15–1 The Puzzle of Life's Diversity

Nature presents scientists with a puzzle. Humans share the Earth with millions of other kinds of organisms of every imaginable shape, size, and habitat. This variety of living things is called biological diversity. How did all these different organisms arise? How are they related? These questions make up the puzzle of life's diversity.

What scientific explanation can account for the diversity of life? The answer is a collection of scientific facts, observations, and hypotheses known as evolutionary theory. **Evolution,** or change over time, is the process by which modern organisms have descended from ancient organisms. A scientific **theory** is a well-supported testable explanation of phenomena that have occurred in the natural world.

Guide for Reading

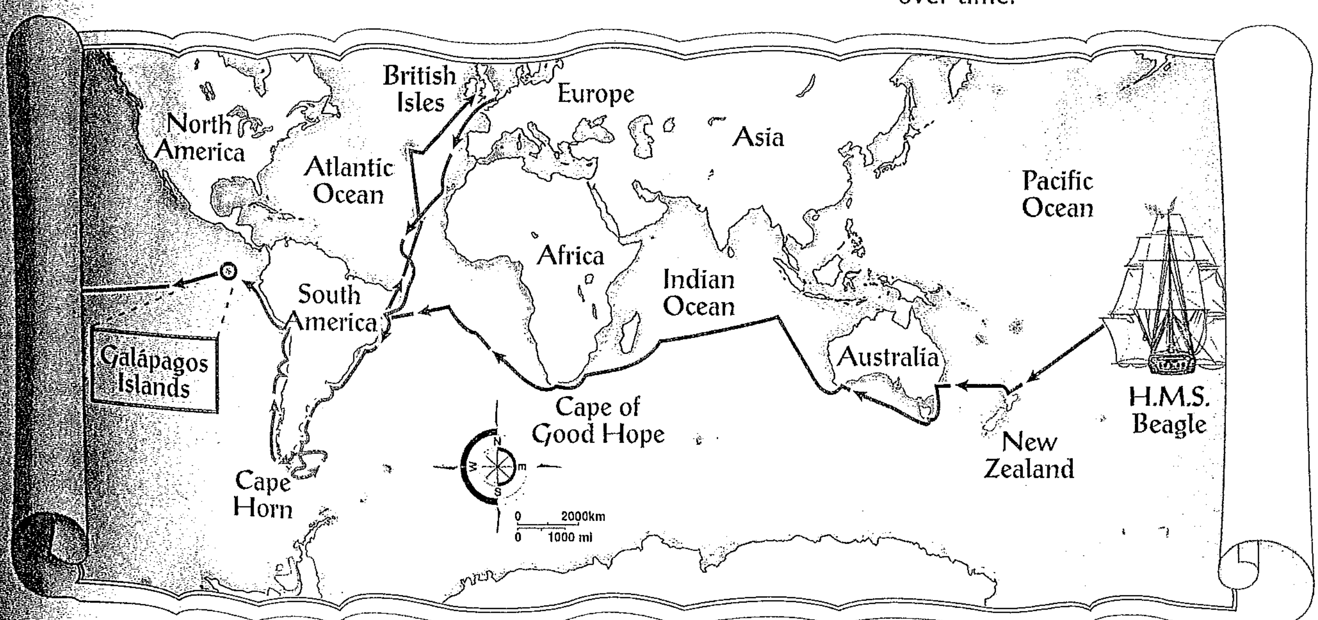
Key Concepts
- What was Charles Darwin's contribution to science?
- What pattern did Darwin observe among organisms of the Galápagos Islands?

Vocabulary
evolution
theory
fossil

Reading Strategy: Using Visuals Before you read, examine **Figure 15–1.** Find the British Isles, where Darwin's journey began, and then trace his route. Write a statement describing his travels.

Voyage of the *Beagle*

The individual who contributed more to our understanding of evolution than anyone was Charles Darwin. Darwin was born in England on February 12, 1809—the same day as Abraham Lincoln. Shortly after completing his college studies, Darwin joined the crew of the H.M.S. *Beagle*. In 1831, he set sail from England for a voyage around the world. His route is shown in **Figure 15–1.** Although no one knew it at the time, this was to be one of the most important voyages in the history of science. **During his travels, Darwin made numerous observations and collected evidence that led him to propose a revolutionary hypothesis about the way life changes over time.** That hypothesis, now supported by a huge body of evidence, has become the theory of evolution.



▼ **Figure 15–1** On a five-year voyage on the *Beagle,* Charles Darwin visited several continents and many remote islands. **Darwin's observations led to a revolutionary theory about the way life changes over time.**

Wherever the ship anchored, Darwin went ashore to collect plant and animal specimens that he added to an ever-growing collection. At sea, he studied his specimens, read the latest scientific books, and filled many notebooks with his observations and thoughts. Darwin was well educated and had a strong interest in natural history. His curiosity and analytical nature were ultimately the keys to his success as a scientist. During his travels, Darwin came to view every new finding as a piece in an extraordinary puzzle: a scientific explanation for the diversity of life on this planet.

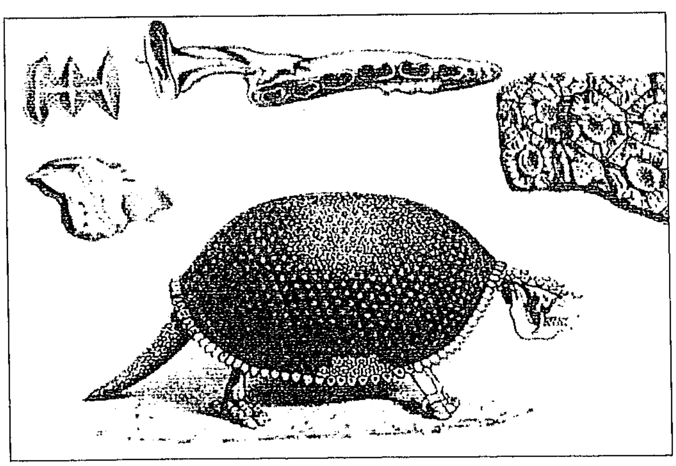
Darwin's Observations

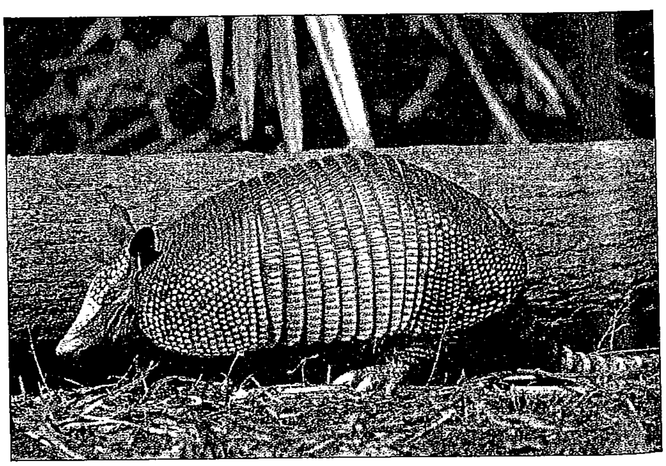
Darwin knew a great deal about the plants and animals of his native country. But he saw far more diversity during his travels. For example, during a single day in a Brazilian forest, Darwin collected 68 different beetle species—despite the fact that he was not even searching for beetles! He began to realize that an enormous number of species inhabit the Earth.

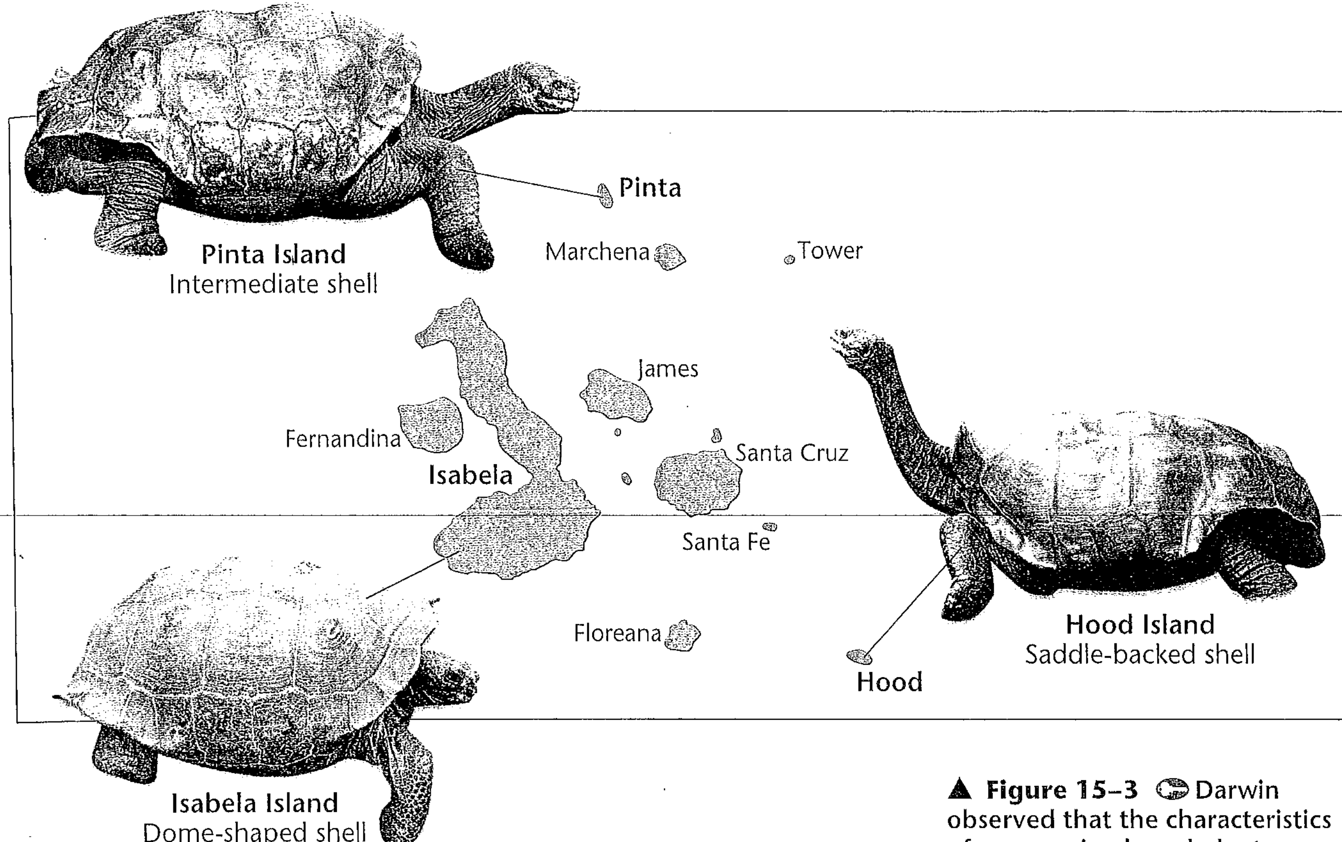
Patterns of Diversity Darwin was intrigued by the fact that so many plants and animals seemed remarkably well suited to whatever environment they inhabited. He was impressed by the many ways in which organisms survived and produced offspring. He wondered if there was some process that led to such a variety of ways of reproducing.

Darwin was also puzzled by where different species lived—and did not live. He visited Argentina and Australia, for example, which had similar grassland ecosystems. Yet, those grasslands were inhabited by very different animals. Also, neither Argentina nor Australia was home to the sorts of animals that lived in European grasslands. For Darwin, these patterns posed challenging questions. Why were there no rabbits in Australia, despite the presence of habitats that seemed perfect for them? Similarly, why were there no kangaroos in England?

Figure 15–2 Many of the fossils that Darwin discovered resembled living organisms but were not identical to them. The glyptodon, an extinct animal known only from fossil remains, is an ancient relative of the armadillo of South America. **Comparing and Contrasting** *What are some similarities and differences between these two types of animals?*







▲ **Figure 15–3 Darwin observed that the characteristics of many animals and plants varied noticeably among the different Galápagos Islands.** Among the tortoises, the shape of the shell corresponds to different habitats. The Hood Island tortoise (right) has a long neck and a shell that is curved and open around the neck and legs, allowing the tortoise to reach the sparse vegetation on Hood Island. The tortoise from Isabela Island (lower left) has a dome-shaped shell and a shorter neck. Vegetation on this island is more abundant and closer to the ground. The tortoise from Pinta Island has a shell that is intermediate between these two forms.

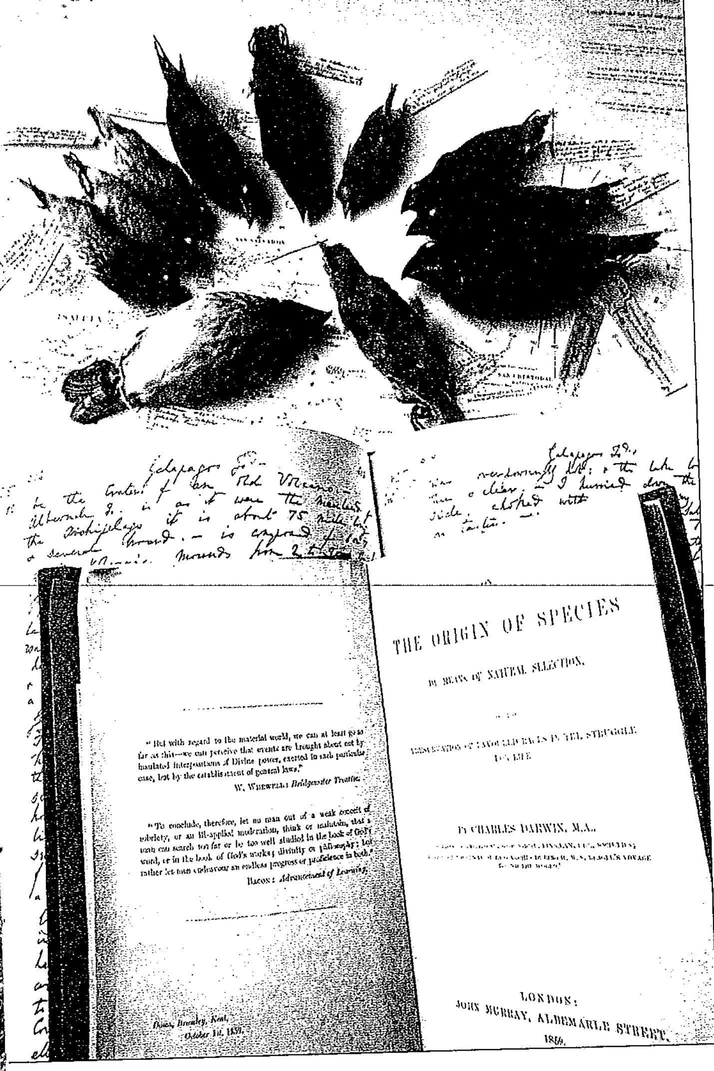
Living Organisms and Fossils Darwin soon realized that living animals represented just part of the puzzle posed by the natural world. In many places during his voyage, Darwin collected the preserved remains of ancient organisms, called **fossils.** Some of those fossils resembled organisms that were still alive, as shown in **Figure 15–2.** Others looked completely unlike any creature he had ever seen. As Darwin studied fossils, new questions arose. Why had so many of these species disappeared? How were they related to living species?

The Galápagos Islands Of all the *Beagle*'s ports of call, the one that influenced Darwin the most was a group of small islands located 1000 km west of South America. These are the Galápagos Islands. Darwin noted that although they were close together, the islands had very different climates. The smallest, lowest islands were hot, dry, and nearly barren. Hood Island, for example, had sparse vegetation. The higher islands had greater rainfall and a different assortment of plants and animals. Isabela Island had rich vegetation.

Darwin was fascinated in particular by the land tortoises and marine iguanas in the Galápagos. He learned that the giant tortoises varied in predictable ways from one island to another, as shown in **Figure 15–3.** The shape of a tortoise's shell could be used to identify which island a particular tortoise inhabited. Darwin later admitted in his notes that he "did not for some time pay sufficient attention to this statement."

✔CHECKPOINT *How did the fossils Darwin observed compare with the living organisms he studied?*

Go Online NSTA SCILINKS
For: Links on evolution
Visit: www.SciLinks.org
Web Code: cbn-5151



▲ **Figure 15–4** Darwin's notebooks and some of the finch specimens he collected have been preserved for today's scientists to study. **Inferring** *What might modern scientists learn from examining evidence collected by earlier investigators?*

Darwin also saw several types of small, ordinary-looking brown birds hopping around, looking for seeds. As an eager naturalist, he collected many specimens, several of which are shown in **Figure 15–4.** However, he did not find them particularly unusual or important. As Darwin examined the birds, he noted that they had differently shaped beaks. He thought that some of the birds were wrens, some were warblers, and some were blackbirds. But he came to no other conclusions—at first.

The Journey Home

While heading home, Darwin spent a great deal of time thinking about his findings. Examining different mockingbirds from the Galápagos, Darwin noticed that individual birds collected from the island of Floreana looked different from those collected on James Island. They also looked different from individuals collected on other islands. Darwin also remembered that the tortoises differed from island to island. Although Darwin did not immediately understand the reason for these patterns of diversity, he had stumbled across an important finding. **Darwin observed that the characteristics of many animals and plants varied noticeably among the different islands of the Galápagos.** After returning to England, Darwin began to wonder if animals living on different islands had once been members of the same species. According to this hypothesis, these separate species would have evolved from an original South American ancestor species after becoming isolated from one another. Was this possible? If so, it would turn people's view of the natural world upside down.

15–1 Section Assessment

1. **Key Concept** What did Darwin's travels reveal to him about the number and variety of living species?
2. **Key Concept** How did tortoises and birds differ among the islands of the Galápagos?
3. What is evolution? Why is evolution referred to as a theory?
4. What is a fossil?
5. **Critical Thinking Inferring** Darwin found fossils of many organisms that were different from any living species. How would this finding have affected his understanding of life's diversity?

Focus on the BIG Idea

Interdependence in Nature In Chapter 5, you learned that both biotic and abiotic factors affect ecosystems. Distinguish between these two factors, give some examples of each, and explain how they might have affected the tortoises that Darwin observed on the Galápagos Islands.

15–2 Ideas That Shaped Darwin's Thinking

Guide for Reading

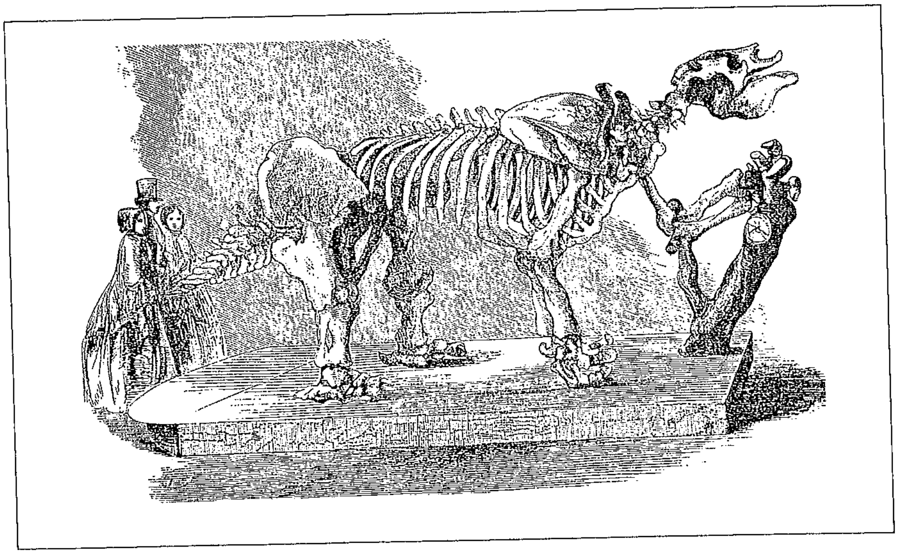
Key Concepts
- How did Hutton and Lyell describe geological change?
- According to Lamarck, how did species evolve?
- What was Malthus's theory of population growth?

Reading Strategy: Finding Main Ideas
As you read about the individuals who influenced Darwin's thinking, write a sentence briefly describing what Darwin learned from each one.

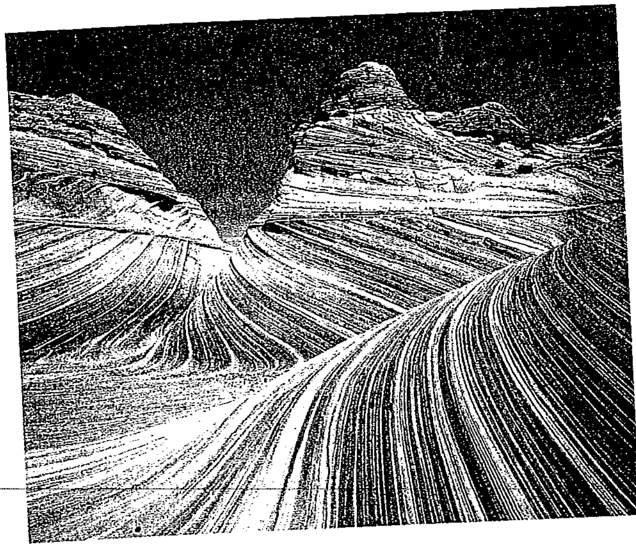
If Darwin had lived a century earlier, he might have done little more than think about the questions raised during his travels. But Darwin's voyage came during one of the most exciting periods in the history of Western science. Explorers were traversing the globe, and great thinkers were beginning to challenge established views about the natural world. Darwin was powerfully influenced by the work of these scientists, especially those who were studying the history of Earth. In turn, he himself greatly changed the thinking of many scientists and nonscientists. Some people, however, found Darwin's ideas too shocking to accept. To understand how radical Darwin's thoughts appeared, you must understand a few things about the world in which he lived.

Most Europeans in Darwin's day believed that the Earth and all its forms of life had been created only a few thousand years ago. Since that original creation, they concluded, neither the planet nor its living species had changed. A robin, for example, has always looked and behaved as robins had in the past. Rocks and major geological features were thought to have been produced suddenly by catastrophic events that humans rarely, if ever, witnessed.

By the time Darwin set sail, numerous discoveries had turned up important pieces of evidence. A rich fossil record, including the example in **Figure 15–5**, was challenging that traditional view of life. In light of such evidence, some scientists even adjusted their beliefs to include not one but several periods of creation. Each of these periods, they contended, was preceded by a catastrophic event that killed off many forms of life. At first, Darwin may have accepted these beliefs. But he began to realize that much of what he had observed did not fit neatly into this view of unchanging life. Slowly, after studying many scientific theories of his time, Darwin began to change his thinking dramatically.



▶ **Figure 15–5** This engraving, made around 1850, shows the fossil remains of a giant sloth from South America. During the 1800s, explorers were finding the remains of numerous animal types that had no living representatives. **Inferring** *What did such fossil evidence indicate about life in the past?*



▲ **Figure 15–6** These huge rocks, which are composed of sandstone, show distinct layers that were laid down over millions of years. **Hutton and Lyell cited geological features such as these rocks as evidence that Earth is many millions of years old.**

An Ancient, Changing Earth

During the eighteenth and nineteenth centuries, scientists examined Earth in great detail. They gathered information suggesting that Earth was very old and had changed slowly over time. Two scientists who formed important theories based on this evidence were James Hutton and Charles Lyell. **Hutton and Lyell helped scientists recognize that Earth is many millions of years old, and the processes that changed Earth in the past are the same processes that operate in the present.**

Hutton and Geological Change In 1795, the geologist James Hutton published a detailed hypothesis about the geological forces that have shaped Earth. Hutton proposed that layers of rock, such as those shown in **Figure 15–6,** form very slowly. Also, some rocks are moved up by forces beneath Earth's surface. Others are buried, and still others are pushed up from the sea floor to form mountain ranges. The resulting rocks, mountains, and valleys are then shaped by a variety of natural forces—including rain, wind, heat, and cold temperatures. Most of these geological processes operate extremely slowly, often over millions of years. Hutton, therefore, proposed that Earth had to be much more than a few thousand years old.

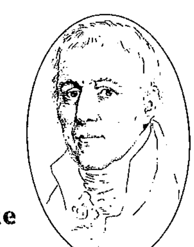
Biology and History

Origins of Evolutionary Thought

The groundwork for the modern theory of evolution was laid during the 1700s and 1800s. Charles Darwin developed the central idea of evolution by natural selection, but others before and during his time also built essential parts of the theory.

1785
James Hutton
Hutton proposes that Earth is shaped by geological forces that took place over extremely long periods of time. He estimates Earth to be millions—not thousands—of years old.

1798
Thomas Malthus
In his *Essay on the Principle of Population,* Malthus predicts that the human population will grow faster than the space and food supplies needed to sustain it.



1809
Jean-Baptiste Lamarck
Lamarck publishes his hypotheses of the inheritance of acquired traits. The ideas are flawed, but he is one of the first to propose a mechanism explaining how organisms change over time.

1750 — 1800

Lyell's *Principles of Geology* Just before the *Beagle* set sail, Darwin had been given the first volume of geologist Charles Lyell's book *Principles of Geology*. Lyell stressed that scientists must explain past events in terms of processes that they can actually observe, since processes that shaped the Earth millions of years earlier continue in the present. Volcanoes release hot lava and gases now, just as they did on an ancient Earth. Erosion continues to carve out canyons, just as it did in the past.

Lyell's work explained how awesome geological features could be built up or torn down over long periods of time. Lyell helped Darwin appreciate the significance of geological phenomena that he had observed. Darwin had witnessed a spectacular volcanic eruption. Darwin wrote about an earthquake that had lifted a stretch of rocky shoreline—with mussels and other animals attached to it—more than 3 meters above its previous position. He noted that fossils of marine animals were displaced many feet above sea level. Darwin then understood how geological processes could have raised these rocks from the sea floor to a mountaintop.

This understanding of geology influenced Darwin in two ways. First, Darwin asked himself: If the Earth could change over time, might life change as well? Second, he realized that it would have taken many, many years for life to change in the way he suggested. This would have been possible only if the Earth were extremely old.

CHECKPOINT *What are some ways the Earth has changed over time?*

Go Online NSTA SCiLINKS

For: Links on Darwin
Visit: www.SciLinks.org
Web Code: cbn-5152

Writing in Science

Use the library or the Internet to find out more about Darwin and Wallace. Write a dialogue between these two men, where the conversation shows the similarities in their careers and theories.

1831
Charles Darwin
Darwin sets sail on the H.M.S. *Beagle*, a voyage that will provide him with vast amounts of evidence leading to his theory of evolution.

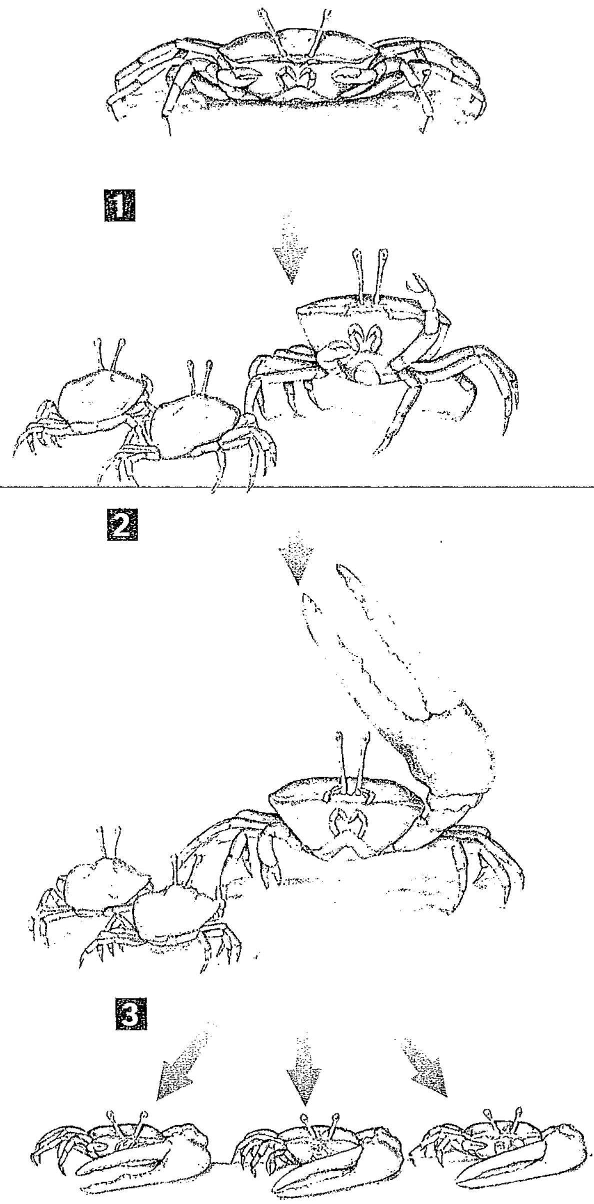
1833
Charles Lyell
In the second and final volume of *Principles of Geology*, Lyell explains that processes occurring now have shaped Earth's geological features over long periods of time.

1858
Alfred Wallace
Wallace writes to Darwin, speculating on evolution by natural selection, based on his studies of the distribution of plants and animals.

1859
Darwin publishes *On the Origin of Species.*

1850

1900



▲ **Figure 15–7** **Lamarck proposed that the selective use or disuse of an organ led to a change in that organ that was then passed on to offspring.** This proposed mechanism is shown here applied to fiddler crabs. (1) The male crab uses its small front claw to attract mates and ward off predators. (2) Because the front claw has been used repeatedly, it becomes larger. (3) The acquired characteristic, a larger claw, is then passed on to the crab's offspring. Lamarck's explanation, proposed in 1809, was found to be incorrect.

Lamarck's Evolution Hypotheses

The French naturalist Jean-Baptiste Lamarck was among the first scientists to recognize that living things have changed over time—and that all species were descended from other species. He also realized that organisms were somehow adapted to their environments. In 1809, the year that Darwin was born, Lamarck published his hypotheses. **Lamarck proposed that by selective use or disuse of organs, organisms acquired or lost certain traits during their lifetime. These traits could then be passed on to their offspring. Over time, this process led to change in a species.**

Tendency Toward Perfection Lamarck proposed that all organisms have an innate tendency toward complexity and perfection. As a result, they are continually changing and acquiring features that help them live more successfully in their environments. In Lamarck's view, for instance, the ancestors of birds acquired an urge to fly. Over many generations, birds kept trying to fly, and their wings increased in size and became more suited to flying.

Use and Disuse Because of this tendency toward perfection, Lamarck proposed that organisms could alter the size or shape of particular organs by using their bodies in new ways. For example, by trying to use their front limbs for flying, birds could eventually transform those limbs into wings. Conversely, if a winged animal did not use its wings—an example of disuse—the wings would decrease in size over generations and finally disappear.

Inheritance of Acquired Traits Like many biologists of his time, Lamarck thought that acquired characteristics could be inherited. For example, if during its lifetime an animal somehow altered a body structure, leading to longer legs or fluffier feathers, it would pass that change on to its offspring. By this reasoning, if you spent much of your life lifting weights to build muscles, your children would inherit big muscles, too.

Evaluating Lamarck's Hypotheses

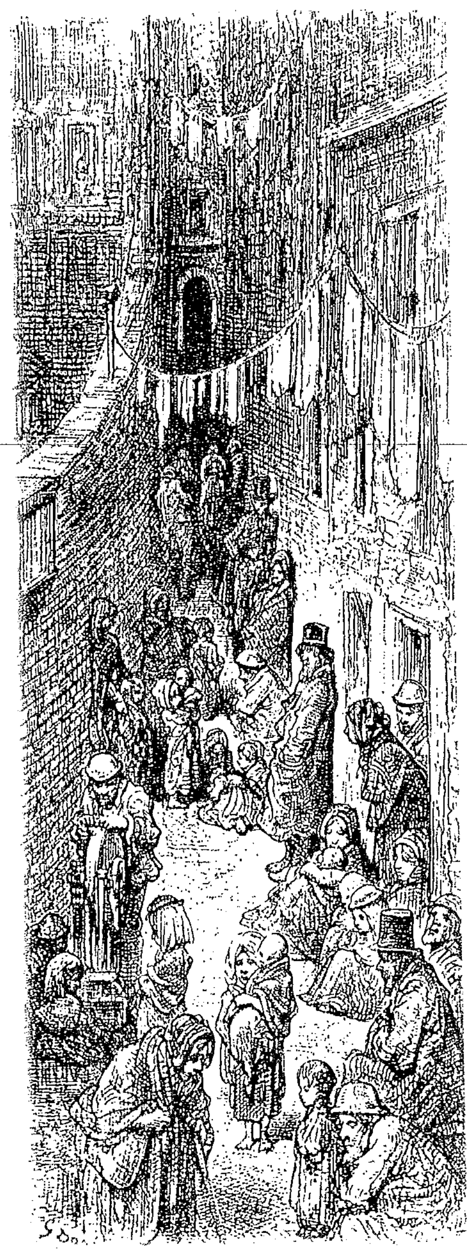
Lamarck's hypotheses of evolution, illustrated in **Figure 15–7,** are incorrect in several ways. Lamarck, like Darwin, did not know how traits are inherited. He did not know that an organism's behavior has no effect on its heritable characteristics. However, Lamarck was one of the first to develop a scientific hypothesis of evolution and to realize that organisms are adapted to their environments. He paved the way for the work of later biologists.

Population Growth

Another important influence on Darwin came from the English economist Thomas Malthus. In 1798, Malthus published a book in which he noted that babies were being born faster than people were dying. **Malthus reasoned that if the human population continued to grow unchecked, sooner or later there would be insufficient living space and food for everyone.** The only forces he observed that worked against this growth were war, famine, and disease. Conditions in certain parts of nineteenth-century England, illustrated in **Figure 15–8,** reinforced Malthus's somewhat pessimistic view of the human condition.

When Darwin read Malthus's work, he realized that this reasoning applied even more strongly to plants and animals than it did to humans. Why? Because humans produce far fewer offspring than most other species do. A mature maple tree can produce thousands of seeds in a single summer, and one oyster can produce millions of eggs each year. If all the offspring of almost any species survived for several generations, they would overrun the world.

Obviously, this has not happened, because continents are not covered with maple trees, and oceans are not filled with oysters. The overwhelming majority of a species' offspring die. Further, only a few of those offspring that survive succeed in reproducing. What causes the death of so many individuals? What factor or factors determine which ones survive and reproduce, and which do not? Answers to these questions became central to Darwin's explanation of evolutionary change.



▶ **Figure 15–8** **Malthus reasoned that if the human population continued to grow unchecked, sooner or later there would be insufficient food and living space for everyone.** He supported his theory with the evidence he observed in the streets of London.

15–2 Section Assessment

1. **Key Concept** What two ideas from geology were important to Darwin's thinking?
2. **Key Concept** According to Lamarck, how did organisms acquire traits?
3. **Key Concept** According to Malthus, what factors limited population growth?
4. How did Lyell's *Principles of Geology* influence Darwin?
5. **Critical Thinking Evaluating** Imagine that you are Thomas Malthus. Write an article describing your ideas. Explain the impact of a growing population on society and the environment.

Focus on the BIG Idea

Science as a Way of Knowing Describe the idea and observations proposed by Lamarck regarding his theory of evolution. Include in your description what Lamarck observed and the conclusions he made based on his observations. In addition, include the scientific evidence that eventually proved Lamarck's theory incorrect.

15–3 Darwin Presents His Case

Guide for Reading

Key Concepts
- How is natural variation used in artificial selection?
- How is natural selection related to a species' fitness?
- What evidence of evolution did Darwin present?

Vocabulary
artificial selection
struggle for existence
fitness
adaptation
survival of the fittest
natural selection
descent with modification
common descent
homologous structure
vestigial organ

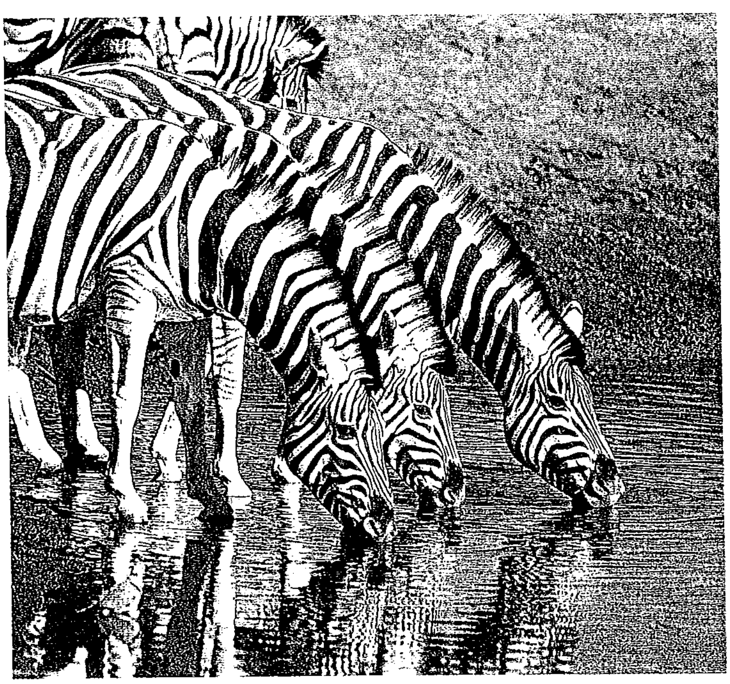
Reading Strategy: Building Vocabulary As you read, write a phrase or sentence in your own words to define each highlighted, boldface term.

When Darwin returned to England in 1836, he brought back specimens from around the world. Subsequent findings about these specimens soon had the scientific community abuzz. Darwin learned that his Galápagos mockingbirds actually belonged to three separate species found nowhere else in the world! Even more surprising, the brown birds that Darwin had thought to be wrens, warblers, and blackbirds were all finches. They, too, were found nowhere else. The same was true of the Galápagos tortoises, the marine iguanas, and many plants that Darwin had collected on the islands. Each island species looked a great deal like a similar species on the South American mainland. Yet, the island species were clearly different from the mainland species and from one another.

Publication of *On the Origin of Species*

Darwin began filling notebooks with his ideas about species diversity and the process that would later be called evolution. However, he did not rush out to publish his thoughts. Recall that Darwin's ideas challenged fundamental scientific beliefs of his day. Darwin was not only stunned by his discoveries, he was disturbed by them. Years later, he wrote, "It was evident that such facts as these . . . could be explained on the supposition that species gradually became modified, and the subject haunted me." Although he discussed his work with friends, he shelved his manuscript for years and told his wife to publish it in case he died.

In 1858, Darwin received a short essay from Alfred Russel Wallace, a fellow naturalist who had been doing field work in Malaysia. That essay summarized the thoughts on evolutionary change that Darwin had been mulling over for almost 25 years! Suddenly, Darwin had an incentive to publish his own work. At a scientific meeting later that year, Wallace's essay was presented together with some of Darwin's work.



◀ **Figure 15–9** Each zebra inherits genes that give it a distinctive pattern of stripes. Those visibly different patterns are an example of natural variation in a species. **Formulating Hypotheses** *What might be some genetic variations that are not visible?*

Eighteen months later, in 1859, Darwin published the results of his work, *On the Origin of Species.* In his book, he proposed a mechanism for evolution that he called natural selection. He then presented evidence that evolution has been taking place for millions of years—and continues in all living things. Darwin's work caused a sensation. Many people considered his arguments to be brilliant, while others strongly opposed his message. But what did Darwin actually say?

Inherited Variation and Artificial Selection

One of Darwin's most important insights was that members of each species vary from one another in important ways. Observations during his travels and conversations with plant and animal breeders convinced him that variation existed both in nature and on farms. For example, some plants in a species bear larger fruit than others. Some cows give more milk than others. From breeders, Darwin learned that some of this was heritable variation—differences that are passed from parents to offspring. Darwin had no idea of how heredity worked. Today, we know that heritable variation in organisms is caused by variations in their genes. We also know that genetic variation is found in wild species as well as in domesticated plants and animals.

Darwin argued that this variation mattered. This was a revolutionary idea, because in Darwin's day, variations were thought to be unimportant, minor defects. But Darwin noted that plant and animal breeders used heritable variation—what we now call genetic variation—to improve crops and livestock. They would select for breeding only the largest hogs, the fastest horses, or the cows that produced the most milk. Darwin termed this process **artificial selection.** **In artificial selection, nature provided the variation, and humans selected those variations that they found useful.** Artificial selection has produced many diverse domestic animals and crop plants, including the plants shown in **Figure 15–10**, by selectively breeding for different traits.

Go Online
active art
For: Artificial Selection activity
Visit: PHSchool.com
Web Code: cbp-5153

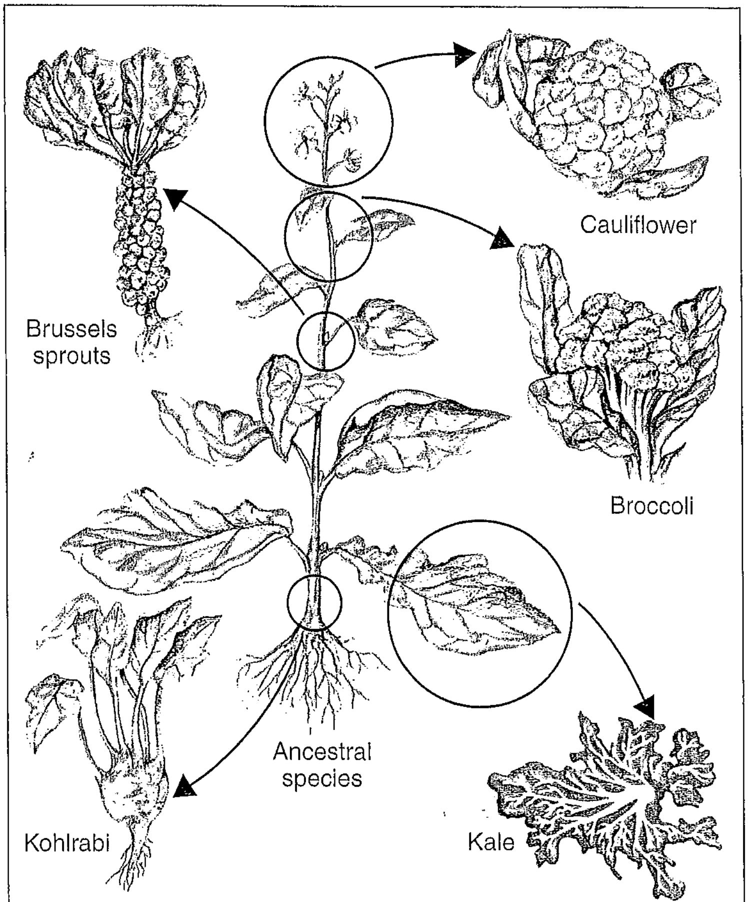


Figure 15–10 From a single ancestral plant, breeders selecting for enlarged flower buds, leaf buds, leaves, or stems have produced all these plants.

Quick Lab

New vegetables from old?

Materials various *Brassica* (cabbage family) vegetables

Procedure
Examine each of the vegetables and compare them. Determine which organ of the ancestral plant breeders may have chosen to produce each vegetable.

Analyze and Conclude
Formulating Hypotheses
Choose one of the vegetables. Explain how breeders might have produced that variety from the ancestral plant, shown below.

Go Online NSTA SCILINKS

For: Links on natural selection
Visit: www.SciLinks.org
Web Code: cbn-5153

Evolution by Natural Selection

Darwin's next insight was to compare processes in nature to artificial selection. By doing so, he developed a scientific hypothesis to explain how evolution occurs. This is where Darwin made his greatest contribution—and his strongest break with the past.

The Struggle for Existence Darwin was convinced that a process like artificial selection worked in nature. But how? He recalled Malthus's work on population growth. Darwin realized that high birth rates and a shortage of life's basic needs would eventually force organisms into a competition for resources. The **struggle for existence** means that members of each species compete regularly to obtain food, living space, and other necessities of life. In this struggle, the predators that are faster or have a particular way of ensnaring other organisms can catch more prey. Those prey that are faster, better camouflaged, or better protected, such as the porcupine shown in **Figure 15–11**, can avoid being caught. This struggle for existence was central to Darwin's theory of evolution.

Survival of the Fittest A key factor in the struggle for existence, Darwin observed, was how well suited an organism is to its environment. Darwin called the ability of an individual to survive and reproduce in its specific environment **fitness.** Darwin proposed that fitness is the result of adaptations. An **adaptation** is any inherited characteristic that increases an organism's chance of survival. Successful adaptations, Darwin concluded, enable organisms to become better suited to their environment and thus better able to survive and reproduce. Adaptations can be anatomical, or structural, characteristics, such as a porcupine's sharp quills. Adaptations also include an organism's physiological processes, or functions, such as the way in which a plant performs photosynthesis. More complex features, such as behavior in which some animals live and hunt in groups, can also be adaptations.

▼ **Figure 15–11** Survival of the fittest can take many different forms. For one species, it may be an ability to run fast, whereas for another species, it may be behavioral tactics that it uses to outsmart predators. For the porcupine, sharp quills make a powerful, hungry predator back away from an attack. **Inferring** *What other types of characteristics might increase chances of survival?*

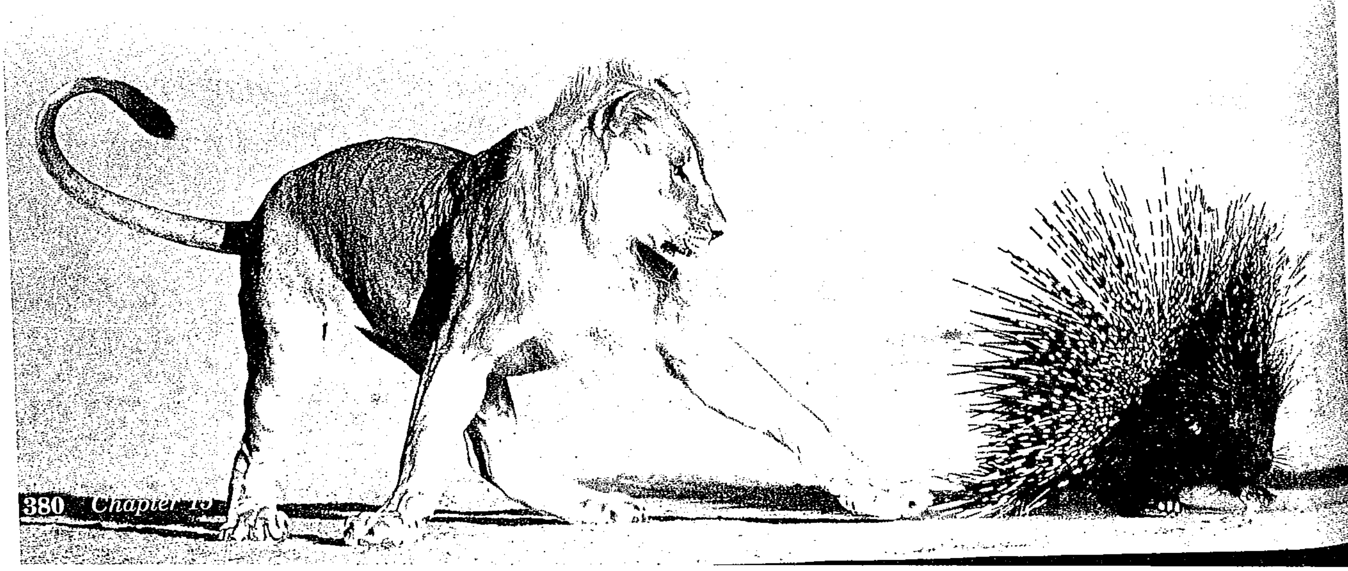


Figure 15–12 Each of these baby tanagers has its own set of inherited traits that affect its survival. A stronger bird may take food from a weaker sibling. A faster bird may escape predators more easily. Only those birds that survive and reproduce have the chance to pass their traits to the next generation. **Over time, natural selection results in changes in the inherited characteristics of a population.**

The concept of fitness, Darwin argued, was central to the process of evolution by natural selection. Generation after generation, individuals compete to survive and produce offspring. The baby birds in **Figure 15–12,** for example, compete for food and space while in the nest. Because each individual differs from other members of its species, each has unique advantages and disadvantages. Individuals with characteristics that are not well suited to their environment—that is, with low levels of fitness—either die or leave few offspring. Individuals that are better suited to their environment—that is, with adaptations that enable fitness—survive and reproduce most successfully. Darwin called this process **survival of the fittest.**

Because of its similarities to artificial selection, Darwin referred to the survival of the fittest as **natural selection.** In both artificial selection and natural selection, only certain individuals of a population produce new individuals. However, in natural selection, the traits being selected—and therefore increasing over time—contribute to an organism's fitness in its environment. Natural selection also takes place without human control or direction. **Over time, natural selection results in changes in the inherited characteristics of a population. These changes increase a species' fitness in its environment.** Natural selection cannot be seen directly; it can only be observed as changes in a population over many successive generations.

CHECKPOINT *What did Darwin mean when he described certain organisms as "more fit" than others?*

Descent With Modification Darwin proposed that over long periods, natural selection produces organisms that have different structures, establish different niches, or occupy different habitats. As a result, species today look different from their ancestors. Each living species has descended, with changes, from other species over time. He referred to this principle as **descent with modification.**

Go Online

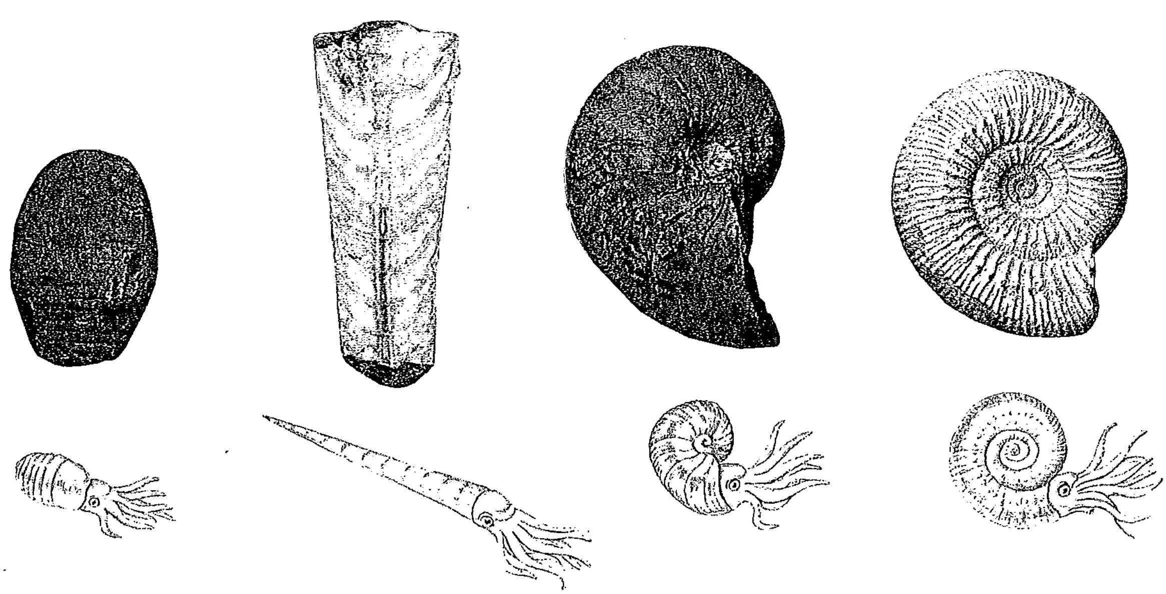
For: Links
Visit:
Web

Descent with modification also implies that all living organisms are related to one another. Look back in time, and you will find common ancestors shared by tigers, panthers, and cheetahs. Look farther back, and you will find ancestors that these felines share with horses, dogs, and bats. Farther back still are the common ancestors of mammals, birds, alligators, and fishes. If we look far enough back, the logic concludes, we could find the common ancestors of all living things. This is the principle known as **common descent.** According to this principle, all species—living and extinct—were derived from common ancestors. Therefore, a single "tree of life" links all living things.

Evidence of Evolution

With this unified, dynamic theory of life, Darwin could finally explain many of the observations he had made during his travels aboard the *Beagle.* **Darwin argued that living things have been evolving on Earth for millions of years. Evidence for this process could be found in the fossil record, the geographical distribution of living species, homologous structures of living organisms, and similarities in early development, or embryology.**

The Fossil Record By Darwin's time, scientists knew that fossils were the remains of ancient life and that different layers of rock had been formed at different times during Earth's history. Darwin saw fossils as a record of the history of life on Earth. Darwin, like Lyell, proposed that Earth was many millions—rather than thousands—of years old. During this long time, Darwin proposed, countless species had come into being, lived for a time, and then vanished. By comparing fossils from older rock layers with fossils from younger layers, scientists could document the fact that life on Earth has changed over time as shown in **Figure 15–13.**



▼ Figure 15–13 Darwin argued that the fossil record provided evidence that living things have been evolving for millions of years. Often, the fossil record includes a variety of different extinct organisms that are related to one another and to living species. The four fossil organisms shown here are cephalopods, a group that includes squid, octopi, and the chambered nautilus. The fossil record contains more than 7500 species of cephalopods, which vary, as these fossils show, from species with short, straight shells, to species with longer, coiled shells. Darwin and his colleagues noticed that the sizes, shapes, and varieties of related organisms preserved in the fossil record changed over time.

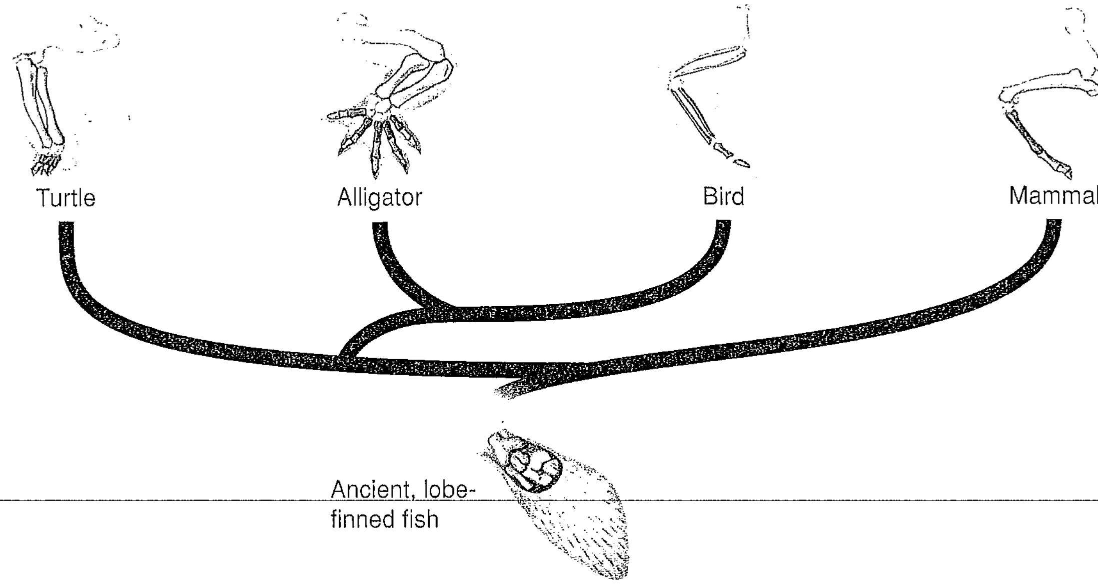
Since Darwin's time, the number of known fossil forms has grown enormously. Researchers have discovered many hundreds of transitional fossils that document various intermediate stages in the evolution of modern species from organisms that are now extinct. Gaps remain, of course, in the fossil records of many species, although a lot of them shrink each year as new fossils are discovered. These gaps do not indicate weakness in the theory of evolution itself. Rather, they point out uncertainties in our understanding of exactly how some species evolved.

Geographic Distribution of Living Species Remember that many parts of the biological puzzle that Darwin saw on his *Beagle* voyage involved living organisms. After Darwin discovered that those little brown birds he collected in the Galápagos were all finches, he began to wonder how they came to be similar, yet distinctly different from one another. Each species was slightly different from every other species. They were also slightly different from the most similar species on the mainland of South America. Could the island birds have changed over time, as populations in different places adapted to different local environments? Darwin struggled with this question for a long time. He finally decided that all these birds could have descended with modification from a common mainland ancestor.

There were other parts to the living puzzle as well. Recall that Darwin found entirely different species of animals on the continents of South America and Australia. Yet, when he looked at similar environments on those continents, he sometimes saw different animals that had similar anatomies and behaviors. Darwin's theory of descent with modification made scientific sense of this part of the puzzle as well. Species now living on different continents, as shown in **Figure 15–14**, had each descended from different ancestors. However, because some animals on each continent were living under similar ecological conditions, they were exposed to similar pressures of natural selection. Because of these similar selection pressures, different animals ended up evolving certain striking features in common.

CHECKPOINT *How can two species that look very different from each other be more closely related than two other species that look similar to each other?*

▲ **Figure 15–14** The existence of similar but unrelated species was a puzzle to Darwin. Later, he realized that similar animals in different locations were the product of different lines of evolutionary descent. Here, the beaver and the capybara are similar species that inhabit similar environments of North America and South America. The South American coypu also shares many characteristics with the North American muskrat. **Interpreting Graphics** *Which animal has a larger geographical range, the coypu or the muskrat?*



▲ **Figure 15–15** The limbs of these four modern vertebrates are homologous structures. They provide evidence of a common ancestor whose bones may have resembled those of the ancient fish shown here. Notice that the same colors are used to show related structures. **Homologous structures are one type of evidence for the evolution of living things.**

Homologous Body Structures Further evidence of evolution can be found in living animals. By Darwin's time, researchers had noticed striking anatomical similarities among the body parts of animals with backbones. For example, the limbs of reptiles, birds, and mammals—arms, wings, legs, and flippers—vary greatly in form and function. Yet, they are all constructed from the same basic bones, as shown in **Figure 15–15.**

Each of these limbs has adapted in ways that enable organisms to survive in different environments. Despite these different functions, however, these limb bones all develop from the same clumps of cells in embryos. Structures that have different mature forms but develop from the same embryonic tissues are called **homologous** (hoh-MAHL-uh-guhs) **structures.** Homologous structures provide strong evidence that all four-limbed vertebrates have descended, with modifications, from common ancestors.

There is still more information to be gathered from homologous structures. If we compare the front limbs, we can see that all bird wings are more similar to one another than any of them are to bat wings. Other bones in bird skeletons most closely resemble the homologous bones of certain reptiles—including crocodiles and extinct reptiles such as dinosaurs. The bones that support the wings of bats, by contrast, are more similar to the front limbs of humans, whales, and other mammals than they are to those of birds. These similarities and differences help biologists group animals according to how recently they last shared a common ancestor.

Not all homologous structures serve important functions. The organs of many animals are so reduced in size that they are just vestiges, or traces, of homologous organs in other species. These **vestigial organs** may resemble miniature legs, tails, or other structures. The legs of the skinks shown in **Figure 15–16** are an example of vestigial organs. Why would an organism possess organs with little or no function? One possibility is that the presence of a vestigial organ may not affect an organism's ability to survive and reproduce. In that case, natural selection would not cause the elimination of that organ.

Word Origins

Homologous, from the Greek words *homos,* meaning "same," and *legein,* meaning "say," describes similar body structures that come from a common ancestor. **If the word *morphe* means "shape," what are homomorphic structures?**

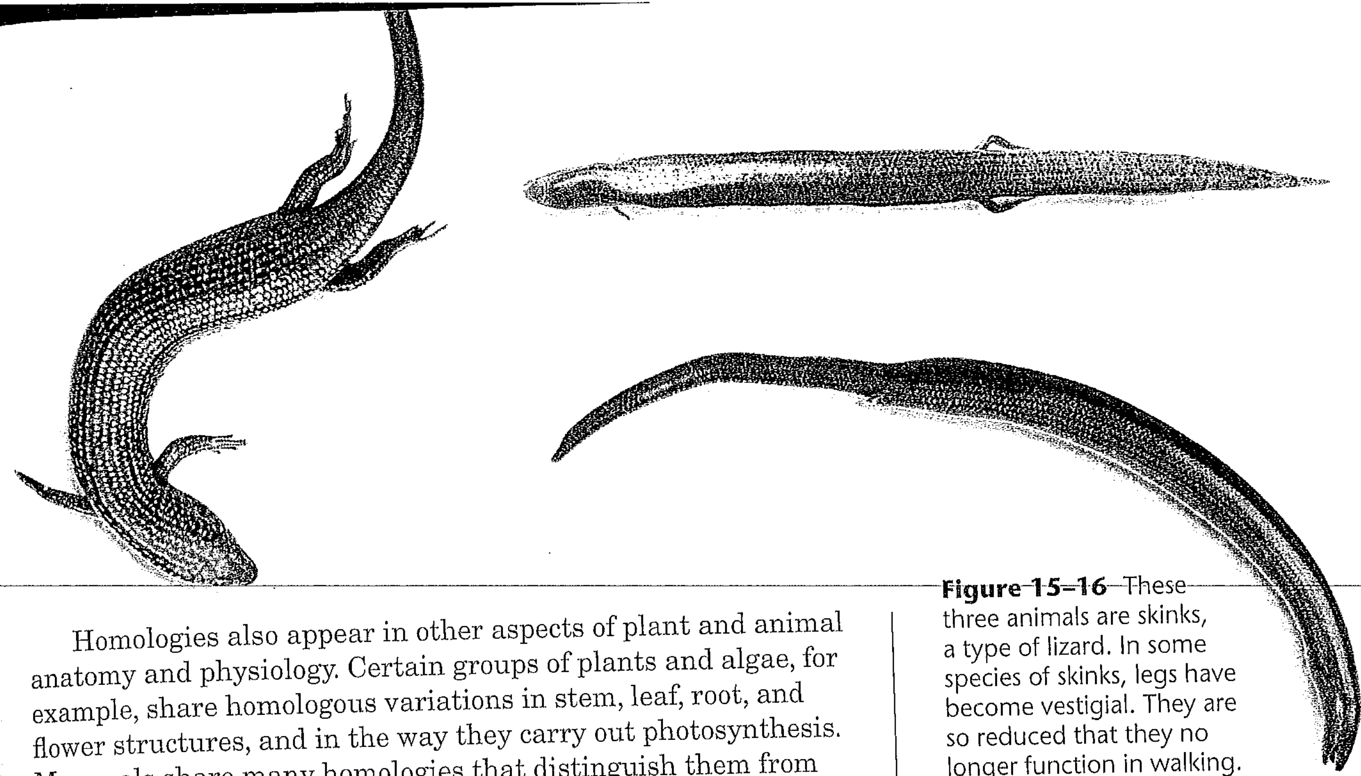


Figure 15–16 These three animals are skinks, a type of lizard. In some species of skinks, legs have become vestigial. They are so reduced that they no longer function in walking. In humans, the appendix is an example of a vestigial organ because it carries out no function in digestion. **Inferring** *How might vestigial organs provide clues to an animal's evolutionary history?*

Homologies also appear in other aspects of plant and animal anatomy and physiology. Certain groups of plants and algae, for example, share homologous variations in stem, leaf, root, and flower structures, and in the way they carry out photosynthesis. Mammals share many homologies that distinguish them from other vertebrates. Dolphins may look something like fishes, but homologies show that they are mammals. For example, like other mammals, they have lungs rather than gills and obtain oxygen from air rather than water.

Similarities in Embryology The early stages, or embryos, of many animals with backbones are very similar. This does not mean that a human embryo is ever identical to a fish or a bird embryo. However, as you can see in **Figure 15–17**, many embryos look especially similar during early stages of development. What do these similarities mean?

There have, in the past, been incorrect explanations for these similarities. Also, the biologist Ernst Haeckel fudged some of his drawings to make the earliest stages of some embryos seem more similar than they actually are! Errors aside, however, it is clear that the same groups of embryonic cells develop in the same order and in similar patterns to produce the tissues and organs of all vertebrates. These common cells and tissues, growing in similar ways, produce the homologous structures discussed earlier.

✓CHECKPOINT *What are homologous structures?*

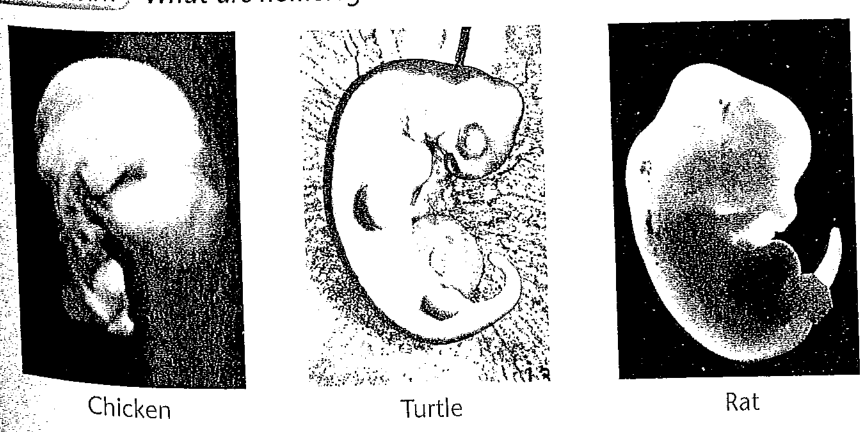


Figure 15–17 In their early stages of development, chickens, turtles, and rats look similar, providing evidence that they shared a common ancestry. **Inferring** *How could a study of these embryos help show the relationships among animals with backbones?*

▲ **Figure 15–18** Darwin's *On the Origin of Species* presented a revolutionary view of the living world. Many scientists agree with Darwin's statement that "There is a grandeur in this view of life, . . . that . . . from so simple a beginning, endless forms so beautiful and wonderful have been and are being evolved." **Applying Concepts** *New species are continually being discovered. How could you use Darwin's theory to learn more about these new species?*

Summary of Darwin's Theory

Darwin's theory of evolution can be summarized as follows:

- Individual organisms differ, and some of this variation is heritable.
- Organisms produce more offspring than can survive, and many that do survive do not reproduce.
- Because more organisms are produced than can survive, they compete for limited resources.
- Each unique organism has different advantages and disadvantages in the struggle for existence. Individuals best suited to their environment survive and reproduce most successfully. These organisms pass their heritable traits to their offspring. Other individuals die or leave fewer offspring. This process of natural selection causes species to change over time.
- Species alive today are descended with modification from ancestral species that lived in the distant past. This process, by which diverse species evolved from common ancestors, unites all organisms on Earth into a single tree of life.

Strengths and Weaknesses of Evolutionary Theory

Scientific advances in many fields of biology, along with geology and physics, have confirmed and expanded most of Darwin's hypotheses. Today, evolutionary theory offers vital insights to all biological and biomedical sciences—from infectious-disease research to ecology. In fact, evolution is often called the "grand unifying theory of the life sciences."

Like any scientific theory, evolutionary theory continues to change as new data are gathered and new ways of thinking arise. As you will see shortly, researchers still debate such important questions as precisely how new species arise and why species become extinct. There is also uncertainty about how life began.

15–3 Section Assessment

1. **Key Concept** How is artificial selection dependent on variation in nature?
2. **Key Concept** The theory of evolution by natural selection explains, in scientific terms, how living things evolve over time. What is being selected in this process?
3. **Key Concept** What types of evidence did Darwin use to support his theory of change over time?
4. **Critical Thinking** **Evaluating** Use scientific evidence to evaluate Darwin's theory of evolution by natural selection.

Writing in Science

Newspaper Article
Write a newspaper article about the meeting in which Darwin's and Wallace's hypotheses of evolution were first presented. Explain the theory of evolution by natural selection for an audience who knows nothing about the subject.