Variation and Adaptation

Natural selection can only take place if there is **variation**, or differences, among individuals in a population. Importantly, these differences must have some genetic basis; otherwise, selection will not lead to change in the next generation. This is critical because variation among individuals can be caused by non-genetic reasons. For example, when it comes to variation in height, environmental factors such as better nutrition can also have an impact on this characteristic.

Genetic diversity in a population ultimately comes from mutation. **Mutation**, a change in DNA, is the ultimate source of new alleles or new genetic variation in any population. An individual that has a mutated gene might have a different trait than other individuals in the population. However, this is not always the case. A mutation can have one of three outcomes on the organisms' phenotype:

- A mutation may affect the phenotype of the organism in such a way that it reduces fitness. In an evolutionary context, fitness is a relative measure of how well individuals with a certain trait will survive and produce viable offspring relative to other traits.
- A mutation may produce a phenotype with a beneficial effect on fitness.
- Many mutations, called neutral mutations, will have no effect on fitness.

When a heritable trait that aids the survival and reproduction of an organism in its present environment becomes more frequent in a population, that is called an **adaptation**. For example, camouflage coloration patterns are adaptations. Frogs that can blend into their environment have a better chance of avoiding predation. Survival means a greater chance to reproduce and pass those heritable traits onto the next generation. Slight variations still often exist amongst the color patterns, however. This means that depending on the environmental conditions, different phenotypes can be favored at any given time.

Whether or not a trait is favorable depends on the environment at the time. The same traits do not always have the same relative benefit or disadvantage because environmental conditions can and often do change. For example, finches with large bills were benefited in one climate, while finches with small bills were at a disadvantage. In a different climate, the relationship may be reversed.

Patterns of Evolution

The evolution of species has resulted in enormous variation in form and function. When two species evolve in different directions from a common point, it is called **divergent evolution**. This process can be seen in the shape of a flowering plant's reproductive organs. Although they share the same basic anatomical organs, these organs can look very different because of divergent evolution (Figure 11.6). One cause of divergent evolution is when populations or species are found in different environments. Because the conditions are different in each environment, natural selection will favor different traits in each.

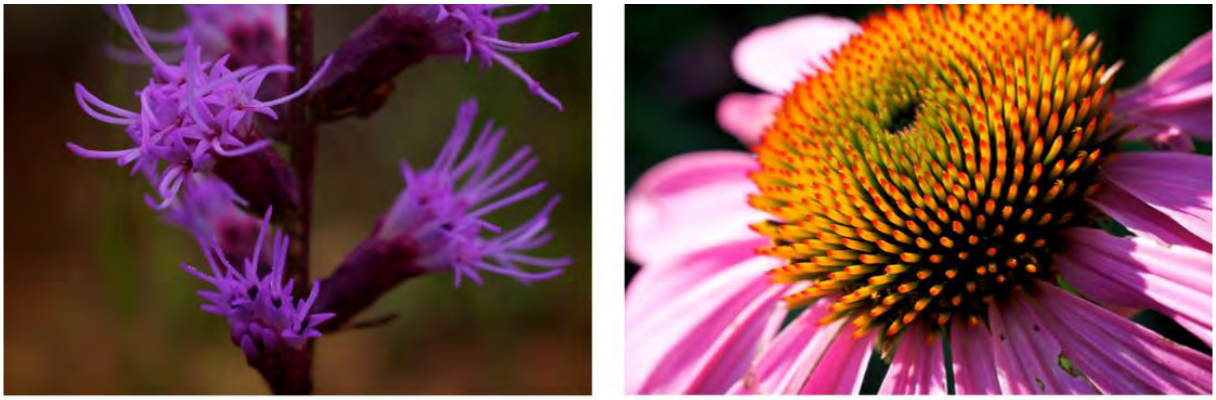

Figure 11.6 Flowering plants evolved from a common ancestor. Notice that the (a) dense blazing star and (b) purple coneflower vary in appearance, yet both share a similar basic morphology. (credit: modification of work by Cory Zanker / Concepts of Biology OpenStax)

In other cases, similar phenotypes evolve independently in distantly related species. For example, flight has evolved independently in both bats and insects. Both have structures that we refer to as wings, which are adaptations to flight. The wings of bats and insects, however, evolved from very different structures and as a result are quite different. For example, the wings of insects do not have bones, but the wings of bats do. When similar structures arise through evolution independently in different species it is called **convergent evolution**. The wings of bats and insects are called **analogous structures**; they are similar in function and appearance, but they were not inherited from a recent common ancestor. Instead, they evolved independently in two separate lineages. The wings of a hummingbird and an ostrich are homologous structures. **Homologous structures** are inherited from a common ancestor. As a result, they share similarities even though they look and function very different. Their differences result from divergent evolution.

The Modern Synthesis

The mechanisms of inheritance and genetics were not understood at the time when Darwin and Wallace were developing their idea of natural selection. This lack of understanding was a stumbling block to comprehending many aspects of evolution. In fact, blending inheritance was the predominant (and incorrect) genetic hypothesis at that time. This made it difficult to understand how natural selection might operate. Darwin and Wallace were unaware of the work done by Gregor Mendel on inheritance, which was published in 1866, not long after publication of *On the Origin of Species*. Mendel's work was rediscovered in the early twentieth century, and it was at this time geneticists began to understand the basics of inheritance. Initially, the newly discovered nature of genes made it difficult for biologists to understand how gradual evolution could occur. However, over the next few decades genetics and evolution were integrated in what became known as the modern synthesis. The **modern synthesis** describes how evolutionary pressures, such as natural selection, can affect a population's genetic makeup, and, in turn, how this can result in the gradual evolution of populations. The theory also connects the gradual change of a population over time, called **microevolution**.

Sometimes major evolutionary events happen at the level of the individual species, a concept called **macroevolution**. Major evolutionary events can lead to **speciation** events, the formation of two species from one original species. For speciation to occur, two new populations must be formed from one original population, and they must evolve in such a way that it becomes impossible for individuals from the two new populations to interbreed. Biologists have proposed mechanisms by which this could occur that fall into two broad categories. **Allopatric speciation**, meaning speciation in "other homelands," involves a geographic separation of populations from a parent species and subsequent evolution. **Sympatric speciation**, meaning speciation in the "same homeland," involves speciation occurring within a parent species while remaining in one location.

Population Genetics

Recall that a gene may have several different versions, or alleles, that code for different traits associated with that characteristic. For example, blood type in humans is determined by three different alleles: I^A, I^B, and I^0. For diploid organisms, each individual in a population can only carry two alleles for a particular gene, even though there may be more than two alleles present in the population. Mendel followed alleles as they were inherited from parent to offspring. In the early twentieth century, biologists began to study what happens to all the alleles in a population over time. This field of study is known as **population genetics**. Using human blood-type as an example, the frequency of one of the alleles, I^A, is the number of copies of that allele divided by all the copies of the gene in the population. For example, a study in Jordan found the frequency of I^A to be 26.1 percent.[3] The frequency of I^B and I^0 alleles made up 13.4 percent and 60.5 percent of the alleles respectively. All three frequencies together add up to 100 percent. A change in these frequencies over time would constitute an evolutionary change in the population.

There are several ways the allele frequencies of a population can change. One of those ways is natural selection. If a given allele results in a phenotype that allows an individual to have more offspring that survive and reproduce, that allele, by virtue of being inherited by those offspring, will be in greater frequency in the next generation. Since allele frequencies always add up to 100 percent, an increase in the frequency of one allele always means a corresponding decrease in one or more of the other alleles. Highly beneficial alleles may, over a very few generations, become "fixed." If an allele becomes "fixed," it means that every individual of the population will carry that allele. Similarly, detrimental alleles may be swiftly eliminated from the gene pool. The **gene pool** represents the sum of all the alleles in a population.

Part of the study of population genetics is tracking how selective forces change the allele frequencies in a population over time. This can give scientists clues regarding the selective forces that may be operating on a given population. For example, as the Industrial Revolution caused trees to darken from soot, darker colored peppered moths were better camouflaged than the lighter colored moths. The dark colored peppered moths were predated less, had more reproductive success, and passed on their dark color traits to their offspring more often than their lighter colored counterparts. This event led to a shift in color within this population. The changes in wing coloration in the peppered moths is a classic example of studying evolution in natural populations (Figure 11.7).