Guide For Reading

- What is a niche?
- How do new species develop from existing species?
- What are the results of divergent evolution? Of convergent evolution?

14–4 The Development of New Species

We are now nearly ready to explain how new species evolve from old ones, a process biologists call **speciation**. But before we can explain how speciation occurs and how it can lead to diversity, we must first understand some basic concepts about the way species interact in their environment.

The Niche: How to Make a Living

Organisms, like members of a human community, need to survive and acquire the necessities of life. But like people crowded into a city, organisms would have difficulty surviving if they all tried to do the same kinds of work, eat the same kinds of food, and live in the same place. Isn't it hard to imagine, for example, an entire city of butchers or tailors? And certainly you wouldn't want the population of an entire city living in your house!

In human cities, thousands of people survive near one another. They have different jobs, they shop in different stores, and they live in different places. Animals and plants do much the same thing. The combination of an organism's "profession" and the place in which it lives is called its **niche** (NIHCH). If two species occupy the same niche in the same location at the same time, they will compete with each other for food and space. One of the species will not survive. **No two species can occupy the same niche in the same location for a long period of time.** Chances are, one of the species will be more efficient than the other. The more efficient species will survive, reproduce, and drive the less efficient species to extinction.

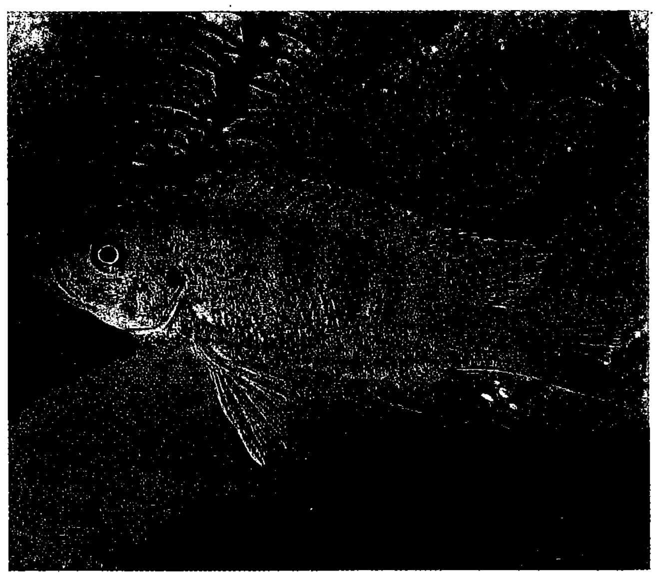


Figure 14–15 *Reproductive isolation can lead to the development of a new species. The fish on the left is a member of the same species as the fish on the right, although it is quite different in appearance. In time, if it is reproductively isolated, it may evolve into another species.*

If two species occupy different niches, however, they will not compete with each other as much. With less competition, there is less chance that one species will cause the other to become extinct. So in the evolutionary struggle for existence, any species (or a population within a species) that occupies an unoccupied niche will be better able to survive. We will soon see how this phenomenon can lead to the formation of entirely new species.

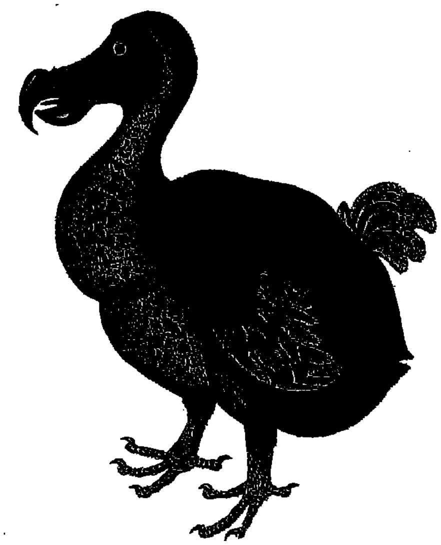


Figure 14–16 *Hundreds of years ago, the dodo was quite common on the island of Mauritius. This large bird, unable to fly, made its nest on the ground. In time, settlers arrived with dogs and other domestic animals. The helpless dodos were killed and their nests destroyed. The expression "dead as a dodo" is used today to refer to any organism that is now extinct.*

The Process of Speciation

Remember that biologists define a species as a group of organisms that can breed with one another and produce fertile offspring in a natural environment. This definition means that individuals in the same species share a common gene pool. Individuals in different species have different gene pools.

One of the most common ways in which new species form is when populations are separated. The separation of populations so that they do not interbreed is called **reproductive isolation.** If a species is divided into two isolated populations, natural selection can work differently on each group. Because their gene pools are separate, adaptations that appear in one group are not passed to the other, and two distinct species may develop.

Reproductive isolation may occur in a variety of ways. Geographic barriers such as rivers, mountains, and even roads may separate populations and prevent them from interbreeding. Differences in courtship behavior or fertile periods may result in organisms that breed only with individuals that are most similar to themselves.

Once reproductive isolation occurs, natural selection usually increases the differences between the separated populations. As the populations become better adapted to different

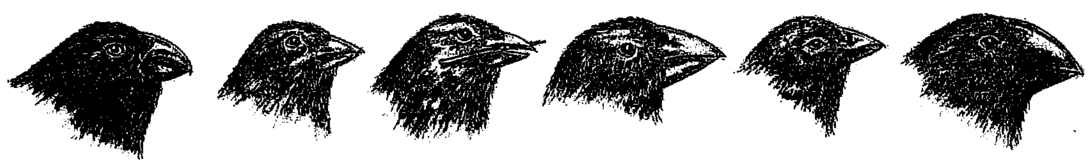
Figure 14–17 *The male bower bird builds a nest, or bower, on the ground to entice females to mate with him. Males compete for females by decorating their bowers with shiny, colorful objects such as shells, flowers, and bits of paper. The bower that attracts the most females earns the greatest reproductive success for its maker. Because different species of bower birds build different types of bowers, this mating behavior helps to ensure reproductive isolation between species.*

environments, their separate gene pools gradually become more dissimilar. Now the populations are separated not only by the physical or behavioral barriers that once separated them, but by vastly different genes. If the populations remain separated for a long time, their gene pools eventually become so different that their reproductive isolation becomes permanent. When this occurs, the groups of organisms are no longer separate populations. They have become separate species.

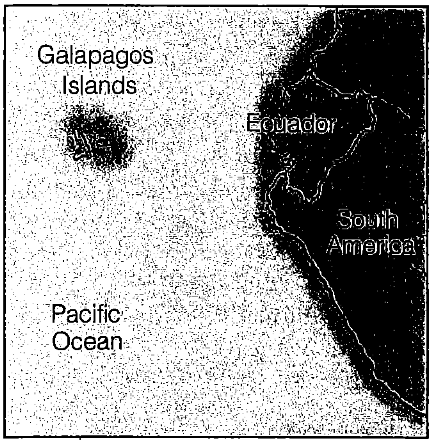
Darwin's Finches: An Example of Speciation

We can now use our understanding of evolution to explain the fascinating case of Darwin's finches, a group of 13 bird species on the Galapagos Islands. All these finch species evolved from a single ancestral species. Yet each of the 13 species exhibits body structures and behaviors that enable it to live in a different niche. For example, each species shows adaptations that allow it to feed differently. Some of the finch species eat small seeds, whereas others crack open much larger seeds or seeds with thicker shells. Some species pick ticks—small insectlike animals—off the islands' tortoises and iguanas. One finch species uses twigs or cactus spines to remove insects from inside dead wood. And some finches, often called vampire finches, drink the blood of large sea birds after pecking them at the base of their tail! How did so many strange and unusual finch species evolve on these islands? The evolution of the various species of finches on the Galapagos Islands shows how geographic and behavioral barriers and reproductive isolation eventually lead to the formation of new species.

__Figure 14–18__ The many kinds of finches that Darwin observed on the Galapagos Islands evolved from a single species that emigrated from the South American mainland some kilometers away. How have the shapes of these birds' beaks contributed to their survival?



Name	Vegetarian tree finch	Large insectivorous tree finch	Woodpecker finch	Cactus ground finch	Sharp-beaked ground finch	Large ground finch
Shape of Bill	Parrotlike bill	Grasping bill	Uses cactus spines	Large crushing bill	Pointed crushing bill	Large crushing bill
Main Food	Fruit	Insects	Insects	Cactus	Seeds	Seeds
Habitat	Trees	Trees	Trees	Ground	Ground	Ground



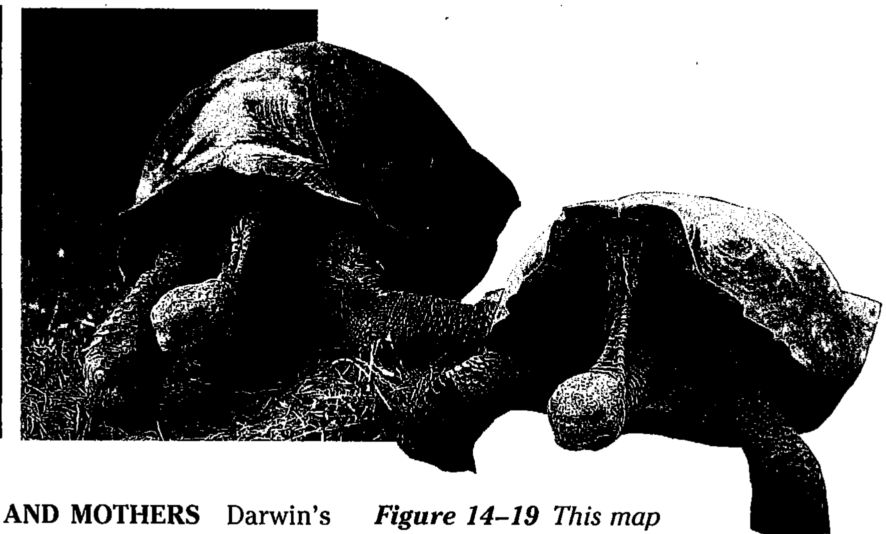


Figure 14–19 *This map shows the location of the Galapagos Islands off the coast of Ecuador (left). Variation exists even among the giant tortoises that live on the Galapagos Islands. The shell of one type of tortoise is raised in the front (right), enabling it to lift its head farther off the ground than the tortoise with a shell rounded in the front (center). How does the shell shape contribute to the survival of each tortoise?*

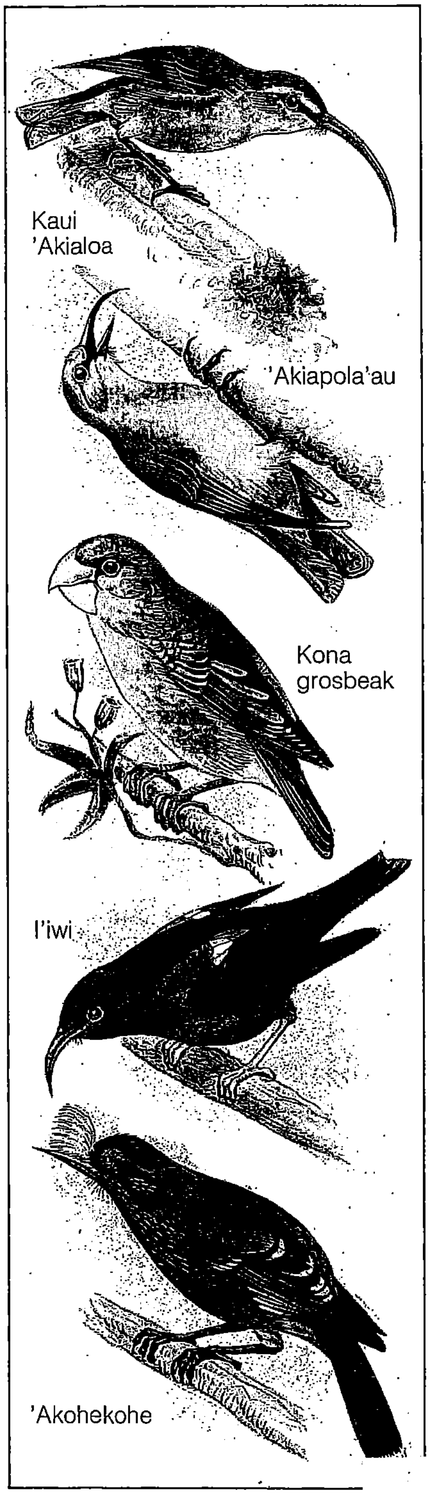
STEP 1: FOUNDING FATHERS AND MOTHERS Darwin's finches are descendants of a few ancestral finches that found their way to the Galapagos Islands from the South American mainland. Finches are small birds that do not usually fly far over open water. They may have gotten lost, or they may have been blown off course by a storm. In any case, once they arrived at one of the Galapagos Islands, which we can call Island A, they managed to survive and reproduce.

STEP 2: SEPARATION OF POPULATIONS Then, some birds from Island A crossed to another island in the Galapagos group. We will call this Island B. Remember, these birds do not like to fly over open water. So the populations on Islands A and B were essentially isolated from each other. Even though they were still members of the same species, the ocean between them prevented the blending of their gene pools.

STEP 3: CHANGES IN THE GENE POOL Over time, the populations on each island became adapted to the needs of their environments. For example, suppose the plants growing on Island A produced mainly small thin-shelled seeds, whereas the plants on Island B had larger thick-shelled seeds. Individual finches in the Island B population with larger, heavier beaks would be able to crack open and eat the seeds more easily. So birds with large beaks would be better able to survive on Island B. Over time, natural selection could have caused that population to evolve larger beaks.

STEP 4: REPRODUCTIVE ISOLATION Now imagine that a few birds from Island A cross to Island B. Will the birds from Island A be able to breed with the birds on Island B? Probably not. It happens that the finches prefer to mate with birds that have the same size beak they do. Thus differences in beak size, combined with mating behavior, act as a mechanism for reproductive isolation. The gene pools of the two bird groups do not mix. The two populations have become separate species.

Figure 14–20 Five million years of adaptive radiation in Hawaiian honeycreepers resulted in a wide array of beak shapes and as many as 43 species. Human actions have resulted in the extinction of most of these species.



STEP 5: SHARING THE SAME ISLAND The fate of the two species on Island B depends on the relationship between the birds and their environment. There are three possibilities: coexistence, extinction, or further evolution. If the two species occupy different niches, they can coexist, or live together without changing. But if the niches of the species are too similar, the species will compete with each other. If one species is much better at making a living than the other, it may cause its competitor to become extinct.

If, however, one species exhibits enough genetic variation, the competition it encounters may cause it to evolve further. A new species may result. For example, if the species' beak changes size again, it will be able to eat another kind of food for which it does not have to compete. Scientists believe that the 13 species of finches on the Galapagos Islands evolved from a single ancestor when speciation happened in this way again and again on different islands over time.

Speciation and Adaptive Radiation

The process we have just described on the Galapagos Islands, in which one species gives rise to many species, is called **adaptive radiation.** The process of adaptive radiation is also known as **divergent evolution.** In adaptive radiation, a number of different species diverge, or move away, from a common ancestral form, much as the spokes of a bicycle wheel radiate from the hub. During a period of adaptive radiation, organisms evolve a variety of characteristics that enable them to survive in different niches. Throughout the history of life on Earth, adaptive radiations have occurred many times and in many places. Adaptive radiation occurred on the Hawaiian Islands among a group of birds called Hawaiian honeycreepers. The dinosaurs experienced an adaptive radiation in their day, only to eventually become extinct. The mammals alive today were produced by another wave of adaptive radiation.

Evidence of past adaptive radiations can be observed in many organisms. The homologous structures discussed in the last chapter are evidence of past adaptive radiations in which the similar body parts of related organisms evolved to perform different tasks.

Adaptive radiations among different organisms often produce species that are similar in appearance and behavior. This phenomenon is known as **convergent evolution.** Convergent evolution has produced many of the **analogous structures** in organisms today. Analogous structures are similar in appearance and function, but they have different origins. Because they have different origins, analogous structures usually have very different internal structures. For example, the wings of butterflies, birds, and bats are analogous structures that allow the organisms to fly. However, a closer examination of these wings shows that a butterfly's wing is made of a thin nonliving membrane with an intricate network of supports. A bird's wing is made of skin, muscles, and arm bones. And a bat's wing is made of skin stretched between elongated finger bones.

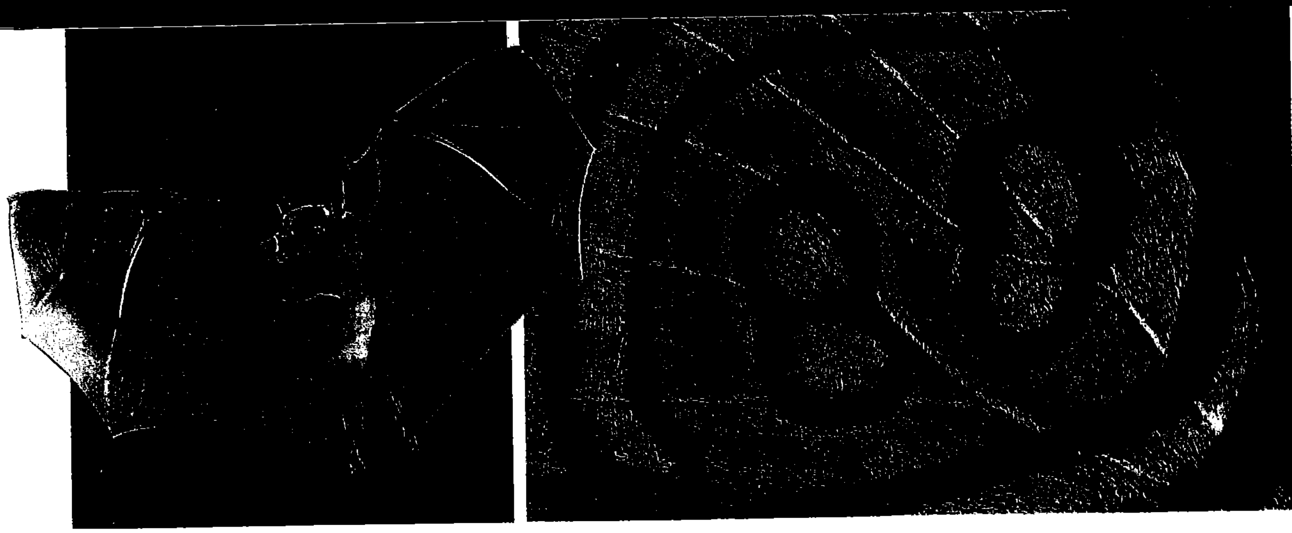


Figure 14–22 The wings of a butterfly and the wings of a bat are analogous structures—similar in appearance and function. Although the wings of both the butterfly and the bat show adaptations for flight, they are made up of different tissues.

14–4 SECTION REVIEW

1. What is a niche? How do niches contribute to speciation?
2. How are speciation and reproductive isolation related?
3. What is adaptive radiation? Explain how Darwin's finches illustrate this process.
4. **Critical Thinking—Identifying Patterns** The first species to reach a newly formed volcanic island often undergoes an adaptive radiation. Explain this observation.

Guide For Reading

- How can evolution occur in the absence of natural selection?
- What are some phenomena that affect the pace of evolution?
- What is the theory of punctuated equilibria?

14–5 Evolutionary Theory Evolves

It should now be apparent to you that evolutionary theory has been modified over the years. With the contributions of scientists such as Lamarck and Darwin and a better understanding of heredity, scientists can now explain how variation occurs and define evolutionary concepts in terms of genetics. But even today, evolutionary theory continues to evolve as scientists formulate theories about the details of evolutionary change.

Genetic Drift

Natural selection is not always necessary for genetic change to occur. **With the aid of theories and genetic experiments, biologists have realized that gene pools can change —in other words, evolution can occur—in the absence of natural selection.** This does not mean that natural selection is not important. However, biologists now realize that chance plays an even larger part in evolutionary change than Darwin thought.

Quick Lab

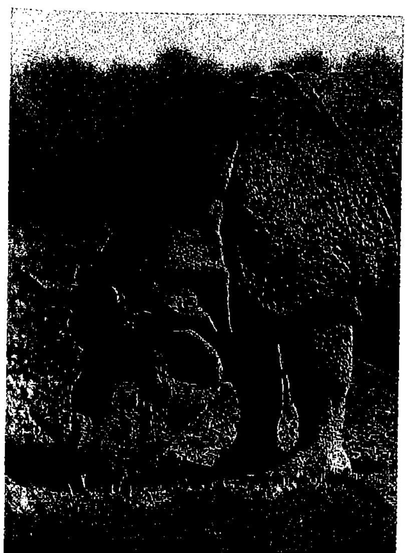
To reinforce the **Main Idea** of evolutionary change, perform the Quick Lab activity called Modeling Genetic Drift on p. 1088.

Geneticists have shown that an allele can become common in a population by chance. This kind of random change in the frequency of a gene is called **genetic drift**.

How does genetic drift work? One possibility is that an individual with a particular allele may produce more offspring than other members of its species—not because it is better adapted but just by chance. It is also possible for environmental events to wipe out many individuals who do not carry a particular allele. For example, the distribution of some alleles in the population of mountain goats in Washington State may have changed when Mount St. Helens erupted in 1980, killing many mountain goats in the area of the volcano. Thus, in very special circumstances, a new or previously rare allele may become common in a population after only a few generations. Genetic drift occurs most efficiently in small populations because chance events, such as a volcanic eruption, are less likely to affect all members of a very large population. Genetic drift could also have played a role in the evolution of Darwin's finches, since each new population was founded by relatively few birds.

Genetic drift implies that all characteristics of an organism do not have to contribute to its fitness. For example, consider the differences between the Indian rhinoceros (which has one horn) and the African rhinoceros (which has two). Both rhinoceros species use their horns to fight predators and to joust among themselves, so having a horn or two is useful. But it is not clear whether having two horns is better for survival than having one horn. If the two types of rhinoceros lived in the same area, the rhinoceros with one horn would probably have the same fitness as the rhinoceros with two horns. Thus the extra horn does not necessarily contribute to fitness. Most likely, the ancestral populations that gave rise to the two modern rhinoceros species developed slightly different horn systems just by chance. Natural selection provided a distinct advantage to individuals with horns; but the two populations developed different numbers of horns because of random genetic drift. Genetic drift probably led also to the evolution of one hump on African camels and two humps on Asian camels.

Figure 14–23 *Natural disasters such as the explosive eruption of Mount St. Helens may drastically shrink a gene pool by killing many individuals and restricting gene flow among the survivors. Such chance events may set the stage for genetic drift.*



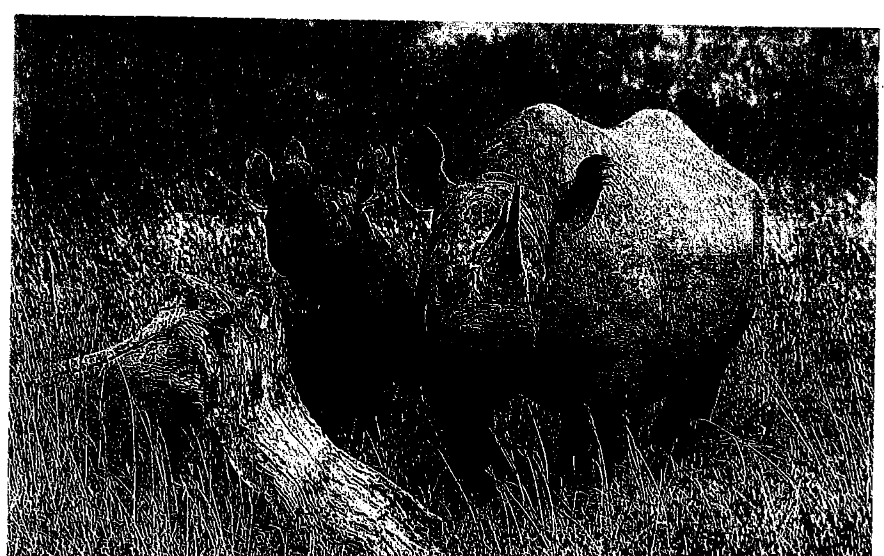


Figure 14–24 *The Indian rhinoceros (left) has a single horn; the African rhinoceros (right) has two. The number of horns may not contribute to survival, since one horn is as good as two in defending animals as grand as these.*

Figure 14–25 This plant-eating dinosaur, which once munched plants on ancient Earth, is today extinct. The environment on Earth changed, but, alas, the dinosaur did not.

Unchanging Gene Pools

Modern evolutionary biologists recognize that although natural selection and genetic drift are both powerful forces of change, they do not cause genetic alterations in all species all the time under all conditions. And because sexual reproduction by itself does not change the frequency of alleles in a population, it is possible for the gene pool of a species to remain the same for a long time.

Every now and then there arises a species, particularly well adapted to an environment, that does not change over time. If no new species enter into competition with that species and if certain other conditions are met, that species may remain nearly unchanged for long periods of time. One example of such a species is the horseshoe crab, *Limulus*, whose living members are nearly identical to ancestors that lived hundreds of millions of years ago. Such organisms are often called living fossils. Though relatively rare among both plants and animals, living fossils are fascinating indications that under some conditions evolution can slow down.

Gradual and Rapid Evolutionary Change

Darwin, convinced by the work of Lyell of the slow and steady nature of geologic change, felt that biological change was also slow and steady. The theory that evolutionary change occurs slowly and gradually is known as **gradualism**. In many cases the fossil record shows that a particular group of organisms has indeed changed gradually over time.

But there is also evidence that many other species did not change very much from the time they appeared in the fossil record to the time they disappeared. In other words, much of the time these groups of animals and plants are in a state of **equilibrium** (ee-kwih-LIHB-ree-uhm), which means they do not change very much.

But every now and then, something happens to upset the equilibrium. At several points in the fossil record, changes in animals and plants occurred over relatively short periods of time. Some biologists argue that these rapid changes—rather than long, slow changes—are what create new species. Remember that when we say "short" and "rapid" we are talking about the geological time scale. Short periods of time for geologists can be hundreds of thousands, even millions, of years!

Rapid evolution after long periods of equilibrium can occur in several ways. It may occur when a small population of a species becomes isolated from the main part of the population. This small population can evolve more rapidly than the larger one because genetic changes can spread more quickly among fewer individuals. Or rapid evolution may occur when a small group of organisms migrates to a new environment, as happened with the Galapagos finches. The organisms then evolve rapidly to fill available niches.

Rapid evolution may also result from dramatic changes on the Earth. Every now and then, many species have vanished in a phenomenon known as a **mass extinction**. Some mass extinctions were caused by changes in global climates that altered many environments. The causes of other mass extinctions remain uncertain. But whatever their causes, the effects of mass extinctions are clear. When many species die, many niches are left unoccupied. The species that remain suddenly find lots of empty niches. Groups of animals with enough genetic variability can undergo adaptive radiations. These adaptive radiations can produce a large number of new species to fill those empty niches.

Scientists use the term **punctuated equilibria** to describe this pattern of long stable periods interrupted by brief periods of change. Punctuated equilibria theory, which has generated much debate, is still controversial among biologists today. It is clear, however, that evolution has often proceeded at different rates for different organisms at different times during the long history of life. But whatever the pace of change might have been, it is certain that organisms have evolved over time.

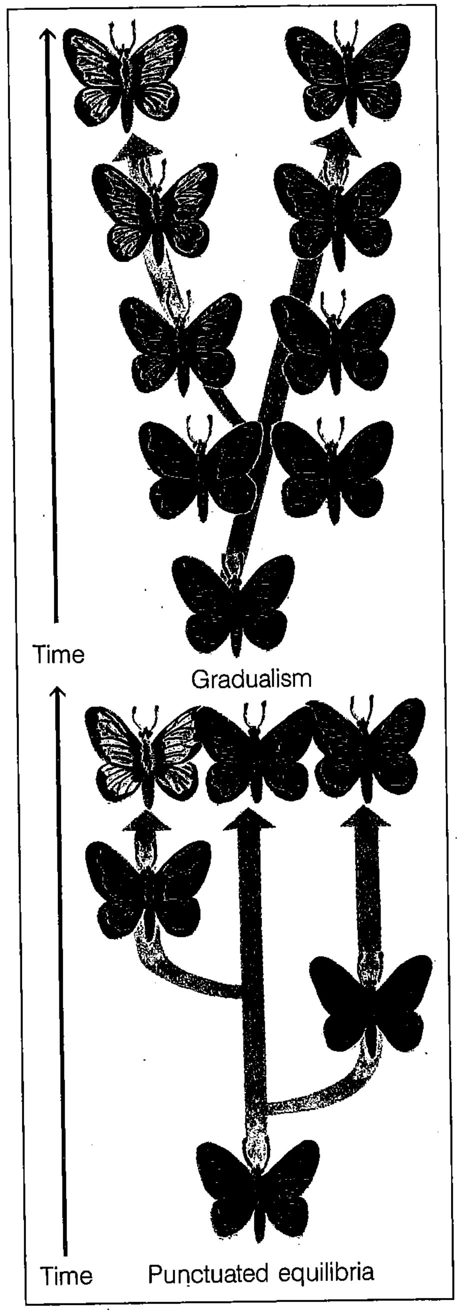


Figure 14–26 *This illustration shows two possible ways in which a population of butterflies changes over time. The insects may change color gradually, with each succeeding generation showing only small color changes. Or the color of the population may remain fairly stable for long periods of time and then make great changes suddenly.*

The Significance of Evolutionary Theory

Evolutionary theory is, in the minds of many biologists, the foundation on which all biological science is built. Only because all living organisms are related through common descent can we talk about universal characteristics of life. Only because the physiological properties of all multicellular organisms are so similar can we study other animals to learn how our own bodies operate. And only through application of evolutionary theory can we truly understand the way that organisms interact with each other and with their environments.

But the influence of evolutionary thought extends far beyond biology. Philosopher J. Collins has written that "there are no living sciences, human attitudes, or institutional powers that remain unaffected by the ideas . . . released by Darwin's work." We cannot even touch on these remote disciplines in this book, although we hope you will be inspired to read about them later in life. We will, however, use the remainder of this book to discuss the products of evolution: Earth's "most beautiful and wonderful" living organisms.

14–5 SECTION REVIEW

1. What is genetic drift? How does genetic drift affect a gene pool?
2. What three factors can cause an increase in the rate of evolution of a species?
3. **Critical Thinking—Describing Concepts** Describe the theory of punctuated equilibria.