CHAPTER

4

Mechanisms of Population Change

Chapter Concepts

4.1 Adaptation, Variation, and Natural Selection

- Sexual reproduction and inherited mutations contribute to variation among individuals in populations.
- Individuals in a population have a selective advantage over other individuals if their mutations allow them to better survive and reproduce under selective pressures.

4.2 Developing a Theory to Explain Change

- Fossil evidence shows that species change over time and that species eventually become extinct.
- To develop the theory of natural selection, which explains evolutionary change, scientists have gathered and organized many pieces of evidence.
- There is evidence that modern species evolved from ancestral forms.

4.3 How Species Form

- A species consists of reproductively compatible populations.
- New species can form when populations become reproductively or geographically isolated from each other.
- The process of adaptive radiation occurs when a common ancestor diversifies into a variety of species.
- Two models for the pace of evolution are gradualism and punctuated equilibrium.

There are about 4000 cockroach species worldwide. The fossil in this photograph shows a 9 cm-long cockroach (*Arthropleura pustulatus*) that lived 300 million years ago. It was more than twice the size of the American cockroach (*Periplaneta americana*), a species common today. It was preserved so well that its mouthparts and antennae, and even the veins in its wings, are visible. When this cockroach was alive, there was a *greater* diversity of life forms than there is today. Fossils have helped to shape our current ideas about the process by which organisms that are living today descended from ancient forms of life and changed with the passing of time. Using fossil evidence, observations of species, experimentation with laboratory populations, and modern techniques, such as genetic analysis, scientists are adding to our understanding of life on Earth.

Launch Lab

Could Cockroaches Rule Earth?

Procedure

1. Read the paragraph below, and answer the questions that follow.

Cockroaches live in many different habitats throughout the world. They are particularly hardy. They are able to survive without food for several weeks and have a varied diet, which can include unusual items such as wallpaper paste and paint. The females can reproduce several times a month, once they are reproductively mature. (Female American cockroaches live for about 14 months and lay their first egg capsule at about one year of age.)

Analysis

1. One female American cockroach can lay an egg capsule containing 16 eggs every five days. If a female is reproductive for two months, approximately how many offspring will she produce?
2. **a)** If half of the cockroach's offspring are female, and all of them reproduce, how many offspring will they produce? (Show your calculations.)
   b) Do you think this is a realistic situation? Explain.
3. While some cockroach species are abundant in certain areas, cockroaches are not "taking over the world." With a partner, discuss what you think might limit their populations. (**Hint:** Review what you learned in Chapter 3 about the factors that limit populations.)
4. People often use insecticides to kill cockroaches. In some cases, however, using insecticides can result in populations of insects that are resistant to—not harmed by—the very insecticide they are exposed to. Then, the insecticide is no longer able to control the insect populations by killing individuals. How do you think insecticide-resistance in a population might happen?

This reconstruction of an ancient tropical forest shows the type of habitat in which cockroaches, and many other insect species, first appeared over 300 million years ago.

SECTION 4.1

Adaptation, Variation, and Natural Selection

Section Outcomes

In this section, you will
- **describe** how sexual reproduction and changes in genetic information result in variation within populations
- **design** an investigation to measure variations in a population
- **describe** how some mutations may improve an individual organism's chance for survival and reproduction
- **define** natural selection

Key Terms

variation
biological species
mutation
selective advantage
natural selection
selective pressure

Figure 4.1 No two organisms, even within the same species, are identical. Some differences, such as colour and size, are visible in the Rocky Mountain bighorn sheep (*Ovis canadensis*) shown above. Other differences, such as resistance to a particular parasite or bacterial infection, are not visible, but all differences are examples of the variations among individuals in a population.

Organisms, such as the bighorn sheep in Figure 4.1, constantly face environmental challenges that limit populations. Severe weather, drought, famine, and competition for food, space, and mates are all challenges that organisms may or may not be able to overcome. Organisms that survive long enough to reproduce have the opportunity to pass along to their offspring the genetic information that helped them survive. In this section, you will learn how variation within species, and organisms' interactions with their environment, help to explain changes in populations from one generation to another.

Adaptations and Survival

The American bittern, Figure 4.2, is found in marshes and fields in Alberta, where it lives among grasses and reeds. The colouring of its plumage helps to camouflage the bittern so that it blends in with its environment. As with other species, the bittern's adaptations make it well-suited to its habitat. An adaptation is a structure, behaviour, or physiological process that helps an organism survive and reproduce in a particular environment. Camouflage is one such adaptation.

Another adaptation is the biochemical and body processes of a Richardson's ground squirrel in hibernation (for example, physiology such as reduced heart and breathing rate). The needle-sharp talons and excellent vision of an owl are structural adaptations that make owls excellent predators in their environment. The thick, leathery leaves of the buffaloberry are also structural adaptations. They help to reduce water loss on hot summer days, which are an abiotic feature of their environment.

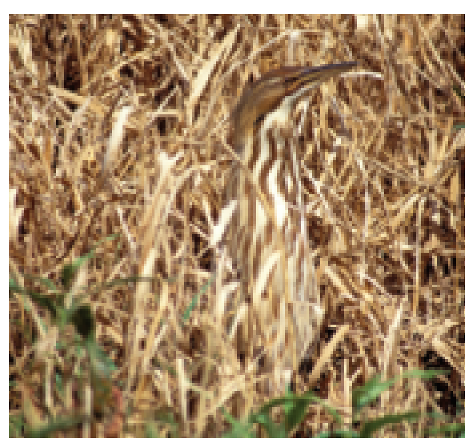


Figure 4.2 The American bittern (*Botaurus lentiginosus*) is well-camouflaged among plants in its habitat. How could the colouration of *individuals* help the survival of a *population*?

BiologyFile

FYI
The American bittern's ability to conceal itself extends to its behaviour, as well. It stands so that the lines on its plumage match the reeds surrounding it. If the reeds are swaying in the breeze, the bittern also sways, mimicking the movement of the reeds.

Figure 4.3 In sexual reproduction, the genes from two parents combine to produce offspring with visible and non-visible variations in their charactertistics. The kittens (*Felis domesticus*) in this litter have different fur colour and patterns, partly because each kitten inherited a different combination of genetic information from its parents.

How do these adaptations develop? Adaptations are the result of a gradual change in the characteristics of members of a population over time. A **variation**—a visible or invisible difference—that helps an individual in a population survive is likely to be passed on from survivor to survivor. Through generations of survivors, this variation will become more common, perhaps so common that it is considered to be a characteristic, or trait, of the population. Not all variations become adaptations. A variation in an individual can be an advantage or disadvantage, or have no effect on the individuals as they live and interact in their environment.

> **Q 1** Sharks have an excellent sense of smell. Is this an adaptation? Explain your answer.

Variation within a Species

A **biological species** is a group of reproductively compatible populations. This means that members of these populations can interbreed and produce offspring that are healthy and are themselves able to reproduce successfully.

You and your classmates are all the same species, but clearly there is a great deal of variety among the individuals in your class. Why? How does this variation arise? Offspring have a combination of genetic material from both parents. Through sexual reproduction, parents pass on distinct units of hereditary information (genes) to their offspring.

The number of possible combinations of genes that offspring can inherit from their parents results in great genetic variation among individuals within a population. The kittens in Figure 4.3, for example, are all from the same litter, yet each has different fur colour and markings. The kittens look different because, through sexual reproduction, each kitten has inherited a different combination of genetic information from its parents. Some of this genetic information is expressed in each kitten's physical appearance and behaviour. Other genetic information has no visible effect but remains part of each kitten's genetic make-up and can be passed on to the next generation.

Genetic variation in a *population* is due to the variety of genetic information in all *individuals* of the population. In the next investigation, you will measure variation within a population.

> **Q 2** How does sexual reproduction lead to variation among individuals in a population?

Mutations Lead to Genetic Variation

Mutations are changes in the genetic material of an organism. Mutations happen continuously in the DNA of any living organism. They can occur spontaneously, when DNA is copied before a cell divides. For example, your own DNA has about 175 mutations, compared with your parents' DNA, because of mistakes that occur as your

INVESTIGATION 4.A

Target Skills

Designing an investigation to describe an inherited variation in a population

Gathering and **recording** data to demonstrate variation

Stating a conclusion based on analysis of collected data

Variations Great and Small

Diversity (variations) within a species can help populations survive environmental changes. Diversity within a species can be monitored genetically, or it can be demonstrated by measuring individuals within a population. Most traits in a population vary in a continuous way from one extreme to the other. A plot of the distribution of the trait in a population often produces a bell-shaped curve. In this investigation, you will design an experiment to measure a particular characteristic in two populations—plant seeds and humans.

Question

Are there measurable differences in size among individuals of the same species?

Hypothesis

Make and record a hypothesis about how a particular characteristic might be distributed throughout a population. (For example, would it be evenly distributed?)

Materials

- ruler
- electronic balance
- bean seeds or peas
- graph paper

Experimental Plan

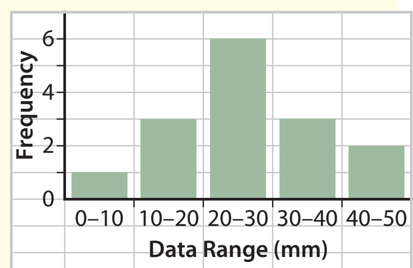
1. With your group, design an investigation to determine the variation in the mass of plant seeds and a second investigation to determine the variation in the length of the human thumb or the width of the human hand.
2. State and record a hypothesis for each investigation.
3. As a group, decide how you will make the appropriate measurements and how many samples you will need. Also decide whether to pool your data with other groups. (Keep in mind that the larger the sample size, the more reliable the results are.)
4. Design a table similar to the one shown in the sample to record data for each investigation.
5. Identify the variables that you will control to ensure that your data are reliable.
6. Show your experimental plan to your teacher before beginning your investigation.

Data and Observations

1. Conduct your investigations, and record your results.
2. Group the data into meaningful categories.
3. Pool data from other groups if required to produce meaningful results.
4. A frequency histogram is a representation of a frequency distribution by means of rectangles whose widths represent class intervals and whose areas are proportional to the corresponding frequencies. Use a computer and spreadsheet software to construct a frequency histogram of data collected. ICT

Sample Data Table and Histogram

Data Range (mm)	Frequency
0–10	1
10–20	3
20–30	6
30–40	3
40–50	2

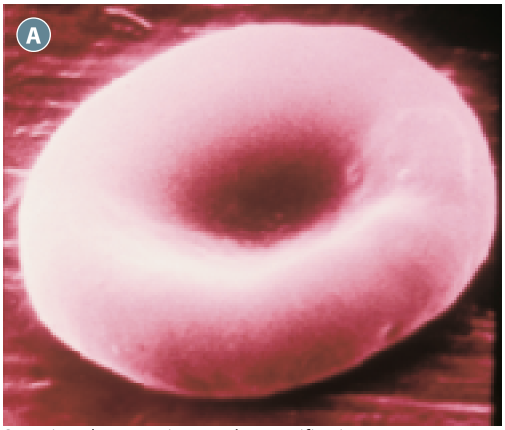


Analysis

1. Identify the range of the data that you collected for each investigation.

Conclusions

2. What can you conclude about the variations within a population? Is there a "typical" length or mass? Or is the frequency the same for each data range?
3. Would you get a greater or smaller variation in the range of data if all of the individuals sampled came from the same parents—for example, if all of the seeds you measured originated from the same plant?
4. What advantage would size (either large size or small size) have to the population studied? (For example, what advantage would large size have to a seed?)



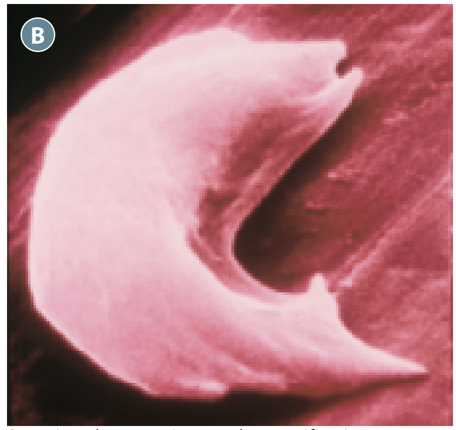


Figure 4.4 Normal, healthy red blood cells are round and smooth. They pass easily through blood vessels. Sickled cells can stick in the blood vessels, resulting in blood clots and reduced blood flow to vital organs. People who inherit the mutated gene for sickled cells from both of their parents have a condition called sickle cell disease.

DNA is copied. Mutagens, such as UV radiation, are environmental agents that can cause mutations in DNA, as well.

When DNA mutates, a cell may exhibit new characteristics. You can see an example of this in Figure 4.4, which shows a healthy blood cell (A) and an abnormal, sickle-shaped red blood cell (B). Other possible results include the cell dying, malfunctioning, or multiplying more than it should, resulting in a cluster of cells that form a tumour. Some mutations will not appear to have any effect on a cell. Whatever the result, if the mutation occurs in a body (somatic) cell, the mutation disappears when the organism dies. If, however, the mutation alters the DNA in a gamete (reproductive cell), the mutation may be passed on to succeeding generations. For example, if the kittens in Figure 4.3 have mutations in their egg or sperm cells, these mutations could be passed on to their offspring. These mutations were not present in their parents' DNA. Thus, mutations are a significant source of genetic variation in populations.

Mutations Can Provide a Selective Advantage

Mutations that significantly alter proteins in DNA often adversely affect the well-being of an organism and can be harmful. In some instances, however, a mutation enables an organism to survive its environment better, which, in turn, means that the organism is more likely to survive and reproduce. This situation is more common when an organism's environment is changing. Mutations that once were no advantage, or perhaps were even a disadvantage, may become favourable in a new environment. In this situation, the mutation provides a **selective advantage** in the new environment.

As an example, there is a mutation in houseflies that makes them resistant to the insecticide DDT. This mutation also reduces the flies' growth rate. So, before the introduction of DDT to their environment, having this mutation would have been a disadvantage to the flies. When DDT was introduced, however, this mutation enabled the individuals that possessed it to survive. These flies had a selective advantage in the population. They were more likely to survive and reproduce, thus potentially passing on this now-helpful mutation to their offspring.

In another study, researchers found that populations of California ground squirrels that overlap the range of northern Pacific rattlesnakes have a factor in their blood that makes them better able to combat the rattlesnakes' venom. Ground squirrels with this factor are likely to be the ones that will survive

BiologyFile

FYI

Mutated genes can cause or contribute to some diseases, such as diabetes, heart disease, Huntington's, cancer, and Alzheimer's. Hereditary conditions can occur because a parent with the mutation can pass it to children. There are tests available and more being developed that can help doctors pinpoint the mutation and the disease. The goal of the research is to improve the ability to treat patients and prevent unwanted mutations from passing on to future generations.

Biology File

FYI

A person who receives the gene for sickled cells from both parents inherits sickle cell disease, which is harmful and can be life-threatening. A person who receives the gene from only one parent, however, can benefit from it. This is because people with a single copy of this gene are more resistant to malaria, an insect-borne disease that is one of the leading causes of illness and death in Africa.

Biology File

FYI

In natural selection, the environment selects for certain characteristics in a population. For centuries, however, people have been selecting organisms for particular traits. This is called *artificial selection*. Early indigenous peoples of Central America—ancestors of the peoples who would develop great cities such as those of the Olmec and Maya—developed the ancestral versions of the corn that we are familiar with today from one or more ancient grasses, including *teosinte*.

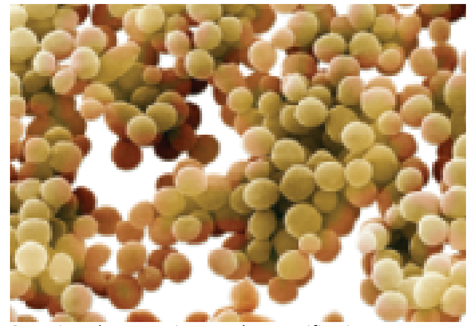
Modern corn kernel compared with *teosinte*

and reproduce, thus passing on the genes for this factor to their offspring. (In other words, the mutation that provided ground squirrels with the protection against snake venom gave those individuals a selective advantage.) As a result, in the future, a high proportion of the population will have the genetic make-up that allows them to withstand rattlesnake venom.

In populations that reproduce quickly, such as bacteria, viruses, and many insects, a rapidly changing environment can result in populations that also become adapted fairly quickly. If the environment changes, the mutated form of a gene that was previously insignificant in the population may provide a selective advantage to some individuals. As a result, the organisms that have the mutant form survive, and the genetic information is passed on to the next generation. In time, the gene that provided the selective advantage becomes more prevalent in the population. The once neutral or even negative mutation can, in some cases, mean the survival of a population.

For instance, populations of cockroaches can become adapted to new environments, such as those where they are sprayed with insecticides, relatively quickly. The cockroaches with a mutation that allows them to survive the insecticide can potentially pass this mutation onto their offspring. In the next generation, this mutation becomes more common in the population and more individuals in the population are resistant to the insecticide. Figure 4.5 shows another species that can quickly become adapted to new environments because it reproduces so quickly.

Q 3 Using a suitable example, distinguish between a mutation that provides a selective advantage and a mutation that provides a selective disadvantage.



Scanning electron micrograph, magnification: 16 000 ×

Figure 4.5 These *Staphylococcus aureus* cells appear to be identical, but some may have a mutation that makes them resistant to antibiotics.

Investigate this type of organism and its ability to adapt in the next Thought Lab.

Natural Selection

Natural selection is a process that results when the characteristics of a *population* of organisms change because *individuals* with certain inherited traits survive specific local environmental conditions and, through reproduction, pass on their traits to their offspring. For natural selection to occur, there must be variety or diversity within a species. This is clearly what caused the antibiotic-resistant *Staphylococcus aureus* you will study in Thought Lab 4.1.

In this population of bacteria, the bacteria that survived were *selected for* by their environment. They survived the change in the environment around them, which was the application of an antibiotic, and thus could reproduce and pass on the genetic information that coded for resistance to that particular antibiotic. *Individuals* did not change during their lifetime; rather, with the passage of time, the *population* changed in its ability to resist certain antibiotics. In other words, populations change, not individuals. An abiotic environmental condition can be said to select *for* certain characteristics in some individuals and select *against* different characteristics in other individuals. In this way, the environment exerts **selective pressure** on a population.

For example, in a population of finches, some of the birds may have wider beaks than others. If there is an environmental change that makes having a wide beak an advantage, these wide-beaked finches will be more likely to survive and pass on the genes for wide beaks to their offspring. In native grasses such as rough fescue, shown in Figure 4.6, individuals that have the ability to withstand drought will survive during conditions of sustained dry conditions. They will then pass on the trait for drought resistance to their offspring. In the next generation, the abundance of the trait for drought resistance will increase in the population, because more of the drought-resistant individuals survive to reproduce. Should there be a big increase in the moisture in the population of

Figure 4.6 Three species of rough fescue, Foothills (*Festuca campestris*), Plains (*Festuca hallii*), and Northern (*Festuca scabrella*), cover approximately two thirds of Alberta. In fact, Alberta is the only place in North America where all three species grow naturally. In 2001, more than 2000 Albertans voted rough fescue as their favourite grass for a provincial emblem. The main reason given was its role as winter food for bighorn sheep, deer, elk, and bison.

Thought Lab 4.1 Evolving "Superbugs"

Target Skills

Analyzing data and **applying** a conceptual model to show how antibiotic resistance could occur in a population of *Staphylococcus aureus*

Gathering and **recording** information about the rise of antibiotic resistance in bacteria

Staphylococcus aureus bacteria, shown in Figure 4.5 on the previous page, can cause painful ear infections in children and life-threatening infections in the wounds of surgery patients. Like many other micro-organisms, *S. aureus* bacteria reproduce quickly. They reproduce asexually by dividing as frequently as every 20 min. This can result in a single cell having close to a billion descendants in about 6 h. Because of these astounding reproductive rates, beneficial mutations in the population may increase in frequency very quickly. This phenomenally rapid asexual cloning of individuals that are resistant to the new environment (for example, to the antibacterial action of an antibiotic) makes it challenging for scientists to develop effective antibiotics.

Procedure

1. Review the data shown in the table. Based on the data, when is bacterial resistance to a particular antibiotic likely to occur in *Staphylococcus aureus*?
2. Using different-coloured playing chips, model how a population of *Staphylococcus aureus* could become resistant to an antibiotic. (**Hint:** Use one colour of chip for bacteria that are resistant to an antibiotic.)

Analysis

1. Explain how the following situation might lead to antibiotic resistance of *Staphylococcus aureus* in patients.

   A patient is prescribed the antibiotic erythromycin for an infected cut. The prescription instructs the patient to take the antibiotic for two weeks. After one week, however, the cut seems to have cleared up and the patient stops taking the antibiotic.

2. With a partner, choose one of the following questions to research. Prepare a written, oral, or computer presentation to share your findings. ICT
   - How can the overuse of antibiotics lead to antibiotic resistance in bacteria?
   - Why do some agricultural practices contribute to antibiotic resistance in some bacteria species, and how can this contribute to antibiotic resistance in bacteria that cause diseases in humans?

Historical Progression of Antibiotic Resistance of *Staphylococcus aureus*

Antibiotic	Year introduced	First reports of resistance in patients
penicillin	1941	1945–1946
streptomycin	1944	1945
tetracycline	1948	1955
erythromycin	1952	1950s
methicillin	1961	1961
gentamicin	1964	1976
ciprofloxacin	1988	1990
vancomycin	1956	1997

rough fescue's environment, the trait for drought resistance will no longer be an advantage. In fact, if no individuals in the population can withstand extremely moist conditions, the population may not survive in that environment.

Natural selection does not anticipate change in the environment. Instead, natural selection is situational. A trait that at one time seems to have no particular relevance to survival becomes the trait that later helps individuals in a population survive and reproduce in a changed environment. This trait then persists within a population, because it is inherited by the offspring of the survivors. Adaptations that are beneficial in one situation may be useless or detrimental in another situation. Complete the next Thought Lab to see how changing environmental conditions affected a finch population over several years.

Q4 Identify two examples, mentioned in this section, that show variation in a species being caused by a mutation.

Q5 Explain how the ability of a population of insects to withstand the effects of an insecticide is an example of natural selection.

Thought Lab 4.2 Analyzing Changes in Beak Depth

Target Skills

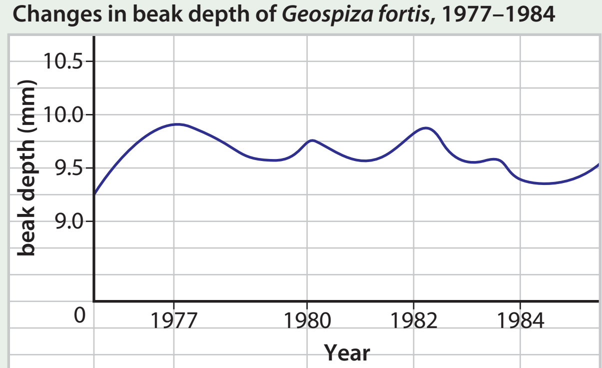
Analyzing data to show how beak depth in the medium ground finch changes with the passage of time

Stating and **defending** a generalization based on data

Rosemary and Peter Grant have been studying the medium ground finch (*Geospiza fortis*) of the Galápagos Islands for several decades. These finches use their strong beaks to crush seeds. They prefer the small seeds that are abundant during wet years. Because fewer small seeds are produced during dry years, the finches also have to eat larger seeds, which are harder to crush. For several years, the Grants have been measuring the depth (dimension from top to bottom) of the finches' beaks.

The medium ground finch, *Geospiza fortis*

Changes in beak depth of *Geospiza fortis*, 1977–1984



Procedure

Use the questions below to interpret the graph.

Analysis

1. 1977, 1980, and 1982 were drought years; 1984 was a wet year. What do you notice about the average beak depth in the finch population during dry years compared with wet years?
2. How do the data relate to selective pressure and natural selection?
3. An observer suggested that the finches exercised their beaks more when they ate large seeds that were tough to open, making their beaks stronger. Evaluate the plausibility of this explanation for the graphed data.

Section 4.1 Summary

- An adaptation is a physical feature, behaviour, or physiological process that helps an organism survive and reproduce in a particular environment. Examples of adaptations include camouflage, night vision, deep roots, nesting, and hibernation.
- Variety within a population and the environment in which an organism lives creates a situation in which natural selection can occur.
- Mutations and reproduction cause variations among individuals in a population.
- A mutation may provide an individual with an advantage or a disadvantage, or neither (neutral).
- Natural selection is the process by which a population of organisms changes because individuals with certain traits can better survive the local environmental conditions and pass on these traits to their offspring.

BiologyFile

Web Link

Health professionals and scientists worldwide are concerned about the resistance of bacteria to antibiotics. Many share information and ideas in an attempt to slow this alarming trend. What practices do health professionals recommend to reduce the spread of antibiotic-resistant bacteria?

www.albertabiology.ca

www

Section 4.1 Review

1. Identify five adaptations of this grizzly bear that make it well suited for survival in its habitat.

2. Describe how variations occur in populations.

3. Using examples from this chapter, show how mutations and natural selection happen by chance.

Use the following information to answer the next question.

Pumpkins

A gardener is trying to win a competition for the largest pumpkin. Every year, she saves the seeds from the largest pumpkin in her garden. The next year, she plants only those seeds in a large plot. She finds that her pumpkins are becoming larger over the years.

4. a) Explain whether there is selective pressure in this pumpkin population.

b) Is this situation an example of natural selection? Justify your answer.

5. Evaluate the following statement: "Natural selection works like a newspaper copy editor; it works only with what is already present in a population." [**Note:** Copy editors check written material, usually as the final step before it is set into type, to correct errors in grammar, spelling, usage, and style.]

6. In a population of sparrows, most birds have a bill that is about 10 mm long. Some birds, however, have bills that are slightly longer or slightly shorter than average. Explain why this variation within a population is important when discussing natural selection.

7. Suppose that you are designing an investigation to measure variation within a population. Explain why it would not be appropriate to measure the length of 100 leaves from the same tree.

Use the following information to answer the next question.

Insect Resistant Pests

Pesticide resistance is a genetically based phenomenon. Resistance occurs when a pest population—insects, for instance—is exposed to a pesticide. When this happens, not all insects are killed. Those individuals that survive frequently have done so because they are genetically predisposed to be resistant to the pesticide.

Repeated applications and higher rates of the insecticide will kill increasing numbers of individuals, but some resistant insects will survive. The offspring of these survivors will carry the genetic makeup of their parents. These offspring, many of which will inherit the ability to survive the exposure to the insecticide, will become a greater proportion with each succeeding generation of the population.

8. Explain how some insects develop resistance to pesticides in terms of natural selection.

9. Explain what is meant by the expression "populations evolve, not individuals."

SECTION
4.2

Developing a Theory to Explain Change

Section Outcomes

In this section, you will
- **compare** different explanations for changes in populations over time
- **describe** evidence to support the theory of evolution
- **explain** how scientific knowledge is accumulated and organized to develop theories
- **analyze** data to determine relatedness among organisms

Key Terms

theory of evolution by natural selection
paleontology
inheritance of acquired characteristics
fossil record
transitional fossils
biogeography
homologous structures
analogous structures

Scientific knowledge develops as people observe the world around them, ask questions about their observations, and seek answers to their questions. A *scientific hypothesis* is a statement that provides one possible answer to a question, or one possible explanation for an observation. Hypotheses are tested to determine their validity, mainly through experiments, observation, developing models from data, or a combination of these. Hypotheses that consistently lead to successful predictions and explanations are sometimes synthesized into a general statement that explains and makes successful predictions about a broad range of observations. Such a statement is called a *scientific theory*.

For centuries, people have been asking questions about how life developed on Earth. They have found objects (such as fossils), made observations (such as recognizing the natural variations in populations), collected and analyzed data, and formulated hypotheses to explain their observations. The resulting **theory of evolution by natural selection** is a well-supported, widely accepted explanation of how life has changed, and continues to change, during Earth's history. In this section, you will survey key events in the development of this theory, as well as scientific observations that support it.

Developing the Theory of Evolution by Natural Selection

Some ancient Greek philosophers believed that life evolved gradually. However, two of the most influential philosophers, Plato (427–347 B.C.E.) and Aristotle (384–322 B.C.E.), believed that all life existed in a perfected and unchanging form. This view of life prevailed in western culture for over 2000 years. By the sixteenth century, the predominant philosophy in western culture was that all species of organisms had been created independently of one another and had remained unchanged ever since.

Buffon's *Histoire Naturelle*

One of the first people to challenge publicly the idea that life forms are unchanging was French naturalist Georges-Louis Leclerc, Comte de Buffon (1707–1788). In 1749, he published the 44-volume *Histoire Naturelle*, which compiled his understandings of the natural world. In this work, Buffon noted the similarities between humans and apes, and speculated that they might have a common ancestor. In other writings, Buffon suggested that Earth was much older than 6000 years, as was commonly believed.

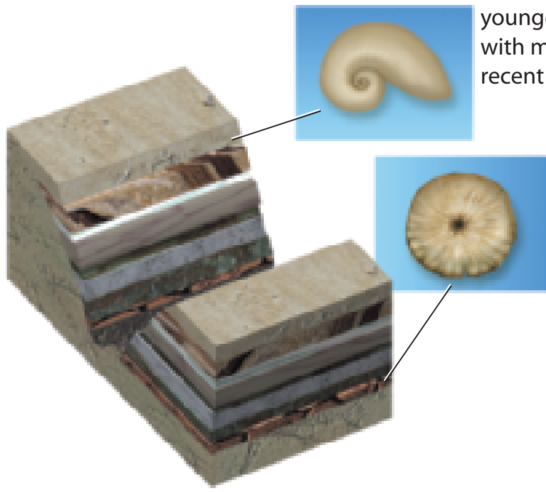
Buffon's ideas were revolutionary for his time. By 1830, however, other scholars from many areas of inquiry—paleontology, geology, geography, and biology—began to share their ideas to explain how life could change with the passage of time.

Cuvier's Fossils

French naturalist Georges Cuvier (1769–1832) is largely credited with developing the science of **paleontology**, the study of ancient life through the examination of fossils. Cuvier found that each stratum (layer of rock) is characterized by a unique group of fossil species. He also found that the deeper (older) the stratum, the more dissimilar the species are from modern life (see Figure 4.7). As Cuvier worked from stratum to stratum, he found evidence that new species appeared and others disappeared over the passage of time. This evidence showed that species could become extinct.

To explain his observations, Cuvier proposed the idea that Earth experienced many destructive natural events, such as floods and volcanic eruptions, in the past.

Figure 4.7 Deep rock strata (layers of rock) are older than strata that are closer to the surface. Different species of fossilized organisms can be found in different rock strata. This is evidence that not all life forms came into existence at the same time. (The arrangement of strata varies when mountains are formed. Often, the strata are tilted and the oldest layers are toward the inside of the mountain.)



BiologyFile

FYI

Writers of history use the term catastrophism to describe Cuvier's ideas about the powerful forces that led to the extinction of species in Earth's past. Cuvier did not use this term himself, although he did refer to these events as catastrophes.

These events, which he called *revolutions*, were violent enough to have killed numerous species each time they occurred.

> **Q 6** A geologist finds the fossil of a species of fish in one stratum but not in the next highest stratum. Infer how Cuvier might have explained this observation.

Lyell's *Principles of Geology*

Other scientists had ideas that differed from Cuvier's theory. Scottish geologist Charles Lyell (1797–1875) rejected the idea of revolutions. He proposed, instead, that geological processes operated at the same rates in the past as they do today. He reasoned that, if geological changes are slow and continuous rather than catastrophic, then Earth might be more than 6000 years old. As well, Lyell theorized that slow, subtle processes could happen over a long period of time and could result in substantial changes. The forces that build and erode mountains, for example, and the rate at which this change happens is no different today than it was in the past. Floods in the past had no greater power than floods that occur today. This idea inspired naturalist Charles Darwin and others. If Earth is slowly changing, they wondered, could slow, subtle changes also occur in populations?

> **Q 7** How did Lyell's observations about changes in geology inspire naturalists' thoughts about changes in life on Earth?

Lamarck: The Inheritance of Acquired Characteristics

In his book *Philosophie Zoologique*, French naturalist Jean-Baptiste Lamarck (1744–1829) outlined his ideas about changes in species over time. By comparing current species of animals with fossil forms, Lamarck observed what he interpreted as a "line of descent," or progression, in which a series of fossils (from older to more recent) led to a modern species. He thought that species increased in complexity over time, until they achieved a level of perfection.

Lamarck also thought that characteristics, such as large muscles, that were acquired during an organism's lifetime could be passed on to its offspring. Following this reasoning, the large, powerful chest muscles of a horse would be passed on to its offspring, which would have the same characteristics. Lamarck called this the **inheritance of acquired characteristics**.

Lamarck provided a hypothesis for how the heredity of characteristics from one generation to the next might happen. More importantly, he noted that an organism's adaptations to the

BiologyFile

FYI

Early Chinese records describe the bones of "underground dragons." These are fossils that scientists, much later, recognized as being parts of dinosaurs. The use of "dragon bones" in traditional medicine dates back at least 3500 years.

environment resulted in characteristics that could be inherited by offspring. At the time, there was little understanding of cell biology and no understanding of genetics. The idea of inheriting acquired characteristics was generally accepted to explain observations that species are not static and could change. Even Charles Darwin, who is credited with developing a comprehensive theory to explain how change in populations can occur, accepted Lamarck's idea of inheritance and acknowledged Lamarck in his writing. Lamarck's ideas were controversial to many people, though, simply because they firmly believed that species never changed.

By the end of the 1800s, as biologists learned about cells, genes, and heredity, Lamarck's mechanism for inheritance was rejected.

> **Q 8** A farmer spends much of her time outdoors and, as a result, has very tanned skin. What would the hypothesis of inheritance of acquired characteristics say about the skin of her children? Why?

Darwin's Evidence

In 1831, 22-year-old Charles Darwin (1809–1882) left England on the HMS *Beagle*, a British survey ship. The primary purpose of the expedition was to map the coast of South America. As well, the journey provided Darwin with an opportunity to explore the natural history of various countries and geographical locations. Figure 4.8 outlines the *Beagle's* journey.

At first, Darwin did not always understand the significance of many of his observations. Years later, however, many of these observations (as well as ideas and observations resulting from new work by Darwin and others) became important to his theory of evolution by natural selection. Darwin's main observations, and the questions he asked about these observations, are summarized in Table 4.1.

> **Q 9** Describe, using two examples, how Charles Darwin used observation of the world around him to develop his hypothesis about how species might change with the passage of time.

Figure 4.8 The five-year voyage of the HMS *Beagle* took the young Charles Darwin around much of the world. Most of his time, however, was spent exploring the coast and coastal islands of South America.

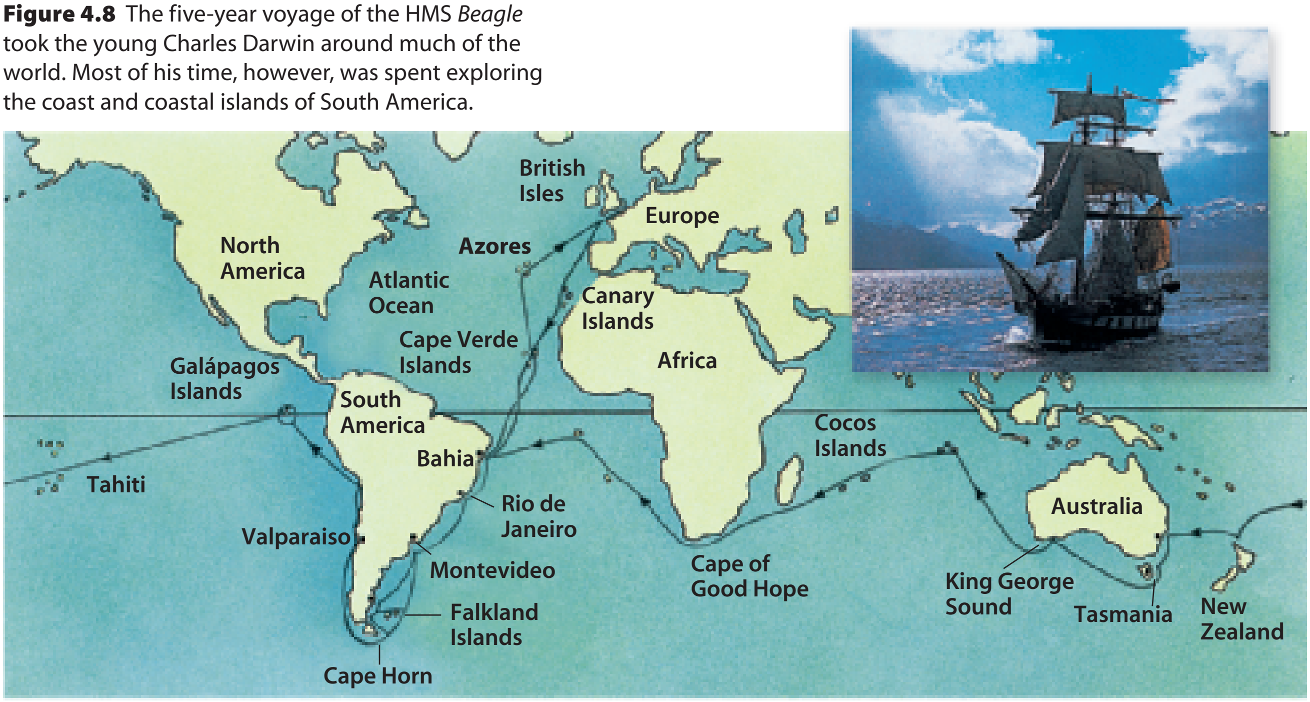
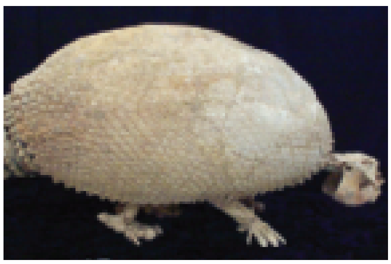
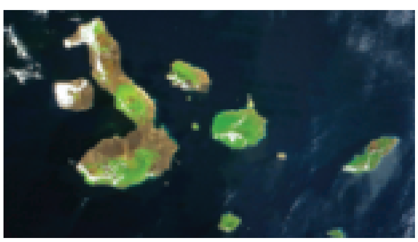
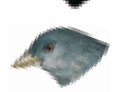
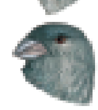


Table 4.1 Darwin's Observations and Questions Arising from Them

Observations	Questions
1. The flora and fauna of the different regions the *Beagle* visited were distinct from those Darwin had studied in England and Europe. For example, the rodents in South America were structurally similar to one another but were quite different from the rodents Darwin had observed on other continents.	If all organisms originated in their present forms during a single event, Darwin wondered, why was there a distinctive clustering of similar organisms in different regions of the world? Why were all types of organisms not randomly distributed?
2. Darwin observed fossils of extinct animals, such as the armadillo-like glyptodont, that looked very similar to living animals.  glyptodont, an ancient 4 m, 2 t animal from South America  modern armadillo from South America (1.5 m)	Why would living and fossilized organisms that looked similar be found within the same region?
3. The finches and other animals Darwin saw on the Galápagos Islands closely resembled animals he had observed on the west coast of South America.  The Galápagos Islands, shown in this satellite image, include more than 20 small volcanic islands located approximately 1000 km off the coast of Ecuador.	Why did the Galápagos species so closely resemble organisms on the adjacent South American coastline?
4. Galápagos species (such as tortoises and finches) looked identical at first, but actually varied slightly between islands. Each type of Galápagos finch, for example, was adapted to eating a different type of food based on the size and shape of its beak. Ten finch species that occur on one of the islands, Santa Cruz, are shown here.  Warbler finch (*Certhidea olivacea*)  Woodpecker finch (*Cactospiza pallida*)  Small insectivorous tree finch (*Camarhynchus parvulus*)  Large insectivorous tree finch (*Camarhynchus psittacula*)  Vegetarian tree finch (*Platyspiza crassirostris*)  Cactus ground finch (*Geospiza scandens*)  Sharp-beaked ground finch (*Geospiza difficilis*)  Small ground finch (*Geospiza fuliginosa*)  Medium ground finch (*Geospiza fortis*)  Large ground finch (*Geospiza magnirostris*)	Why was there such a diversity of species in such a small area? Could these species have been modified from an ancestral form that arrived on the Galápagos Islands shortly after the islands were formed?
5. Through his experience in breeding pigeons and studying breeds of dogs and varieties of flowers, Darwin knew that it was possible for traits to be passed on from parent to offspring, and that sexual reproduction resulted in many variations within a species.	Could a process similar to artificial selection also operate in nature?

Biology File

FYI

Darwin did not use the word "evolution" in the original edition of *On the Origin of Species*. ("Evolved" is used once; it is the final word in the book.) Instead, Darwin wrote about "descent with modification." One reason he did not use "evolution" is that he felt it implied progress—that each generation was improving in some way. Natural selection is different from progress. It results from an ability to survive local conditions and reproduce successfully, thereby giving the survivors the opportunity to pass on the trait that helped them survive and reproduce.

Darwin and Wallace and the Theory of Evolution by Natural Selection

Charles Darwin was not the only person to organize his and others' observations and ideas into a comprehensive theory to explain how species changed over time. Alfred Russel Wallace (1823–1913), another British naturalist, reached conclusions that were similar to Darwin's. The findings of both scientists were made public in a presentation by Charles Lyell in 1858.

Darwin and Wallace accepted that populations changed as time passed, but they were unclear *how* populations changed. An essay by economist Thomas Malthus (1766–1834), called *Essay on the Principles of Population*, provided them with a key idea. Malthus had proposed that populations produced far more offspring than their environments (for example, their food supply) could support and were eventually reduced by starvation or disease.

According to Darwin and Wallace, individuals with physical, behavioural, or other traits that helped them survive in their local environments were more likely to survive to pass on these traits to offspring. Darwin and Wallace reasoned that competition for limited resources among individuals of the same species would *select for* individuals with favourable traits—traits that increased their chances of surviving to reproduce. Thus, a growing proportion of the population would have these traits in later generations and, as time passed, the population as a whole would have them. Darwin called this process natural selection. He published his ideas in 1859 in *On the Origin of Species by Means of Natural Selection*.

Q 10 How might competition for resources lead to natural selection?

Darwin proposed two main ideas in *On the Origin of Species*:

1. Present forms of life have arisen by descent and modification from an ancestral species.
2. The mechanism for modification is natural selection working for long periods of time.

Darwin proposed that all life on Earth had descended from some unknown organism. As descendants of this organism spread out over different habitats during the millennia, they developed adaptations that helped them better survive in their local environments. Darwin's theory of natural selection showed how populations of individual species became better adapted to their local environments over time.

Compare Darwin's hypothesis to explain evolution with Lamarck's ideas about inheritance in the next Thought Lab.

Further Evidence of Evolution

In *On the Origin of Species*, Darwin assembled a group of facts that had previously seemed unrelated. Darwin certainly was not the only person to conclude that life had changed during long periods of time, but he was the first person to publish these ideas in a comprehensive manner. Darwin's ideas were developed, for the most part, by his observations of the distribution of organisms throughout the world (Table 4.1 on the previous page). Before and after publication of *On the Origin of Species*, biologists, geologists, geographers, and paleontologists provided a wealth of information that supported and strengthened what scientists now call the theory of evolution by natural selection.

The Fossil Record

Sedimentary rock with fossils provides a **fossil record** of the history of life by showing species that were alive in the past. (See Figure 4.9.) For instance, when people examined the Burgess Shale fossil

Figure 4.9 **(A)** The animals unearthed in the Burgess Shale lived over 500 million years ago during the Cambrian Explosion, when a stunning "explosion" of Earth's biodiversity occurred. Remarkably, even some soft parts of animals, such as gills and digestive systems, are preserved. **(B)** This 60 cm fossil of *Anomalocaris canadensis* was found in the Burgess Shale near Field, British Columbia.

Thought Lab 4.3 Comparing the Ideas of Lamarck and Darwin

Target Skills

Comparing Darwinian and Lamarckian explanations of evolutionary change

Evaluating and **communicating** the merits of alternative explanations for evolutionary change

Flying fish (*Exocoetus volitans*) are actually superb gliders, not flyers. To escape predators, the fish, which are about 18 cm long, aim toward the surface of the water and beat their powerful tails back and forth. When they break the surface, they continue to beat their tails, which increases their forward speed up to about 55 km/h. By spreading their side-fins, they are able to glide up from and over the surface for distances as great as 200 m!

Darwin and Lamarck both developed ideas about the inheritance of characteristics. Although Darwin read Lamarck's work and learned from his ideas, Darwin eventually proposed an alternative hypothesis that gave a different explanation for the mechanism that resulted in change. Read the following quotations from the writings of Lamarck and Darwin:

> "The environment exercises a great influence over the activities of animals, and as a result of this influence the increased and sustained use or disuse of any organ are causes of modification of the organization and shape of animals and give rise to the anomalies observed in the progress of the complexity of animal organization."
>
> —Jean-Baptiste Lamarck in *Philosophie zoologique*, 1809

> "… natural selection, or the survival of the fittest, does not necessarily include progressive development—it only takes advantage of such variations as arise and are beneficial to each creature under its complex relations of life. And it may be asked what advantage, as far as we can see, would it be to an … intestinal worm … to be highly organised. If it were no advantage, these forms would be left, by natural selection, unimproved or but little improved, and might remain for indefinite ages in their present lowly condition."
>
> —Charles Darwin in *On the Origin of Species*, 1859

Procedure

1. Rewrite each quotation in your own words.
2. How does Lamarck's idea of "use or disuse" differ from Darwin's idea, which was later called "descent with modification?"

Analysis

1. Flying fish use large pectoral fins to glide in air. Explain how (a) Lamarck and (b) Darwin might account for the origin of the large pectoral fins and the ability to glide.
2. Lamarck suggested that organisms arise spontaneously and then become increasingly more complex. With a partner, discuss why this idea is not supported by the theory of natural selection. (**Hint:** You might want to consider an organism such as a snake, which evolved from a population of animals that had legs.)

BiologyFile

Web Link

The Burgess Shale in British Columbia, the rich fossil beds near Drumheller, Alberta, and the Joggins Fossil Cliffs in Nova Scotia are just a few of many Canadian sites with a rich store of fossils. What have Canadian fossils contributed to our understanding of evolution?

www.albertabiology.ca

beds in British Columbia, they found fossils of animals that had lived in an ancient ocean during the Cambrian period, over 500 million years ago. Not only are micro-organisms and soft-bodied animals preserved in the Burgess Shale, but also these fossil beds contain some of the earliest animals with hard parts to be seen in the fossil record. Some of the fossilized animals found in the Burgess Shale are ancestors of animals that are common today. Others have long been extinct and are unlike anything in our modern oceans.

The fossil record provides the following evidence:

- Fossils found in young layers of rock (from recent geological periods and usually closer to the surface) are much more similar to species alive today than fossils found in deeper, older layers of rock.
- Fossils appear in chronological order in the rock layers. So, probable ancestors

Geologic Time Scale

Era	Period	Million years ago	Major evolutionary events	Representative organisms
Cenozoic	Quaternary	5	Humans evolve	
	Tertiary		First placental mammals	
Mesozoic	Cretaceous	65	Flowering plants dominant	
	Jurassic	144	First birds First mammals First flowering plants	
	Triassic	213	First dinosaurs	
Paleozoic	Permian	248	Cone-bearing plants dominant	
	Carboniferous	286 320	First reptiles Great coal deposits form First seed plants	
	Devonian	360	First amphibians	
	Silurian	408	First land plants First jawed fish	
	Ordovician	438	Algae dominant First vertebrates	
	Cambrian	505	Simple invertebrates	
Precambrian		590	Life diversifies Eukaryotes Prokaryotes Life evolves	
		3500		

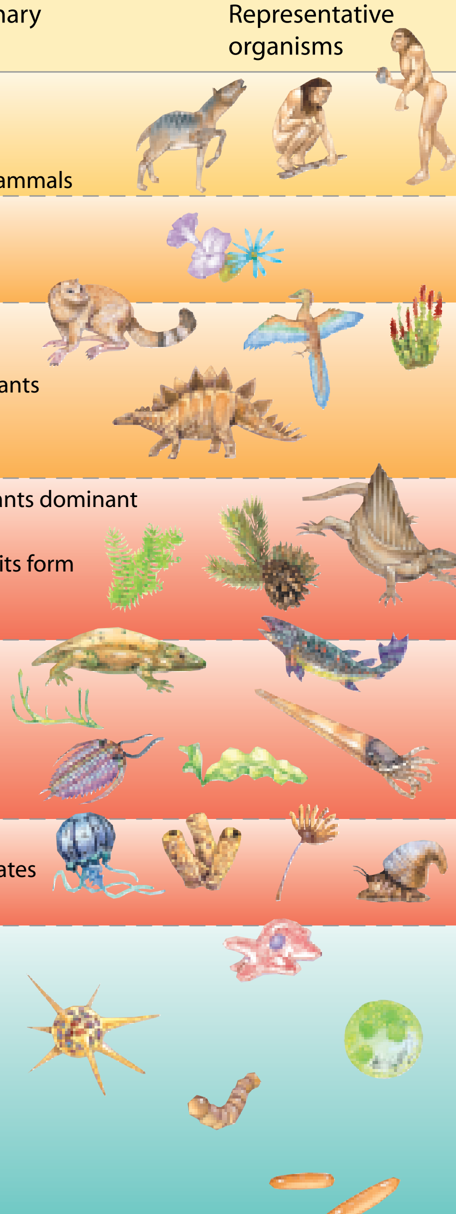


Figure 4.10 This geologic time scale shows when organisms first appear in the fossil record.

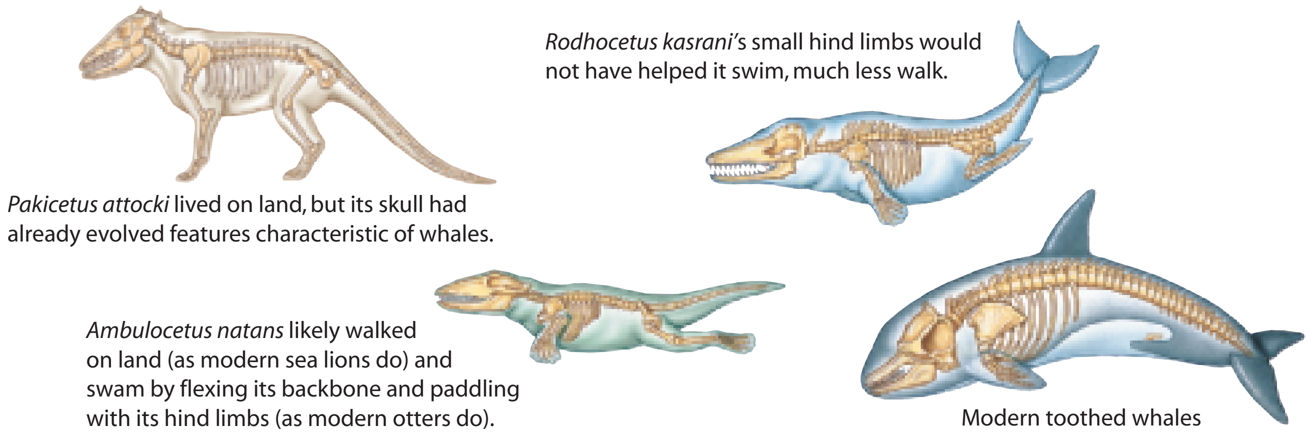


Figure 4.11 Fossil evidence suggests that modern, aquatic, toothed whales evolved from a terrestrial ancestor, *Pakicetus attocki*. *Basilosaurus* and *Dorudon*, not shown in this illustration, appear more recently in the fossil record, after the appearance of *Rodhocetus*.

for a species would be found in older rocks, which would usually lie beneath the rock in which the later species was found.

- Not all organisms appear in the fossil record at the same time. For example, the fossil history of vertebrates shows that fish are the oldest vertebrates. In subsequent layers, the fossils of other vertebrates—amphibians, reptiles, mammals, and birds—appear. This reinforces scientific evidence that amphibians evolved from ancestral fish, reptiles evolved from ancestral amphibians, and both mammals and birds evolved from different groups of reptiles (mammals first, and then birds). It is important to remember that these changes were slow and took millions of years. The geological time scale in Figure 4.10 shows when organisms first appear in the fossil record.

Q 11 List two ways that the fossil record has helped scientists understand that organisms change over time.

Transitional Fossils

The original fossil record gave only scattered "snapshots" of ancestral forms, and critics of the theory were concerned about the "gaps." The ongoing discovery of hundreds of **transitional fossils**—fossils that show intermediary links between groups of organisms—has helped scientists better understand the process and relationships between groups of organisms. Transitional fossils link the past with the present. For example, scientists have found fossilized whales that lived 36 to 55 million years ago. These fossils link present-day whales to terrestrial ancestors. The *Basilosaurus* and *Dorudon* were ancient whales that had tiny hind limbs, but led an entirely aquatic life. *Dorudon* was about the size of a large dolphin, about 5 m long. It had a tiny pelvis (located near the end of its tail) and 10-cm legs, both of which would have been useless to an animal that lived an aquatic life. A more recently discovered transitional form, *Ambulocetus*, announced in 1994, had heavier leg bones. Scientists hypothesize that it lived both on land and in water. Figure 4.11 shows *Ambulocetus*, as well as two other ancestors of present-day whales, whose discovery has filled gaps in the fossil record of whales.

In 1995, the fossil of a previously unknown dinosaur called *Atrociraptor* ("savage robber") was discovered near Drumheller (see Figure 4.12). *Atrociraptor* was a small meat-eating dinosaur, about the size of a 10-year-old child. It is thought to be a close non-birdlike relative of *Archaeopteryx*. Fossils

Figure 4.12 Based on where *Atrociraptor* was found in the fossil record, it was alive about 70 million years ago, during the Cretaceous period.

of *Archaeopteryx* show a transitional stage in the fossil record because this species had characteristics of both reptiles (dinosaurs) and birds. *Archaeopteryx* had feathers, but, unlike any modern bird, it also had teeth, claws on its wings, and a bony tail.

In early 2005, a Canadian team of paleontologists made another amazing discovery at a fossil site in China. They found a pair of shelled eggs inside a fossilized dinosaur. The dinosaur, a kind of theropod, is considered to be an ancestor of modern birds. The shape of the eggs, the evidence at the fossil site, past fossil discoveries, and the paleontologists' understanding of the biology of birds and reptiles suggested to them that this dinosaur laid its eggs in intervals like modern-day birds, rather than all at once like reptiles do.

Patterns of Distribution

As you know from Chapter 3, organisms are not distributed evenly over Earth. **Biogeography** is the study of the past and present geographical distribution of organisms. Many of the observations that Darwin and Wallace used to develop their theories were based on biogeography. Darwin and Wallace hypothesized that species evolve in one location and then spread out to other regions.

Biogeography supports this hypothesis with examples such as the following:

- Geographically close environments (for example, desert and forest habitats in South America) are more likely to be populated by related species than are locations that are geographically separate but environmentally similar (for example, a desert in Africa and a desert in Australia). So, for instance, cacti are native only to the deserts of North, Central, and South America. They are not naturally found in other deserts in the world, such as those in Australia or Africa.
- Animals found on islands often closely resemble animals found on the closest continent. This suggests that animals on islands have evolved from mainland migrants, with populations becoming adapted over time as they adjust to the environmental conditions of their new home. For example, the lizards found on the Canary Islands, off the northwest coast of Africa, are very similar to the lizards found in west Africa.
- Fossils of the same species can be found on the coastline of neighbouring continents. For example, fossils of the reptile *Cynognathus* have been found in Africa and South America. How can this be explained? The location of continents are not fixed; continents are slowly moving away from one another. At one time, the continents of Africa and South America were joined in one "supercontinent."
- Closely related species are almost never found in exactly the same location or habitat.

Anatomy

Vertebrate forelimbs can be used for various functions, including flying (birds and bats), running (horses and dogs), swimming (whales and seals), and swinging from tree branches (monkeys). Despite their different functions, however, all vertebrate forelimbs contain the same set of bones, organized in similar ways. How is this possible? The most plausible explanation is that the basic vertebrate forelimb originated with a common ancestor. **Homologous structures** are those that have similar structural elements and origin but may have a different function. The limbs shown in Figure 4.13 have similar structures, such as number of bones, muscles, ligaments, tendons, and blood vessels. These structural elements are arranged, however, to be best suited for different functions: walking, flying, or swimming. Homologous structures are similar because they were inherited from a common ancestor. As you can see in Figure 4.13, homologous structures differ in their anatomy based on an

Biology File

Web Link

The theory of plate tectonics, developed by geologists and paleontologists, explains how the locations of continents have changed over Earth's history. What pivotal role did Canadian geologist John Tuzo Wilson play in formulating this theory? How does this theory support the theory of evolution by natural selection?

www.albertabiology.ca
WWW

Biology File

FYI

Aboriginal people have lived off the land in the Wood Buffalo region in Northern Alberta for more than 8000 years. The Wood Buffalo National Park was created with the help of local Aboriginal groups to preserve the cultural history of the area and to protect the world's largest free-roaming bison (*Genus Bison*) herd and the last natural nesting site for the endangered whooping crane (*Grus americana*).

organism's lifestyle and environment. For example, the bones in a horse's leg are larger and heavier than the bones in a bat's wing.

Homologous structures can be similar in structure or function or both. The limbs in Figure 4.13 are structurally similar. As well, the lower limbs of the human, frog, and horse perform the same function: movement on land. Functional similarity in anatomy, however, does not necessarily mean that species are closely related. The wings of insects, birds, bats, and pterosaurs (extinct flying reptiles) are similar in function, but not in structure. (For example, bones support bird wings, whereas a tough material called chitin makes up insect wings.) All of these organisms evolved independently of one another and did not share a common ancestor with wings.

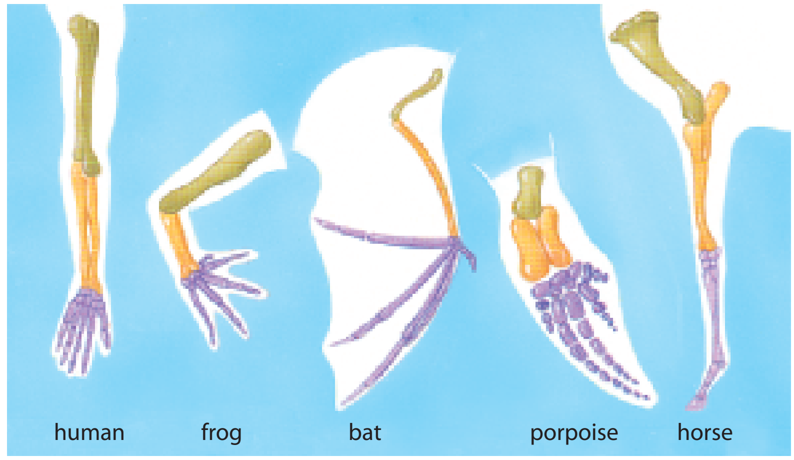


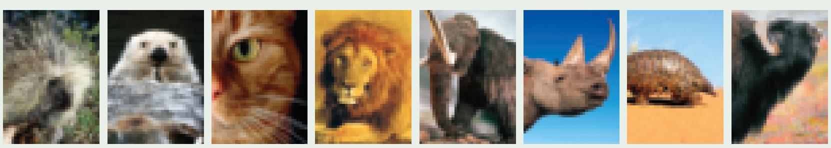
Figure 4.13 These vertebrates have the same basic arrangement of bones (as indicated by the colours), but the bones have different uses.

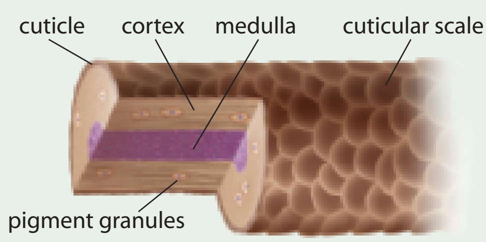
Thought Lab 4.4 Homologies of Hair

Target Skills

Hypothesizing the adaptive significance of variations in the structure of hair

Using electronic research techniques to **analyze** and **synthesize** ideas related to hair as a homologous structure, in order to determine patterns and links





Cross Section of a Hair

Mammals are the only animals that have hair. Among mammalian species, hair can vary in length, density, texture, and colour. The basic structure of hair, however, is the same for all mammals. Each hair has a central medulla that is surrounded by a dense cortex, which contains most of the pigment granules that give each hair its colour. The cortex is covered by a layer called the cuticle. The scales of the cuticle are specific to a particular genera or even species of mammals. Thus, mammalian hair has a common origin, yet may serve different functions. In this activity, you will investigate variations in the functions of mammalian hair.

Procedure

1. Work in small groups of three or four.
2. Each person in your group should choose a different type of mammalian hair from the following list:
   - **a)** the stout, strong hairs of a porcupine
   - **b)** the dense underfur, or underhairs, of a sea otter
   - **c)** the vibrissae ("whiskers") of a cat
   - **d)** the thick mane of a lion
   - **e)** the long, thick hair of a woolly mammoth
   - **f)** the horn of a rhinoceros, which is made of densely packed hair
   - **g)** the "scales" of a pangolin, which are modified hairs
   - **h)** the soft, fluffy qiviut (fur) of a muskox
3. Conduct research to investigate the structure of the hair you have chosen. Research how the animal's lifestyle and habitat might explain the particular function(s) of its hair.

Analysis

1. Based on the information you collected and your understanding of natural selection,
   - **a)** hypothesize how the structure of the hair is related to abiotic conditions in an animal's environment
   - **b)** write a hypothesis stating how the variations might have arisen from the basic hair structure of a common mammalian ancestor
2. Present your findings to the others in your group in a written or oral report, a computer presentation, or another form that is easily shared. ICT
3. Write a statement that describes one similarity and one difference in the adaptations of the hair studied by the members of your group.

Biology File

Try This

Some structures evolved for one function and became useful for another function as time passed. For example, feathers might have evolved originally as an adaptation for insulation and later might have become useful for flight. Adaptations that were originally selected for one function but later became useful for another function are called *exaptations*. Originally, exaptations were called pre-adaptions. How could the term "pre-adaptation" lead to some misconceptions about natural selection?

Body parts that perform similar *functions*, even though the organisms do not have a common evolutionary origin, are called **analogous structures**.

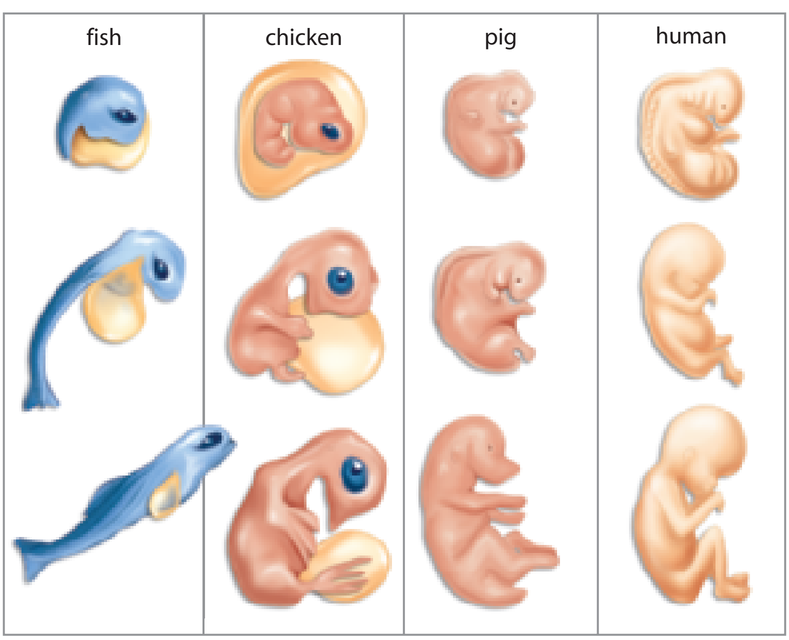
12 Are bird wings and bat wings homologous structures or analogous structures? Explain your answer.

Embryology

The embryos of different organisms exhibit similar stages of embryonic development. For example, all vertebrate embryos have paired pouches, or out-pocketings of the throat. In fish and some amphibians, the pouches develop into gills. In humans, the pouches become parts of the ears and throat. At certain stages in the development of the embryo, the similarities among vertebrates are more apparent than the differences, as you can see in Figure 4.14.

The similarities among embryos in related groups (such as vertebrates) point to a common ancestral origin. It follows that related species would share both adult features (such as basic arm-bone arrangements, as discussed earlier) and embryonic features (such as the presence of paired pouches in the throat).

Figure 4.14 Similarities in the embryos of fish, reptiles, birds, and mammals provide evidence of evolution.



13 How does an understanding of embryology support the idea that similar organisms, such as vertebrates, have a common ancestor?

Molecular Biology

The evolutionary relationships among species are reflected in their DNA and proteins. The field of molecular biology developed as technologies to identify molecules, such as DNA and protein molecules, developed. This field has provided evidence that helps to support the idea of common ancestry and evolution through natural selection. From molecular biology, we have learned the following information about life on Earth:

- All cells consist of membranes filled with—among other components—water, genetic material, proteins, lipids, and carbohydrates.
- Proteins called enzymes control biochemical reactions in all organisms.
- In all organisms, proteins are synthesized from amino acids.
- In all organisms, all cells that can replicate contain DNA. Since DNA carries genetic information, scientists can determine how closely related two organisms are by comparing their DNA. If two species have similar patterns in portions of their DNA, this similarity indicates that these portions of their DNA were most likely inherited from a recent common ancestor.

Genetics

The use of modern technology has led to many discoveries that support Darwin's theory. Scientists now know how species passed on their traits to their offspring, and how the blueprints (genes) for these traits could change by mutation, as you learned in section 4.1. Current evolutionary theory connects genetics with the theory of natural selection, and how natural selection operates on populations. Thus, genetic evidence and the understanding of heredity and mutations lend support to hypotheses that stem from observations of fossils, anatomy, biogeography, embryology, and molecular biology.

> **Q 14** List five different fields of science that have contributed to the theory of evolution by natural selection. How has each field contributed to refining this theory?

Section 4.2 Summary

- Scientific theories explain facts and tie them together in a comprehensive way, enabling scientists to make predictions about new situations and experimental outcomes.
- The theory of evolution ties together facts to provide a logical framework that explains how life on Earth has changed and is still changing.
- Charles Darwin and Alfred Russel Wallace both developed hypotheses to explain natural selection.
- Contributions by Cuvier, Lamarck, Malthus, Lyell, and others helped to develop the hypotheses that have become the theory of evolution by natural selection.
- The fossil record, biogeography, anatomy, molecular biology, and genetics all provide evidence for evolution.
- New discoveries of fossils, called transitional fossils, help fill in the "gaps" in the fossil record.
- Homologous structures are those that have similar structural elements and origin but may have a different function. Analogous structures perform similar functions, even though the organisms do not have a common evolutionary origin.

Section 4.2 Review

1. Describe the contributions of the following people to the understanding of evolution:
   a) Cuvier
   b) Malthus
   c) Wallace
   d) Lyell
2. Although Lamarck and Darwin proposed different explanations for how characteristics are passed from parent to offspring, their theories had some similarities. Identify and compare these similarities.
3. Is a bat more closely related to a bird or to a mouse? Explain your answer using the terms "analogous structure" and "homologous structure."
4. Much of the theory of evolution has been developed by interpreting certain observations or by making logical inferences about these observations. Outline the inferences that Darwin and other scientists made from each of the following observations.
   a) Some species found on islands are very similar to species found on neighbouring continents.
   b) No two individuals are exactly alike.
   c) Resources, such as food, are limited.
5. List three facts that support the idea of organisms sharing a common ancestor.
6. An athlete breaks her leg. Years later, she has a child who walks with a limp. Is this an example of a trait being passed from one generation to the next? Justify your answer.
7. 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? Explain your reasoning.
8. Define the term transitional fossils and explain how these help scientists to better understand relationships between groups of organisms.
9. Use word processing or spreadsheet software to create a table summarizing the differences between homologous and analagous structures. Use the following headings: structure, function, and origin. ICT
10. Explain how scientists can use DNA to determine the evolutionary relationship between two organisms.

Debating Science

"When I consider healthy discussions that take place in the scientific world, vigorous debate (or at least consideration) of opposing alternatives is critical for the successful development of ideas and identification of promising new areas of research. The ideas that withstand critical challenges from colleagues end up being the most robust and strongest theories."

—Brent Edwards, PhD,
Starkey Hearing Research Centre

How often have you read about a scientific "breakthrough" only to see it disputed (or completely contradicted) a few months later? What's good for you one year seems to be bad for you the next. *What is going on?*

Science is a process of constructing, refining, and revising knowledge and understanding. Individuals or small groups of scientists start the process. However, the result of their work—a new discovery, a rejected hypothesis, or a modified theory—is a collaborative process that requires feedback, discussion, and the eventual consensus of others in the scientific community.

The Role of Scientific Review

Science requires, and is founded on, the practice of peer review. In 1560, an Italian scholar, Giambattista della Porta, founded the first organization for the exchange of scientific ideas, known as The Academy of the Mysteries of Nature. Its purpose was to present scientific ideas for review and discussion. Since that time, countless societies, associations, journals, symposia, conferences, and now Internet resources have been set up to give scientists a place to communicate their ideas and findings for the evaluation of their peers.

This scrutiny is an essential part of the scientific process. Peer reviewers compare assumptions with their own knowledge, attempt to replicate or verify findings, and frequently challenge their colleagues' conclusions. This is why it is so important to document all procedures and carefully record the resulting data.

The review process has uncovered faulty experimental designs, incorrect conclusions, and—at times—deliberately fraudulent data. In many cases, however, the process of peer review and scientific debate has led to the development, refinement, and acceptance of scientific laws and theories that help shape our understanding of the world around us.

The process is not foolproof. The sheer volume of material being published today in a variety of increasingly specialized journals makes it very difficult for the field to police itself effectively. Individual publications must have strict guidelines for submissions to ensure that legitimate research is being presented for review.

In Darwin's day, 1858, he publicly reported on the studies he and Alfred Russel Wallace had done related to the origin and diversity of life to the Linnean Society in London. *On the Origin of Species* was published the next year as a book, and scientific colleagues used it to review the evidence presented and the conclusions. That review continues as more evidence is found, and more conclusions are reached, published, and debated.

Science and Society

Scientific debates are not always confined to the topics of scientific evidence and conclusions. Scientists do not exist in a vacuum; they are part of society. Their discoveries have led to inventions that have transformed the ways in which we live our lives. Some scientific discoveries go beyond practical applications to challenge assumptions that sustain social institutions.

For example, since the days of Aristotle, people in western society had believed that Earth was the centre of the universe. Theologians and political authorities had based their justification of social order on this understanding. In 1543, Nicolaus Copernicus, a Polish astronomer, challenged this Earth-centred view by publishing a new theory about Earth orbiting the Sun. In the 1600s, the astronomer and physicist Galileo Galilei (1564–1642) was imprisoned and threatened with torture for supporting Copernicus's theory. Representatives of the state felt that a Sun-centred universe was a dangerous idea that would undermine social structures and authority.

When Darwin published his book in 1859, those debating his theories and conclusions were not just scientists. Many non-scientists were alarmed by the implications of Darwin's conclusions, which were thought to challenge the idea that humans were created intentionally by God for a special purpose and that, again, this would undermine the social order.

The social debate over evolution was still raging in 1925 when the state of Tennessee passed legislation that made it "unlawful" for any teacher there to "teach any theory that denies the story of the Divine Creation of man as taught in the Bible, and to teach instead that man has descended from a lower order of animals." A high school biology teacher named John Thomas Scopes was soon charged with the offense. His trial, which became known through the media as "The Scopes Monkey Trial," was held in a packed courthouse and followed by national newspapers in the U.S. (It also was the first trial to be broadcast on national radio.)

The arguments for and against the indictment largely revolved around preserving the separation of church and state, the validity of various interpretations of the Bible, and whether a conviction created a special status for one faith. The actual science related to the theory of evolution was not the focus of the debate; the concern was about its social impact.

Some of the current debates among scientists—for example, about climate change and the importance of preserving biodiversity—have also moved beyond the sphere of science and entered the public forum. Once again, scientific conclusions are under fire, not because the science is thought to be wrong, but because there are concerns that the implications will somehow undermine social (and economic) principles and practices.

Some observers of the Scopes Monkey Trial suggested that if they had a chance to debate the issue, monkeys might have strong objections.

• • •

1. You and your colleagues at the university have discovered a protein that you believe is a major trigger for certain types of heart disease. You've rerun your tests many times and gotten consistent results. Now it's time to publish them. Choose two potential journals in which you could publish the research.
   a) Describe the readership, including the total number and their general areas of expertise.
   b) Describe the process for submitting research for review.
   c) Explain how the publication is funded.
   d) Assess and describe any potential impact the factors you've researched might have on the quality of attention and review your team's work on proteins and heart disease will receive.

2. When and why do you think members of the general public should get involved in discussions about scientific findings? Describe the best forum for holding such discussions (for example, schools, courts, newspapers, radio, television, public meetings, or the Internet) and why you think it is the most effective.

3. The peppered moth, *Biston betularia*, has been the subject of scientific study since 1848, when it was noted that the numbers of individuals of flecked and dark moth populations fluctuated over relatively short periods of time that corresponded to the amount of air pollution in the moth's habitat. Numerous studies confirm the hypothesis that natural selection is driving these population changes. However, this hypothesis has been challenged, mainly in the popular media, rather than in scientific journals. Do research to find and summarize the evidence that has been cited to challenge the hypothesis.

4. *The Journal of Negative Results in Biomedicine* is one of a handful of scientific journals devoted to communicating the negative results of failed investigations and disproved hypotheses. Some scientists suggest that all scientific journals should do a better job of providing such information. Do you agree? Justify your reasoning.

SECTION 4.3

How Species Form

Section Outcomes

In this section, you will
- **explain** ways in which species can become reproductively isolated
- **describe** how new species form
- **compare** two models that explain the rate of evolution

Key Terms

speciation
geographical barriers
biological barriers
adaptive radiation
gradualism
punctuated equilibrium

Figure 4.15 The Northern leopard frog (*Rana pipiens*) **(A)** and Southern leopard frog (*Rana sphenocephala*) **(B)** were once thought to be part of a single, extremely variable species. Today, scientists agree that what they thought was one species of leopard frog is at least seven different, but related, species in North America.

The two leopard frogs in Figure 4.15 look remarkably similar, but they are different species. How is a species defined? Historically, biologists defined species in terms of their physical form. Physical similarity, however, does not necessarily mean that organisms are the same species. Biologists now consider physiology, biochemistry, behaviour, and genetics, as well, when distinguishing one species from another.

What Is a Species?

As you read in Section 4.1, a biological species consists of populations that can interbreed and produce a group of viable offspring, which can also reproduce in nature. Biological species that are geographically isolated cannot interbreed. What about biological species that share the same habitat?

Biological species can also be described as being reproductively isolated from other species. Obviously, highly dissimilar species, such as elephants and frogs, cannot mate, so they are reproductively isolated. Populations that breed at different time periods, such as those that breed in the spring and those that breed in the fall, are also reproductively isolated. What about species that are similar, such as two species of warbler? In this section, you will learn how populations remain reproductively isolated from one another and how this can lead to the formation of new species.

Forming a New Species

There are two general pathways that can lead to the formation of new species, or **speciation**. As shown in Figure 4.16A, a new species may result from accumulated changes in the population over a long period of time. A new species gradually develops as a result of mutation and adaptation to changing environmental conditions, and the old species is gradually replaced. This is known as *transformation*. The evolution of mammoths followed this pathway. The ancestral mammoth lived approximately 2.6 million to 700 000 years ago. It slowly evolved into the steppe mammoth that lived 700 000 to 500 000 years ago, and finally into the woolly mammoth that lived 350 000 to 10 000 years ago.

If this pathway were the only mechanism for the creation of new species, however, the total number and diversity of species in existence would remain virtually unchanged. In the second pathway to speciation, shown in Figure 4.16B, one or more species arise

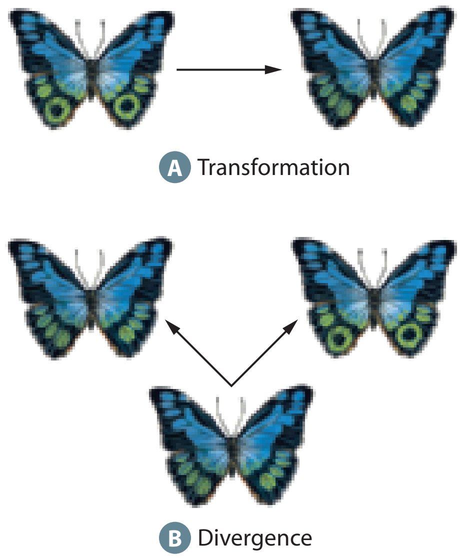


Figure 4.16 There are two pathways to speciation: **(A)** one species evolves into another species and **(B)** one or more species arise from a parent species.

from a parent species that continues to exist. This is known as *divergence*. For example, the small hoofed *Hyracotherium*, which lived approximately 50 million years ago, is thought to have been the common ancestor of modern horses, tapirs, and rhinoceroses.

Both pathways to speciation are the result of natural selection. The second pathway increases biological diversity because it increases the number of species.

> **Q 15** Define speciation and the two general pathways to speciation.

Keeping Populations Separate

For speciation to occur, two populations must be prevented from interbreeding. This means that the populations must become isolated from one another through geographical or biological barriers. If the populations remain isolated long enough, speciation will eventually occur because of changes accumulated in the population due to natural selection, which affects reproduction. When this happens, individuals in one population are no longer able to reproduce successfully with individuals in the other population.

Geographical Barriers

Geographical barriers, such as mountains and rivers, prevent interbreeding and result in speciation because they keep populations *physically* separated. For example, a substantial lava flow may isolate populations, changes in ocean levels may turn a peninsula into an island, or a few colonizers may reach a geographically separate habitat (such as a newly formed island). After a long period of time, speciation will occur. The separated populations will no longer be able to mate and reproduce successfully with others members of the original population.

The geographic isolation of a population does not have to be maintained forever for speciation to occur. It must be maintained long enough, however, for the population to become reproductively incompatible with the original population.

Members of the ancestral species of Galápagos finches reached one of the islands in the archipelago, possibly as a result of being blown off course in a tropical storm. Unable to return to the mainland, the ancestral species evolved differently from their mainland relative. The ancestral birds, and their successive generations, have since spread through the islands. New species developed as they evolved in response to the unique environments on individual islands.

Figure 4.17 on page 138 shows the hypothesized descent of multiple species from one common ancestor. The length of each vertical line reflects how much the DNA of each species has mutated from the group's common ancestor.

Biological Barriers

Even if the ranges of species overlap, there are many **biological barriers** that can keep the species reproductively isolated. For example, behaviour is a biological barrier that will keep

BiologyFile

Try This
Most woolly mammoths became extinct about 11 000 years ago. (A smaller form, called the dwarf woolly mammoth, survived until as recently as 3500 to 5000 years ago on an island off the coast of northern Russia.) Fossil records show that human hunting had a role to play in the extinction of the woolly mammoth, as did global warming. Many scientists are concerned about how global warming might affect populations today. (For example, changes in climate or water levels can affect food supplies or result in a loss of habitat.) With a partner, discuss ways in which global warming might affect the evolution of species by natural selection.

BiologyFile

FYI
Charles Darwin used the variations he could see and measure in the Galápagos finches to hypothesize how speciation might have happened in the Galápagos Islands. Today, DNA evidence supports Darwin's original hypothesis and adds further information to help scientists understand how the different lineages of finches could have arisen from an ancestral population.

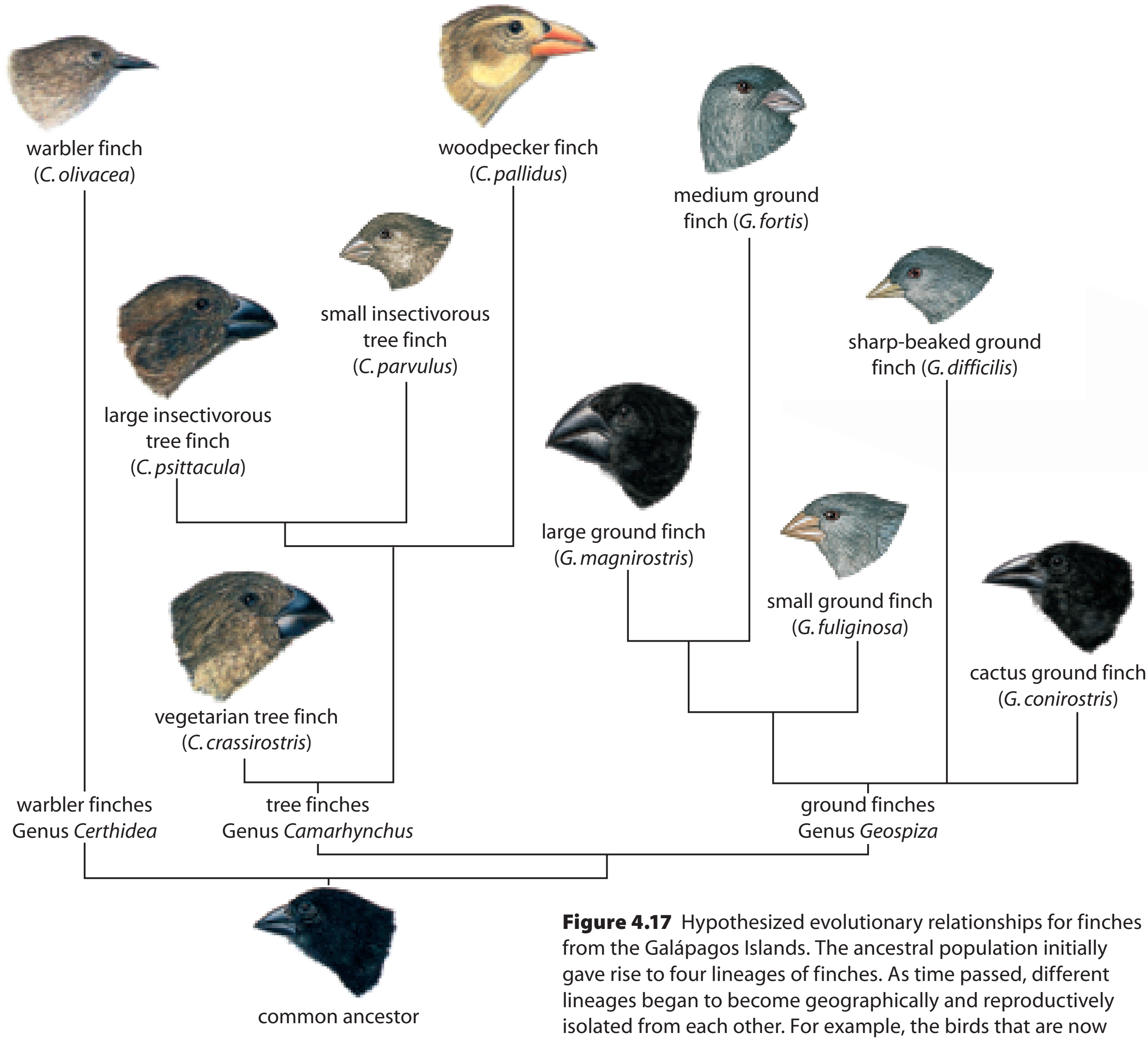


Figure 4.17 Hypothesized evolutionary relationships for finches from the Galápagos Islands. The ancestral population initially gave rise to four lineages of finches. As time passed, different lineages began to become geographically and reproductively isolated from each other. For example, the birds that are now called warbler finches developed beaks that were more slender than the beaks of their ancestor to specialize in eating insects.

BiologyFile

Web Link
Scientists at the University of British Columbia have been tracking the speciation of greenish warblers (*Phylloscopus trochiloides*) in various habitats in Asia. The songs of different populations of this bird differ slightly in each habitat throughout their range. What other differences have resulted from the birds' isolation?

www.albertabiology.ca
WWW

individuals separate. The courtship songs of birds are one type of behavioural barrier. Male birds use distinct calls that are recognized by other birds of the same species during their mating season. Birds that have diverged from a common ancestral species may have similar calls, but their calls are different enough from the calls of neighbouring species to provide a biological barrier to reproduction.

Species of spiders also use biological barriers. Female spiders use pheromones (chemical signals) to attract mates of the same species. Some male spiders, such as the one in Figure 4.18, use specific movements to identify themselves to the females.

Other species may live in the same general area but use different habitats, and therefore encounter each other rarely, if at all. An example is two species of garter snakes. One species usually lives near water, and the other species lives in open areas, rarely near water. This is different from a geographical barrier because there is no physical impediment keeping the populations apart.

Take a look at the behavioural barriers to reproduction in leopard frogs in the following Thought Lab.

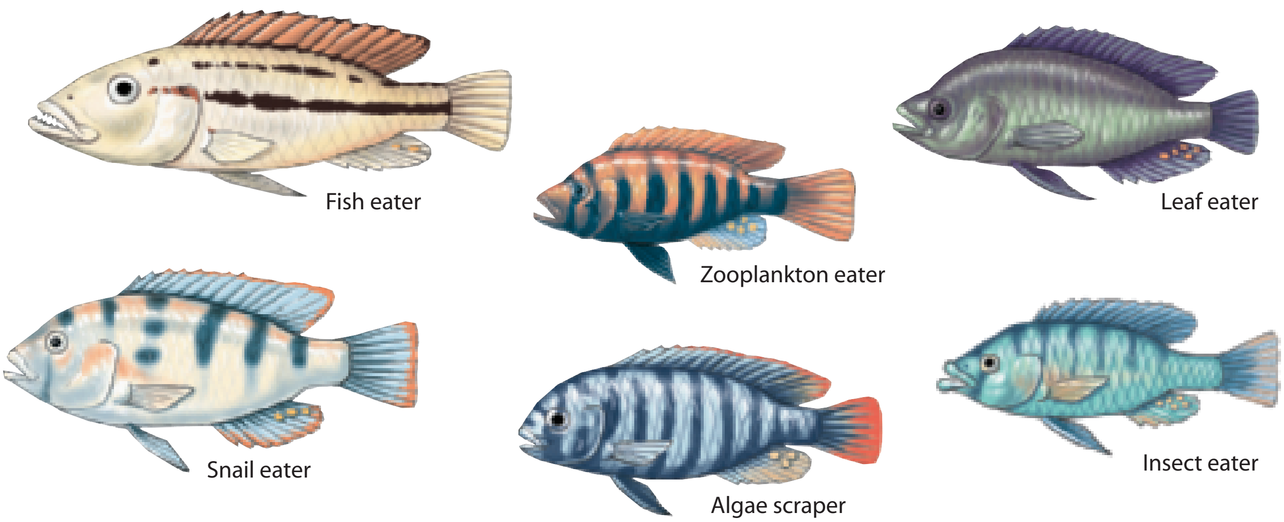
Figure 4.18 The small (15 to 20 mm), male golden orb spider (from the Genus *Nephila*) signals his identity and intentions to the female (20 to 30 mm, shown on the left) by plucking a strand of the web. His "love song" keeps his species reproductively isolated from other spider species because the female recognizes the signals of his particular mating behaviour. This prevents him from being mistaken for an interloper and being eaten by the female.

16 How is a bird's call a barrier to speciation?

Speciation Occurs in Reproductively Isolated Populations

When populations become reproductively isolated—even when they have not become geographically isolated—speciation has occurred. For example, animals can become reproductively isolated within the geographical range of a parent population if they begin to use resources that are not used by their parents. Lake Victoria in Africa is the largest tropical lake in the world. The lake is home to hundreds of species of closely related fishes, called cichlids (see Figure 4.19). Each species has features

Figure 4.19 At one time, more than 600 species of cichlids lived in Africa's Lake Victoria. By analyzing a specific gene in the fish, scientists have estimated that the first cichlids entered Lake Victoria 200 000 years ago.



Thought Lab 4.5 Leopard Frogs: One Species or Seven?

Target Skills

Using a range of tools to **gather** and **record** data and information about species of leopard frogs

Using appropriate modes of representation to **communicate** ideas

Procedure

How do frog calls result in keeping species separate? Listen to the calls of two different species of leopard frogs, supplied by your teacher.

Analysis

1. How is a frog call a barrier that keeps species distinct?
2. Leopard frogs in North America include the northern leopard frog (*Rana pipiens*), southern leopard frog (*Rana sphenocephala*), Rio Grande (*Rana berlandieri*), plains (*Rana blairi*), Florida (*Rana sphenocephala sphenocephala*), Ramsey Canyon (*Rana subaquavocalis*), and lowland (*Rana yavapaiensis*). Choose two of these species. Use print or electronic resources to help you describe, in point form, the differences that result in their being considered separate species. ICT

Biology File

FYI

In the 1950s, the Nile perch was introduced to Lake Victoria as a source of food for the local human population. This species preyed heavily on cichlids and, by 1990, more than half of the known species of Lake Victoria cichlids had vanished. Now, however, the perch is being fished heavily and some cichlid populations appear to be recovering.

that make it unique from other cichlid species in the lake, and none of these species is found anywhere else on Earth. Remarkably, these species all are descended from a single common ancestor—a species of cichlid that entered Lake Victoria from the Nile River. This incredible explosion of speciation within the same lake happened as small groups of the parent population began to exploit different food sources and habitats in the lake. The lake level has risen and fallen many times during its history, periodically isolating small groups of fish, and these fish have changed extensively because of selective pressures. Scientists studying the cichlids hypothesize that many of the species in the lake today originated after the lake dried to just a few small pools of water about 14 000 years ago. Populations were isolated in these pools of water until the water level rose again. The speciation of cichlids has produced a remarkable variety of cichlids with a fascinating diversity of teeth, jaws, mating behaviours, and coloration.

Q 17 How could the rise and fall of lake levels over thousands of years result in the speciation of a population of fish?

Adaptive Radiation

The diversification of a common ancestral species into a variety of species, all of which are differently adapted, is called **adaptive radiation**. The speciation of finches throughout the Galápagos Islands is an example of adaptive radiation. Another example is the fruit fly genus *Drosophila* of the Hawaiian islands. Descendents of the ancestral *Drosophila* proliferated on the first island they inhabited. Then, individuals began to disperse to other islands. The islands were ecologically different enough to have different environmental situations acting on individuals. The various selective pressures resulted in different feeding and mating habits, as well as morphological (physical) differences of the hundreds of types of fruit flies that now inhabit the islands.

The Pace of Evolution

How fast is evolutionary change? There are currently two models that scientists have proposed for the pace of evolution: gradualism and punctuated equilibrium. Since Darwin's time, many evolutionary biologists have supported the model of **gradualism**, which says that gradual change occurs steadily, in a linear fashion. According to this model, big changes (such as the evolution of a new species) occur as a result of many small changes. The fossil record, however, rarely reveals fossils that show this gradual transition. Instead, paleontologists most often find species that appear suddenly in the fossil record and then disappear from the record just as abruptly. (It should be remembered, however, that not all species have necessarily left fossils, and many fossils have not yet been discovered.)

The different rates of evolution and evidence in the fossil record that show periods of rapid change (for example, rapid speciation after mass extinctions) have led to another model to explain the rate of evolution: **punctuated equilibrium**. This model proposes that evolutionary history consists of long periods of equilibrium where there is little change, "punctuated" or interrupted by periods of speciation. According to the model of punctuated equilibrium, most species undergo most of their morphological changes when they first diverge from the parent species—for example, if a population colonizes a new area. After that, species change relatively little, even as they give rise to other species. Gradualism and punctuated equilibrium are modelled in Figure 4.20.

Questions about the pace of evolution have stimulated much

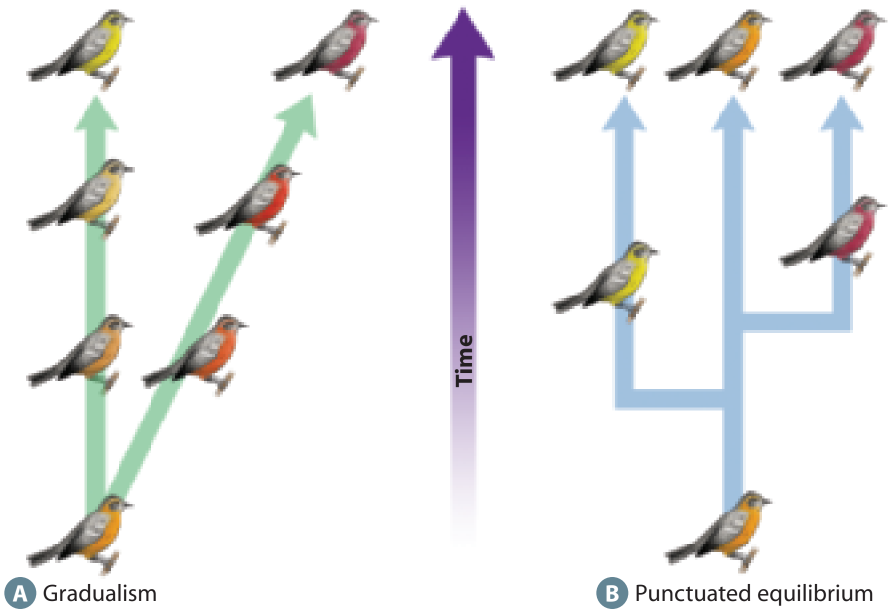


Figure 4.20 Two models have been proposed to explain the pace of evolution: **(A)** gradualism and **(B)** punctuated equilibrium.

discussion and research, as do all good scientific hypotheses. Debate over the specific details of the mechanisms of evolution by natural selection will continue; details may be adjusted as new technologies and scientific techniques are developed. Nevertheless, the theory of evolution by natural selection forms the backbone of biology as a science, and provides a framework to understand the world in which we live. The theory of evolution explains observations seen in fossils, anatomy, animal behaviours, molecular biology, biogeography, genetics, and geology. It is summarized in the box below.

The theory of evolution by natural selection includes the following ideas:

1. Life forms have developed from ancestral species.
2. All living things are related to one another by varying degrees through common descent.
3. All living things on Earth have a common origin (share a common ancestor).
4. The mechanism by which one species evolves into another species involves random heritable genetic mutations. Some mutations result in a survival advantage for an individual; if so, the individual is more likely to survive and pass this mutation on to its offspring. Eventually, the successful mutation increases in the population and causes the population as a whole to start to change.

Section 4.3 Summary

- A species consists of a reproductively compatible population.
- A new species can form via one of two pathways: transformation or divergence. Both are the result of natural selection; only divergence increases biological diversity.
- Speciation (the formation of a new species) can occur when two populations are prevented from interbreeding. Barriers to reproduction can be geographical or biological. Speciation has occurred when populations become reproductively isolated (they cannot interbreed).
- Adaptive radiation is the diversification of a common ancestral species into a variety of species, all of which are differently adapted.
- Scientific debate about the pace of evolution continues. Two models are being proposed: gradualism, that is,

gradual change occurred in a steady, linear way over time; and punctuated equilibrium, whereby evolutionary history is said to consist of long periods of equilibrium, interrupted by periods of speciation.

Section 4.3 Review

1. Explain how geographical isolation leads to speciation.
2. Use word processing or other software to create a flow chart illustrating the two pathways that can lead to the formation of a new species. Identify the pathway that leads to an increase in biodiversity. ICT
3. Explain the difference between habitat isolation and a geographical barrier to reproduction.
4. In the Hawaiian Islands, there are thousands of species of plants and animals that are found nowhere else on Earth. How would you explain this phenomenon?
5. Suppose that you are asked to catalogue the species of birds living in a remote area that has never before been visited by biologists. List the criteria you would use to determine whether the individual birds you observe or collect are the same species or different species.
6. Use word processing or spreadsheet software to create a table or chart that compares and contrasts the ideas of gradualism and punctuated equilibrium. ICT

Use the following information to answer the next question.

Red Island and Blue Island are hypothetical islands 500 km off the coast of South America. Red Island is volcanic in origin and is only five million years old. Blue Island separated from South America more than 80 million years ago.

7. Predict the origins of the animals on both islands and explain how they may be similar to or different from the animals of South America.

Use the following information to answer the next question.

Adaptive Radiation

A team of researchers led by Washington University biology professor Jonathan Losos has spent the last several years studying lizards of the genus *Anolis* (commonly called "anoles") that live on large Caribbean islands. He has focussed on Puerto Rico, Cuba, Haiti, and Jamaica. All four islands are inhabited by a diverse array of anole lizards (there are 57 species on Cuba alone), and all four islands have quite similar habitats and vegetation.

Unlike rats and cockroaches, which are generalists and are much the same wherever you find them, anole lizards are specialists. In Puerto Rico, for example, one slender anole species with a long tail lives only in the grass. On narrow twigs at the base of trees you find a different species, also slender, but with stubby legs. On the higher branches of the tree a third species is found, of stocky build and long legs. High up in the leafy canopy of the tree lives a fourth giant green species.

The DNA data are clear-cut: specialist species on one island are not closely related to the same specialists elsewhere and are closely related to other anoles inhabiting the same island.

8. Explain how the situation described above would be an example of adaptive radiation.

Chapter 4 SUMMARY

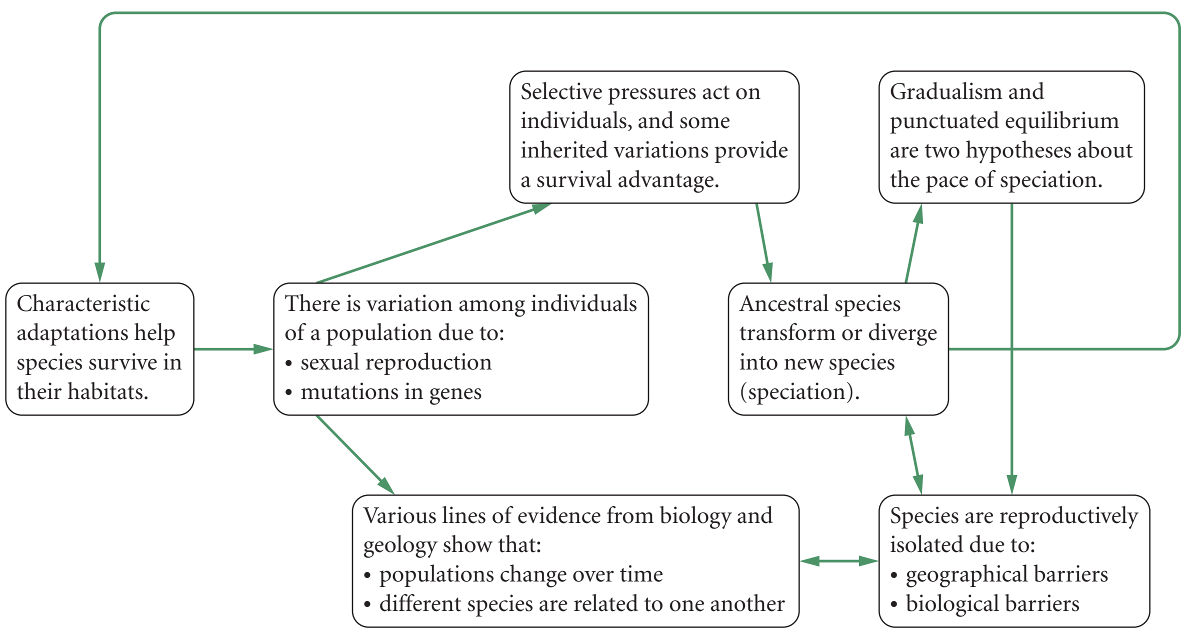
Sexual reproduction, which combines the genetic information from two parents, results in variations in the characteristics of offspring. These variations may or may not give the organism a survival advantage. If it does, the variation is likely to be passed on to an increasing number of organisms in the population.

The main source of variations is mutations. Mutations occur when DNA is copied during cell division; mutations that occur in reproductive cells are the ones that can be passed on. When the characteristics of a population change because more individuals with certain inherited traits survived in the local environment and passed the traits on, it is called the process of natural selection. For this reason, the environment can be considered to be the driving force of population changes as time passes. If, however, an environmental change is so sudden or severe that no individuals of a population have characteristics that enable them to survive it, extinction is inevitable.

The theory of evolution was developed from the ideas and observations of a number of scientists. Darwin and Wallace developed similar theories to explain evolution by natural selection, and Darwin published his version in *On the Origin of Species* in 1859. Since publication, discoveries in fields such as paleontology, biogeography, anatomy, embryology, genetics, and molecular biology have produced supporting evidence for the theory.

Organisms that can interbreed and produce healthy offspring that can also reproduce are considered to be a biological species. New species form when populations become reproductively isolated, due to either geographical or biological barriers. Natural selection will occur differently within isolated populations, resulting in variations that could mean the isolated populations can no longer mate. Speciation may or may not result in increased biodiversity.

Chapter 4 Graphic Organizer



Understanding Concepts

1. Explain the term "selective pressure" as it relates to the study of evolution.
2. How might the colour of a field mouse affect its survival?
3. Describe the possible fates of a mutation and the effects that a mutation may have on a population.
4. Describe the relationships among variations, adaptations, and natural selection.
5. Darwin incorporated observations he made on the *Beagle* expedition into what would eventually become the theory of evolution by natural selection. Summarize some of these observations.
6. Explain why Darwin referred to "descent with modification" rather than "evolution" in *On the Origin of Species*.

Use the following information to answer the following question.

Ord's Kangaroo Rat

The Ord's kangaroo rat seems perfectly suited to its habitat, the sand dunes of southwestern Alberta. Using its long tail and long hind legs, this small mammal can jump 2 m in the air as it hops away from predators, such as snakes and owls.

7. Explain how (a) Lamarck and (b) Darwin would account for the origin of the long hind legs of the Ord's kangaroo rat.

Use the following information to answer the following question.

Homologous vs. Analogous Structures

The wing of a butterfly and the wing of a bird share a common function and are both called wings. The bird wing and insect wing did not arise from an original ancestral structure that became modified through evolution into bird wings and butterfly wings.

8. Are the bird wing and the bat wing homologous structures? Explain.
9. Describe how the anatomy of animals is used to explain evolution.
10. Baleen whales, such as grey and humpback whales, have teeth and body hair as embryos, but not as adults. What does this suggest to you about the evolutionary history of these animals?
11. Explain the role of the environment in the pace of speciation.

Applying Concepts

12. Describe a breeding program that would help a farmer develop a herd of dairy cows that produced more milk per cow than another herd of dairy cows.

Use the following information to answer the following question.

Fruit Flies

A researcher sets up an experiment involving two populations of fruit fly that are genetically very different from each other. The two populations are placed in two enclosed areas that are connected by a narrow tube through which the flies can fit.

13. Illustrate, using words or diagrams or both, how these populations could develop as separate species.

Use the following information to answer the next question.

Bean Seeds

A bean is an example of a dicotyledon (having two embryonic seed leaves). The cotyledons make up the majority of the bean seed. The cotyledons store food for the developing embryo in the form of starch.

Suppose that you measured variations in a population of bean seeds and found that 80% of the population you measure had seeds that were 13 to 17 mm long.

14. a) Describe an advantage a large seed size might have to a newly germinated bean seedling.
    b) Identify two environmental pressures that might favour a small seed over a larger seed.
    c) Briefly outline a breeding strategy that a gardener could use to produce beans with larger cotyledons.

Use the following information to answer the next question.

Proteins

Proteins are a class of organic compounds that are present in and vital to every living cell. Proteins are made of a long chain of amino acids. The primary structure of protein molecules is determined by the sequence of amino acids. The amino acid sequence of a protein determines the higher levels of structure of the molecule. A single change in the primary structure (the amino acid sequence) can have a profound biological change in the overall structure and function of the protein.

Scientists compare differences in amino acid sequences to determine evolutionary relationships among organisms. Some short amino acid sequences are given below.

Amino Acid Sequences in Four Primates

Baboon	Chimpanzee	Lemur	Human
ASN	SER	ALA	SER
THR	THR	THR	THR
THR	ALA	SER	ALA
GLY	GLY	GLY	GLY
ASP	ASP	GLU	ASP
GLU	GLU	LYS	GLU
VAL	VAL	VAL	VAL
ASP	GLU	GLU	GLU
ASP	ASP	ASP	ASP
SER	THR	SER	THR
PRO	PRO	PRO	PRO
GLY	GLY	GLY	GLY
GLY	GLY	SER	GLY
ASN	ALA	HIS	ALA
ASN	ASN	ASN	ASN

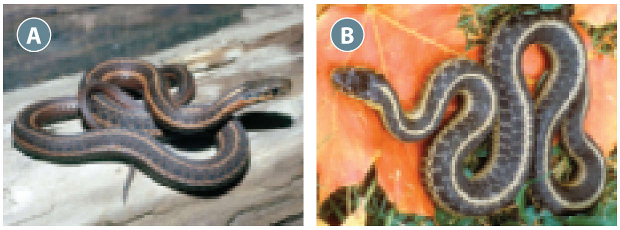
15. a) Count how many amino acids in a baboon differ from the amino acids in a human. Calculate the percentage difference by determining the number of different amino acids divided by the total number of amino acids studied, and multiply by 100. Do the same for the chimpanzee and for the lemur.

b) Identify the primate that appears to be most closely related to the human and identify the primate that appears to be least closely related to the human.

c) Would an evolutionary biologist draw a conclusion based solely on the evidence provided in this chart? Explain.

Use the following information to answer the next question.

Garter Snakes



The northwest garter snake (*Thamnophis ordinoides*) (**A**) and the common garter snake (*T. sirtalis*) (**B**) occupy different habitats in a similar geographic area. The northwest garter snake prefers open areas such as meadows and rarely enters water. The common garter snake is most commonly found near water.

16. Explain why these garter snakes are likely to remain separate species.

Making Connections

17. Choose a fossil, either one described in this chapter or one you have researched. Describe how this particular fossil helps provide scientists with information on how populations change over time.

18. Suppose that you are a family physician who often prescribes antibiotics. Make a list of criteria for your patients, to help them understand (in terms of developing antibiotic resistant bacteria), why they must take antibiotics only as prescribed.

Use the following information to answer the next question.

Hawaiian Plants

You are a biologist who is working with a student to collect plants in Hawaii. You notice that your assistant did not label a plant with the name of the island on which is was collected. When asked, he explains that he did not think this was necessary because he thought that the plant was found on all the Hawaiian Islands.

19. Write a memo to your assistant clearly outlining why it is necessary to label the exact island and location where the plant was found, as well as the time when the plant was found. Focus your memo on the concepts presented in this chapter.

Career Focus: Ask a Paleontologist

Since childhood, Dr. Darla Zelenitsky has been fascinated by dinosaurs. Today, she is a paleontologist and researcher at the University of Calgary. She works in conjunction with the Royal Tyrrell Museum in Drumheller, Alberta. Dr. Zelenitsky's research on dinosaur eggs is changing the way that scientists look at dinosaur evolution and may help to explain the success of many dinosaur species.

Q Why are other scientists interested in your research findings?

I've been looking at the interrelationships or relationships of dinosaurs based on their reproduction. This is an approach that's never been used before.

Q What made you think of studying dinosaur reproduction?

Generally, scientists have looked more at the demise of the dinosaurs and why they went extinct. However, I'm interested in why dinosaurs survived for so long [165 million years]. I think their long evolutionary success can be explained by studying their reproductive strategies.

Q How do you study the reproductive strategies of dinosaurs?

We examine evidence from dinosaur eggs and compare this to evidence from eggs of modern crocodiles and birds. We can look at the number of eggs in a clutch, the size and shape of the eggs, or the pores in the eggshells, which would have allowed the embryos inside the eggs to breathe. These features can tell us what kind of nesting environment dinosaurs most likely used: open, like bird nests, or buried, like crocodile nests.

Q What else can you learn about dinosaur reproduction from dinosaur eggs?

We can learn about their nesting behaviours. There are fossils of dinosaurs sitting on top of their eggs, much like modern birds do, from the Gobi Desert in Mongolia. Birds use their bodies to incubate or brood their eggs.

Q Do you think dinosaurs are more related to birds than to reptiles?

Actually, birds are a lineage of dinosaurs—and they represent an extremely successful group of living animals. With respect to reproduction, I suspect that dinosaurs shared strategies with crocodiles and birds, or just with birds, or they had reproductive strategies unique to themselves. Brooding is an example of a reproductive strategy that some dinosaurs share with modern birds, but do not share with alligators and crocodiles. On the other hand, crocodiles and birds only have one functional oviduct, whereas we suspect that dinosaurs had two functional oviducts and that they laid two eggs at a time. We see evidence of this in some dinosaur nests, where the eggs appear to be laid in pairs.

Q Which dinosaurs' eggs do you work with?

I've worked with eggs from various dinosaurs all over the world—some meat-eating, some plant-eating. I've looked at giant sauropod eggs from France, hadrosaur (duck-billed dinosaur) eggs from Alberta, prosauropod eggs from South Africa, and the eggs of bird-like dinosaurs, called oviraptorids, from Asia.

Q Where are you currently doing most of your fieldwork?

In southern Alberta at Devil's Coulee, a fossilized nesting site with preserved dinosaur eggs, embryos, and nests. Dinosaurs are a tremendous natural resource in Alberta, and we've got some of the most prolific dinosaur sites in the world.

Q Does one have to be a research scientist to be involved in paleontology?

No. There are a lot of amateurs involved in paleontology, looking for and studying fossils. The Royal Tyrrell Museum has volunteer programs in which people help to excavate and prepare fossils.

Other Careers Related to Paleontology

Paleoartist Trained artists, or researchers with a skill for drawing, rely on fossils and other evidence to create visual representations of what past life might have looked like. Paleoartists may illustrate books, research papers, and magazine articles, and may create paintings and other visuals for museums, films, and television.

Paleotechnician Technicians (also called fossil preparators), along with researchers and volunteers, search for and excavate fossils and prepare fossils for study. For example, paleotechnologists may carefully remove rock from fossilized bones and create models of dinosaurs. Paleotechnologists may also help researchers reconstruct dinosaur skeletons. An undergraduate degree in geology, paleontology, or zoology is good preparation for a career as a paleotechnician.

Professional Paleontologist Researchers with expertise in vertebrate or invertebrate paleontology, or other areas of paleontology, may work as curators at natural history museums. Some paleontologists are professors at universities; they teach, train graduate students, and conduct various kinds of paleontological research.

Paleoclimatologist Scientists examine evidence of Earth's ancient climates by studying tree rings, glaciers, and rocks. Paleoclimatologists, who may have graduate degrees in Earth sciences, sometimes work with paleoecologists, who study ancient environments and populations. Paleoclimatologists can help to develop computer models for predicting future climate change.

Stratigrapher Geoscientists study the formation of rock layers in order to learn about past environments. As well, they help governments and industries make decisions about resource development. To conduct fieldwork and analyses for government agencies, such as the Geological Survey of Canada, a doctorate degree in geology is required.

Micropaleontologist Microscopic fossils, such as diatoms, are the most abundant type of fossils, and their presence can indicate nearby oil or gas deposits. Micropaleontologists, who have undergraduate degrees in geology, work with petroleum companies to find sources of fossil fuels.

This model shows what a newly hatched dinosaur may have looked like in a nest.

Go Further…

1. List and research three methods, other than studying dinosaur eggs, that paleontologists could use to study the evolutionary relationships between dinosaurs and birds.
2. How might geneticists contribute to the study of past life forms?
3. Why is it important to understand the process of evolution in order to make informed decisions about human actions that could affect Earth's biodiversity?

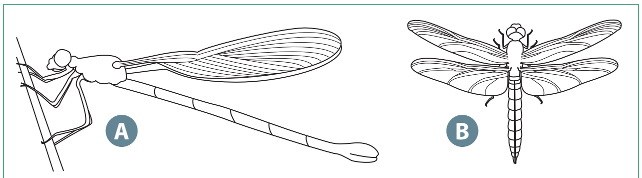
UNIT 2 REVIEW

Understanding Concepts

1. Define the term "population."
2. Describe the study of ecology.
3. Hypothesize what might happen if all the predators were eliminated from an ecosystem.
4. Explain why organisms are not evenly distributed across Earth.
5. Identify three abiotic factors that create different habitats within a pond, and illustrate their effects on the pond ecosystem.
6. Identify four factors that might limit the population size of animals (such as a raven) that live as scavengers.
7. Give an example of (a) biome, (b) an ecosystem within the biome, and (c) a community within this ecosystem.
8. Explain why two species classified in the same family must also be in the same order.
9. Give an example of how (a) an abiotic factor and (b) a biotic factor can limit population growth.
10. Identify the factors that might produce regular population cycles typical of small herbivore species, such as mice and squirrels.
11. The following metaphor can be used to describe the terms habitat and niche. "The habitat of a species can be compared to an address, while its ecological niche can be compared to a job." Write another metaphor to describe the range of an organism.
12. Pick an organism that lives in an environment you are familiar with. List the factors that might limit the growth of its population.
13. Give three examples of how a population of deer mice in a field might compete for the available resources.
14. Explain why diversity within a population is necessary for evolution.
15. Explain the differences among structural (physical), physiological, and behavioural adaptations. Give an example of each.
16. Are a bat wing and a butterfly wing homologous structures? Explain your answer.
17. Explain why it is correct to talk about the evolution of populations, but it is incorrect to talk about the evolution of individual organisms.
18. Distinguish between a fact and a theory. Give an example of each.
19. Explain why DNA is a useful tool for determining possible relationships among species of organisms. Give an example to support your answer.
20. Describe how the following items contributed to Darwin's theory of evolution:
    a) his experiences on the voyage of the *Beagle*
    b) Lyell's *Principles of Geology*
    c) Malthus's essay about populations
21. a) Describe the possible fates of a mutation and the effects that a mutation may have on a population.
    b) Explain what could happen in a population when a mutation provides a selective advantage.
22. a) Give an example of a geographical barrier and a biological barrier.
    b) Explain how each barrier keeps species separate.
23. Life is very diverse, but all species share many features, especially at the cellular and molecular level. How can evolution explain this seeming contradiction?
24. You are a paleontologist and find a fossilized skeleton of a whale-like aquatic animal with tiny legs. Is this a transitional fossil? Explain your answer.

Applying Concepts

Use the following information to answer the next question.



Dichotomous Key

1a. front and hind wings similar in size and shape, and folded parallel to the body when at rest… damsel fly

1b. hind wings wider than front wings near base, and extended on either side of the body when at rest… dragonfly

25. a) Use the dichotomous key provided to identify the organisms in the diagrams. Explain how you arrived at your decision.
    b) From the key and the diagrams, explain why you could infer that dragonflies and damsel flies evolved from a common ancestor.

Use the following information to answer the next question.

The following shows the levels of classification for a grey wolf. These levels are not in order according to the hierarchical classification system in use today.

order: Carnivora
class: Mammalia
kingdom: Animalia
phylum: Chordata
domain: Eukarya
species: lupus
family: Canidae
genus: Canis

26. a) Place the levels of classification in order from most general to most specific.

b) Identify the scientific name of the grey wolf.

Use the following information to answer the next question.

Grizzly Bears

Female grizzly bears typically have only one offspring every three to five years. Black bears, however, have their offspring (often twins or even triplets) every two years. Female grizzlies do not begin breeding until they are five to seven years old, whereas female black bears begin breeding when they are from three to five years old. Grizzly bears and black bears are omnivores, but grizzly bears have a more restricted diet and are more particular about their dining sites. Grizzly bears are also larger than black bears.

27. a) Identify which species of bear is more likely to become endangered as changes occur in their habitat and explain your reasoning.

Use the following information to answer the next question.

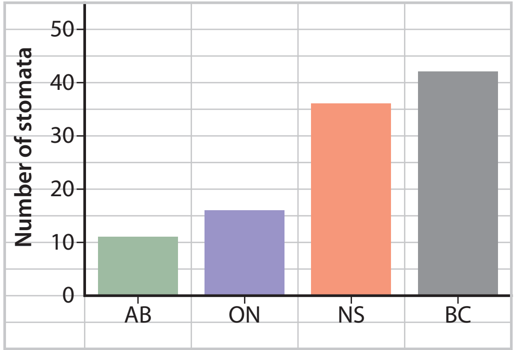
Grizzly bears can mate with black bears, but the offspring are not fertile. On the other hand, grizzly bears can mate with polar bears, and the offspring are fertile.

b) Infer the evolutionary relationship among grizzly bears, black bears, and polar bears.

Use the following information to answer the next question.

Stomata are openings on the surfaces of leaves that allow plants to release water. The following graph shows the number of stomata on the leaves of one tree species.

Average number of stomata in 10 leaves of 10 trees of one species in four Canadian provinces



28. a) Describe what these data might tell you about the precipitation in the areas where the data were collected.

b) Based on these data, infer the relationship between precipitation and number of stomata on trees.

Use the following information to answer the next question.

Transect

In order to estimate the size of a population of oak tress, a forester runs several 100 m transects through a 100 ha (hectare) woodlot and counts the number of oaks within 5 m of the transect line. Five transects produced counts of: 15, 17, 25, 16, and 20 oak trees respectively.

29. a) Use this information to calculate the density of oak trees in this area.

b) Estimate the size of the oak population in the woodlot.

c) Identify another method the forester could have used to sample the population of trees in this woodlot.

30. Outline an experimental procedure that would demonstrate variation within a population of corn. Consider using the length of corn cob or the number of kernels of corn per cob in your experimental design. Include a suitable hypothesis.

31. Describe the relationships among mutations, variations, adaptation, and natural selection.

32. An evolutionary biologist said, “Evolution is like modifying a machine while it’s still running.” Interpret this statement.

33. a) Use graphics software and point-form notes to show the two pathways that can lead to the formation of a new species. ICT
b) Identify the evolutionary pathway that leads to an increase in biodiversity and explain why.

34. Explain how the following situations are reproductive barriers that keep species separate.
a) Species of fireflies use distinctive patterns of flashes.
b) Two species of grass flower at different times of year, yet live in the same environment.
c) The crossing of two species of fly produces a fertile hybrid offspring, whose offspring is weak and infertile.

35. Use word processing or graphics software to make a graphic organizer showing the relationship among climate, soil, plants, and animals in a biome. ICT

Use the following information to answer the next question.

Protecting our Forests

Governments restrict the movement of plants or animals across boundaries, including provincial borders. In Alberta, for example, people are not allowed to transport wood with bark on it into the province. These measures are designed to help prevent the spread of mountain pine beetles and Dutch elm disease that can harm Alberta's forests—one of the prime concerns during outbreaks of pine mountain beetle is the death of high-value pines in thousands of hectares of forest.

The fungus that accompanies the mountain pine beetle larvae reduces the aesthetic value of forests by staining the wood blue; the mountain pine beetle also reduces the timber volume, and the monetary gains of the high-value mature tree. During the last mountain pine beetle outbreak (1977 to 1987) in Alberta, an estimated 1 068 167 m^3 of lodgepole pine were killed.

36. Explain, both in terms of the ecosystems in Alberta and the economic impact of these types of pest outbreaks, why it is important for all citizens to respect this type of restriction.

Use the following information to answer the next question.

Trout

The population of trout in a small lake has fluctuated around 2000 for the last 10 years. The owner of a fishing resort on the lake wants to increase the number of trout available for clients to catch. The owner plans to stock the lake with 1000 more individuals of the same species.

37. Predict the short term and long terms effects of adding the additional fish on the population of trout in this lake.

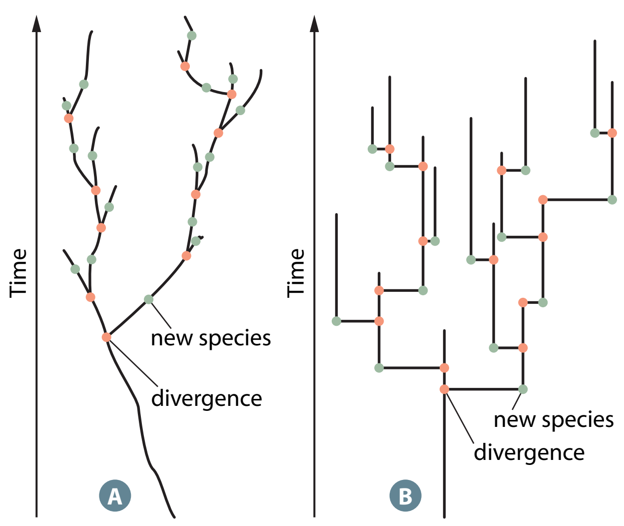
38. Compare the diversity of habitats and the biodiversity in a forest that has been logged and replanted with a single species of tree to a forest that has not been logged.

39. Explain how the examination of proteins in individual organisms can demonstrate relatedness among species.

40. Explain the conditions in which a seemingly neutral mutation that is present in a small portion of a population might become quickly perpetuated in, and advantageous to, the entire population.

Use the following information to answer the next question.

Models for Evolution



Two models for evolution are shown in the diagram above.

41. Identify each model, and explain how each is used to model evolution.

42. Use word processing or graphics software to produce a timeline outlining the major events and ideas that have led to the current theory of evolution. ICT

Making Connections

Use the following information to answer the next question.

Frog Populations

Imagine two frog populations in two different locations. The frogs differ only in the colour of their skin.

43. a) Suggest data that would help you decide if both populations belong to the same species of frog.

b) Assume that the two populations are different species. Suggest data that would help you decide how closely related these two species are to each other.

44. Should people be as concerned about some species of mosses becoming extinct as they are about whales becoming extinct? Explain.

45. All populations eventually face limits to their population because of abiotic and biotic factors. Compare a micro-organism (such as the bacteria *E. coli*), a plant species (such as a tree), and a mammal (such as a deer), with respect to the types of factors that might limit the growth of populations of these species.

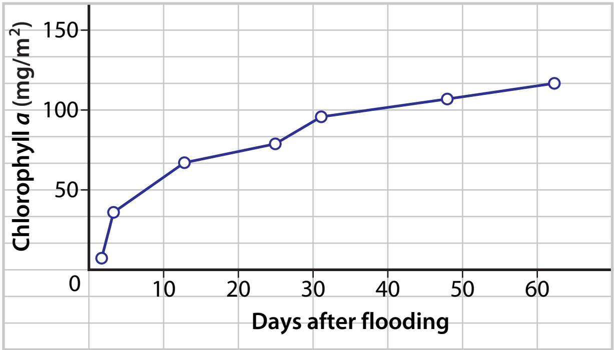
46. Many of the endangered species in the world have very specific, or narrow, ecological niches. Explain why species with narrow ecological niches are more likely to become extinct than species with broader ecological niches.

47. Given your understanding of diversity within a species and natural selection, explain why it is important to maintain biodiversity.

48. Do you think antibiotics should be available in a pharmacy without a prescription? Explain your answer in terms of natural selection.

Use the following information to answer the next question.

Level of Chlorophyll *a*



The graph above shows the level of chlorophyll *a* (a pigment needed for photosynthesis) in a stream, in the days following a flood that nearly scoured all life from the stream. The chlorophyll indicates the growth of algae in the stream.

49. a) Compare the amount of growth in the first 30 days with the amount of growth in the second 30 days.

b) Explain what might be enhancing or limiting the algae growth in this 60-day period.

c) The main animals in this stream are invertebrates that feed off the algae. Predict what might be happening to the populations of these herbivorous invertebrates during this 60-day time period.

Use the following information to answer the next question.

Pests

You are a gardening expert who runs a local greenhouse and nursery. A gardener calls you and explains that she had an insect infestation in her garden. When she applied an insecticide, 99 percent of the insects were killed. After a few weeks, she noticed that the insect problem was back so she applied more pesticide. This time, only 50 percent of the insects were killed by the pesticide.

50. Explain why the insecticide did not work as well the second time it was applied.