10.2 Developing the Theory of Evolution

EXPECTATIONS

- **Describe, and put in historical context, some scientists' contributions that have changed evolutionary concepts.**
- **Evaluate the scientific evidence that supports the theory of evolution.**
- **Identify questions to investigate that arise from concepts of evolution and natural selection.**

Ideas about natural selection and evolution began to be discussed in earnest in the early nineteenth century. Although the name Charles Darwin is often mentioned synonymously with the theory of evolution, in fact the work and ideas of many others helped to shape our current understanding of evolution. Indeed, as our technological and scientific techniques improve and our knowledge of the principles of evolution grows, our understanding of the processes of evolution also improves.

A Historical Context

The English naturalist Charles Darwin was by no means the first (or only) person to influence thought on what is commonly referred to as the theory of evolution. Several Greek philosophers believed that life gradually evolved. However, two of the most influential philosophers in Western culture, Plato and Aristotle, did not support ideas that organisms could change. For example, Aristotle thought that all organisms that ever would exist were already created. He also believed that these organisms were permanent and perfect and would not change. Religious beliefs of Darwin's time said that all organisms and their individual structures resulted from the direct actions of a Creator who formed the entire universe. It was thought that all species were created during a single week and that they remained unchanged over the course of time. The predominant belief that Earth was only a few thousand years old fortified the idea of a single act of creation.

In the nineteenth century, however, some scholars began to present new ideas. Some thinkers proposed that living things did change during the course of the history of Earth, and that the organisms that exist now might be different from the organisms that existed previously in history. Others said that populations of organisms perhaps even changed from one generation to the next. They observed variations in populations and saw that populations could adapt to particular situations. Although these ideas were discussed, especially in scholarly circles, they were contrary to the religious teachings of the time and as such were often dismissed as heresy. As well, no one could propose a plausible mechanism that explained these phenomena. Darwin's name is so closely associated with the theory of evolution because he linked all of the prevailing knowledge from paleontology, geology, geography, and biology with his own observations. In doing so, he developed a theory describing a mechanism that showed convincingly that life could change over time. (Another English naturalist, Alfred Russel Wallace, also came to the same conclusion as Darwin.)

Cuvier's Fossils

The science of **paleontology**, which is the study of fossils, provided important clues that helped to develop the theory of evolution. French scientist Georges Cuvier (1769–1832) is largely credited with developing the science of paleontology. Cuvier realized that the history of life was recorded in Earth's layers of rocks, which contained fossils. Cuvier found that each of the layers, or strata, of rock is characterized by a unique group of fossil species and that the deeper (older) the stratum, the more dissimilar the plant and animal life are from modern life (see Figure 10.4 on page 341). Cuvier also recognized that extinction of species was a fairly common occurrence in the history of life on Earth. As he worked from stratum to stratum, he found evidence that new species appeared and others disappeared over the course of millions of years.

Cuvier's work showed that something was causing species to appear and disappear, but he was strongly opposed to the ideas of evolution being suggested at the time. Instead, he proposed the idea of **catastrophism**. According to this idea,

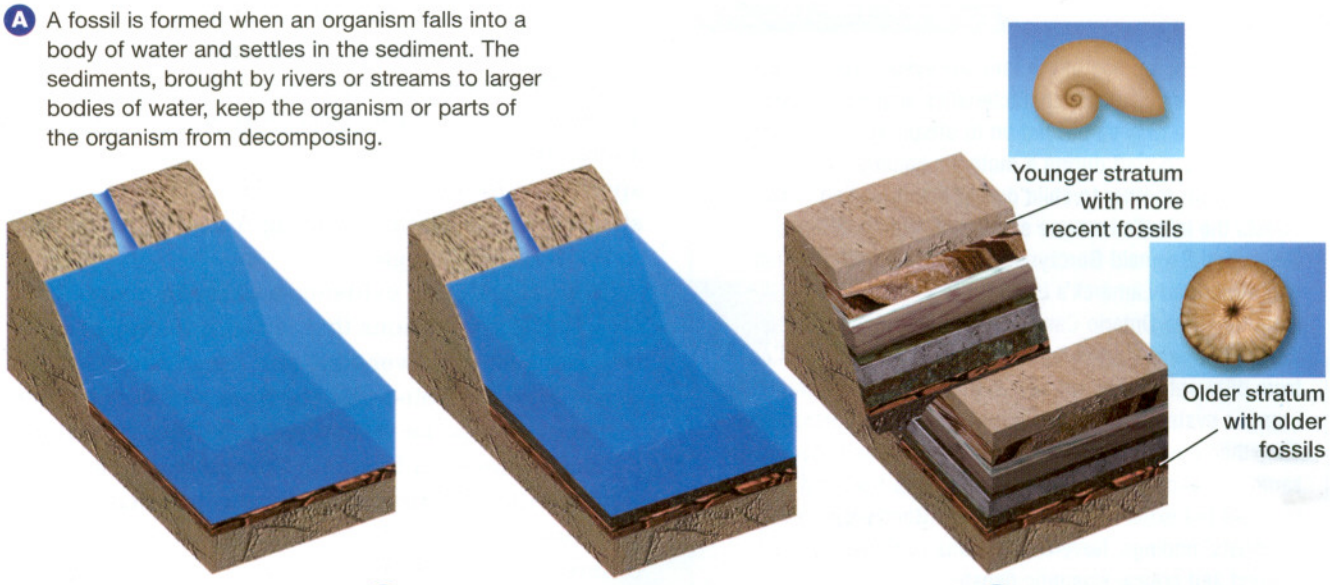

Figure 10.4 Layers of sedimentary rocks are of different ages and contain different groups of fossils.

catastrophes (such as floods, diseases, or droughts) had periodically destroyed species that were living in a particular region. He hypothesized that these catastrophes corresponded to the boundaries between each stratum in his studies. Cuvier proposed that these catastrophes were limited to local geographical regions, and that the area would be repopulated by species from nearby unaffected areas. This is how he explained the appearance of "new" species in the fossil record.

Lamarck's Theory of Inheritance of Acquired Characteristics

French naturalist Jean-Baptiste Lamarck published a theory of evolution in 1809, the year Charles Darwin was born and 50 years before Darwin would finally publish his own ideas on evolution. While working at the Natural History Museum in Paris, where he was in charge of the invertebrate collections, Lamarck compared current species of animals with fossil forms. He could see that there appeared to be a "line of descent" where the fossil record showed a series of fossils (from older to more recent) that led to a modern species. Lamarck proposed that microscopic organisms arose continually and spontaneously from non-living sources. He thought that species were initially very primitive, and that they increased in complexity over time until they achieved a sort of perfection. Lamarck believed that the organisms would become progressively better and better adapted to their environments. It was thought at the time that body parts that were used extensively to cope with conditions in the environment would become larger and stronger (the idea of "use and disuse"). Lamarck's idea fit with this line of reasoning. For example, he proposed that a blacksmith would develop a larger biceps in the arm in which he holds his hammer.

Lamarck further proposed that characteristics acquired during an organism's lifetime, such as large size, short hair, or large muscles, could then be passed on to its offspring. Following this reasoning, Lamarck claimed that the large biceps of a blacksmith would then be passed on to his offspring. He called this the **inheritance of acquired characteristics**. Lamarck's proposed mechanism of evolution is now known to be incorrect, but his ideas provoked thought and discussion. They also influenced the thoughts of others, including Charles Darwin. Although controversial for the time, Lamarck's thinking was visionary, especially his idea that adaptations to the environment result in the evolution of species.

BIO FACT

Recent understanding of the immune system has shown that, in some instances, characteristics acquired throughout one's lifetime *may* be passed on to offspring. For example, antibodies acquired during a mother's lifetime can be passed from mother to child during breastfeeding. This boosts the infant's immune system. Scientists Edward Steele and Reginald Gorczynski conducted an experiment that supported Lamarck's basic tenet when they were working at the Ontario Cancer Institute in Toronto in the 1970s. The researchers injected infant male mice with cells from different groups of mice and found that the infants' immune systems developed a tolerance to the foreign cells. They then observed that the offspring of these mice had the same tolerance. Other scientists who have tried and failed to replicate the experiment of Steele and Gorczynski refute the scientists' findings. Nevertheless, this work has sparked interest and critical scientific debate.

Darwin's Evidence

In 1831, a young man left England on the HMS *Beagle*, a British survey ship used for voyages of scientific discovery. No one, including 22-year-old Charles Darwin himself, knew what the voyage would mean to Darwin and the study of biology as he stepped aboard. The expedition had a primary mission to survey the coast of South America, yet it provided Darwin with an opportunity to travel much of the world with ample time to explore the natural history in various locations. Figure 10.5 shows the voyage of the *Beagle*. While the crew surveyed the coastline, Darwin spent hours on shore observing and collecting thousands of specimens in the diverse environments that the ship visited, from the towering Andes Mountains to the Brazilian jungle.

Darwin gathered evidence and made many important observations that led him to realize how life forms change over time and vary from place to place. First, he noted that the flora and fauna of the different regions he visited were distinct from those he had explored in England, Europe, and elsewhere. For example, the rodents in South America were structurally similar to one another but were quite different from rodents he had observed on other continents. Of particular importance was Darwin's observation that species living in the cooler, temperate regions of South America were more closely related to species living in the tropical regions of that continent than to the species in the temperate regions of Europe or elsewhere in the world. He noted that lands that have similar climates seemed to have unrelated plants and animals. Darwin and many others in his time wondered why it was that if all organisms originated from a single act of creation, there existed this distinctive

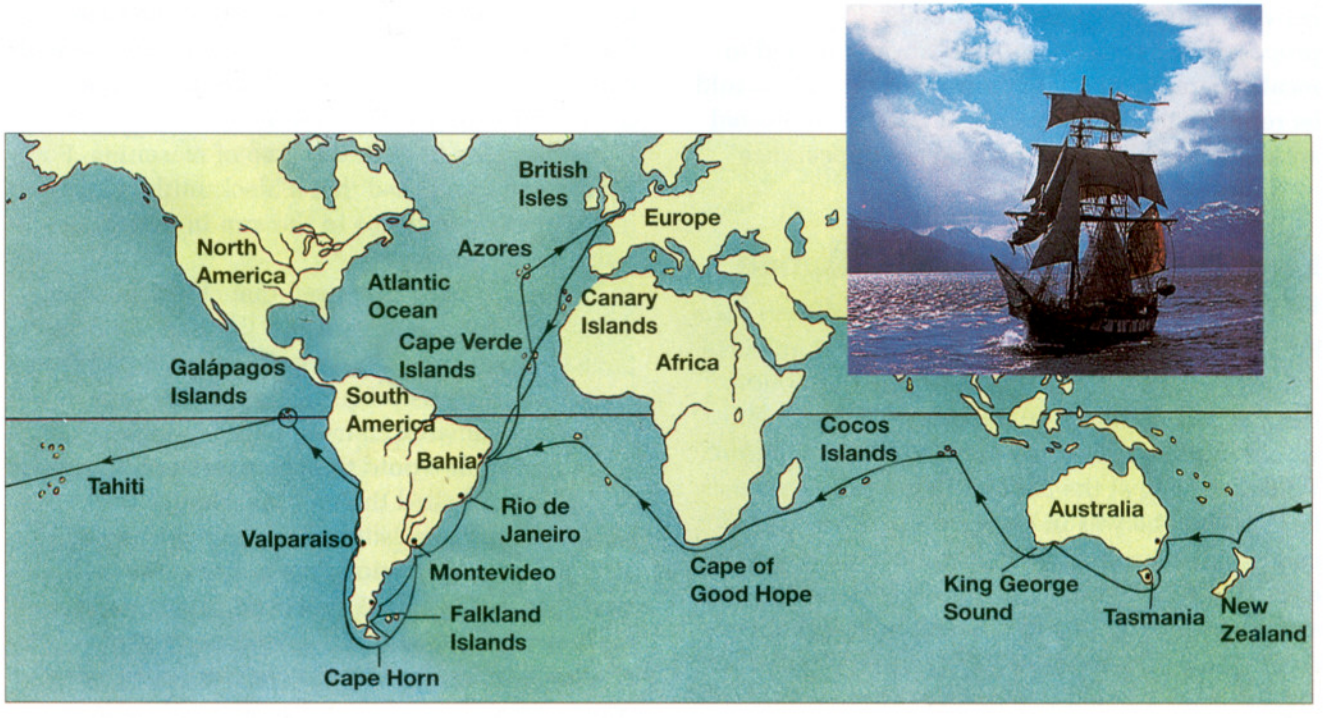

Figure 10.5 The five-year voyage of the HMS *Beagle* took Darwin around the world. Most of his time, however, was spent exploring the coast and coastal islands of South America.

clustering of similar organisms in different regions of the world. Why weren't organisms randomly distributed across Earth?

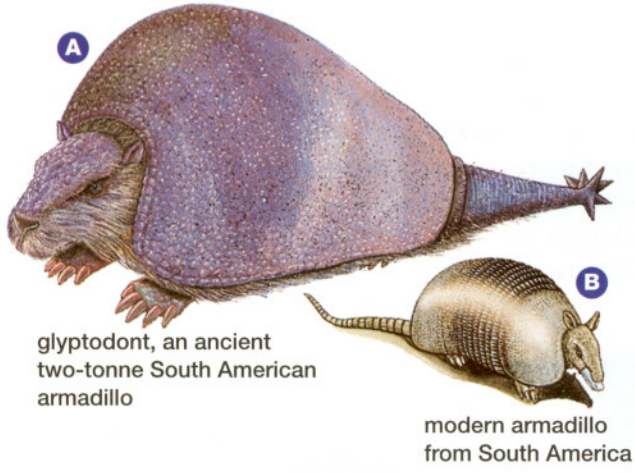

Figure 10.6 Comparison of the extinct glyptodont and a modern armadillo

Darwin also found several important fossil remains, including that of a glyptodont, an extinct armadillo-like animal. He wondered if this fossil was somehow related to the living forms of armadillos that lived in the same region (see Figure 10.6). Why would there be living and fossilized organisms that were directly related to one another in the same region? Could one have risen from the other?

Although it was not entirely evident to Darwin at the time, the *Beagle*'s five-week stop in the Galápagos Islands was particularly important in helping Darwin formulate his ideas on evolution. The Galápagos Islands are a group of over 20 small volcanic islands located in the Pacific Ocean approximately 1000 km off the coast of Ecuador. Darwin noted that the islands in the Galápagos supported relatively few animal species. (There was only one land mammal, for instance, and no frogs or other amphibians.) The species that were there, however, closely resembled animals of the west coast of South America, the nearest continental land mass. Darwin wondered: if these organisms had been created independently and placed in the Galápagos Islands (as the prevailing ideas of the time suggested), why did they so closely resemble organisms on the adjacent South American coastline? A single act of creation did not seem to support the trend Darwin was observing.

In the Galápagos, Darwin observed many new species, including huge land tortoises and giant cactus trees like those shown in Figure 10.7. These species were unique to the Galápagos, and were fairly common in the islands. Some of the species, such as the Galápagos tortoise, were slightly different from island to island. Darwin did not

BIO FACT

Although Darwin is often identified as being the naturalist on the *Beagle*, in fact he was not. Rather, he was welcomed aboard as a "gentleman's companion" to Captain Robert FitzRoy. At that time, captains did not socialize with their crew. Since the voyage was a long one, FitzRoy decided that he needed a companion and selected Darwin. The *Beagle*'s "official" naturalist was the ship's surgeon, Robert McKormick. At that time it was very common for the job of ship's surgeon to be combined with ship's naturalist.

A Galápagos tortoise

B Cactus trees

Figure 10.7 Unique species of the Galápagos

observe this himself. Rather, he was told by the vice-governor of the Galápagos that local residents could tell which island captured tortoises came from, just by looking at them. At the time Darwin dismissed this, later writing, "I did not for some time pay attention to this statement ... I have never dreamed that islands, about fifty or sixty miles apart, and most of them in sight of each other, formed of precisely the same rocks, placed under a quite similar climate, rising to a nearly equal height, would have been differently tenanted." As it turns out, this fact became a critical piece of information that helped Darwin develop his theory.

Darwin also collected a variety of birds while in the Galápagos Islands, including 13 species of finches (as shown in Figure 10.8). "Darwin's finches" have since become well known in the history of evolutionary thought and, like the information on tortoises, they also became a key to the formulation of Darwin's final theory. While he was in the Galápagos Islands, Darwin scarcely gave the finches much thought, however. He collected several dozen birds but assumed they were similar to birds on the coast of South America or on other Galápagos islands.

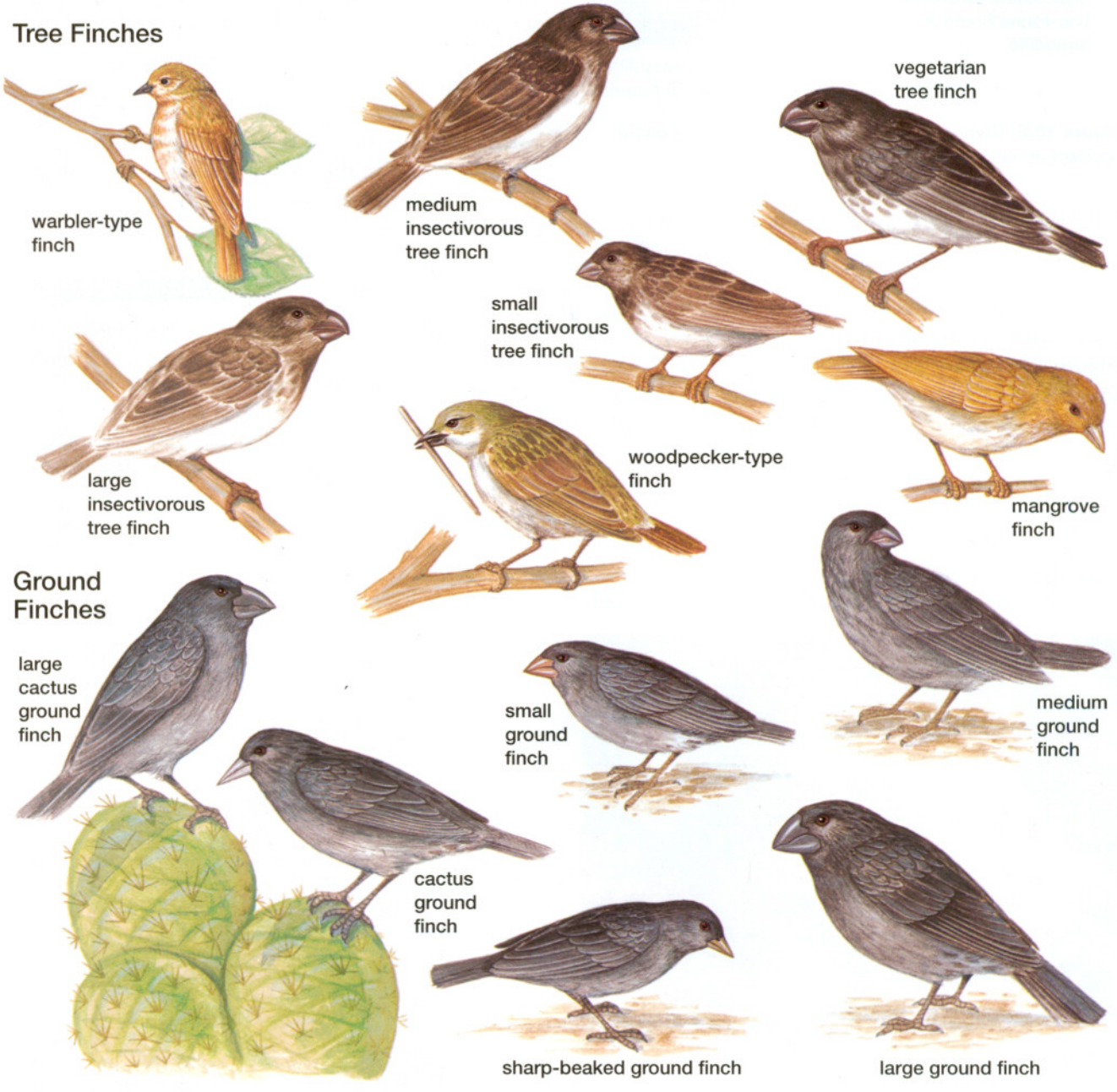

Figure 10.8 Galápagos finches are adapted to gathering and eating different types of food.

Darwin *did* wonder why there was such a diversity of species in such a small area. Each type of Galápagos finch (see Figure 10.8) is adapted to gathering and eating a different type of food based on the size and shape of its beak. Tree finches, for example, have beaks largely adapted to eating insects and, at times, plants. Ground finches have beaks adapted to eating cactus or different-sized seeds. The woodpecker-type finch uses a tool, a cactus spine or twig, to probe in the bark of trees for insects.

In Britain, a colleague catalogued the birds for Darwin and became particularly excited about Darwin's finches. All of the birds were new species that had never been described before. On reflection, Darwin could now see that although the finches were somewhat similar to finches on the coast of South America, they were clearly distinct species. This suggested that they had been modified from an ancestral form of the bird that was blown by chance into the newly formed Galápagos Islands. In the *Voyage of the Beagle* Darwin wrote, "...in the thirteen species of ground-finches, a nearly perfect gradation may be traced, from a beak extraordinarily thick, to one so fine, that it may be compared to that of a warbler. I very much suspect, that certain members of the series are confined to different islands. ..." He continued, "Seeing this gradation and diversity of structure in one small, intimately related group of birds, one might really fancy that, from an original scarcity of birds in this archipelago, one species had been taken and modified for different ends."

In summary, Darwin's experience in the Galápagos Islands, particularly the information gathered on tortoises and finches, demonstrated a mechanism for how new species could arise from ancestral ones in response to the local environment.

While on the voyage, Darwin also read *Principles of Geology* by the geologist Charles Lyell. Lyell expanded on ideas first proposed in 1795 by another geologist, James Hutton. Hutton said that Earth's geological features were in a slow, continuous cycle of change. For example, the slow action of rivers eroding through rocks eventually forms canyons. This is called **gradualism**. Lyell expanded on Hutton's ideas to develop a theory known as **uniformitarianism**. Lyell said that geological processes operated at the same rates in the past as they do today. He rejected the idea of irregular, unpredictable, catastrophic events shaping Earth's history.

Lyell's work was significant and a strong influence on Darwin. If geological changes were indeed slow and continuous rather than catastrophic, then Earth was certainly older than the 6000 or so years espoused by biblical scholars. As well, Lyell's work showed that slow, subtle processes happening over a long period of time could result in substantial changes. Darwin, and others searching to explain the changes they saw in the organisms around them, applied Hutton's and Lyell's ideas to biology. Darwin hypothesized that slow, subtle changes in populations of organisms could translate into substantial changes over time.

Summarizing Darwin's Evidence

1. Plants and animals observed in the temperate regions of South America were more similar to plants and animals in the South American tropics than to plants and animals in other temperate regions in the world.
2. Darwin found fossils of extinct animals (such as the glyptodont) that looked very similar to animals presently living in the same region (for example, the armadillo).
3. Plants and animals living in the Galápagos Islands closely resembled plants and animals living on the nearest continental coast (the west coast of South America).
4. Species of animals (such as tortoises) that at first looked identical actually varied slightly from island to island in the Galápagos.
5. Finches collected in the Galápagos looked similar to finches from South America but were, in fact, different species. Finch species also varied from island to island.
6. After reading Lyell's work, Darwin understood that geological processes that are slow and subtle can result in substantial changes. As well, forces that affect change are the same now as in the past.

WEB LINK

www.mcgrawhill.ca/links/biology12

Upon his return to England, Charles Darwin wrote the memoirs of his journey and published *The Voyage of the Beagle* in 1839. This book, along with Darwin's other works, is still widely available today. To read some of the original text, go to the web site above, and click on **Web Links**. Read an entry that Darwin made about his time in the Galápagos Islands and the observations he made there.

WEB LINK

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Today, the Galápagos Islands continue to be an important site for scientific research in many subject areas, including evolutionary biology. The islands have been recognized by the United Nations and have been designated a Biosphere Reserve, World Heritage Site, and national park. To find out more about current scientific research in the Galápagos Islands, go to the web site above, and click on **Web Links**.

Darwin's Theory of Evolution by Natural Selection

After returning to England, Darwin compiled his memoirs of the voyage. He then devoted eight years to a study of barnacles, in which he filled four volumes on their classification and natural history. Darwin continued to develop his ideas and collect evidence to support his conclusion that species could and did change over time. He investigated variations in species by breeding pigeons and studying breeds of dogs and varieties of flowers. From this work he knew it was possible for traits to be passed on from parent to offspring, so it was clear that species could change over time. He could not explain, however, exactly *how* it happened.

In 1838, Darwin read *Essay on the Principles of Population*, which was written by English economist Thomas Malthus in 1798. In Malthus's paper Darwin found the key idea he had been searching for to explain his observation of changes in species over time. This idea was that plant and animal populations grew faster than their food supply and eventually a population is reduced by starvation, disease, or (as in the case of humans) war. How did this idea help Darwin's thinking? Malthus's idea helped Darwin refine his thoughts. Darwin knew that many species produce large numbers of offspring, but he also knew that population levels tended to remain unchanged. Malthus's vision of struggle and crowding helped Darwin realize that individuals had to struggle somehow to survive. This struggle was the force that constantly prevents a population explosion. A struggle could be competition for food, shelter, or a mate, for example. Only some individuals survive the struggle and produce offspring. Darwin recognized that the struggle between individuals of the same species competing for limited resources *selected for* individuals with the traits that would increase their chances of surviving. Then, the survivors could potentially pass this favourable trait on to their offspring. He realized this was similar to humans selecting for favourable traits when breeding dogs, horses, or plants.

BIO FACT

Erasmus Darwin (1731–1802), Charles Darwin's grandfather, also proposed that competition between individuals could result in changes in species. Erasmus Darwin was a physician, naturalist, and influential intellectual in eighteenth century England. He formulated one of the first formal theories on evolution, and published his ideas in papers and in a poem, *The Temple of Nature*.

ELECTRONIC LEARNING PARTNER

Refer to your Electronic Learning Partner for more information on the diversity of species in the Galápagos.

THINKING LAB

Could Pumpkins Rule Earth?

Background

Charles Darwin applied Malthus's ideas to various organisms. For example, he calculated that a single pair of elephants could have 19 million descendents in 750 years. He knew, of course, this could not be true and began to think about the mechanism that must be controlling populations of all species on Earth. The largest number of offspring produced by the members of a population is known as the **biotic potential** of a species.

You Try It

1. Assume there are 70 seeds in one pumpkin. These 70 seeds are planted and each seed grows into a plant that produces two pumpkins. Calculate the number of seeds produced by this generation.
2. If you plant all of the seeds from step 1, how many seeds are available at the end of the next generation?
3. Why is the maximum biotic potential never actually reached in nature?

WEB LINK

www.mcgrawhill.ca/links/biology12

Many scientists have contributed to our current understanding of evolutionary biology, and exciting work continues today. To learn more about the various contributions of scientists and philosophers, go to the web site above, and click on **Web Links**. Choose one of the individuals on the list and summarize his/her contribution to evolutionary biology.

Darwin's thinking was catalyzed by Malthus's ideas, his experience with pigeon breeding and artificial selection, and the observations he made during and after the voyage of the *Beagle*. He gradually synthesized his ideas to show that individuals that possess physical, behavioural, or other traits that help them to survive in the local environment are more likely to pass these traits on to offspring than those that do not have such advantageous traits. These favourable characteristics then begin to increase in the population and, over time, the nature of the population as a whole changes. Darwin called this process natural selection. Darwin drafted his initial ideas in two manuscripts shown only to trusted friends in 1842 and 1844. We know he realized their importance because he asked his wife to ensure they would be published in the event of his untimely death. Curiously, however, Darwin did not present his ideas publicly until 1859, when he released *On the Origin of Species by Means of Natural Selection*. (In this text we will refer to this book as *The Origin of Species*.)

Why did Darwin wait so long to publish his ideas? Thinking and discussions about evolutionary theory were becoming more and more commonplace in the mid-nineteenth century, but the discussions were inevitably heated. The subject was controversial, since it was perceived as being contrary to the religious teachings of the time. Perhaps Darwin was reluctant to publish because he anticipated the response and possible uproar it would cause. His friend Lyell, whose book on fossils had influenced Darwin, encouraged him to publish on the subject before someone else did, even though Lyell himself was not convinced of evolution.

Lyell's prediction came true in June 1858, when Darwin received a paper from British naturalist Alfred Russel Wallace. As a result of his studies in a group of islands near Indonesia, Wallace had reached a conclusion similar to Darwin's. In the paper, Wallace outlined an essentially identical theory of evolution by natural selection. With Wallace's paper was a letter asking Darwin to evaluate the paper and pass it on to Lyell if he thought it should be published. Darwin did as Wallace asked and in a letter to Lyell he wrote, "Your words have come true with a vengeance... I never saw a more striking coincidence... so all my originality, whatever it may amount to, will be smashed." Lyell presented Wallace's paper and parts of Darwin's unpublished 1844 essay to the scientific community on July 1, 1858. Darwin quickly went to work and wrote *The Origin of Species*, which was published in 1859. With *The Origin of Species*, Darwin was the first to gather an array of facts related to evolution and present them cohesively.

Descent with Modification

Darwin did not use the word "evolution" in the original edition of *The Origin of Species*. ("Evolved" is used once — it is the final word in the book.) Instead, Darwin spoke of **descent with modification**. One reason he did not use the word "evolution" is that he felt it implied progress — that each generation was somehow getting better (that is, was improving in some way). Natural selection does *not* demonstrate progress; it has no set direction. It results purely from an ability to survive local environmental conditions, thereby giving the survivors the opportunity to pass on the trait that helped them survive in the first place.

Darwin proposed two main ideas in *The Origin of Species*: present forms of life have arisen by descent and modification from an ancestral species; and the mechanism for modification is natural selection working continuously for long periods of time. Darwin said that all organisms descended from some unknown organism. As descendants of that organism spread out over different habitats over the millennia, they developed modifications, or adaptations, that helped them fit in their local environment. Darwin's theory of natural selection showed how populations of individual species became better adapted to their local environments. These ideas are summarized in the text box on the following page.

As Darwin anticipated, *The Origin of Species* created a sensation, since the ideas outlined in the work were deeply disturbing to many. Within a few years, however, his view was widely accepted by most scholars. This was partly because the gap between religious viewpoints and the idea of natural selection narrowed, and because Darwin supported his ideas logically with a great deal of

evidence. *The Origin of Species* continues to be one of the most famous and influential books of all time.

Summary of Darwin's Ideas

Natural selection means that organisms with traits best suited to their environment are more likely to survive and reproduce. The factors Darwin identified that govern natural selection are:

1. Organisms produce more offspring than can survive, and therefore organisms compete for limited resources.
2. Individuals of a population vary extensively, and much of this variation is heritable.
3. Those individuals that are better suited to local conditions survive to produce offspring.
4. Processes for change are slow and gradual.

The work of Darwin, Lyell, Lamarck, and Cuvier helped shape the understanding of evolution. Many other people also helped advance these ideas. For example, Darwin was influenced by reading a work by Lyell on geology. Darwin supported his ideas with evidence of natural selection. In the next section, you will study some of the scientific evidence that supports the theory of evolution.

BIO FACT

Unfortunately, Alfred Russel Wallace, co-discoverer with Darwin of the idea of natural selection, is not well known by the general public. Wallace was an accomplished naturalist and contributed a great deal of knowledge to biological sciences, geography, and other disciplines. During his long life Wallace published over 150 works (including essays, books, and letters) and travelled and lectured widely. He did not, however, agree with all of the contents of Darwin's *The Origin of Species*. In fact, Wallace eventually became a "spiritualist" and could not extend the idea of natural selection to apply fully to humans. He believed that while natural selection worked at a biological level, there was a spiritual process that operated at the level of human consciousness. Humanity, he felt, had a special connection with God.

SECTION REVIEW

1. K/U An athlete breaks her leg. Years later she has a child who walks with a limp. Is this an example of evolution? Explain your answer.
2. K/U Describe the contributions of the following people to the understanding of evolution:
   (a) Cuvier
   (b) Malthus
   (c) Wallace
   (d) Lyell
3. K/U Charles Darwin was not the only person to discuss the idea of evolution. Why is his name most often mentioned synonymously with the idea of evolution?
4. C Write a brief presentation that explains the difference between catastrophism and uniformitarianism and how these ideas related to the development of the theory of evolution.
5. K/U Explain the idea of use and disuse as it relates to the theory of evolution by the inheritance of acquired characteristics.
6. K/U Summarize some of the observations Darwin made while on the voyage of the *Beagle* that he later incorporated into his theory of evolution by natural selection.
7. MC Nature writer Wallace Stegner once wrote of a population of trout in a mountain lake that were in a "Malthusian dilemma." Explain what Stegner meant.
8. K/U Describe what is meant by the term "biotic potential."
9. K/U Explain why Darwin referred to "descent with modification" rather than "evolution."
10. I At the site of a fossil bed, you come across fossils in a number of layers in the sediment. Which layers would have the oldest fossils and which would have the youngest fossils?

UNIT PROJECT PREP

For your Unit Project on Searching for a Common Ancestor, consider how evolution and fossils help scientists find examples of early forms of life.