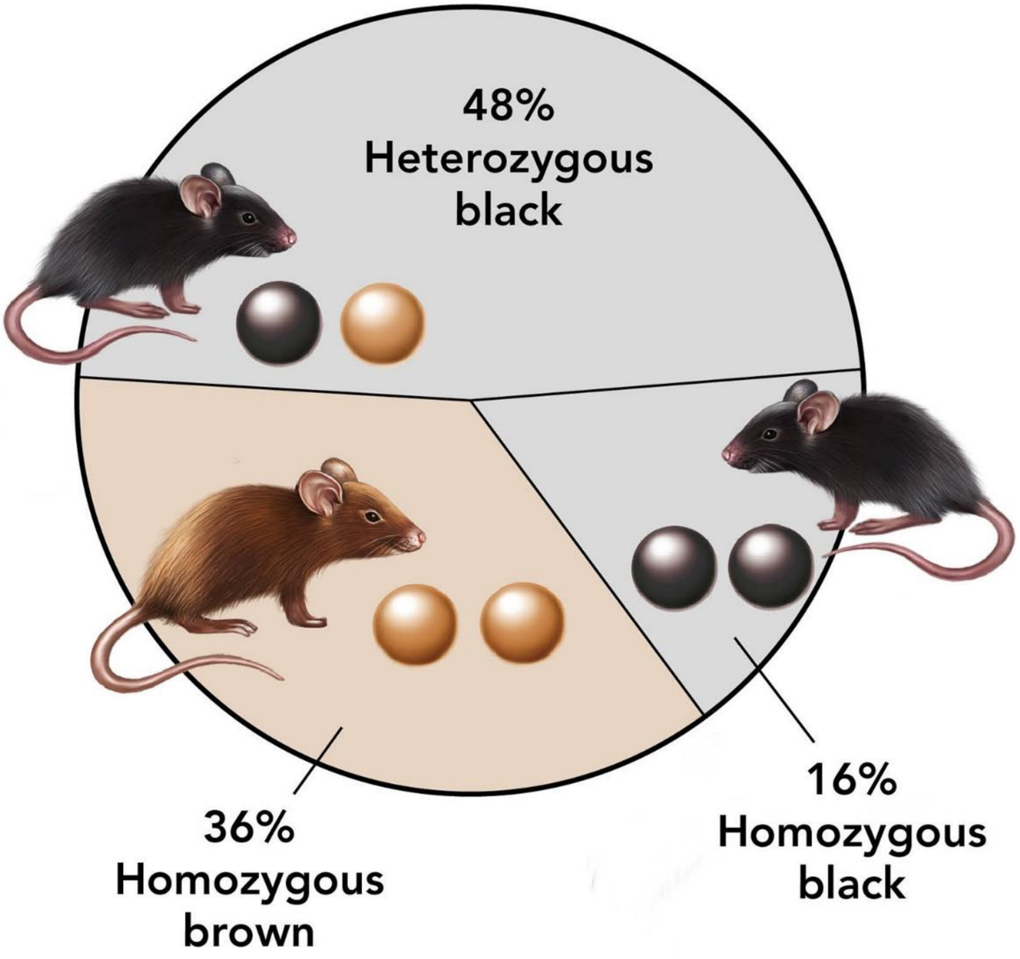
LESSON 18.1

This content is unavailable when printing.

Populations and Gene Pools

Here's where population genetics comes in. Because members of a population interbreed with one another, they share a common group of genes called a gene pool. A **gene pool** consists of all genes present in a population, including all alleles for each gene. Researchers describe gene pools by the numbers of different alleles they contain. The number of times an allele occurs in a gene pool, as a percentage of the total occurrence of all alleles for that gene in that gene pool, is called **allele frequency**. For example, in the mouse population in **Figure 18-1**, the allele frequency of the dominant *B* allele (black fur) is 40 percent (8 out of 20), and the allele frequency of the recessive *b* allele (brown fur) is 60 percent (12 out of 20). Note that allele frequency has nothing to do with whether the allele is dominant or recessive. In this mouse population, the recessive allele occurs more frequently than the dominant allele.

Sample Population



Frequency of Alleles

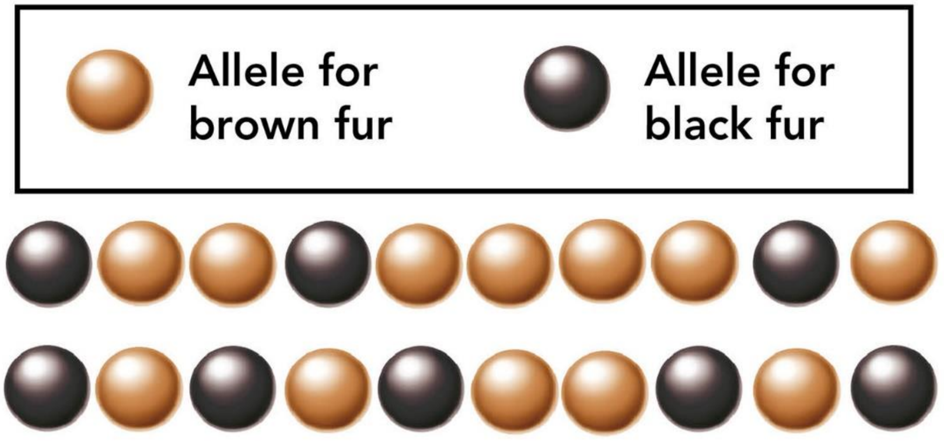


Figure 18-1 Alleles in a Population

When scientists try to determine whether a population is evolving, they study its allele frequencies. This diagram shows allele frequencies for fur color in a mouse population. **Calculate**Here, in a total of 50 alleles, 20 alleles are *B* (black) and 30 are *b* (brown). How many of each allele would be present in a total of 100 alleles?

NOTEBOOK

With this understanding as background, we can now define evolution in genetic terms. ***Evolution involves any change in the frequency of alleles in a population over time.*** If the frequency of the *B* allele in **Figure 18-1**, for example, drops to 30 percent, the population is evolving. Again, it's important to note that populations, not individuals, evolve. Natural selection can act by increasing or decreasing the relative fitness of individual organisms. But those individuals don't evolve during their lifetimes. The results of natural selection show up as changes in allele frequencies in populations over time.

Genotype, Phenotype, and Evolution

It is important to remember that natural selection "selects" an entire organism, either to survive and reproduce or to die without reproducing. Recall that the combination of alleles an individual carries is called its genotype. An individual's genotype, together with environmental conditions during its lifetime, produces its phenotype. A phenotype includes all physical, physiological, and behavioral characteristics of an organism, such as eye color or height. Natural selection acts directly on an organism's phenotype, not its genotype.

In any population, some individuals have phenotypes that are better suited to their environment than the phenotypes of other individuals. Better-suited individuals have higher fitness, produce more offspring, and pass more copies of their genes to the next generation. Thus, inherited variation can lead to natural selection because it can result in differential reproductive success. In genetics terms, evolutionary fitness is an individual's success in passing genes to the next generation. And an evolutionary adaptation is any genetically controlled trait that increases an individual's fitness.

READING CHECK

Cause and Effect Describe how natural selection affects genotypes by acting on phenotypes.

LESSON 18.1

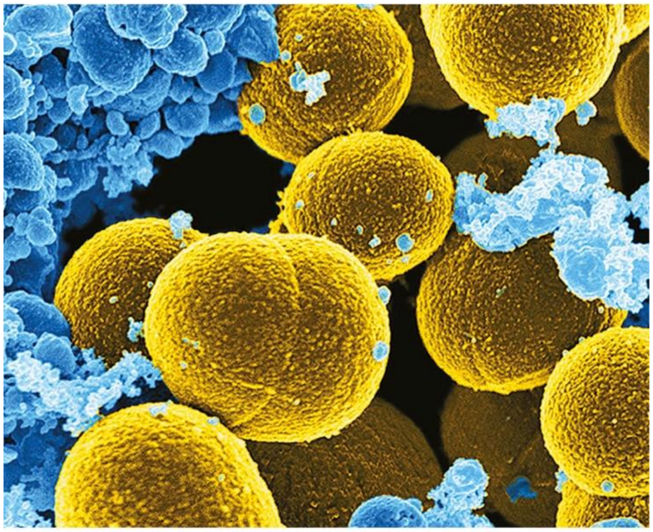
This content is unavailable when printing.

Sources of Genetic Variation

Understanding how genes and chromosomes work enables us to understand how the heritable variation so important in evolutionary change is produced. ***Genetic variation is produced in three main ways: mutation, genetic recombination during sexual reproduction, and lateral gene transfer.*** These mechanisms can all generate diversity within species. Let's see how that works.

Mutations

CASE STUDY Figure 18-2 Genetic Variation



SEM 20,000×

A mutation that stopped the production of pigment resulted in the white deer. Mutations in bacteria can make them resistant to antibiotics. The puggle is a result of breeding of a pug and a beagle.

Much of the time, genes are duplicated and passed from one generation to the next without change. But every so often an error occurs. A mutation is a heritable change in genetic information.

Many early geneticists assumed that mutations were usually "bad," because the kinds of mutations that first came to their attention didn't function as well as "wild-type" alleles. But "mistakes" in DNA replication are actually essential to a species' long-term survival. A population in which DNA replicates flawlessly, producing new generations without any genetic change, would lack much of the variation on which natural selection operates. That kind of population wouldn't evolve. And in a world where environments change, populations that can't evolve don't survive for long.

Some mutations—called neutral mutations—do not affect phenotype, and therefore don't affect fitness. Mutations that do produce changes in phenotype may or may not affect fitness. Some mutations may lower fitness by decreasing an individual's ability to survive and reproduce. Other mutations, such as those that cause genetic diseases, may be lethal. Still other mutations may result in adaptations that improve an individual's ability to survive and reproduce.

Note that mutations, such as those shown in Figure 18-2, matter in evolution only if they can be passed from generation to generation. For that to happen in plants and animals, mutations must occur in gametes (eggs or sperm). A mutation in a skin cell that produces skin cancer, for example, will not be passed to the next generation. Research suggests that each of us carries roughly 300 mutations that make our DNA different from that of our parents.

Genetic Recombination During Sexual Reproduction Mutations aren't the only source of heritable variation. You don't look exactly like your biological parents, even though they gave you all your genes. You probably look even less like any brothers or sisters you may have. Yet no matter how you feel about your relatives, they don't look different from you because either they (or you) are mutants! Most heritable differences within families are caused by genetic recombination. The puggle shown in Figure 18-2 is a result of the combination of genes from its pug and beagle parents. Remember that during meiosis one member of each chromosome pair is shuffled randomly into each egg or sperm with one member of every other chromosome pair. In humans, who have 23 pairs of chromosomes, this can produce 8.4 million gene combinations

LESSON 18.1

This content is unavailable when printing.

As you read this section, write down questions you have about how the three main sources of genetic variation play a role in evolution. Answer your questions as you continue reading the chapter.

Crossing-over is another mechanism that can produce genetic recombination. Recall that during meiosis, paired chromosomes often swap lengths of DNA at random. This crossing-over further increases the number of new genotypes created in each generation. You can now understand why, in species that reproduce sexually, no two siblings (except identical twins) look exactly alike. With all that recombination, you can end up with your mother's eyes, your father's nose, and hair that combines qualities from both parents.

Lateral Gene Transfer

Most of the time, genes are passed only from parents to offspring during reproduction. Sometimes, however, genes pass from one individual to another individual that is not its offspring. This passing of genes produces a kind of gene flow called *lateral gene transfer*. Lateral gene transfer can occur between individuals of the same species or individuals of different species.

Gene flow can increase genetic variation, and therefore increase diversity, in any species that picks up "new" genes. Many bacteria, for example, swap genes on plasmids. This kind of lateral gene transfer is important in the evolution of antibiotic resistance. Lateral gene transfer among single-celled organisms has been common, and important, in generating diversity among species during the history of life.

READING CHECK

Describe Explain how different sources of genetic variation contribute to the total diversity of individuals in a population.

NOTEBOOK

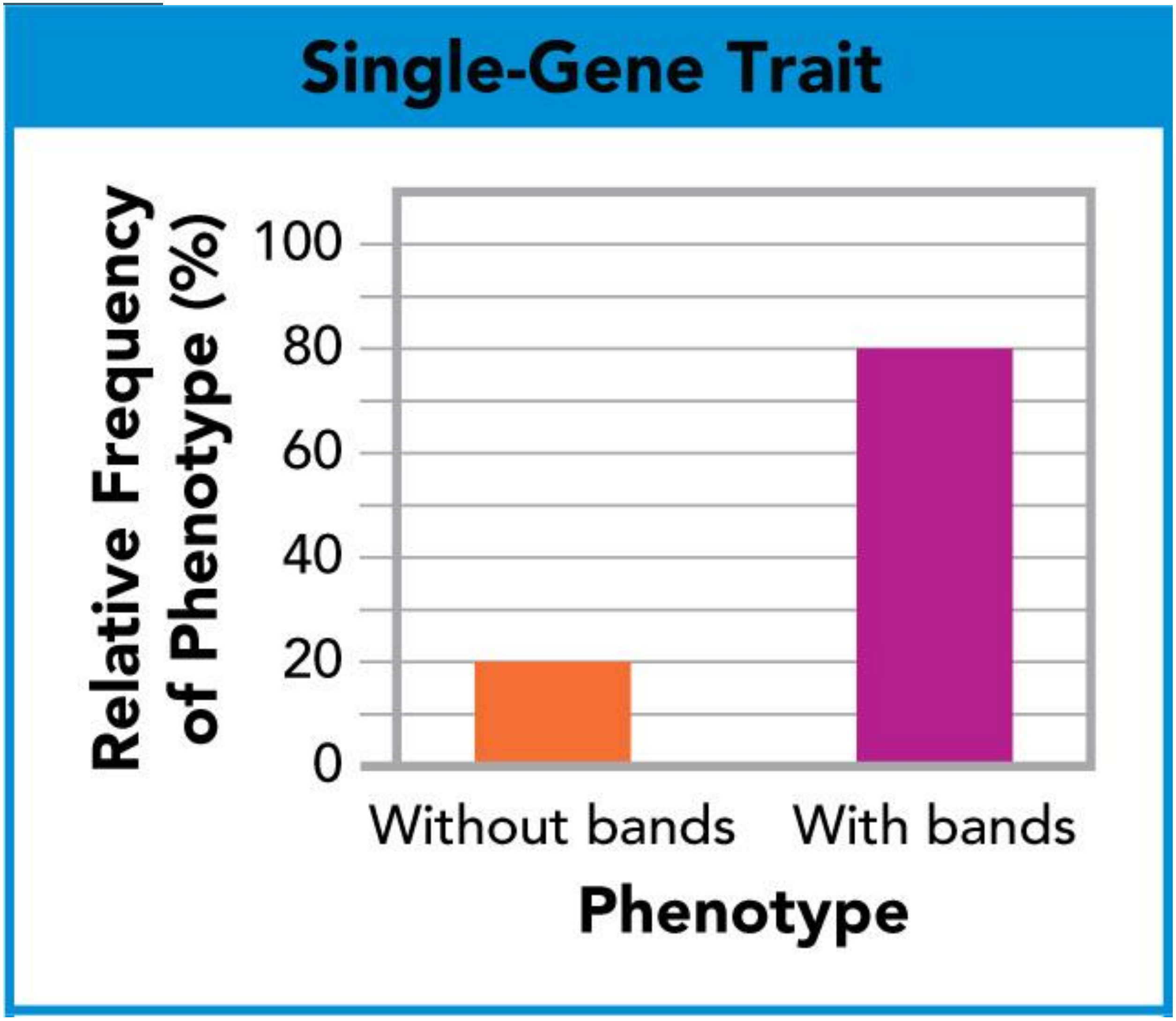


Figure 18-3 Two Phenotypes

In this species of snail, a single gene with two alleles controls whether or not a snail's shell has bands. The graph shows the percentage, in one population, of snails with bands, and snails without bands.

Image long description

without bands	20 percent
with bands	80 percent

Single Gene Trait

Single-Gene and Polygenic Traits

Genes relate to phenotypes in different ways. In some cases, a single gene produces a simple trait. Mendel was very lucky that several of the traits he studied in pea plants were controlled by a single gene. Other times, several genes interact to control a more complex trait. ***The number of phenotypes produced for a trait depends on how many genes control the trait.***

Single-Gene Traits

Traits controlled by a single gene may have only two or three distinct phenotypes, depending on the number of alleles involved. In the snail species shown in **Figure 18-3**, some snails have dark bands on their shells, and other snails don’t. Shell banding is controlled by a single gene that has two alleles, and is therefore a **single-gene trait**—a trait controlled by only one gene. The allele for no bands is dominant over the allele for dark bands. All genotypes for this trait have one of two phenotypes: bands or no bands.

To explore this topic further, launch this interactivity.

This content is unavailable when printing.

LESSON 18.1

This content is unavailable when printing.

The bar graph in **Figure 18-3** shows the relative frequency of phenotypes for this trait in one snail population. This graph shows that the presence of dark bands may be more common in a population than the absence of bands. This is true even though the allele for shells without bands is the dominant form. In populations, phenotypic ratios are determined by the frequency of alleles in the population as well as by whether the alleles are dominant or recessive.

Polygenic Traits

Many traits are controlled by two or more genes and are called **polygenic traits**. Each gene of a polygenic trait often has two or more alleles. As a result, a single polygenic trait often has many possible genotypes and an even greater variety of phenotypes. Often those phenotypes are not clearly distinct from one another.

Height in humans is one example of a polygenic trait. Height varies from very short to very tall and everywhere in between. You can sample phenotypic variation in this trait by measuring the height of all the students in your class. You can then calculate average height for this group. Many students will be just a little taller or shorter than average. Some, however, will be very tall or very short. If you graph the number of individuals of each height, you may get a graph similar to the one in **Figure 18-4**. The symmetrical bell-like shape of this curve is typical of polygenic traits. A bell-shaped curve is also called a normal distribution.

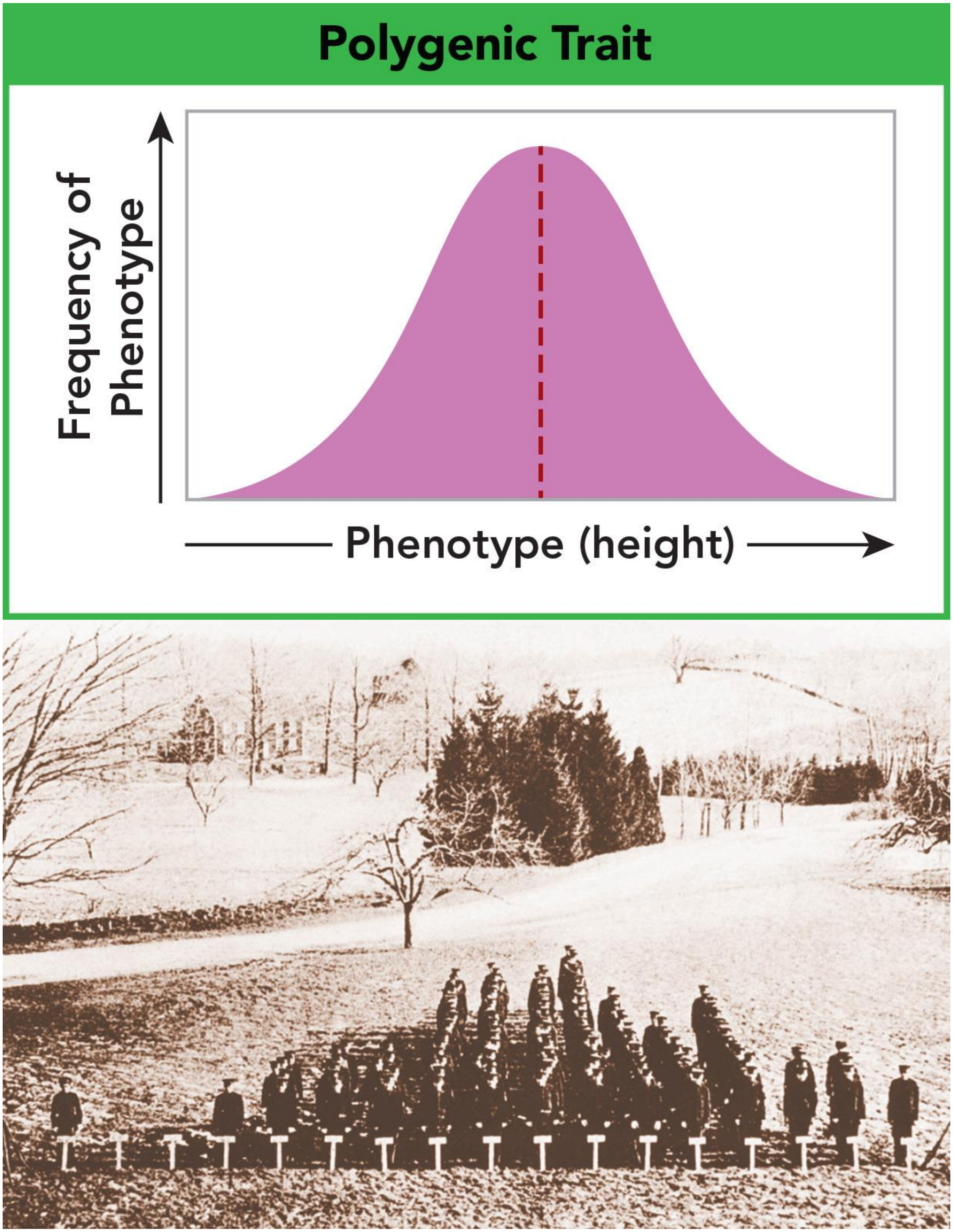


Figure 18-4 A Range of Phenotypes

The graph shows the distribution of phenotypes that would be expected for a trait if many genes contributed to the trait. The photograph shows the actual distribution of heights in a group of young men.

Image long description

Phenotype (height) (horizontal axis) is graphed against frequency of phenotype (vertical axis). The curve is symmetrical and bell-shaped, with the highest frequency in the center. In the photo, the men are lined up in columns by height from left to right, shortest to tallest, with the men of height closest to average clustered around the middle, replicating the bell-shaped curve of the graph.

Lesson Review

Standards

-
-
-

This content is unavailable when printing.

KEY QUESTIONS

1. In genetic terms, what indicates that evolution is occurring in a population?

NOTEBOOK

2. How do mutation, genetic recombination during sexual reproduction, and lateral gene transfer produce genetic variation?

NOTEBOOK

3. What is the difference between a single-gene trait and a polygenic trait?

NOTEBOOK

CRITICAL THINKING

4. **Construct an Explanation** A bright orange color begins to appear in a population of butterflies. How could evolutionary fitness help explain this change?

NOTEBOOK

5. **Develop Models** In a model of genetic inheritance, how do mutations help explain genetic variability?

NOTEBOOK

6. CASE STUDY How does lateral gene transfer help explain the evolution of antibiotic resistance in bacteria?

LESSON 18.2

Standards

This content is unavailable when printing.

Key Questions

Vocabulary

- directional selection
- stabilizing selection
- disruptive selection
- genetic drift
- bottleneck effect
- founder effect
- genetic equilibrium
- Hardy-Weinberg principle
- sexual selection
- gene flow

Focusing on the similarities and differences of each subject in the lesson, fill in the chart in the **Foundations Reading and Study Guide Workbook** on your digital course to differentiate the concepts for each section.

Spraying pesticide on a field of corn

Farmers have battled crop-eating insects since the dawn of agriculture. Many now use chemicals called insecticides to kill pests. At first, the early insecticides, like DDT, killed most insects. But after a few years, the poisons stopped working. These days, scientists develop new insecticides, but insects become resistant to those new weapons too. Doctors face a similar challenge. Bacteria once controlled by antibiotics are becoming resistant to almost every antibiotic known. This is often called an "arms race," because as soon as farmers and doctors develop new "weapons," the organisms they are fighting develop ways to resist their effects. This arms race is a result of evolution in response to natural selection.

How Natural Selection Works

In evolutionary terms, when insecticides or antibiotics are introduced, those compounds become part of the environment. They dramatically reduce the fitness of any individuals susceptible to their effects. But almost always, just by chance, some individuals in the pest population carry one or more genetic variations that enable them to resist the pesticide. Similarly, a few bacteria, also by chance, carry genetic variation that lets them resist antibiotics. Both of these kinds of resistance are adaptations that enable individuals to survive and reproduce.

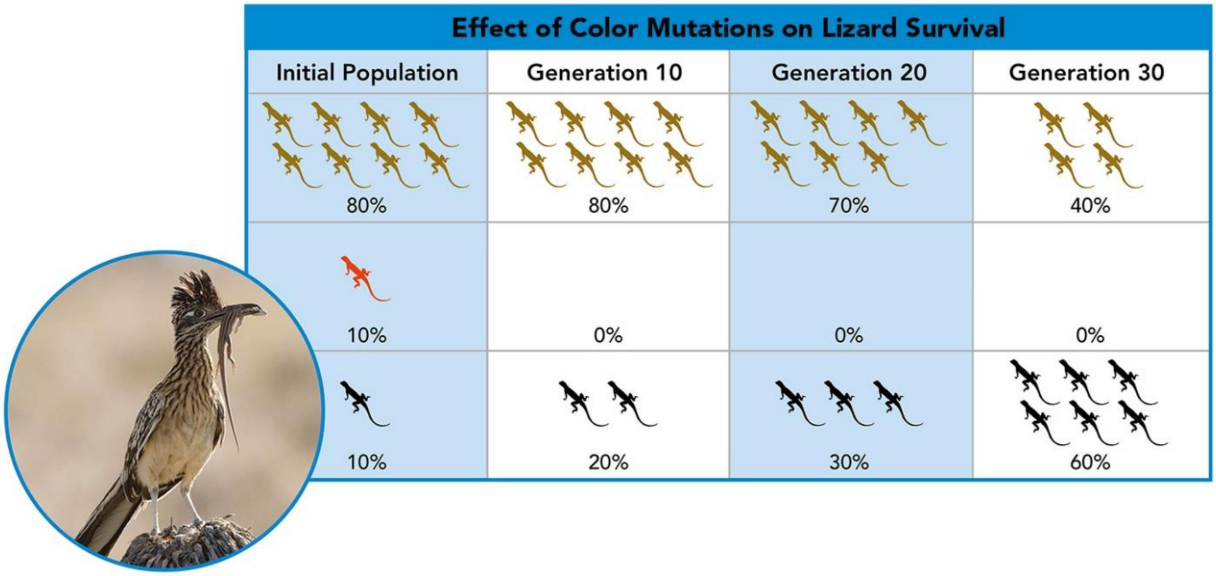
So, how does this happen? The presence of the pesticide or antibiotic increases the relative fitness of the few individuals that carry the resistance adaptation. The resistant individuals survive and thrive, because in dramatically reduced populations, there is less competition for resources. Resistant insects and bacteria reproduce, passing resistance alleles to their offspring. Nonresistant individuals die without reproducing. Over time, the frequency of resistance alleles increases in the population. This differential survival and reproduction of individuals with beneficial characteristics is called natural selection.

LESSON 18.2

This content is unavailable when printing.

Natural Selection on Single-Gene Traits

When natural selection produces differential reproductive success, the effects on phenotype can look different for single-gene and polygenic traits. ***Natural selection on single-gene traits can produce changes in allele frequencies that may be reflected by simple changes in phenotype frequencies.*** Imagine, for example, that a population of brown lizards undergoes mutations in a gene that determines body color. The mutations produce red and black forms, as shown in **Figure 18-5**. What happens to allele and phenotype frequencies?



CASE STUDY Figure 18-5 Selection on a Single-Gene Trait

Natural selection on a single-gene trait can lead to changes in allele frequencies and, thus, to evolution. This type of evolution can occur in bacteria as well. **Apply Concepts**What kind of mutation in disease-causing bacteria would lead to a change in allele and phenotype frequencies?

NOTEBOOK

Image long description

Green	80 percent	80 percent	70 percent	40 percent
Red	10 percent	0 percent	0 percent	0 percent
Black	10 percent	20 percent	30 percent	60 percent

Effect of Color Mutation on Lizard Survival

If red lizards are more visible to predators, they might be less likely to survive and reproduce, and the allele for red coloring might not become common. Black coloration might enable individuals to absorb more sunlight and warm up faster. If high body temperature allows individuals to move faster when feeding and avoid predators, black coloration might act as an adaptation that increases fitness. Then the allele for black coloration and the black phenotype will both increase in frequency. If black coloration has no effect on fitness, the phenotype produced by the mutant allele will not act as an adaptation. The allele will not be under pressure from natural selection.

Natural Selection on Polygenic Traits

When a trait is controlled by more than one gene, both the trait and the effects of natural selection on the trait are more complex. Polygenic traits often display a range of phenotypes that form a bell curve. The fitness of individuals may vary from one end of such a curve to the other, and natural selection can act in one of three ways. ***Natural selection on polygenic traits can affect the relative fitness of phenotypes in three types of selection: directional selection, stabilizing selection, or disruptive selection.*** These three types of selection are shown in **Figure 18-6**.

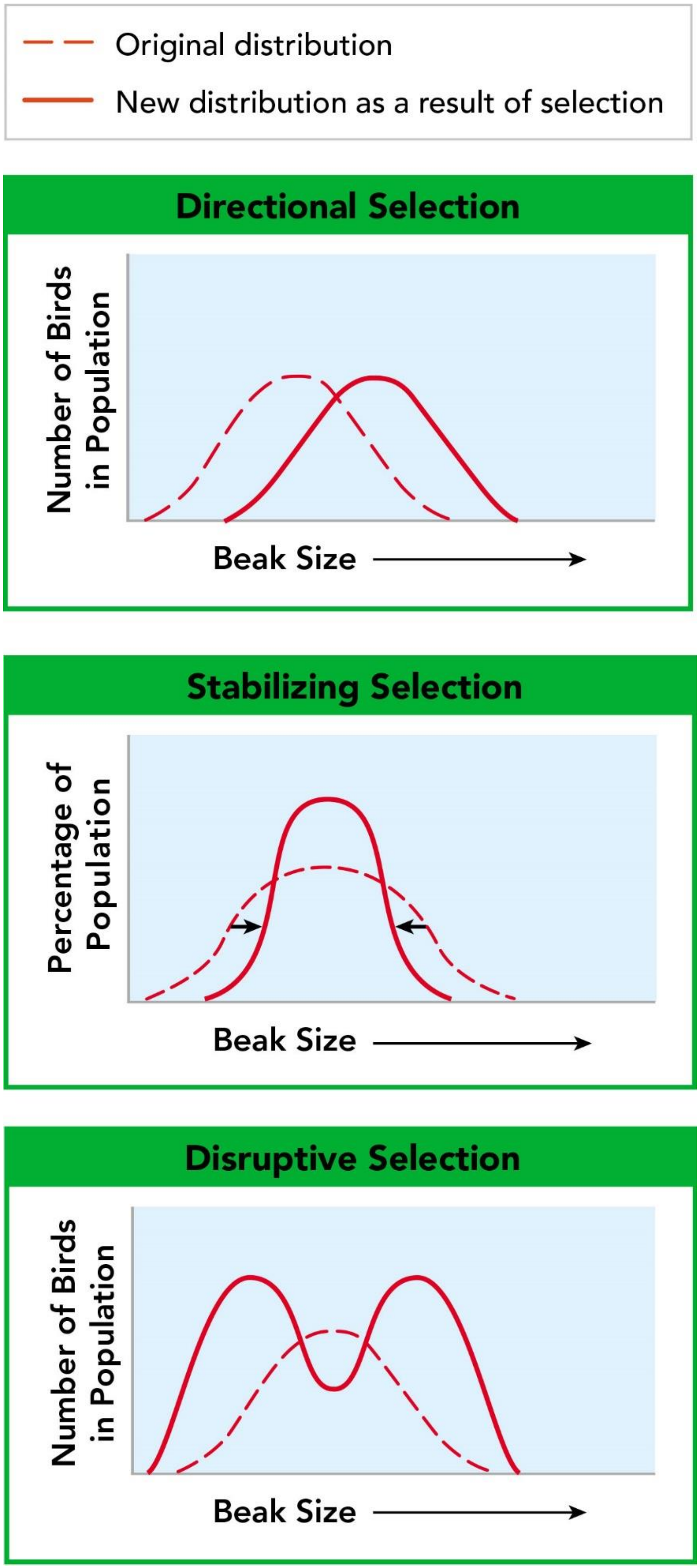

Original distribution
New distribution as a result of selection
Directional Selection
Number of Birds in Population
Beak Size
Stabilizing Selection
Percentage of Population
Beak Size
Disruptive Selection
Number of Birds in Population
Beak Size

Figure 18-6 Selection on Polygenic Traits

Natural selection on polygenic traits has one of three patterns: directional selection, stabilizing selection, or disruptive selection. These graphs describe the evolution of beak size in birds.

Image long description

Each graph shows the number of birds in a population versus beak size. There are 2 curves on each graph, the original distribution and the new distribution after selection.

Direction selection	Both bell curves are the same size and shape. The original curve peaks at a smaller beak size than the new curve.
Stabilizing selection	The original bell curve is flatter and wider than the new bell curve and has a lower peak. Both curves peak at the same beak size.
Disruptive selection	The original bell curve has one peak. The new curve is wider and has 2 peaks - one at smaller beak size and one at a larger beak sizes than the original curve. The new curve also has higher peaks than the original. The trough between the two peaks is lower than the height of the original peak.

LESSON 18.2

This content is unavailable when printing.

Directional Selection

When individuals at one end of the curve have higher fitness than individuals elsewhere in the curve, **directional selection** occurs. The range of phenotypes shifts because individuals with adaptations that result in higher fitness experience higher reproductive success.

Think back to the experiments on the seed-eating Galápagos finches. Birds with big, thick beaks can feed more easily on large, hard, thick-shelled seeds than birds with smaller beaks. When the supply of small- and medium-sized seeds runs low, only larger seeds are left. Under these conditions, big-beaked birds can feed more easily than small-beaked birds. The big-beaked adaptation produces higher fitness, and greater reproductive success. Over time, the average beak size of this population will increase.

Stabilizing Selection

If individuals near the center of the curve have higher fitness than individuals at either end, **stabilizing selection** takes place. The center of the curve remains at its current position, but the curve overall becomes more narrow.

Suppose that, on some islands, supplies of both big and small seeds varied between wet and dry seasons, but sizes of available seeds stayed fairly constant. Individuals with either very large or very small beaks might be outcompeted by birds that can eat both kinds of seeds. Over time, a greater proportion of the population would have a beak size in between the two extremes.

Disruptive Selection

When phenotypes at both the upper and lower ends of the curve have higher fitness than individuals near the middle, **disruptive selection** can occur. Disruptive selection lowers the fitness of intermediate phenotypes. If the pressure of natural selection is strong and lasts long enough, the single curve can split. Two distinct phenotypes are created, increasing diversity within species.

Suppose a bird population lived in an area where medium-sized seeds became less common than large and small seeds. Birds with unusually small or unusually large beaks would both have higher fitness. As shown in the graph, the population might split into two groups: one with smaller beaks and one with larger beaks.

READING CHECK

Compare and Contrast How is the action of natural selection similar for single-gene and polygenic traits? How is it different?

LESSON 18.2

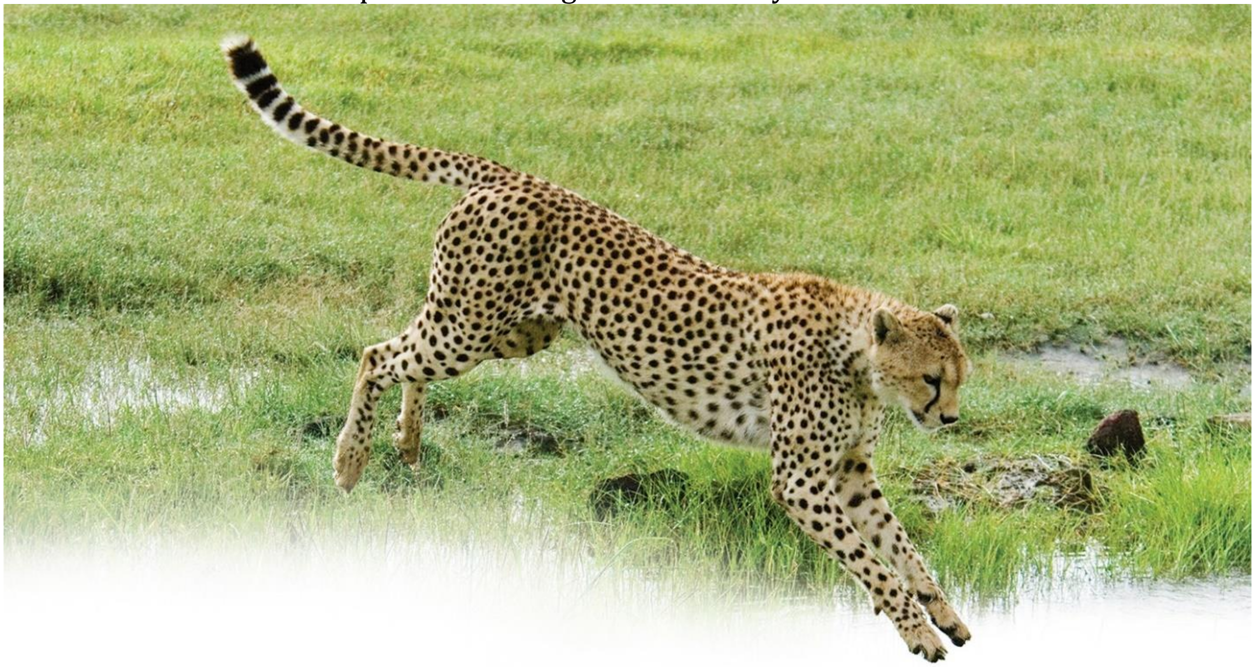
This content is unavailable when printing.

Genetic Drift

Natural selection is not the only evolutionary mechanism that can change allele frequencies. ***In small populations, individuals that carry a particular allele may leave more descendants than other individuals, just by chance. Over time, a series of chance occurrences can cause an allele to become more or less common in a population.*** This kind of random change in allele frequency is called **genetic drift**.

Genetic Bottlenecks

Sometimes a natural disaster, such as a storm or flood, kills many individuals in a population. The gene pool of the surviving population may have allele frequencies that differ from those of the original gene pool just by chance. The allele frequencies of the population may thus be different from the original population. This kind of **bottleneck effect** is a change in allele frequency following a dramatic reduction in the size of a population. A severe population bottleneck can sharply reduce a population's genetic diversity, and thus decrease diversity within the species. The cheetah shown in **Figure 18-7** is often used as an example of reduced genetic diversity.



LESSON 18.2

Standards

-

This content is unavailable when printing.

GUIDED INQUIRY

Download the worksheet to complete the activity.

This content is unavailable when printing.

Modeling Genetic Drift

1. Choose 10 candies at random from a bag of colored candies. The 10 candies represent a small population of a species.

2. Mix up the candies and then arrange them in a single row. Record the number of candies of each color.

3. Model the growth of the population. For each of the 5 candies on the left side of the row, add another candy of the same color.

4. Repeat steps 2 and 3 two more times.

5. Now remove 20 candies at random, leaving only 5 candies. Then again repeat steps 2 and 3 two more times.

Analyze and Interpret Data

1. **Reason Quantitatively** How did the distribution of colors change during the procedure?
2. **Use Models** How does the model represent the evolution and change in allele frequency of the population?
3. **Evaluate Models** What evolutionary mechanism is shown by step 5 of the model? Describe this mechanism.

LESSON 18.2

This content is unavailable when printing.

The Founder Effect

Genetic drift may also occur when a few individuals colonize a new habitat. These founding individuals may carry alleles that differ in relative frequencies from those of the main population, just by chance. The new gene pool therefore starts out with allele frequencies that differ from those of the parent gene pool, as shown in **Figure 18-8**. This situation, in which allele frequencies change as a result of the migration of a small subgroup of a population, is known as the **founder effect**.

To explore this topic further, launch this interactivity.

This content is unavailable when printing.

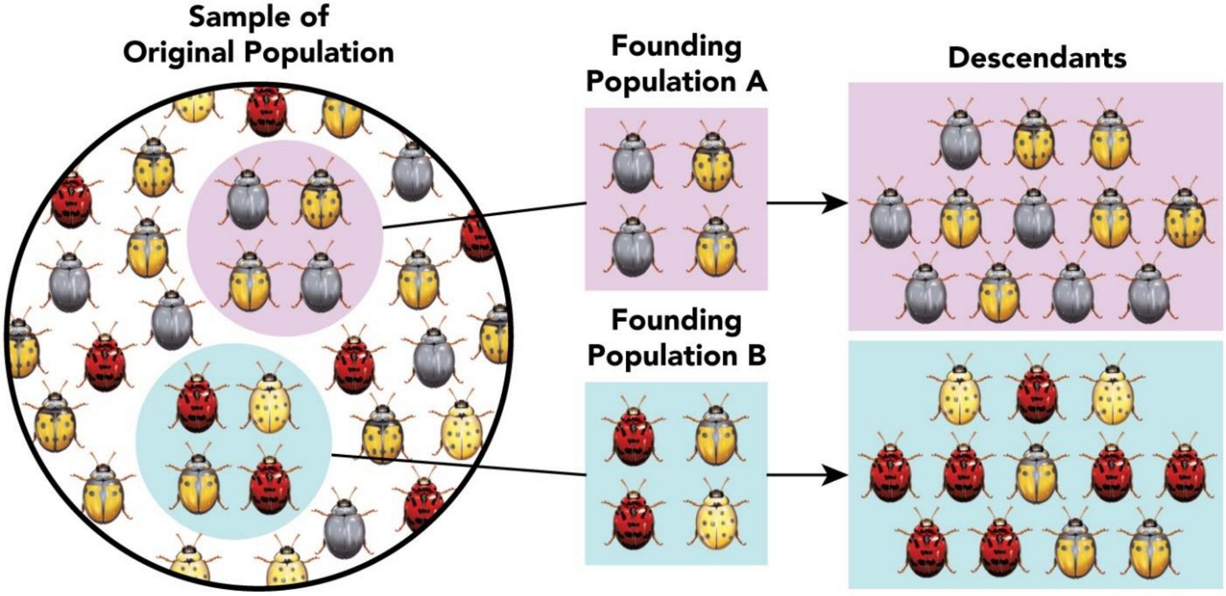


Figure 18-8 Founder Effect

This illustration shows how two small groups from a large, diverse population could produce new populations that differ from the original group. **Compare and Contrast**Explain why the two populations of descendants are so different from one another.

NOTEBOOK

Image long description

- The original population has yellow with 2 spots, yellow with many spots, red, and gray beetles. Two founding population are circles in the original population.
- Founding Population A has 2 gray beetles and 2 yellow beetles with only 2 spots. Founding population B has 2 red beetles, 1 yellow beetle with 2 spots , and 1 yellow beetle with many spots.

- The Descendants of Population A include 11 beetles: 5 are gray beetles and 6 are yellow beetles with 2 spots. The Descendants of Population B include 12 beetles: 7 are red beetles, 2 are yellow beetles with many spots, and 3 are yellow beetles with many spots.

One example of the founder effect is found in the evolution of several hundred species of fruit flies on different Hawaiian islands. Genetic and molecular evaluation of these flies suggests that they are descended from the same mainland fruit fly population. However, species on different islands have allele frequencies that are different from those of the original species.

READING CHECK

Describe What are two circumstances under which genetic drift may occur?

NOTEBOOK

Evolution Versus Genetic Equilibrium

How and why do populations evolve? And when might a population *not* evolve? One way to answer this question is to imagine a model of a hypothetical population that does not evolve. What would that population look like in terms of population genetics? If the population is not evolving, allele frequencies in its gene pool are not changing, and that population is in **genetic equilibrium**.

Sexual Reproduction and Allele Frequency

Gene shuffling during sexual reproduction can produce many different gene combinations. But a century ago, researchers realized that meiosis and fertilization, by themselves, do not change allele frequencies. So, hypothetically, a population of sexually reproducing organisms could remain in genetic equilibrium.

LESSON 18.2

As you read about the Hardy-Weinberg principle, draw upon your prior knowledge in solving mathematical expressions. Remember when solving expressions to use the correct order of operations: parentheses, exponents, multiplication, division, addition, and subtraction.

The Hardy-Weinberg Principle

According to the **Hardy-Weinberg principle**, allele frequencies in a population should remain constant unless one or more factors causes those frequencies to change. The Hardy-Weinberg principle makes predictions like Punnett squares—but for populations, not individuals. Here's how it works.

Suppose that there are two alleles for a gene: *A* (dominant) and *a* (recessive). A cross of these alleles can produce three possible genotypes: *AA*, *Aa*, and *aa*. The frequencies of genotypes in the population can be predicted by these equations, where *p* and *q* are the frequencies of the dominant and recessive alleles:

In symbols:

$$p^2 + 2pq + q^2 = 1 \text{ and } p + q = 1$$

p2 + 2pq + q2 = 1 and p + q = 1

In words:

$$(\text{frequency of AA}) + (\text{frequency of Aa}) + (\text{frequency of aa}) = 100\%$$

(frequency of AA) + (frequency of Aa) + (frequency of aa) = 100%

$$\text{and } (\text{frequency of A}) + (\text{frequency of a}) = 100\%$$

and (frequency of A) + (frequency of a) = 100%

Here's how the Hardy-Weinberg equation can be used to evaluate the likelihood that evolution is taking place in a population. Suppose that, in one generation, the frequency of the *A* allele were 40 percent ($p = 0.40$p = 0.40) and the frequency of the *a* allele were 60 percent ($q = 0.60$q = 0.60). If this population were in genetic equilibrium, the chances of an individual in the next generation having genotype *AA* would be $16\% \ (p^2 = 0.40^2 = 0.16 \text{ or } 16\%)$16% (p2 = 0.402 = 0.16 or 16%). The probability of genotype *aa* would be $36\% \ (q^2 = 0.60^2 = 0.36)$36% (q2 = 0.602 = 0.36). The probability of genotype *Aa* would be 48% ($2pq = 2\,(0.40)\,(0.60) = 0.48$)48% ($2pq = 2\,(0.40)\,(0.60) = 0.48$). If a population doesn't show these predicted phenotype frequencies, evolution is taking place. ***The Hardy-Weinberg principle predicts that five conditions can disturb genetic equilibrium and cause evolution to occur: (1) nonrandom mating, (2) small population size, (3) gene flow from immigration or emigration, (4) mutations, or (5) natural selection.***

Nonrandom Mating

In genetic equilibrium, individuals must mate at random. But females of many animal species select mates based on size, strength, or coloration, as shown in **Figure 18-9**, a practice known as **sexual selection**. When sexual selection occurs, genes for traits selected for or against are not in equilibrium.

LESSON 18.2

This content is unavailable when printing.

Small Population Size

Genetic drift does not usually have major effects in large populations, but can affect small populations. Evolution due to genetic drift thus happens more easily in small populations. An example is described in **Figure 18-10**.

Figure 18-10 Small Population Size

The population of black-footed ferrets was once as low as 18 individuals, all in captivity. By 2013, the population had increased to 500, but much genetic diversity had been lost.

Gene Flow from Immigration or Emigration

Changes in allele frequency can be produced by **gene flow**, the movement of genes into or out of a population. Individuals who join a population (through immigration) may introduce new alleles, and individuals who leave (through emigration) may remove alleles. If allele frequency in the population changes, gene flow has caused evolution to occur.

Mutations

Mutations can introduce new alleles into a gene pool, changing allele frequencies and causing evolution to occur.

Natural Selection

If different genotypes have different fitness, natural selection will disrupt genetic equilibrium, and evolution will occur.

If you think about it, almost any population in nature is likely to experience one or more of these conditions. So, most of the time, in most populations, in typical habitats, evolution happens.

Lesson Review

KEY QUESTIONS

1. How does natural selection affect a single-gene trait?
2. Define genetic drift.
3. What five conditions are necessary to maintain genetic equilibrium?

CRITICAL THINKING

4. **Compare and Contrast** direction selection and disruptive selection.
5. **Infer** Do you think populations stay in genetic How does natural selection affect a single-gene trait?
6. **CASE STUDY** Use the concepts of natural selection, genetic variation, and relative fitness to explain how antibiotic resistance evolves in bacteria.

LESSON 18.3

Standards

-
-

This content is unavailable when printing.

Key Questions

-
-

Vocabulary

- speciation
- reproductive isolation
- behavioral isolation
- geographical isolation
- temporal isolation

As you read, think about the three types of reproductive isolation and what causes them.

Fill in the flowchart in the **Foundations Reading and Study Guide Workbook** on your digital course.

Marine iguanas, like this one, are found only in the Galápagos.

In his book, *On the Origin of Species*, Darwin describes how species adapt to changing environments. But despite the book's title, it says little about the origin of new species—the process called **speciation**.

Darwin made observations whenever he found unusual species. And he described the Galápagos Islands as "a little world within itself" and "very remarkable" in its species. Years later, he suggested that those islands might hold the clues to "...that mystery of mysteries—the first appearance of new beings on this Earth." Darwin's intuition was on target. He had a sense that something about the islands was connected, somehow, with speciation. We now know that a lot of isolated island groups are home to species found nowhere else. So what gives with islands and speciation? Again, gene pools and evolution as genetic change help to answer that question.

Isolating Mechanisms

To understand how a species can give rise to a new species, recall that evolution is any change in relative frequencies of alleles in a population's gene pool. Interbreeding enables any genetic change that occurs in a population to spread throughout that population.

But what would happen if some members of a population were to stop breeding with other members? If that occurred, the species gene pool could split into two populations, as shown in **Figure 18-11**. And if, over time, members of those two populations stopped interbreeding altogether, changes in one gene pool could not spread to the other. When this happens, we say that those populations have become reproductively isolated from one another. If this **reproductive isolation** lasts long enough, those populations may split into two separate species. ***Reproductive isolation can develop in several ways, including behavioral isolation, geographic isolation, and temporal isolation.***

To explore this topic further, launch this interactivity.

hhmi | BioInteractive

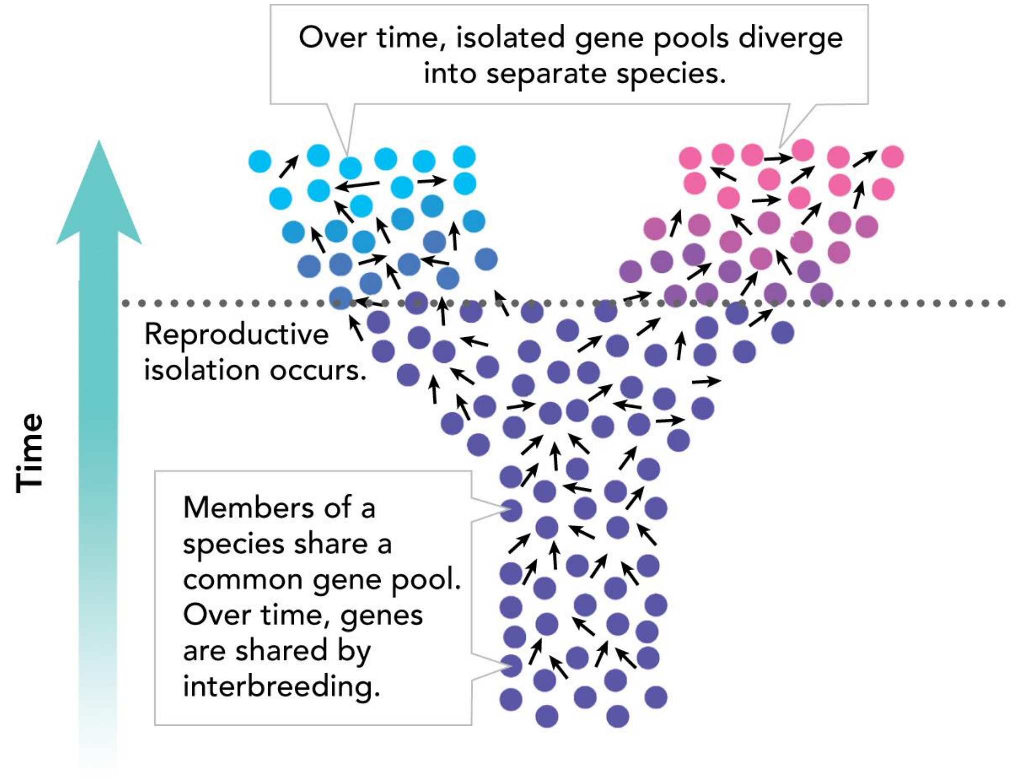


Figure 18-11 An Example of Speciation

If two populations of a species become reproductively isolated, their gene pools can diverge, producing new species.

Image long description

In the Y-shaped diagram, individuals are represented by many circles of the same color in a group at the base of the Y, showing how members of a species share a common gene pool. Over time, genes are shared by interbreeding. When reproductive isolation occurs, isolated gene pools diverge into separate species, represented by circles of different colors in the two forks of the Y.

LESSON 18.3

This content is unavailable when printing.

Behavioral Isolation

If two populations that were once able to interbreed evolve differences in courtship rituals or other behaviors, **behavioral isolation** can occur. For example, eastern and western meadowlarks are similar birds whose habitats overlap. But members of the two species will not mate with each other, partly because they use different songs to attract mates.

Geographic Isolation

When two populations are separated by geographic barriers such as rivers, mountains, or bodies of water, **geographic isolation** occurs. The Galápagos Islands, for example, are far enough from the mainland of South America that small birds like finches very rarely make the crossing. The islands are also isolated from one another.

Biological islands come in many more “flavors” than just chunks of land surrounded by water. A biological island is any habitat that is isolated in some way from other, similar habitats. Punctuating the tropical forests of Venezuela and Guyana, for example, are craggy, tabletop mountains called tepuis, as shown in **Figure 18-12**. The cool, misty environment on the summits of these steep-walled mountains differs dramatically from the steamy, lowland jungle surrounding their bases. Organisms on each plateau are isolated by jungle.

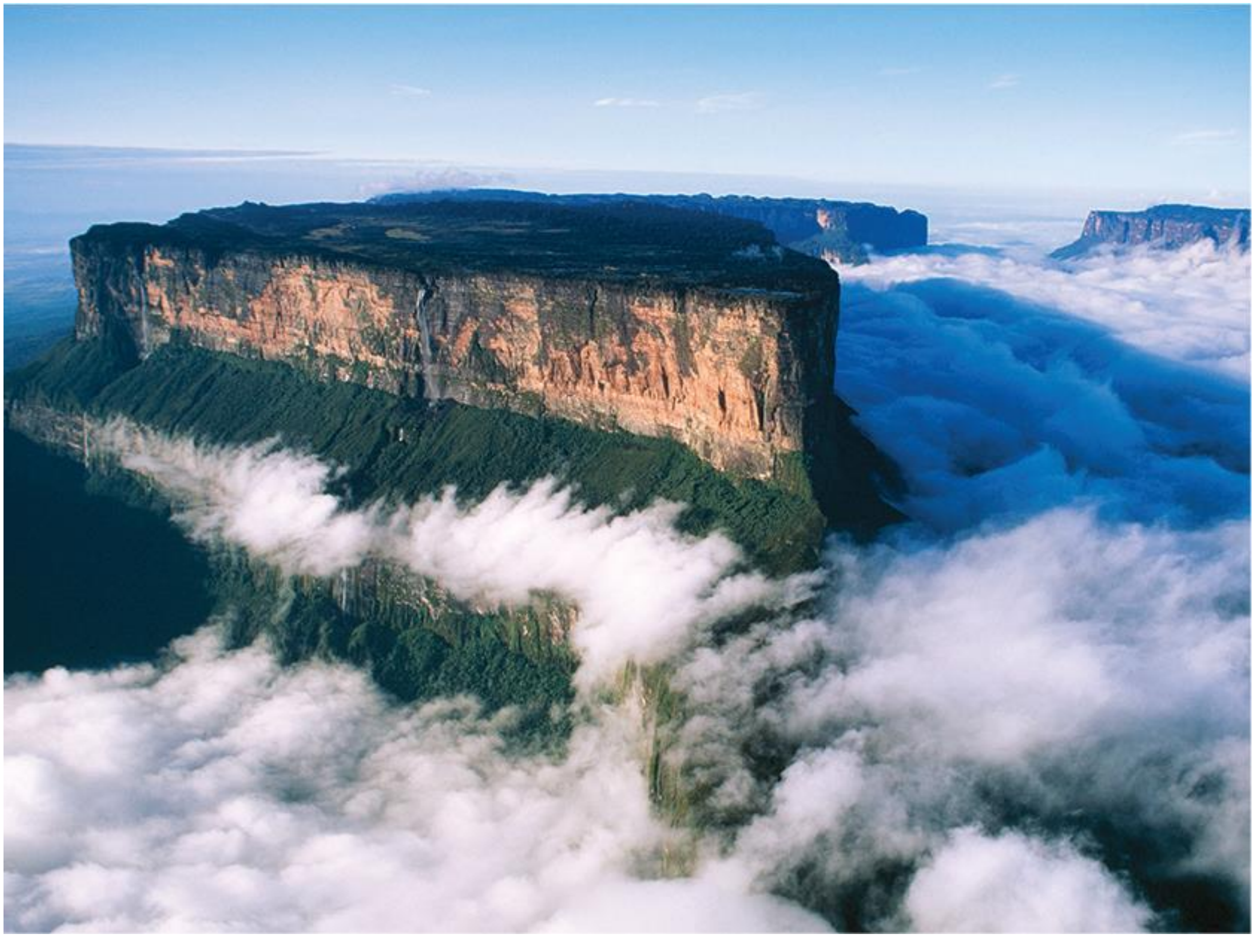


Figure 18-12 Geographic Isolation

Tepuis are like isolated islands in a sea of jungle. Organisms that live on top of these tepuis are not found anywhere else in the world.

Geographic barriers do not always guarantee isolation. Floods, for example, may link separate lakes, enabling their fish populations to mix and interbreed. Also, a geographic barrier may separate certain organisms but not others. A large river may keep squirrels and other rodents apart, but probably won't isolate bird populations.

Temporal Isolation

A third isolating mechanism, known as **temporal isolation**, happens when two or more species reproduce at different times. For example, suppose three similar species of orchids live in the same rain forest. Each species has flowers that last only one day. If the species bloom at different times of the year, they cannot pollinate one another.

LESSON 18.3

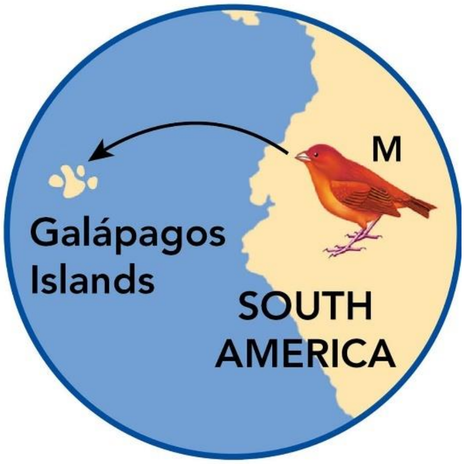
This content is unavailable when printing.

Speciation in Darwin’s Finches

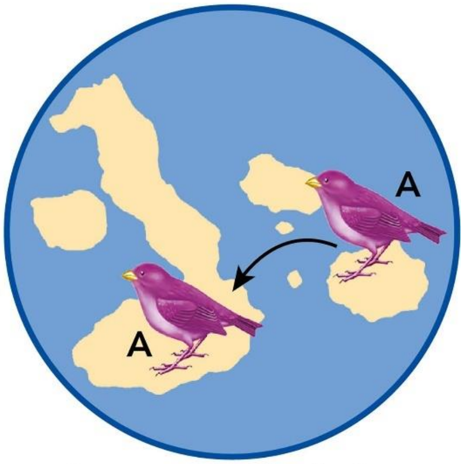
Recall that Peter and Rosemary Grant spent years in the Galápagos studying finch populations. They measured and recorded anatomical characteristics such as beak length, beak depth, and other traits. When data for each trait were graphed, they formed bell-shaped distributions typical of polygenic traits. As environmental conditions changed, the Grants documented directional selection. When drought struck the island of Daphne Major, finches with larger beaks capable of cracking the thickest seeds survived and reproduced more often than others. Over many generations, the proportion of large-beaked finches increased.

We can now combine these studies by the Grants with evolutionary concepts to form a hypothesis that answers a question: How might the founder effect and natural selection have led to reproductive isolation and speciation among Galápagos finches? ***Speciation in Galápagos finches occurred by the founding of a new population, geographic isolation, changes in the new population’s gene pool, behavioral isolation, and ecological competition.***

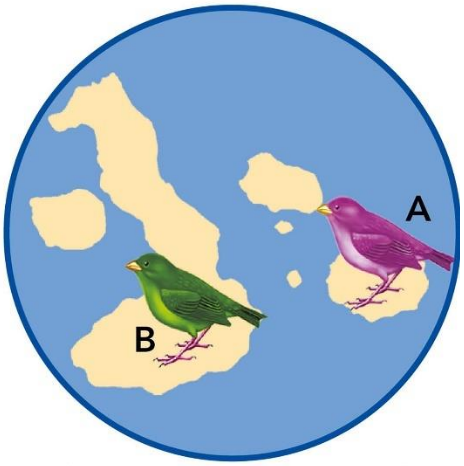
Founders Arrive



Founders Arrive



Geographic Isolation



Changes in Gene Pools

Many years ago, a few finches from South America—species M—arrived on one of the Galápagos Islands. These birds may have gotten lost or been blown off course by a storm. Once on the island, they survived and reproduced. Because of the founder effect, allele frequencies of this founding finch population could have differed from allele frequencies in the original South American population.

Geographic Isolation

The environment the birds encountered in the Galápagos was different from the environment they came from on the mainland of South America. Some combination of the founder effect, geographic isolation, and natural selection resulted in differential reproductive success, adaptation, and evolution of this island population into a new species—species A. Later, a few birds of species A crossed to another island. Because these birds do not usually fly over open water, they move from island to island very rarely. Thus, finch populations on the two islands were geographically isolated, and no longer shared a common gene pool.

Changes in Gene Pools

Over time, populations on each island further adapted to local environments. Plants on the first island may have produced small, thin-shelled seeds, whereas plants on the second island may have produced larger, thick-shelled seeds. On the second island, directional selection would have favored individuals with larger, heavier beaks. These birds could crack open and eat the large seeds more easily. Thus, birds with large beaks would be better able to survive on the second island. Over time, natural selection would have caused that population to evolve larger beaks, forming a new population, B, with a new phenotype.

LESSON 18.3

Standards

-

This content is unavailable when printing.

GUIDED INQUIRY

Download the worksheet to complete the activity.

This content is unavailable when printing.

Competing for Resources

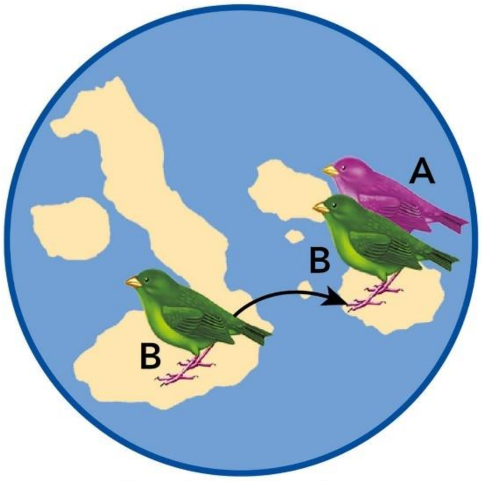
Problem How can competition lead to speciation?

In this lab, you will model variation in the size and shape of finch beaks using different tools. You will determine which “beaks” are better adapted to small seeds and large seeds. You will also observe how competition and the abundance or scarcity of food affects survival.

LESSON 18.3

This content is unavailable when printing.

Behavioral Isolation

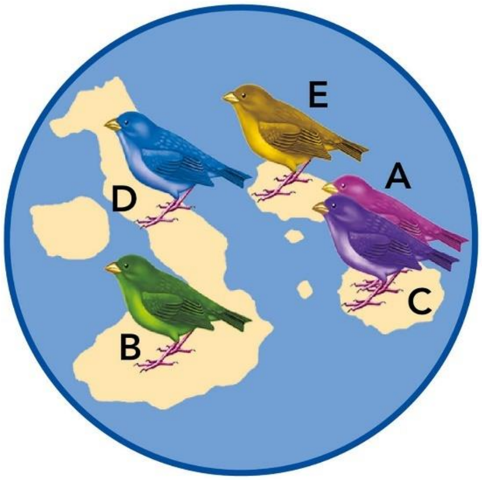


Behavioral Isolation

Now, imagine that a few birds from the second island cross back to the first island. Will population A birds breed with population B birds? Probably not. During courtship, these finches closely inspect a potential partner's beak. Finches prefer to mate with birds that have the same size beak as they do. Big-beaked birds prefer to mate with other big-beaked birds, and smaller-beaked birds prefer to mate with other smaller-beaked birds. Because the populations on the two islands have evolved different-sized beaks, they would probably not mate with each other.

Thus, differences in beak size, combined with mating behavior, could lead to reproductive isolation. The gene pools of the two bird populations remain isolated—even when individuals live in the same place. The populations have now become two distinct species.

Competition and Continued Evolution



Competition and Continued Evolution

As these two new species live together on the first island, they compete for seeds. During the dry season, birds that are most different from each other have the highest fitness. That is because the more specialized birds experience less competition for certain kinds of seeds and other foods. Over time, the species evolve in a way that increases the differences between them. Birds on the first island that once belonged to species B may evolve into a new species, C.

These processes of geographic isolation, genetic change, and behavioral isolation could have repeated again and again across the Galápagos chain. Over many generations, therefore, natural selection could have produced the diversity among the 13 different finch species found there today.

Lesson Review

KEY IDEAS

1. What is geographic isolation?

NOTEBOOK

2. What types of reproductive isolation may have been important in Galápagos finch speciation? Explain.

NOTEBOOK

CRITICAL THINKING

3. **Apply Scientific Reasoning** On the Galápagos Islands, different types of seeds are common on different islands. How did the seed types affect the evolution of Darwin's finches?

LESSON 18.4

Standards

-

This content is unavailable when printing.

Key Questions

-
-
-

Vocabulary

- Hox gene

As you read, identify the details that describe the headings listed in the **Foundations Reading and Study Guide Workbook** on your digital course.

Changes to regulatory genes can affect numbers of legs and body segments.

Charles Darwin worked almost a century before the DNA double helix was discovered. Yet Darwinian theory applies just as much to molecules as it does to the animals and plants that Darwin studied. Today, as we study and compare genomes, we can evaluate evolutionary theory by making testable predictions about evolutionary change in genes and genomes.

New Genes, New Functions

Consider one of the most basic questions in biology: Where did the roughly 25,000 genes in the human genome come from? Modern genes descended from a much smaller number of genes in early life forms. But how could that have happened? ***One way new genes can evolve is through duplication, followed by modification, of existing genes.***

Gene Duplication

Recall that during meiosis, paired chromosomes swap DNA in a process called crossing-over. Sometimes, an unequal swap gives one chromosome in the pair an “extra” copy of one or more genes. If mutations occur in those duplicate copies, they don’t affect the function of the original gene. **Figure 18-13** shows how this happens. The evolving duplicate genes, however, can gain new functions over time.

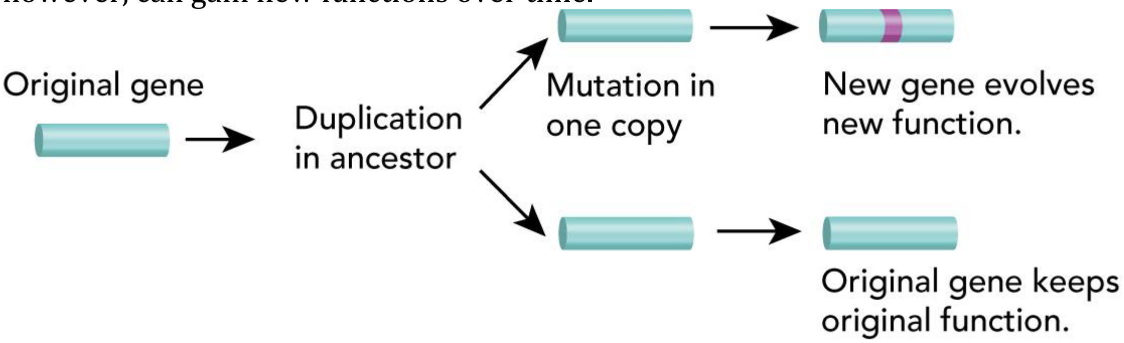


Figure 18-13 Gene Duplication

In this diagram, a gene is first duplicated, and then one of the two resulting genes undergoes mutation.

Image long description

1 copy has mutation	new gene evolves new function
1 copy does not have mutation	original gene keeps original function

LESSON 18.4

This content is unavailable when printing.

One way to evaluate this idea is to check to see if genomes of living organisms contain duplicate genes. It turns out that they do! For example, the human genome contains six copies of the gene for beta-globin, one of the polypeptides in the blood protein hemoglobin. Although these six beta-globin genes are similar, mutations have slightly changed their characteristics since they were produced by duplication of a single ancestral globin gene. In other cases, gene duplication has allowed copies of genes to acquire completely new functions.

Genetic Rearrangement

Chromosomes are not static DNA sequences. They can break and reconnect, lose bits and pieces of DNA, and acquire DNA sequences from viruses, microorganisms, and even other chromosomes. In fact, exons from one gene can mix and combine with exons from other genes. These changes can produce new genes that code for completely different proteins.

Over time, gene duplications and rearrangements have greatly increased the size and complexity of eukaryotic genomes. They have also left evidence for evolution in the form of gene “families.” These gene families can be analyzed to trace the course of evolution, and to help establish evolutionary relationships between different species.

READING CHECK

Review Describe how new genes are created through duplication and rearrangement.

NOTEBOOK

Developmental Genes and Body Plans

One exciting new research area is nicknamed “evo-devo” because it studies the relationship between evolution and development. Researchers have now shown how small changes in master control genes can produce the kinds of evolutionary changes seen in the fossil record.

Hox Genes and Evolution

A group of regulatory genes known as **Hox genes** determines which parts of an embryo develop into arms, legs, or wings. Groups of Hox genes also control the sizes and shapes of those structures. In fact, homologous Hox genes shape the bodies of animals as different as insects and humans—even though those animals last shared a common ancestor no fewer than 500 million years ago!

Small changes in Hox gene activity during embryological development can produce large changes in adult animals. For example, insects and crustaceans are related to ancient common ancestors that possessed dozens of legs. Today's crustaceans, including shrimp and lobsters, have 5 pairs of legs, and insects have just 3 pairs. What happened to all those extra legs? Recent studies have shown that mutations in a single Hox gene, known as *Ubx*, turns off the growth of legs in the abdominal regions of insects. Thus, a small change in one Hox gene accounts for a major evolutionary difference between two important animal groups, as shown in **Figure 18-14**.

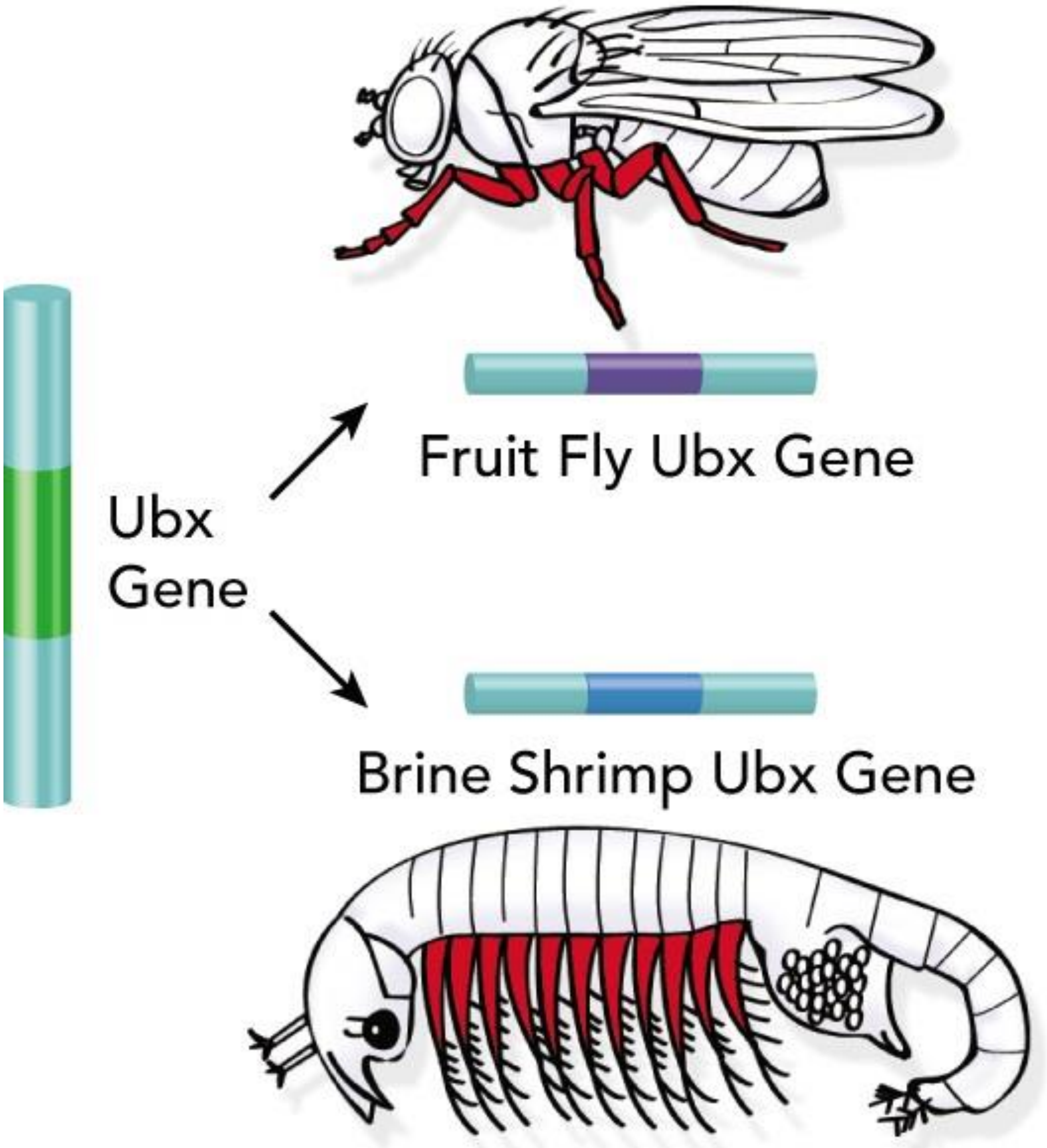


Figure 18-14 Change in a Hox Gene

In the illustration, the legs of the fruit fly and the legs of the brine shrimp are the same color (red) because a variant of the same Hox gene, *Ubx*, directs the development of the legs of both animals.

LESSON 18.4

This content is unavailable when printing.

Timing Is Everything

Each part of an embryo starts to grow at a specific time, grows for a specific length of time, and stops growing at a specific time. Small changes in start and stop times can make a big difference in adult body shape. For example, small timing changes can make the difference between long, slender fingers and short, stubby toes. No wonder "evo-devo" is one of the hottest areas in evolutionary biology!

READING CHECK

Summarize How do Hox genes affect the development of embryos?
NOTEBOOK

Molecular Clocks

Because changes in DNA drive evolution and record organisms' common ancestors, we can compare the DNA sequences of different organisms to determine their evolutionary relationships. If two species share a common ancestor, changes in their DNA should have accumulated since they became separate species. Biologists can use these differences as a kind of "molecular clock" to mark the passage of evolutionary time. ***A molecular clock uses mutation rates in DNA to estimate the time that two species have been evolving independently.***

Neutral Mutations as "Ticks"

To understand molecular clocks, think about mechanical clocks. They mark time with a mechanism that clicks every second, creating the ticking sound. A molecular clock also relies on a repeating process—mutation—to mark time. Simple mutations occur all the time, causing slight changes in DNA sequences.

Some mutations have a major positive or negative effect on an organism's phenotype. These mutations are under powerful pressure from natural selection. Many small mutations, however, have no effect on phenotype. These neutral mutations tend to accumulate in the DNA of different species at about the same rate. Researchers can compare such DNA sequences in two species. The comparison can reveal how many mutations have occurred independently in each group, as shown in **Figure 18-15**. The more differences there are between the DNA sequences of the two species, the more time has elapsed since the two species shared a common ancestor.
To explore this topic further, launch this interactivity.

This content is unavailable when printing.

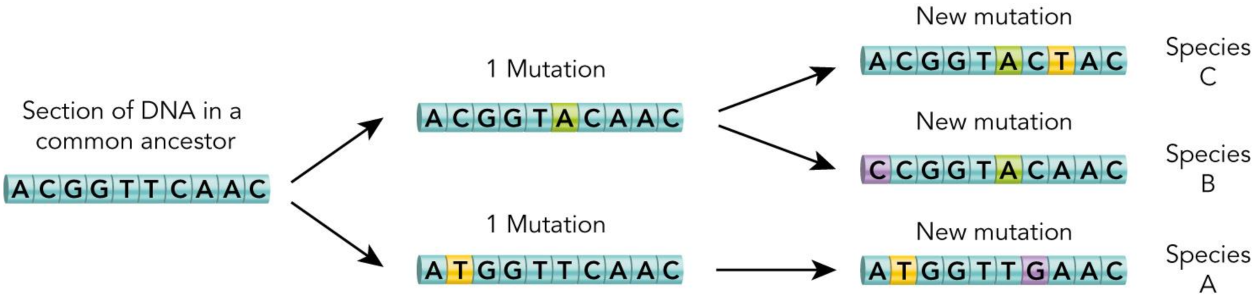


Figure 18-15 Molecular Clock

By comparing the DNA sequence of two or more species, biologists estimate how long the species have been separated. **Analyze**What evidence indicates that species C is more closely related to species B than to species A?

NOTEBOOK

Image long description

A section of DNA in a common ancestor has the genetic code A C G G T T C A A C. It replicates, and in one mutation the first C becomes T, and then in a second mutation the second C becomes G, resulting in A T G G T T G A A C (Species A). In the other mutation from the common ancestor, the second T becomes A, then this strand also replicates; in one of the new mutations, the first A becomes C, resulting in C C G G T A C A A C (Species B), and in the other mutation the second A becomes T, resulting in A C G G T A C T A C (Species C).

LESSON 18.4

Standards

-

This content is unavailable when printing.

Download the worksheet to complete the activity.

This content is unavailable when printing.

Variation of Expressed Traits

Suppose that in a population of a mammal species, almost all of the animals have brown fur, but occasionally an animal with white fur appears. One explanation is that fur color is controlled by a single gene with two alleles: a dominant allele for brown fur and a recessive allele for white fur. Use this model to generate and analyze statistics on the variation of fur color.

1. Read the procedure. Prepare a data table to record the results.
2. Prepare two paper bags, each with 7 brown counters and 3 white counters. Each bag represents the alleles for fur color in the population.
3. Randomly pick a counter from each bag to model the genes of an offspring. Record the two alleles, and the fur color they produce.
4. Repeat step 3 to generate 20 samples.

Analyze and Interpret Data

1. **Calculate** Find the percentages of brown and white animals among the first 5 offspring, the first 10 offspring, and all 20 offspring in your model.
2. **Evaluate Models** Why is it more useful to generate and analyze data from 20 offspring compared to a smaller number?
3. **Construct an Explanation** As shown by your model, how do allele frequencies help explain the variation and distribution of the trait of fur color?
4. **Predict** What events in nature might change the percentages of fur color in this species? Explain your prediction.

LESSON 18.4

This content is unavailable when printing.

Calibrating the Clock

The use of molecular clocks is not simple, because there is not just one molecular clock in a genome. There are many different clocks, each of which “ticks” at a different rate. This is because some DNA sequences accumulate mutations faster than others. Think of a conventional clock. If you want to time a brief event, you use the second hand. To time an event that lasts longer, you use the minute hand or the hour hand. In the same way, researchers choose a different molecular clock for comparing great apes than for estimating when mammals and fishes shared a common ancestor. Researchers check the accuracy of molecular clocks by trying to estimate how often mutations occur. In other words, they estimate how often the clock they have chosen “ticks.” To do this, they compare the number of mutations in a particular gene in species whose ages have been determined by other methods.

Lesson Review

KEY QUESTIONS

1. How can crossing-over result in gene duplication?

NOTEBOOK

2. In evolution, why have small changes in Hox genes had a significant impact?

NOTEBOOK

3. How does a molecular clock allow scientists to study evolutionary history?

NOTEBOOK

CRITICAL THINKING

4. **Construct an Explanation** How can duplicated genes lead to the development of new adaptations in a species?

NOTEBOOK

5. **Evaluate Models** A computer simulation is used to predict the effect of a mutation in a Hox gene in fruit flies. Why is it important for the model to specify the timing of the mutation?

NOTEBOOK

6. **Ask Questions** You are studying corresponding DNA sequences from three species of trout, which is a type of fish. What questions can you ask, and then investigate, to help determine the evolutionary relationship among the trout species?

Chapter 18

Case Study Wrap-Up

Standards

This content is unavailable when printing.

How can antibiotics keep up with drug-resistant bacteria?

A new antibiotic may be very effective at first. Then, over time, bacterial populations evolve resistance to it.

MAKE YOUR CASE

Natural selection can drive changes in gene frequency in populations—especially if organisms' environment changes in a dramatic way. The widespread use and overuse of antibiotics created just such a change by making antibiotics part of the environment. Unfortunately, antibiotic resistance poses a very serious threat to human health. As old antibiotics become less effective, new ones are needed to replace them. Some good news came in 2015 with the discovery of a new antibiotic called teixobactin. It is the first new antibiotic in decades.

Construct an Argument

1. **Conduct Research** Look for reliable data that show how and why the effectiveness of an antibiotic changes if that antibiotic is widely used.

   NOTEBOOK

2. **Construct an Explanation** When an antibiotic is used for many years, how does natural selection lead to bacteria that are resistant to it? Use the data you researched as evidence to support your explanation.

   NOTEBOOK

3. **Engage in Argument** When new antibiotics such as teixobactin are developed, when and how widely should they be used? Cite evidence and use logical reasoning in your argument.

   NOTEBOOK

CHAPTER18

Case Study Wrap-Up

This content is unavailable when printing.

Careers on the Case

Work Toward a Solution

The problem of antibiotic resistance means that new antibiotics are always needed. People in many careers work together to find or invent a new drug, test it carefully, and develop ways to manufacture it for wide distribution.

Pharmaceutical Scientist

Some potential drugs are found in nature, while others involve chemical changes to existing drugs. Pharmaceutical scientists work in teams to develop new drugs. Most people with this career work for drug companies. Pharmaceutical scientists may also work at universities or for government agencies.

Watch this video to learn about other careers in biology.

hhmi | BioInteractive

CHAPTER18

Case Study Wrap-Up

Society on the Case

Drugs for Livestock

Bacteria can and do infect livestock. In fact, modern practices for raising livestock make them especially prone to bacterial infections. The animals are often kept in very crowded, stressful conditions. Bacteria can spread quickly within a crowded cattle pen or chicken coop.

For these reasons, closely packed livestock are generally given heavy doses of antibiotics. The U.S. government regulates this practice. The stated goals of the regulations are to keep the food supply safe and keep antibiotic resistance at a minimum. Critics, however, argue that the laws and regulations are not strict enough. Several organizations are working to reduce or eliminate the need for heavy antibiotic use on livestock, such as by decreasing the density of animals kept in close quarters.

In 2015, California became the first state to ban the use of antibiotics in feedlots to speed up an animal’s growth. The law allows animals to receive certain antibiotics only when it is necessary for their health.

Consumers are becoming more aware of the use of antibiotics in livestock that is raised for food. As a result, some American poultry producers have begun to voluntarily reduce or limit the routine use of antibiotics.

CHAPTER18

Study Guide

This content is unavailable when printing.

Lesson Review

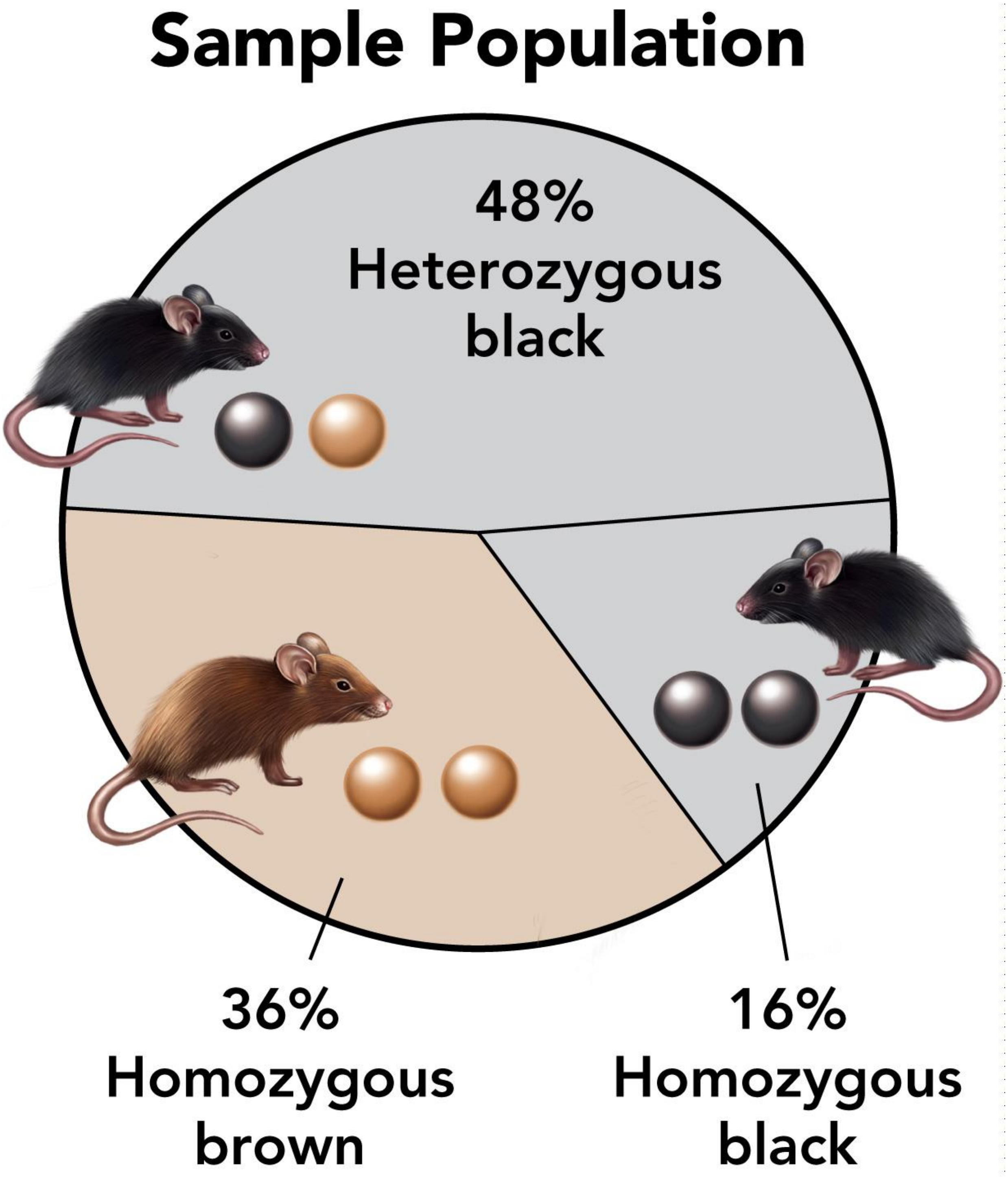
18.1 Genes and Variation

Evolution is a change in the frequency of alleles in a population over time. In genetics terms, evolutionary fitness is an individual's success in passing genes to the next generation.

Genetic variation is produced in three main ways. Mutation is a change in a genetic sequence. Sexual reproduction creates new combinations of genes. Lateral gene transfer occurs when one individual passes genes to another that is not its offspring, as when a bacterium transfers a plasmid.

The number of phenotypes produced for a trait depends on how many genes control the trait. Traits can be determined by a single gene or by many genes.

- gene pool
- allele frequency
- single-gene trait
- polygenic trait



1. **Calculate** In a population of 200 mice, how many are heterozygous black? how many are homozygous brown? how many are homozygous black?

CHAPTER 18

Study Guide

This content is unavailable when printing.

Lesson Review

18.2 Evolution as Genetic Change

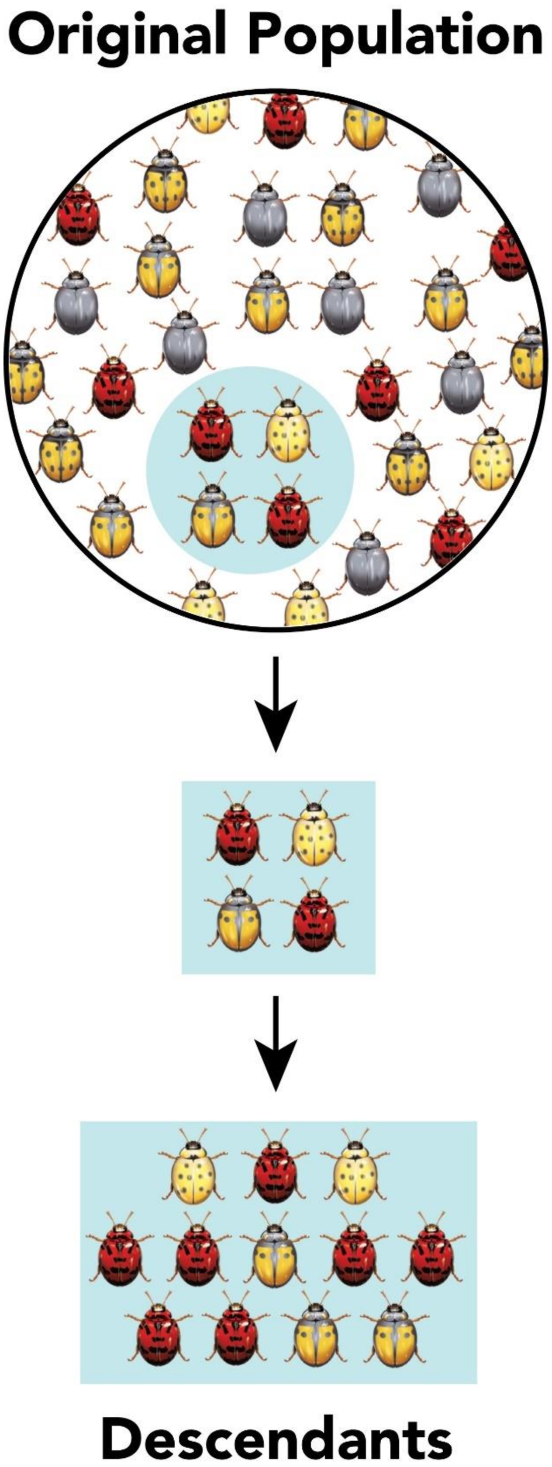
Natural selection on single-gene traits can lead to changes in allele frequencies and, thus, to changes in phenotype frequencies.

Natural selection on polygenic traits can affect the relative fitness of phenotypes and thereby produce one of three types of selection: directional selection, stabilizing selection, or disruptive selection.

In small populations, individuals that carry a particular allele may leave more descendants than other individuals leave, just by chance. Over time, a series of chance occurrences can cause an allele to become more or less common in a population.

The Hardy-Weinberg principle predicts that five conditions can disturb genetic equilibrium and cause evolution to occur: (1) nonrandom mating, (2) small population size, (3) immigration or emigration, (4) mutations, or (5) natural selection.

- directional selection
- stabilizing selection
- disruptive selection
- genetic drift
- bottleneck effect
- founder effect
- genetic equilibrium
- Hardy-Weinberg principle
- sexual selection
- gene flow



1. **Summarize** Which process of evolution does the figure show? Explain the events that occur.

CHAPTER 18

Study Guide

This content is unavailable when printing.

Lesson Review

18.3 The Process of Speciation

When populations become reproductively isolated, they can evolve into two separate species. Reproductive isolation can develop in several ways, including behavioral isolation, geographic isolation, and temporal isolation.

The classic example of speciation is seen in the 13 species of Galápagos finches. Speciation resulted from the founding of a new population, geographic isolation, changes in the new population's gene pool, behavioral isolation, and ecological competition.

- speciation
- reproductive isolation
- behavioral isolation
- geographic isolation
- temporal isolation

CHAPTER 18

Study Guide

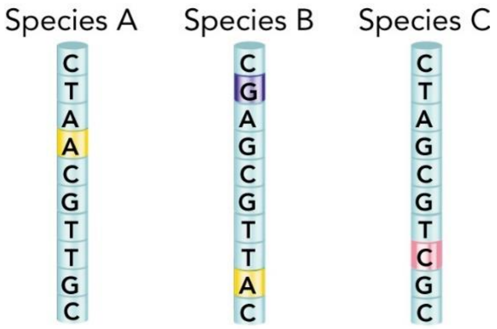
Lesson Review

18.4 Molecular Evolution

One way new genes can evolve is through the duplication, followed by modification, of existing genes.

Small changes in Hox gene activity during embryological development can produce large changes in adult animals.

A molecular clock uses mutation rates in DNA to estimate the time that two species have been evolving independently.



- Hox gene

1.

Image long description

C	C	C
T	G (color coded purple)	T
A	A	A
A (color coded yellow)	G	G
C	C	C
G	G	G
T	T	T
T	T	C (color coded pink)
G	A (color coded yellow)	G
C	C	C

Interpret Diagrams The colored bands in the diagrams represent mutations in a segment of DNA in species A, B, and C. Which two of the three species probably share the most recent common ancestor?

CHAPTER 18

Study Guide

Organize Information

Complete the graphic organizer about sources of genetic variation.

Mutations	1.	2.
3.	In independent assortment, each chromosome in a pair moves independently during meiosis. During crossing-over, paired chromosomes often swap lengths of DNA.	4.
5.	6.	Many bacteria swap genes on plasmids, leading to antibiotic-resistant bacteria.

Performance-Based Assessment

SCIENCE PROJECT

Standards

-
-
-

When Weeds Fight Back!

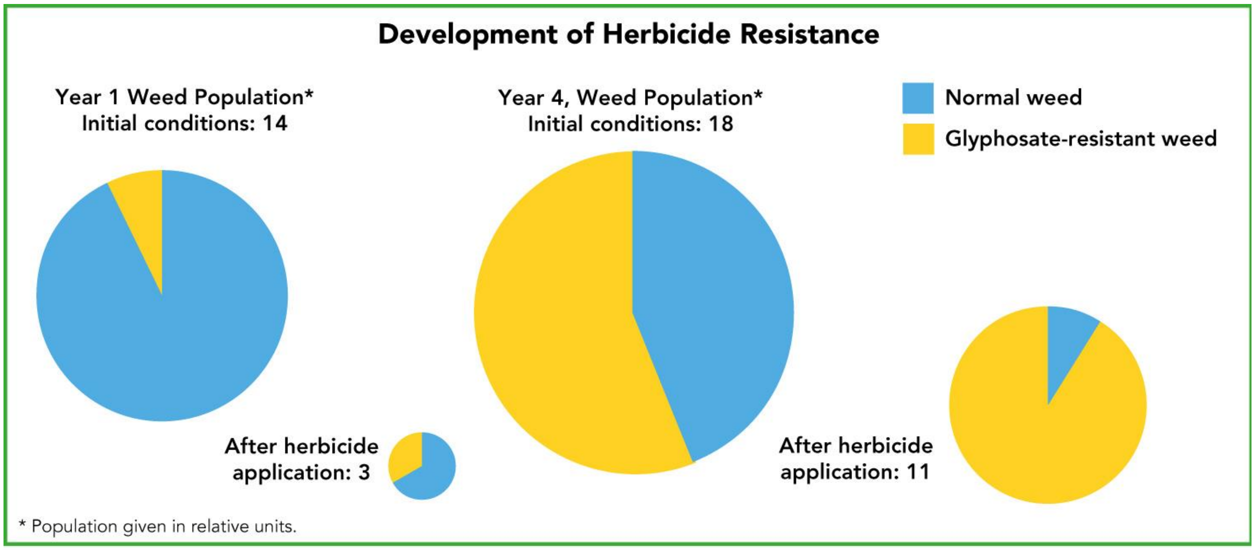
STEM Construct an Explanation

Cotton farmers face many challenges, including weeds.
For cotton farmers, a green tassel-like weed called Palmer amaranth is bad news. This invasive weed, native to the southwest, spread across the Midwest and into the southeast. Each female plant can produce up to 600,000 seeds, which germinate throughout the season. It competes with cotton for space, light, soil, water, and nutrients.

During the 1970s, cotton farmers began using a weed-killing chemical called glyphosate, which is sold to both the commercial and consumer market. It worked temporarily to keep weed growth down and to slow the invasive's spread. It wasn't a perfect solution, as weed-killing chemicals can have negative effects on the environment, and on human health. But even that imperfect solution didn't last.

In 2004, a farmer in Georgia reported glyphosate-resistant weeds. That resistance spread rapidly. By 2011, weeds were decreasing cotton yields by 50 percent. Today, farmers must use a variety of herbicides. Still, Palmer amaranth remains a nuisance.

The series of circle graphs describe a model of a weed population that evolves resistance to an herbicide. The width of each circle shows the relative size of the weed population, and the colors show the percentages of normal and herbicide-resistant weeds. Study the graphs, and then apply your knowledge of evolution by natural selection to answer these questions.



Based on information from Grains Research & Development Corporation

Image long description

Year 1 Initial Conditions	14	92 percent	8 percent
Year 1 after herbicide application	3	33 percent	67 percent
Year 4 Initial Conditions	18	43 percent	57 percent
Year 4 after herbicide application	11	8 percent	92 percent

1. **Interpret Graphs** What do the circle graphs show about the effect of herbicide on the weed population in the model?
   NOTEBOOK
2. **Support an Explanation** Consider this explanation of natural selection:
   When a heritable trait provides some individuals in a population with higher fitness under specific conditions, organisms with that trait tend to become more common.

   Support this explanation using the data shown in the circle graphs, and by applying concepts of statistics and probability.

   NOTEBOOK
3. **Conduct Research** One company has recently been given approval to produce genetically modified varieties of cotton and soybeans that are resistant to the weeds. Research these new weed-resistant varieties. What are the pros and cons of the commercial use of these genetically modified crops?
   NOTEBOOK
4. **Communicate** Prepare a poster, an oral or a written report, or a computer presentation to communicate your findings. Share your knowledge and conclusions with classmates.

CHAPTER 18 Assessment

Standards

-
-
-

This content is unavailable when printing.

KEY QUESTIONS AND TERMS

18.1 Genes and Variation

1. The combined genetic information of all members of a particular population forms a

   A. gene pool.
   B. niche.
   C. phenotype.
   D. population.

   NOTEBOOK

2. Mutations that improve an individual's ability to survive and reproduce are

   A. harmful.
   B. neutral.
   C. beneficial.
   D. chromosomal.

   NOTEBOOK

3. Traits, such as human height, that are controlled by more than one gene are known as

   A. single-gene traits.
   B. polygenic traits.
   C. recessive traits.
   D. dominant traits.

   NOTEBOOK

4. Explain what the term *allele frequency* means. Include an example illustrating your answer.

   NOTEBOOK

5. Explain what determines the number of phenotypes for a given trait.

   NOTEBOOK

6. What is *lateral gene transfer*?

   NOTEBOOK

7. Define evolution in genetic terms.

KEY QUESTIONS AND TERMS

18.2 Evolution as Genetic Change

8. The type of selection in which individuals of average size have greater fitness than small or large individuals is called

A. disruptive selection.
B. stabilizing selection.
C. directional selection.
D. neutral selection.

NOTEBOOK

9. A random change in a small population's allele frequency is known as

A. a gene pool.
B. genetic drift.
C. variation.
D. fitness.

NOTEBOOK

10. The situation in which allele frequencies change as a result of the migration of a small subgroup of a population is known as

A. the bottleneck effect.
B. the founder effect.
C. genetic equilibrium.
D. sexual selection.

NOTEBOOK

11. What effect does natural selection have on single-gene traits?

NOTEBOOK

12. How do stabilizing selection and disruptive selection differ?

NOTEBOOK

13. What is genetic equilibrium? In what kinds of situations is it likely to occur?

14.

KEY QUESTIONS AND TERMS

18.3 The Process of Speciation

14. Temporal isolation occurs when two different populations

A. develop different mating behaviors.
B. become geographically separated.
C. reproduce at different times.
D. interbreed.

NOTEBOOK

15. When two populations no longer interbreed, what is the result?

A. genetic equilibrium
B. reproductive isolation
C. stabilizing selection
D. artificial selection

NOTEBOOK

16. If coat color in a rabbit population is a polygenic trait, which process might have produced the graph below?

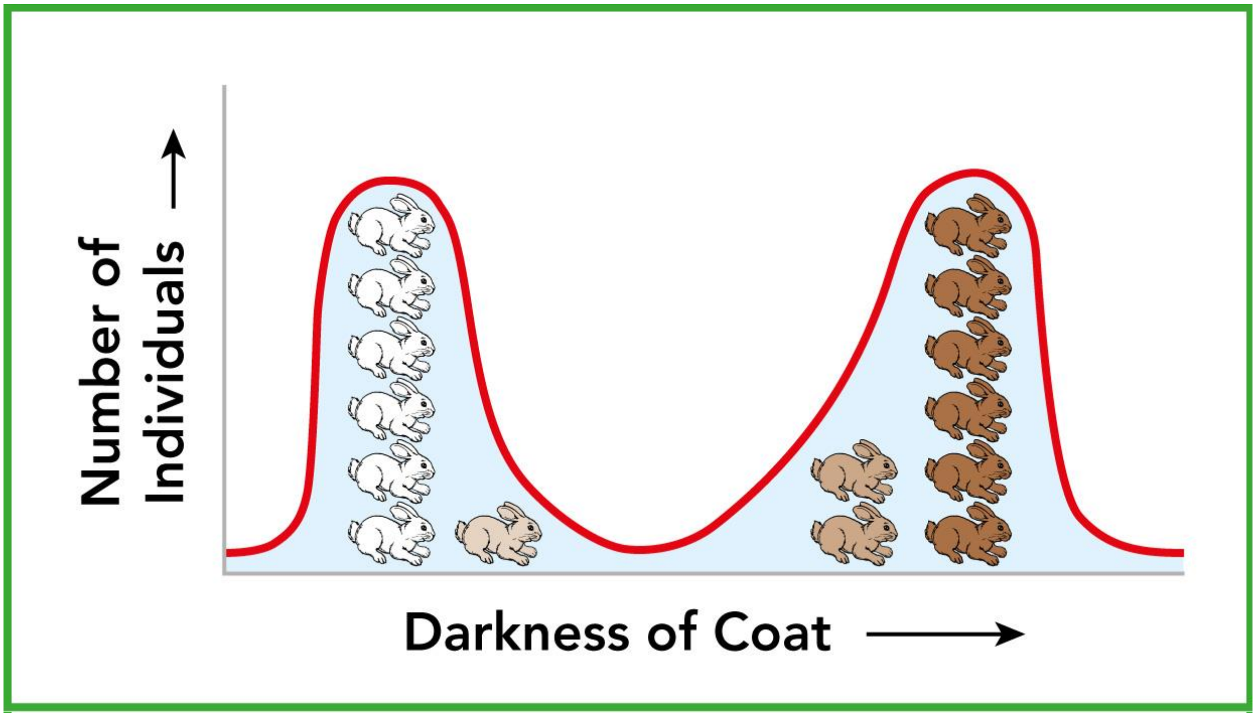


Image long description

6	white
1	off-white
2	light brown
6	dark brown

NOTEBOOK

17. Describe three ways populations can become reproductively isolated.

NOTEBOOK

18. List three types of geographic barriers that may lead to the geographic isolation of a species.

KEY QUESTIONS AND TERMS

18.4 Molecular Evolution

19. A group of regulatory genes that determine which parts of an embryo develop into arms, legs, or wings are known as

A. polygenic genes.
B. molecular clocks.
C. neutral genes.
D. Hox genes.

NOTEBOOK

20. Each "tick" of a molecular clock is an occurrence of

A. genetic drift.
B. crossing-over.
C. DNA mutation.
D. mitosis.

NOTEBOOK

21. How do chromosomes gain an extra copy of a gene during meiosis?

NOTEBOOK

22. What is the study of "evo-devo," and how is it related to evolution?

NOTEBOOK

23. What are neutral mutations?

CRITICAL THINKING

24. **Cite Evidence** In the DNA of any individual human, about 300 mutations may differentiate the genome from either parent. As a result of the mutations, should an individual expect 300 distinct effects in phenotype? Or is the number of effects much fewer? Cite evidence about DNA and its role in controlling traits to support your answer.

NOTEBOOK

25. **Infer** A black guinea pig and a white guinea pig mate and have offspring. All the offspring are black. Is the trait of coat color probably a single-gene trait or a polygenic trait? Explain.

NOTEBOOK

26. **Predict** A newly formed lake divides a population of a beetle species into two groups. What other factors besides isolation might lead to the two groups becoming separate species?

NOTEBOOK

27. **Use Models** The Hardy-Weinberg principle provides a model for genetic equilibrium in a species. Why is random mating a necessary assumption for this model?

NOTEBOOK

28. **Synthesize Information** Why are many islands, such as the Galápagos Islands, home to species that differ from those on the nearby mainland?

NOTEBOOK

29. **Predict** Pine trees grow throughout a large tract of forest. Suppose a highway is built through the forest, effectively dividing it in half. Is it likely that the two groups of pine trees will evolve separately? Explain your prediction.

NOTEBOOK

30. **Construct an Explanation** How are changes in Hox genes significant in the evolution of species?

NOTEBOOK

31. **Apply Scientific Reasoning** Scientists compare the DNA of two species to draw conclusions about their evolutionary relationship, and determine when the species diverged from a common ancestor. What assumption about mutations is necessary to support these types of conclusions?

NOTEBOOK

In turkeys, feather color is controlled by several genes, each with at least two alleles. In a population of turkeys, the trait of black feathers is gradually becoming more common than the trait of bronze feathers. Use this information to answer questions 32–34.

32. **Draw Conclusions** Can you conclude that the gene pool for feather color is changing in the turkey population? Explain your reasoning and identify a possible change in the gene pool that could be occurring.

NOTEBOOK

33. **Construct an Explanation** Apply Darwin’s theory of natural selection to explain why the trait of black feathers might be becoming more common.

NOTEBOOK

34. **Integrate Information** Some turkeys live in the wild, while others are domesticated. How does the type of turkey population (wild or domesticated) affect the explanation you constructed about the changes to the population?

CROSSCUTTING CONCEPTS

35. **Cause and Effect** Why does sexual reproduction provide more opportunities for genetic variation than asexual reproduction?

NOTEBOOK

36. **Connect to Society** Why is it important for physicians to keep some antibiotics in reserve, using them only for the most serious infections?

MATH CONNECTIONS

Analyze and Interpret Data

A research team studied two lakes in an area that sometimes experiences flooding. Each lake contained two types of similar fishes: a dull brown form and an iridescent gold form. The team wondered how all the fishes were related, and they considered the two hypotheses in the diagram. Use this information and the diagram to answer questions 37–39.

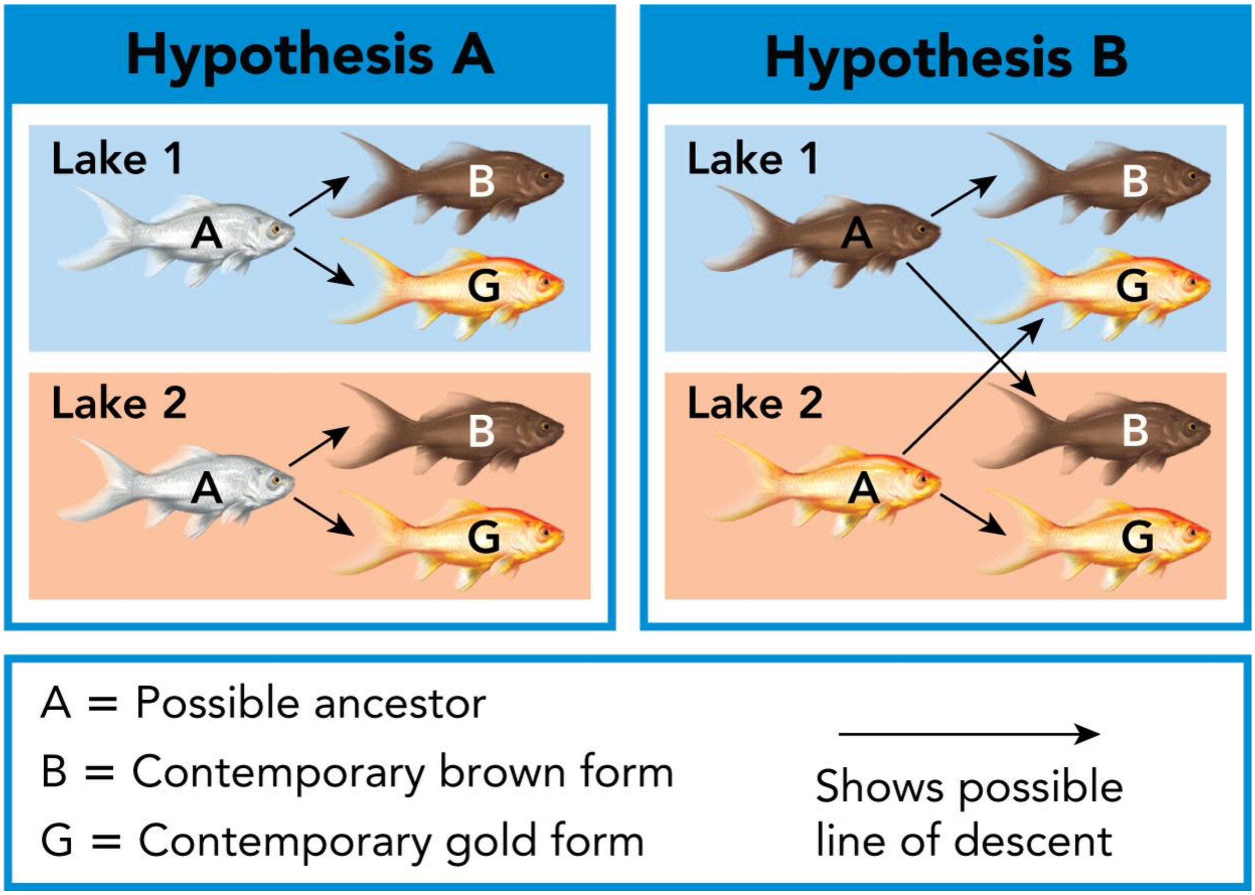


Image long description

Lake 1 - a silver colored form is the common ancestor to both the dull brown form and iridescent gold form in lake 1.	Lake 1 - a dull brown form is the common ancestor to the dull brown forms in Lake 1 and Lake 2.
Lake 2 - a silver colored form is the common ancestor to both the dull brown form and iridescent gold form in lake 2.	Lake 2 - an iridescent gold form is the common ancestor to the iridescent gold forms in Lake 1 and Lake 2.

37. **Use Models** Study the two diagrams. What does hypothesis A indicate about the ancestry of the fishes in Lake 1 and Lake 2? What does hypothesis B indicate?

NOTEBOOK

38. **Compare and Contrast** According to the two hypotheses, what is the key difference in the way the brown and gold fish populations might have formed?

NOTEBOOK

39. **Construct Explanations** A DNA analysis showed that the brown and gold fishes from Lake 1 are the most closely related. Which hypothesis does this evidence support?

NOTEBOOK

Use the data table to answer questions 40 and 41.

Year	Frequency of Allele B	Frequency of Allele b
1910	0.81	0.19
1930	0.49	0.51
1950	0.25	0.75
1970	0.10	0.90

40. **Interpret Data** Describe the trend shown by the data in the table.

NOTEBOOK

41. **Analyze Data** What might account for the trend shown by the data?

LANGUAGE ARTS CONNECTION

Write About Science

42. **Write Explanatory Texts** Write a paragraph to explain how reproductive isolation may lead to speciation. Include references to **Figure 18-8** to help support your explanation.

NOTEBOOK

43. **Draw Evidence** At least 13 species of finches live on the Galápagos Islands. Did a small population of finches colonize the islands, and then evolve into the 13 species? Write an argument for or against this conclusion. Draw evidence and use logical reasoning to support your answer.

NOTEBOOK

Read About Science

44. **Summarize Text** How can random events affect evolution?

End-of-Course Test Practice

This content is unavailable when printing.

1. The table provides information about a population in which natural selection acts on a single-gene trait.

1910	0.81	0.19
1930	0.49	0.51
1950	0.25	0.75
1970	0.10	0.90

2. What can be inferred from the information in the table?

A. Diversity in the gene pool increased over time.
B. Allele *B* was dominant in 1910 but became recessive over time.
C. The population was in genetic equilibrium during this time period.
D. The probability of genotype *Bb* increased over time.
E. The likelihood of surviving and reproducing became higher for individuals with Allele *b* than for individuals with Allele *B*.

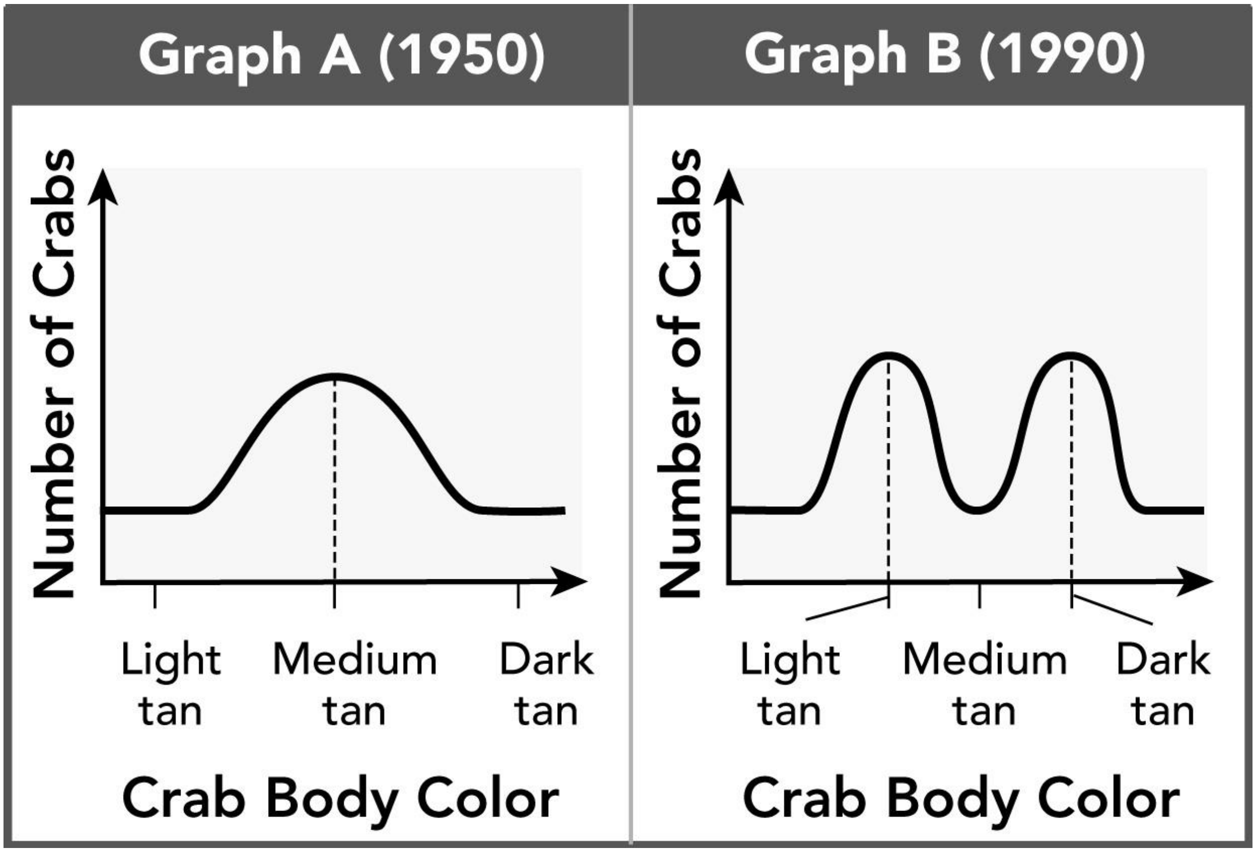
NOTEBOOK

3. Scientists want to estimate the time when two species began evolving separately from a common ancestor. What would be the most useful strategy for calculating this estimate?

A. comparing DNA sequences from each species for the same gene
B. comparing DNA sequences from each species for different genes
C. comparing the length, size, or weight of an average member of each species
D. identifying the traits of the common ancestor
E. identifying the genetic diversity of each species

NOTEBOOK

4. The graphs below show the changes in crab color at one beach.



Which of the following is most likely to have caused the change in the distribution?

A. A new predator arrived that preferred dark-tan crabs.
B. A new predator arrived that preferred light-tan crabs.
C. A change in beach color made medium-tan crabs the least visible to predators.
D. A change in beach color made medium-tan crabs the most visible to predators.
E. A change in beach color made light-tan crabs the most visible to predators.