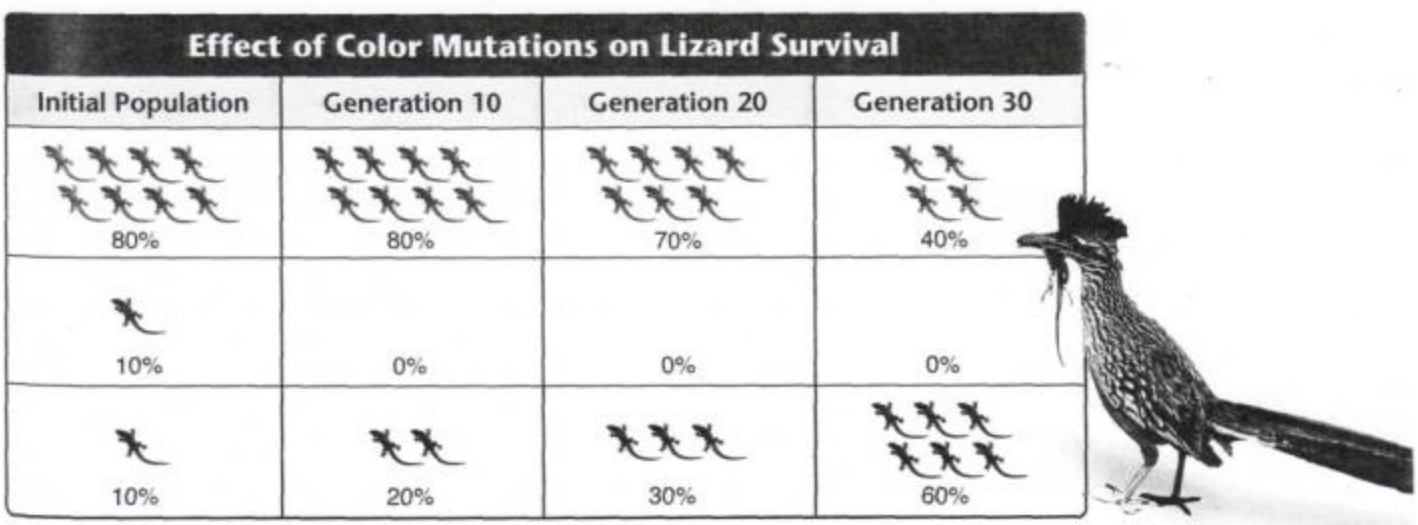
16-2 Evolution as Genetic Change

Standards: Bio 7a, Bio 8c

Vocabulary
directional selection, stabilizing selection, disruptive selection, genetic drift, founder effect, Hardy-Weinberg principle, genetic equilibrium

A genetic view of evolution offers a new way to look at key evolutionary concepts. Each time an organism reproduces, it passes copies of its genes to its offspring. We can therefore view evolutionary fitness as an organism's success in passing genes to the next generation. In the same way, we can view an evolutionary adaptation as any genetically controlled physiological, anatomical, or behavioral trait that increases an individual's ability to pass along its genes.

Natural selection never acts directly on genes. Why? Because it is an entire organism — not a single gene — that either survives and reproduces or dies without reproducing. Natural selection, therefore, can only affect which individuals survive and reproduce and which do not. If an individual dies without reproducing, the individual does not contribute its alleles to the population's gene pool. If an individual produces many offspring, its alleles stay in the gene pool and may increase in frequency. Now recall that evolution is any change over time in the relative frequencies of alleles in a population. This reminds us that it is populations, not individual organisms, that can evolve over time. Let us see how this can happen in different situations.



Black lizards, on the other hand, might absorb more sunlight and warm up faster on cold days. If high body temperature allows them to move faster to feed and to avoid predators, they might produce more offspring than brown forms. The allele for black color might then increase in relative frequency. If a color change has no effect on fitness, the allele that produces it would not be under pressure from natural selection.

Natural Selection on Polygenic Traits

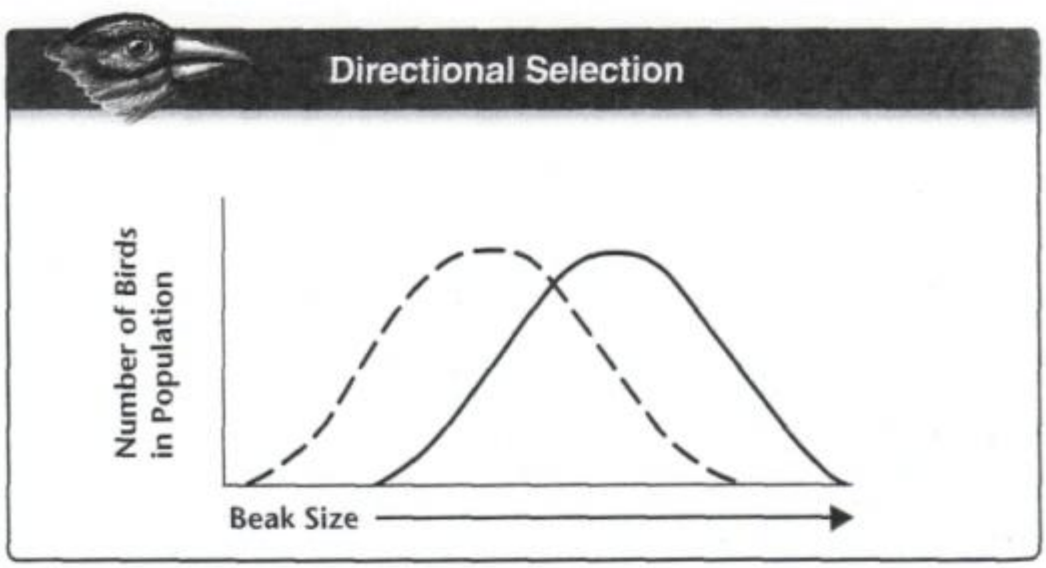
Natural selection on single-gene traits can lead to changes in allele frequencies and thus to evolution. Imagine that a hypothetical population of lizards, shown, is normally brown, but experiences mutations that produce red and black forms. What happens to those new alleles? If red lizards are more visible to predators, they might be less likely to survive and reproduce, and the allele for red coloring might not become common.

Variation and Gene Pools

When traits are controlled by more than one gene, the effects of natural selection are more complex. As you learned earlier, the action of multiple alleles on traits such as height produces a range of phenotypes that often fit a bell curve. The fitness of individuals close to one another on the curve will not be very different. But fitness can vary a great deal from one end of such a curve to the other. And where fitness varies, natural selection can act. **Natural selection can affect the distributions of phenotypes in any of three ways: directional selection, stabilizing selection, or disruptive selection.**

Directional Selection When individuals at one end of the curve have higher fitness than individuals in the middle or at the other end, **directional selection** takes place. The range of phenotypes shifts as some individuals fail to survive and reproduce while others succeed. To understand this, consider how limited resources, such as food, can affect the long-term survival of individuals and the evolution of populations.

Among seed-eating birds such as Darwin's finches, for example, birds with bigger, thicker beaks can feed more easily on larger, harder, thicker-shelled seeds. Suppose a food shortage causes the supply of small and medium-sized seeds to run low, leaving only larger seeds. Birds whose beaks enable them to open those larger seeds will have better access to food. Birds with the big-beak adaptation would therefore have higher fitness than small-beaked birds. The average beak size of the population would probably increase, as shown.

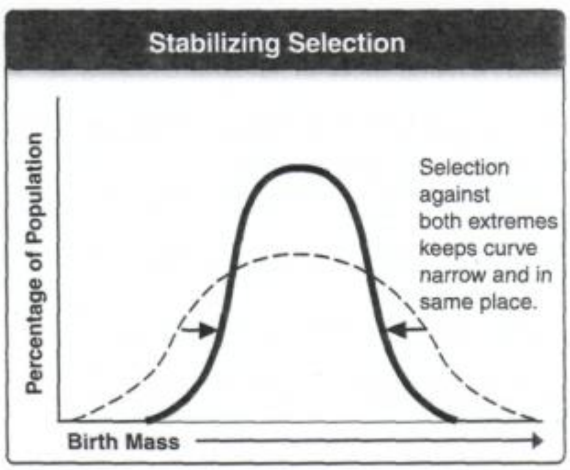


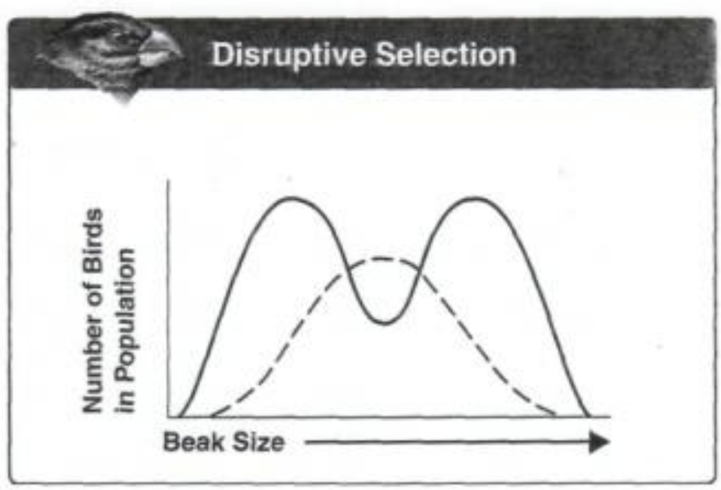
Stabilizing Selection When individuals near the center of the curve have higher fitness than individuals at either end of the curve, **stabilizing selection** takes place. This situation keeps the center of the curve at its current position, but it narrows the overall graph.

As shown in Figure 16-7, the mass of human infants at birth is under the influence of stabilizing selection. Human babies born much smaller than average are likely to be less healthy and thus less likely to survive. Babies that are much larger than average are likely to have difficulty being born. The fitness of these larger or smaller individuals is, therefore, lower than that of more average-sized individuals.

Disruptive Selection When individuals at the upper and lower ends of the curve have higher fitness than individuals near the middle, **disruptive selection** takes place. In such situations, selection acts most strongly against individuals of an intermediate type. If the pressure of natural selection is strong enough and lasts long enough, this situation can cause the single curve to split into two. In other words, selection creates two distinct phenotypes.

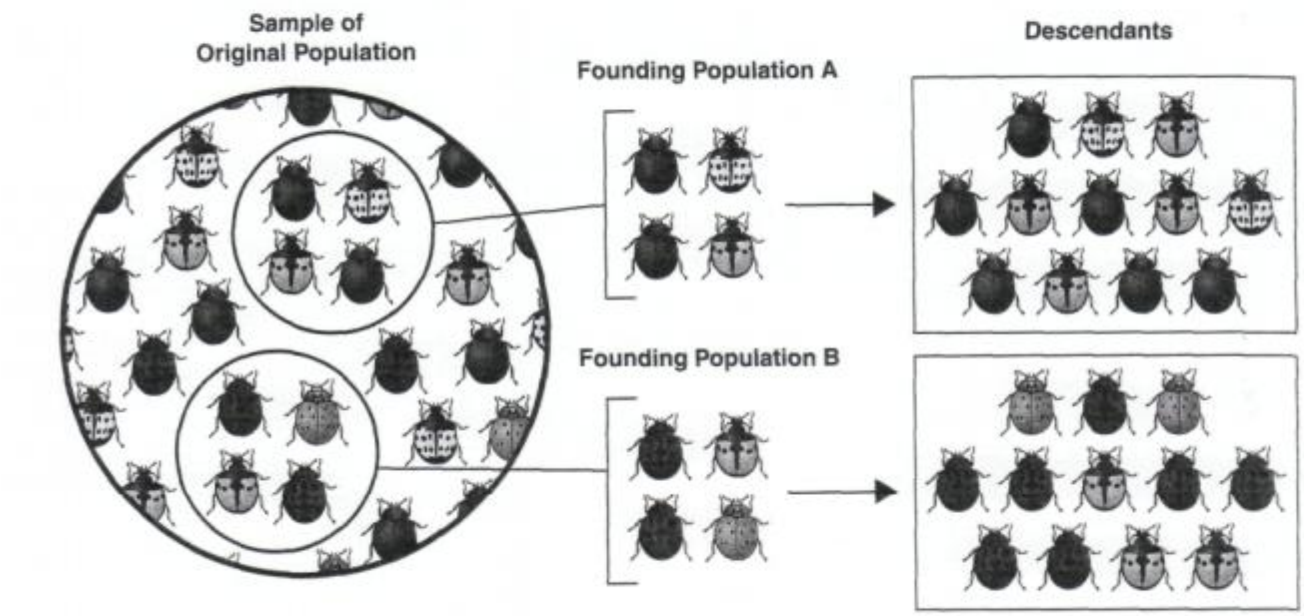
For example, suppose a population of birds lives in an area where medium-sized seeds become less common and large and small seeds become more common. Birds with unusually small or large beaks would have higher fitness. As shown in Figure 16-8, the population might split into two subgroups: one that eats small seeds and one that eats large seeds.





Genetic Drift

In small populations, an allele can become more or less common simply by chance, rather than because it has positive or negative effects on fitness. The smaller a population is, the greater the chance that it will experience this kind of random change in allele frequency. This kind of random change in allele frequency is called **genetic drift**. How does genetic drift take place? **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 of this type can cause an allele to become common in a population.**



Genetic drift may occur when a small group of individuals colonizes a new habitat. These individuals may carry alleles in different relative frequencies than did the larger population from which they came. If so, the population that they found will be genetically different from the parent population. Here, however, the cause is not natural selection but simply chance—specifically, the chance that particular alleles were in one or more of the founding individuals, as shown above. A 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**:" One example of the founder effect is the evolution of several hundred species of fruit flies found on different Hawaiian Islands. All of those species descended from the same original mainland population. Those species in different habitats on different islands now have allele frequencies that are different from those of the original species.

Hardy-Weinberg and Genetic Equilibrium

To clarify how evolutionary change operates, scientists often find it helpful to determine what happens when no change takes place. So biologists ask: Are there any conditions under which evolution will not occur? Is there any way to recognize when that is the case? The answers to those questions are provided by the Hardy-Weinberg principle, named after two researchers who independently proposed it in 1908.

The **Hardy-Weinberg principle** states that allele frequencies in a population will remain constant unless one or more factors cause those frequencies to change. The situation in which allele frequencies remain constant is called genetic equilibrium. If the allele frequencies do not change, the population will not evolve.

Under what conditions does the Hardy-Weinberg principle hold? **Five conditions are required to maintain genetic equilibrium from generation to generation: (1) There must be random mating: (2) the population must be very large; and (3) there can be no movement into or out of the population, (4) no mutations, and (5) no natural selection**.

In some populations and in rare situations, these five conditions may be met or nearly met for long periods of time. If, however, the conditions are not met, the genetic equilibrium will be disrupted, and the population will evolve.

Solving Problems Using Hardy-Weinberg

It turns out that the Hardy- Weinberg principle is based on an equation that allows us to check its predictions. That equation can also be used to calculate and predict the frequency of certain genotypes.

Imagine that you are a geneticist studying a trait controlled by two alleles, A and a. You know that these alleles follow rules of simple dominance. You survey a population for the trait, and discover that 4% of the population exhibits the phenotype produced by the homozygous recessive genotype aa. Fully 96% of the population is AA or Aa and exhibits the dominant phenotype. The Hardy-Weinberg equations represent the frequency of the dominant A allele asp and the frequency of the recessive a allele as q. The sum of the frequencies must always equal the entire population (100%). In mathematical form, this can be written as the equation:

$$p + q = 1$$

Recall from Chapter 11 , that any cross that involves these alleles can produce three possible genotypes: AA, Aa, and aa.

Now, when eggs and sperm are produced in members of this population, those gametes will carry these alleles in the same relative frequencies at which those alleles occur in the population. Thus, the relative frequency of eggs and sperm that carry the A allele will be equal to p, and the relative frequency of eggs and sperm that carry the a allele will be equal to q. The three types of zygotes produced by these eggs and sperm will have the same relative numbers as the individuals in the Punnett square.

Those numbers can be expressed by the following equation:

$$p^2 + 2pq + g^2 = 1$$

p^2 = frequency of AA homozygotes

2pq = the frequency of Aa heterozygotes

q^2 = the frequency of aa homozygotes

1 = the sum of frequencies of all genotypes (100%)

In a particular generation, we find that p = 0.8, and q = 0.2. How can you figure out the relative frequencies of AA, Aa, and aa individuals?

1. First, write the following equation:

$p^2 + 2pq + q^2 = 1$ (or $A^2 + 2Aa + a^2 = 1$)

2. Fill in the values.

(0.8)2 + 2(0.8 x 0.2) + (0.2)2 = 1

3. Calculate.

(0.8 x 0.8) + 2(0.16) + (0.2 x 0.2) = 1
0.64 + 0.32 + 0.04 = 1.00

4. Convert the fractions to percentages.

0.64 x 100 = 64%, so 64% is the frequency of homozygous dominant individuals (AA).
0.32 x 100 = 32%, so 32% is the frequency of heterozygous recessive individuals (Aa).
0.04 x 100 = 4%, so 4% is the frequency of homozygous recessive individuals (aa).

As long as the Hardy-Weinberg equilibrium conditions hold, neither the frequency of the genotypes nor the frequencies of the alleles (p and q) will change from generation to generation.

16-2 Section Assessment

1. Describe how natural selection can affect traits controlled by single genes.
2. Describe three patterns of natural selection on polygenic traits. Which one leads to two distinct phenotypes?
3. How does genetic drift lead to a change in a population's gene pool?
4. What is the Hardy-Weinberg principle?
5. You are studying a population of 100 people and discover that 36 of these people are ss for a genetic condition. Use the Hardy- Weinberg equation to figure out the frequencies of the S and s alleles. What are the frequencies of the SS, Ss, and ss genotypes?