Chapter 9

Evidence of Evolution

9.1 Mechanisms of Evolution

So far, we've seen how natural selection acts on organisms' traits—giraffe neck length, cheetah speed, peppered moth color, and so on. Traits are only part of the story, though, because what gets passed from parents to offspring are not traits—they are genes. A unification of modern genetics and Darwin's theory of evolution took place in the middle of the twentieth century and produced many new insights about how populations evolve.

Evolution and Genetics

Consider the peppered moths we discussed in Chapter 8. There, you learned that some peppered moths have light wings and others have dark wings. You also learned that, depending on the colors and conditions of the environment, one color pattern in peppered moths may be advantageous over the other. But how do genes determine the colors of peppered moths?

In peppered moths, there is a light color allele (*a*) and a dark color allele (*A*). The dark *A* allele is dominant over the light *a* allele. This means that *aa* moths have light wings, whereas *Aa* and *AA* moths have dark wings.

FIGURE 9.1

Natural selection acts on phenotype, not genotype. In the case of these two dark moths, it's the phenotype (dark wing color) that matters, not the genotype (AA versus Aa).

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We already know that natural selection, through the action of predators such as birds, can make a particular phenotype, or trait, advantageous in a peppered moth population. For example, you learned that in a non-polluted area, light wings are advantageous because moths with light wings are better camouflaged from birds. What does this means in terms of genes and alleles? If light wings are advantageous, then the light color allele *a* is advantageous in the population. If dark wings are advantageous, then the dark color *A* is advantageous.

Now let's think about all the wing color alleles in an entire population of peppered moths. In a population with many light moths and fewer dark moths, we might see that overall, the population has 92% *a* alleles and 8% *A* alleles. We use the term *allele frequency* to describe how common different alleles are in a population. This population has allele frequencies of 92% *a* alleles and 8% *A* alleles.

If this population's habitat became more polluted, dark moths would become more common, and the dark allele would increase in frequency. The allele frequencies might change to 5% *a* and 95% *A*. The evolution of that population over time is seen in the changing of allele frequencies.

We can look again at natural selection and evolution and describe these processes in terms of genetics. Remember from Chapter 8 that the key features are genetic variation, natural selection, and evolution:

1. *Genetic variation*. Genetic variation exists when there are multiple alleles for a gene within a population. For example, in peppered moths, there are two alleles for color, *a* and *A*.

2. *Natural selection*. A specific allele may give an organism an advantage that allows it to reproduce more than other organisms in the population. In a polluted habitat, for example, the *A* allele is advantageous. In an unpolluted habitat, on the other hand, the *a* allele is advantageous.

3. *Evolution*. As a result of natural selection, more copies of the advantageous allele are passed to the next generation, and the frequency of the advantageous allele increases in the population. In a polluted habitat, the frequency of the *A* allele increases. In an unpolluted habitat, the frequency of the *a* allele increases.

Notice that, although natural selection *affects* genes and allele frequencies, natural selection does not act *directly* on genes. Here's another way to say this: Natural selection acts on an organism's phenotype (its traits), not on its genotype (its genes). To see why, go back to the peppered moth. In peppered moths, the dark allele (*A*) is dominant and the light allele (*a*) is recessive. This means that both *AA* moths and *Aa* moths have dark wings (Figure 9.1). Whether a bird is likely to eat the moth depends on the moth's phenotype (whether it is dark or light), not its genotype. A bird is equally likely to eat a dark moth whether it has genotype *AA* or *Aa*.

Natural selection is the driving force behind evolution, and it causes populations to become adapted to their environments. However, natural selection is not the only mechanism that causes populations to evolve. Populations also change over time because of mutation pressure, genetic drift, and gene flow. In order to understand these other mechanisms of evolution, let's consider each using the example of peppered moths again.

Mutation Pressure

Remember that an allele is a version of a gene—in other words, it is a specific sequence of nucleotides within an organism's DNA. Any gene can mutate. This happens when the sequence of nucleotides is altered, sometimes due to environmental factors and sometimes spontaneously due to errors in the copying of DNA.

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Thus, it is possible for a dominant allele to mutate into a recessive allele, and vice versa.

Mutation pressure exists if an allele is more likely to mutate in one direction than the other. For example, a genetic mutation may be more likely to turn a dark allele into a light allele than vice versa. That is, an *A* allele is more likely to mutate into an *a* allele than the other way around. If this is the case, then over time the frequency of the dark allele *A* will decrease, and the frequency of the light allele *a* will increase.

Genetic Drift

Genetic drift is the evolution of populations due to chance. Imagine a half-polluted town where light moths and dark moths are equally successful—neither allele is advantageous in this town. Now suppose a sudden storm wiped out part of the town's peppered moth population. It *just might happen*—just by chance—that more dark moths survive. If so, then the frequency of the dark allele will increase. Notice that genetic drift produces evolution (inherited changes in a population over time) but that this evolution is not the result of natural selection—the dark allele was not advantageous.

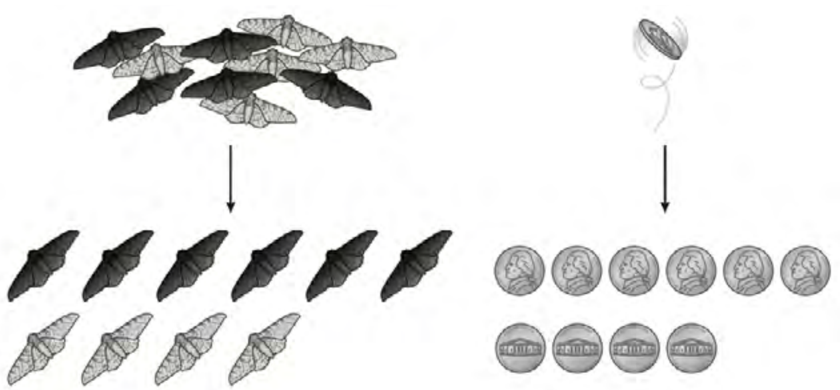

FIGURE 9.2
If light and dark moths have equal fitness, we would expect them to leave the same number of offspring. However, just by chance, one group could leave more offspring than the other, resulting in genetic drift. This is true for the same reason that, even though you expect the same number of heads and tails when you flip a coin 10 times, you might get more heads or more tails.

Genetic drift can also occur when, just by chance, more alleles of one type are transmitted to the next generation than alleles of the other type. For example, even if light and dark moths have equal fitness, light moths might just happen to leave more offspring (and therefore more light alleles) one year. Genetic drift works a lot like a coin flip (Figure 9.2). In our imaginary town, light and dark moths are equally likely to survive and reproduce the same way you are equally likely to get heads or tails when you flip a coin. But, if you flip a coin 100 times, you won't always get *exactly* 50 heads and 50 tails. Similarly, of 100 moths born in the next generation, there won't necessarily be *exactly* 50 light ones and 50 dark ones.

Genetic drift is particularly important in small populations because chance is more likely to change allele frequencies significantly in a small population. To see why, consider flipping a coin 10 times (a small population) versus 1000 times (a large population). With 10 flips, it is not at all unlikely that you'll get heads 60% of the time—that is, 6 heads and 4 tails. On the other hand, a similar result with 1000 flips—600 heads and 400 tails—is most unlikely.

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Gene Flow

Gene flow describes changes in allele frequencies that result from a net movement of alleles into or out of a population. For example, our half-polluted town may be next to a woodland that is home to a population of light moths. If a few of these light moths migrate from the woodland into town, the frequency of the light allele in the town will increase.

Where Genetic Variation Comes From

Natural selection cannot happen without genetic variation. Furthermore, populations with more variation have a better chance of adapting to a changing environment. This is because in a population with more genetic variation, it is more likely that there are alleles that will allow some individuals to survive under the new conditions. For instance, what would have happened to peppered moths during the Industrial Revolution if all the moths had been light and none were dark? In polluted areas, populations with only light moths might have died out.

But where does genetic variation come from? An understanding of genetics enabled biologists to answer this question. Genetic mutations constantly create new variations within populations. For example, when a genetic mutation changes the amino acids in a protein, it may produce a new allele for a given gene. Sexual reproduction also contributes to variation by bringing together alleles for different traits in new combinations. Then, any of the mechanisms of evolution—natural selection, mutation pressure, genetic drift, or gene flow—may affect whether that new allele becomes more or less common in the population.

READING CHECK

1. **In a peppered moth population, genetic drift causes the frequency of the dark allele to increase one year. Will genetic drift also cause the frequency of the dark allele to increase the following year?**

2. **Twenty dark moths migrate into a peppered moth population, and 30 light moths migrate out. What effect does gene flow have on this population?**

CHECK YOUR ANSWERS

1. Genetic drift is evolution due to chance, and there is no guarantee that chance will have the same effect the following year. The situation is the same as flipping coins—when you flip a coin 100 times and then do it again, you may get more heads the first time and more tails the second time.

2. Gene flow causes the frequency of the dark allele to increase in this population.

To read more about the mechanisms of evolution, check out this website:

https://evolution.berkeley.edu/evolibrary/article/evo_14

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