unit

20 B

Ecosystems and Population Change

The biosphere is constantly undergoing change. The conditions in an ecosystem and the organisms that live there can change, sometimes in unexpected ways. For example, University of Calgary researcher Dr. Dennis Parkinson says there is no evidence that earthworms lived in the Kananaskis area in the past. However, earthworms have been found in Kananaskis country since the mid-1980s. Most likely, they were introduced into the region by tourists. Earthworm eggs easily stick to hiking boots, all-terrain vehicles, and horses' hooves, and drop off during trail-rides. In 2004, the environmental impact of the invasion of earthworms into the Kananaskis country was assessed. In some locations, researchers have found as many as 2500 earthworms per square metre.

As you progress through the unit, think about these focusing questions:

- What are the major biotic and abiotic characteristics that distinguish aquatic and terrestrial ecosystems?
- What data would one need to collect in a field study to illustrate the major abiotic characteristics and diversity of organisms?
- What mechanisms are involved in the change of populations over time?

UNIT 20 B PERFORMANCE TASK

The Sixth Extinction

The dinosaurs disappeared about 65 million years ago in a "mass extinction" event. Investigate past mass extinction events, and compare and contrast them to species extinctions that are occurring in the present day. You will consider the biotic and abiotic factors that influence such extinction rates, both historically and today.

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GENERAL OUTCOMES

In this unit, you will

- explain that the biosphere is composed of ecosystems, each with distinctive biotic and abiotic characteristics
- explain the mechanisms involved in the change of populations over time

Unit 20 B

Ecosystems and Population Change

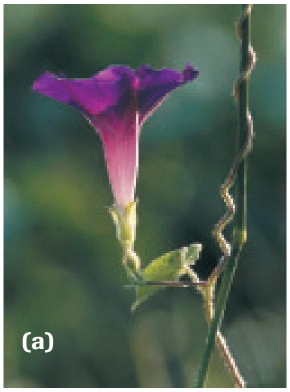
ARE YOU READY?

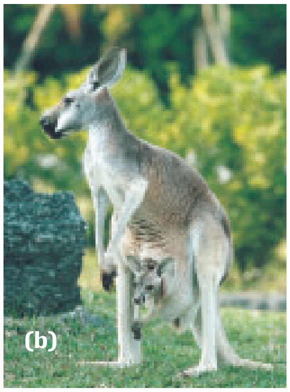
These questions will help you find out what you already know, and what you need to review, before you continue with this unit.

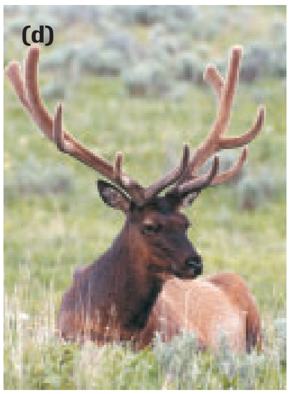
Knowledge

1. In your notebook, indicate whether the statement is true or false. Rewrite a false statement to make it true.
   (a) Ecosystems with greater biodiversity tend to be less fragile.
   (b) Natural ecosystems usually have greater biodiversity than artificial ecosystems.
   (c) A biome is geographical region with a particular climate, and the organisms that are adapted to that climate.
   (d) Introducing exotic species into an ecosystem helps improve biodiversity, and helps all organisms within an ecosystem.
   (e) An organism's physical traits are affected by both its genetic makeup and the environment.
   (f) Virtually all large populations exhibit genetic variation among individuals.

2. Each of the organisms in **Figure 1** exhibits special adaptations. For each species, describe two obvious adaptations and state how they enhance the biological success of the organism.







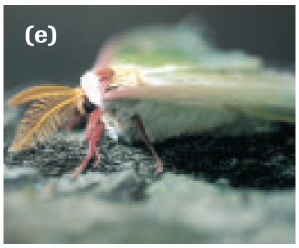


Figure 1
(a) morning glory; (b) kangaroo; (c) sea nettle; (d) bull elk; (e) luna moth; (f) blue-footed booby

Skills

3. A field study of temperatures throughout the day in a forest produced the observations in **Table 1** on the next page.
   (a) Identify the variables being measured in this study.

Prerequisites

Concepts

- ecosystems and biomes
- biological diversity
- adaptations
- inheritance of traits

Skills

- identify variables
- create hypotheses
- draw and interpret graphs

You can review prerequisite concepts and skills on the Nelson Web site and in the Appendices.

A Unit Pre-Test is also available online.

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Table 1 Temperature Readings (°C) Taken over a 24-h Period in a Forest

Location	Time of day: 12 midnight	3 a.m.	6 a.m.	9 a.m.	12 noon	3 p.m.	6 p.m.	9 p.m.	12 midnight
air	17.5	17.0	17.5	18.5	19.5	21.5	21.0	19.0	18.0
litter	17.0	17.0	16.5	17.0	18.5	19.5	20.0	19.0	18.0
topsoil	16.5	16.5	16.0	15.5	16.0	16.5	17.5	18.0	17.5
subsoil	14.0	14.0	13.5	13.5	13.5	13.0	13.5	14.0	14.0

(b) Propose a hypothesis to explain the variation in temperature among the locations.
(c) Use these data to produce a line graph illustrating the observations.

4. Use **Table 1** or the graph from question 3 to answer the following questions:
   (a) Which location in the forest showed the greatest variation in temperature?
   (b) Which location in the forest showed the least variation in temperature?

5. The graph in **Figure 2** shows the growth in the world human population over the last 50 years.
   (a) Describe the trend in population growth.
   (b) Is the rate of population growth increasing, decreasing, or staying the same? Explain your answer.
   (c) Predict human population growth for the next 30 years. Do you think it is very likely that the population will actually reach that number? Explain.
   (d) At the current population growth rate, in approximately what year will the world population reach 12 billion?

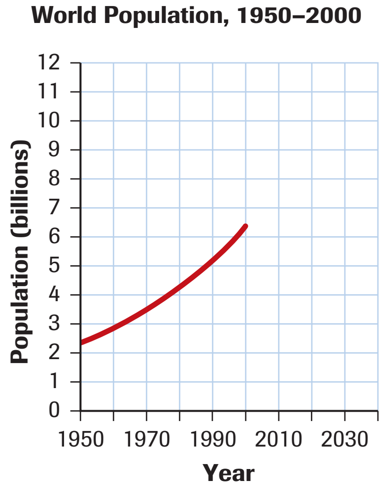


Figure 2

STS Connections

6. For each of the following, list two examples—one that is not genetically inherited and one that might have been genetically inherited:
   (a) physical characteristics
   (b) diseases and medical conditions
   (c) behaviours, and likes and dislikes

7. **Table 2** shows energy requirements per person per day for different societies.

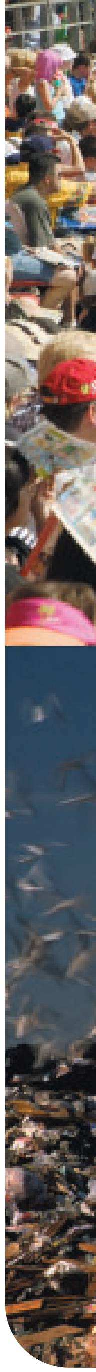
Table 2 Energy Requirements for Humansin Different Societies

Society	Energy expenditure (kJ per person per day)
industrialized (e.g., Canada)	961 400
early industrialized	251 200
advanced agricultural	83 700
early agricultural	50 200
hunter–gatherer	20 900

   (a) Why would early agricultural societies require more energy per person than hunter–gatherer societies?
   (b) What activities require the enormous energy usage by the modern world?
   (c) Which society is able to support the greatest number of people? Why?

chapter

4 Characteristics of Ecosystems



In this chapter

- Exploration: Establishing Ecosystems in Space
- Investigation 4.1: A Schoolyard Ecosystem
- Web Activity: Mary Thomas
- Case Study: Natural and Artificial Ecosystems
- Web Activity: The Zebra Mussel
- Explore an Issue: Genetically Modified Crops
- Web Activity: Critical Ecoregions of the World
- Investigation 4.2: A Forest Ecosystem
- Mini Investigation: How Does Temperature Affect Seed Germination?
- Mini Investigation: Measuring Undissolved Solids
- Investigation 4.3: Biological Oxygen Demand and Organic Pollutants
- Investigation 4.4: Biological Indicators of Pollution in Streams
- Web Activity: Whose Lake Is It?
- Explore an Issue: Selling Water

It is often difficult to place a value on sustaining the ecosystems around the world. Wetlands are drained to make way for more farmland to feed people, and forests are cut to supply wood for housing and industries. But at what cost? A sustainable ecosystem survives and functions over a long time. Long-term sustainability is not sacrificed for short-term gains. Similarly, a sustainable human society manages its economy and population size without exceeding the planet's ability to replenish resources.

If you think of a balance sheet of deposits and withdrawals, living sustainably means living within your means and not depleting your savings. Failure to conserve the capital of the planet jeopardizes current and future generations. We have a limited supply of resources on Earth. The use of non-renewable resources, such as coal, oil, iron, and sulfur, must be budgeted so that future generations will also have enough. Potentially renewable resources, such as water, topsoil, forests, wildlife, and food, must be monitored so that use does not exceed the rate at which they are replenished.

In this chapter, you will discover how ecosystems remain in balance and how they change. You will learn how the organisms within an ecosystem interact and then you will examine the characteristics of ecosystems. You will look at the factors that characterize and affect ecosystems.

STARTING Points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. Examine the photographs in **Figure 1**, on the next page. For each photograph, answer the following questions.
   - (a) What are some of the resources in this ecosystem? Explain.
   - (b) Which of these resources are renewable?
   - (c) What are some factors that affect the ecosystem?
   - (d) Explain how each factor you identified in Part (c) affects the ecosystem.
   - (e) Is the ecosystem sustainable? If you answer no, identify the factor(s) that would prevent the ecosystem from being sustainable.
   - (f) Identify the main environmental problem shown. Can this environmental problem be solved by technology? Why or why not?

Career Connections:
Fish and Wildlife Officer; Wildland Firefighter; Environmental Education Specialist

Figure 1
Human activity plays a role in each of these ecosystems.

Exploration — *Establishing Ecosystems in Space*

The colonization of other planets or the Moon will require the establishment of ecosystems able to support humans. Using a terrarium, construct a model ecosystem that might be able to support life if it were transported to the Moon. Think about the following when you construct your model.

- How will you provide a continuous supply of oxygen?
- How will you provide a continuous supply of food?
- What will happen to the waste?

(a) Make a list of plants and animals that are essential to humans.

(b) Describe the things that would be needed for the survival of each plant and animal you mentioned on your list.

4.1 Interactions within Ecosystems

ecology the study of interactions between organisms and their living and non-living environment

abiotic factor a non-living factor that influences an organism

biotic factor a living factor that influences an organism

Ernst Haeckel, a German biologist, first coined the word **ecology** in 1866, to describe the study of how organisms interact with each other. Ecology combines the Greek words *oikos*, meaning "the place where one lives," with *logos*, meaning "study of."

Ecological studies can begin at the level of a single organism. For example, an investigation could be designed to determine how the individual interacts with its environment, and how factors in the environment affect its growth, feeding habits, and reproduction. Non-living factors or influences on organisms, such as amount of sunlight and temperature are called **abiotic factors**. Factors caused by the presence and roles of other living things are called **biotic factors**.

Organisms do not live in isolation however; they usually group with others of the same species. All of the members of the same species, living in the same ecosystem or habitat, are referred to as a population. For example, all the pike in a lake form a population.

Since there is usually more than one species in an ecosystem, there is also more than one population. The collection of all the populations of all the species in an ecosystem or habitat is called the community of organisms. For example, the community in a lake might include populations of pike, perch, tadpoles, mosquito larvae, and algae, among others.

When studying a community, an ecologist might determine how biotic factors affect each population. For example, an ecologist studying a forest community might examine the interactions between different types of plants and animals in the area.

Ecologists can extend their study beyond the community of organisms to the physical environment. When they do so, they begin investigating ecosystems. An ecosystem includes the community of living things and its physical environment. For example, in studying a forest ecosystem, an ecologist could measure how much sunlight reaches the forest floor, and how the amount of sunlight affects the plants and animals that live in the ecosystem.

Practice

1. In your own words, define the term *ecology*.
2. Describe how a population differs from a community, using your own examples.
3. Describe how an ecosystem differs from a community, using your own examples.

INVESTIGATION 4.1 *Introduction*

A Schoolyard Ecosystem

Ecosystems are constantly changing in response to changes in biotic and abiotic factors. In this investigation, you will make observations on the differences in biotic and abiotic factors at different locations in your schoolyard, and relate these to the number and types of weeds.

Report Checklist

○ Purpose	○ Design	● Analysis
○ Problem	○ Materials	● Evaluation
○ Hypothesis	○ Procedure	● Synthesis
● Prediction	● Evidence	

To perform this investigation, turn to page 123.

Ecotones and Biodiversity

Ecosystems rarely have sharp boundaries, and organisms can move back and forth from one ecosystem to another. There is often a grey area between ecosystems where organisms from both ecosystems interact with each other. These transition areas or **ecotones** (**Figure 1**) contain species from both bordering ecosystems, so they often contain greater biodiversity (more species) than either ecosystem.

Ecosystems with greater biodiversity tend to be less fragile. For example, if a predator has to rely on a single species as a food source, its very existence is tied to the survival of the prey. In ecotones and other diverse areas there are more species, and a predator may have an alternative prey if something happens to the population of its main prey. By providing alternative food sources, ecotones help guard against extinction.

ecotone a transition area between ecosystems

DID YOU KNOW?

Biodiversity in Quebec

Quebec is home to many different types of ecosystems. Within these ecosystems live almost 40 000 species of plants and animals. Quebec was one of the first Canadian provinces to propose a strategy to protect biodiversity.

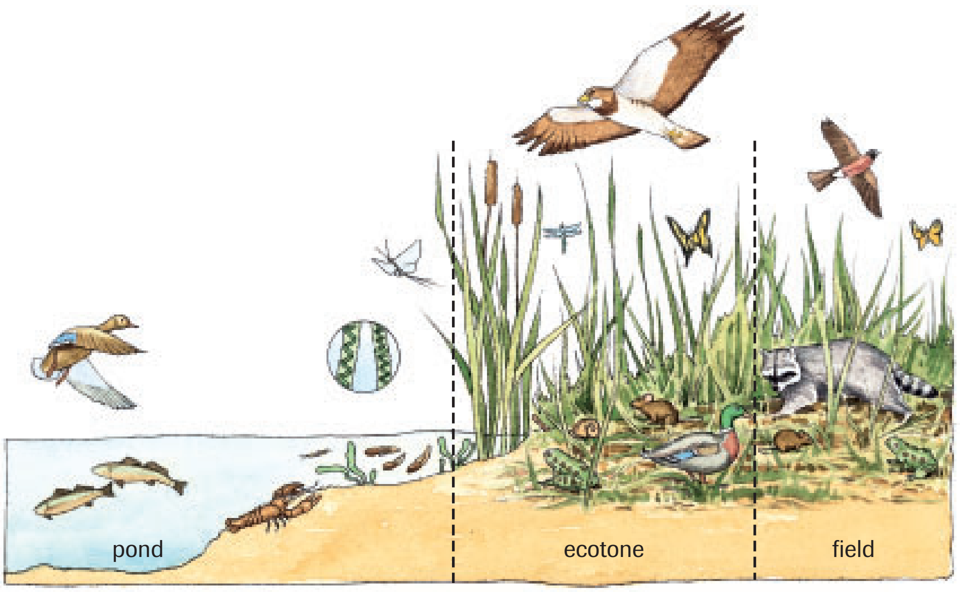


Figure 1
In the ecotone between the pond and the field, species from both ecosystems meet.

WEB Activity

Canadian Achievers—Mary Thomas

Mary Thomas (**Figure 2**) has spent her lifetime educating people of all cultures about the need for environmental awareness and the relevance of the traditional ways to preserve ecosystems. She received the National Aboriginal Achievement Award in 2001, for her work as an educator and environmentalist. In 1997, she became the first Aboriginal in North America to receive the Indigenous Conservationist of the Year award from the Seacology Foundation. In 2000, she received an honorary doctorate from the University of Victoria. Find out more about Mary Thomas' contributions to protecting ecosystems and preserving traditional knowledge.

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Figure 2
Mary Thomas

Case Study

Natural and Artificial Ecosystems

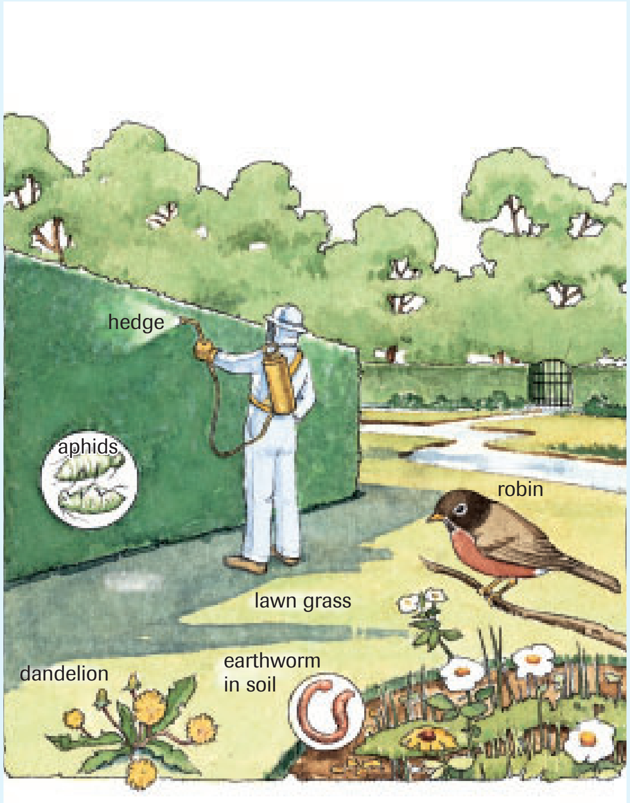

Figure 3
A park ecosystem

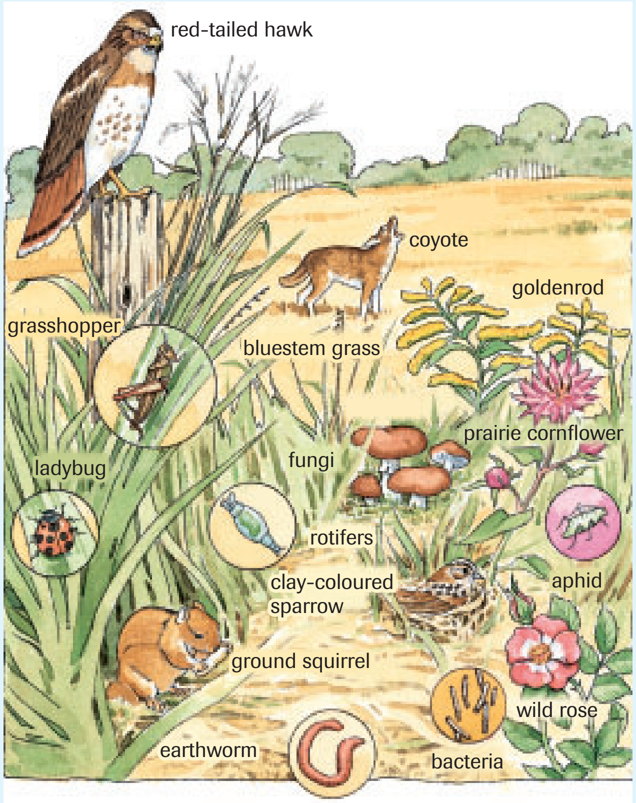

Figure 4
A prairie ecosystem

Your schoolyard, local parks, farms, and managed forests are artificial ecosystems. An **artificial ecosystem** is planned or maintained by humans. Lakes, rivers, forests, deserts, and meadows can all be classified as natural ecosystems. In a **natural ecosystem**, the living community is free to interact with the physical and chemical environment (see **Figure 4**). However, this does not mean that the area is untouched by humans: humans are a natural part of many ecosystems. Natural ecosystems haven't been planned or maintained by humans. In this case study, you will compare a prairie grassland (natural) and a park (artificial).

Change within a park is limited because of human interference. Although the trees grow, most parks look somewhat the same from year to year (**Figure 3**). Humans manage change. Natural ecosystems undergo subtle changes as one plant or animal species gradually replaces another. In natural ecosystems, only plants suited for the environment flourish. In an artificial ecosystem, plants selected by humans have an advantage.

Case Study Questions
Study **Figures 3** and **4**.

1. What human activities prevent the artificial ecosystem of the city park from changing?
2. Which ecosystem demonstrates the greater biodiversity? Explain your conclusion.
3. Speculate about why clay-coloured sparrows, found in the prairie, are less likely to be found in a city park.
4. Speculate about why coyotes are not common in city parks.

Table 1, on the next page, provides data collected from a city park and a prairie ecosystem. All measurements were taken on the same day at the same times. Relative humidity is the percentage of the amount of water vapour in a mass of air compared with the maximum amount of vapour that could be held at that temperature. Evaporation rate measures the volume of water lost from soil in one day. "Soil litter" is a

Table 1 Abiotic and Biotic Factors in Two Ecosystems

Abiotic factors	**City park**	**Prairie**
temperature (maximum)	28 °C	26 °C
temperature (minimum)	12 °C	10 °C
wind speed at ground	22 km/h	15 km/h
evaporation rate	10 L/day	3.5 L/day
relative humidity	85 %	64 %
light at ground (% of sunlight available)	95 %	91 %
soil nitrogen rating	very high	low
soil phosphorus rating	high	low
Biotic factors		
soil litter	56 g/m^2	275 g/m^2
robin density	3/100 m^2	1/100 m^2
ground squirrel density	0/100 m^2	14/100 m^2

measure of the mass of decomposing organic matter found above the soil.

5. Why is it important to take measurements on the same day and at the same time?
6. Why might the wind velocity at ground level differ in the two ecosystems?
7. Why might you expect the temperature to be higher in the park than in the prairie?
8. Explain the differences in the evaporation rate in the two ecosystems.

Table 2 provides detailed counts for some species in the two ecosystems.

9. Suggest reasons why goldenrod is found in the prairie but not the city park.
10. Provide a hypothesis that explains why more earthworms are in the prairie than the park.
11. Why are more spiders found in the prairie?
12. List abiotic factors of the city park and prairie.
13. Explain how human interference influences each of the factors you listed in question 12.
14. Which of the two ecosystems, the prairie or the park, would provide a better habitat for a fox? Give reasons for your answer.
15. Not all natural ecosystems have more biodiversity than all artificial ecosystems. Give two examples of an artificial ecosystem that might have more biodiversity than a natural ecosystem. Provide an explanation of each example.
16. **Tables 1** and **2** provide some data on two ecosystems. What additional data would be useful in making a comparison of an artificial and a natural ecosystem?
17. Some animals, such as the raccoon and the tree squirrel, do very well in artificial ecosystems. What special adaptations or behaviours make these two animals successful in human-dominated environments? Report on the results of your research.

Table 2 Inventory of Species in 10 m × 10 m Study Areas

	City park		**Prairie**	
Types of organism	**Number of species**	**Population of all species**	**Number of species**	**Population of all species**
grass	1	100 000/m^2	3	40 000/m^2
goldenrod	0	0	1	51
plants considered weeds	3	6	17	459
earthworms	1	25	8	210
beetles	4	7	22	39
spiders	1	2	2	13
birds	3	10	11	39
rodents	0	0	3	45

Roles in Ecosystems

ecological niche an organism's role in an ecosystem, consisting of its place in the food web, its habitat, its breeding area, and the time of day at which it is most active

Each organism has its own place within an ecosystem. The organism's place in the food web, its habitat, breeding area, and the time of day that it is most active constitute its **ecological niche**. The niche that an organism fills in an ecosystem includes everything it does to survive and reproduce.

Each species in an ecosystem tends to have a different niche, or a different role to play. This helps reduce competition between species for the same territory and resources.

Owls and hawks (**Figure 5**) feed on many of the same organisms, but they occupy distinctly different niches. The owl, with its short, broad wings, is well adapted to hunt down prey within forests. The longer wings of the hawk are ideal for soaring above grasslands and open fields but present problems for flight through dense brush. Owls are active during dusk and at night, while hawks hunt by daylight. Although the two birds do prey on some of the same species, different prey are active during the night and the day.

Figure 5
Even though the red-tailed hawk and the great grey owl eat some of the same food, they are not in competition because they have different ecological niches.

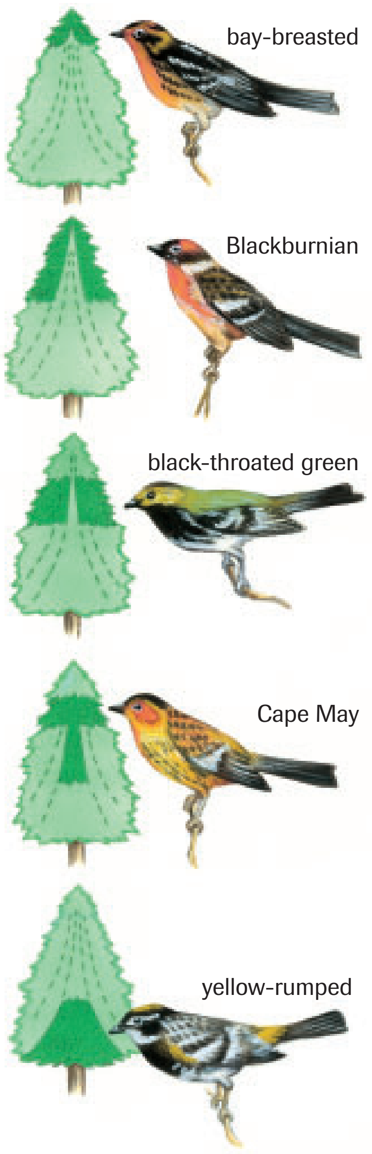

Figure 6
Competition is reduced because each species of warbler prefers to feed in a different section of the tree.

To support their roles, owls and hawks have different adaptations. In addition to their different wing shapes, they also differ in their senses, particularly their eyes. Hawk eyes are excellent at detecting changes in colour patterns, which helps them see rodents even when they are well hidden by their camouflage. Owl eyes see colour poorly, but are excellent at detecting motion, even in the dark. Owls also have excellent hearing, so they can detect the tiniest rustling noises of mice and other rodents as they move.

Competition is further reduced because owls and hawks nest in different areas. Many owls seek the deep cover of trees; hawks nest near the tops of the taller trees of a forest, overlooking grassland.

The different species of warblers that inhabitant forests of Atlantic and central Canada make up one of the best examples of how species reduce competition by occupying different niches. Each species of insect-eating bird feeds in a different part of the tree (**Figure 6**). Even though all warblers eat insects, they don't compete much with each other because different species of insects are found in the feeding area of each warbler species.

In general, the higher the number of different niches in an ecosystem, the more organisms that will be found. For example, a natural forest will have trees of many different ages and sizes than a planted forest in which all the trees are the same age and size. The natural forest therefore has more niches, and also has more biodiversity than the planted forest.

Competition for Niches

When a new species enters an ecosystem, it causes a disturbance. The new species comes into competition for a niche with one or more of the species already in the ecosystem. The introduction of new species (often called "exotic species" because they are not native to the ecosystem) happens naturally. Animals are mobile and can move from one ecosystem to another. Plant seeds can be carried by the wind or animals and take root in new areas. Sometimes a completely new route to an area is opened up, allowing organisms that were separated from each other to mix.

The results of opening up a new route can be dramatic. For example, when North and South America came together about 5 million years ago, animals could move freely from north to south. This was devastating for ecosystems in South America, where many of the native species came into competition with invaders from the north, and lost. Only a few animals from the south managed to cross over to northern ecosystems and find a niche. One of these animals is the opossum (**Figure 7**).

Figure 7
The opossum, once native to South America, can now be found in North America. It competed for, and established, its own niche in forest ecosystems.

Introduction of Exotic Species

The introduction of new species to an ecosystem by humans is one of the main causes of species depletion and extinction, second only to habitat loss. The ecosystem may lack the natural population controls of the introduced species, such as predators or diseases. When a population is unchecked by predators or disease, it has an advantage over the native (indigenous) populations and can increase very quickly. Native species might not be able to compete successfully for space, food, or reproductive sites. If the introduced species is a predator, prey organisms may not have defence mechanisms against it.

For example, in the 1890s, a misguided fan of Shakespeare brought all of the birds mentioned in his plays from the United Kingdom and released them in Central Park in New York City. One of the birds was the starling (**Figure 8 (a)**). A single pair of starlings multiplied so rapidly that starlings are now one of the most abundant and widespread birds in North America. In Alberta, starlings settle in prime nesting sites long before the mountain bluebird (**Figure 8 (b)**) returns from the south. Starlings even evict swallows and mountain bluebirds from their nesting sites. As a result, the population of indigenous bluebirds has declined.

The actual number of introduced species that have established themselves in Canada is widely debated, but even the most conservative estimates are well over 3000 species. Exotic species change natural ecosystems and cost Canadians billions of dollars annually just to control their numbers. Many of the weeds we struggle to control, such as Canada thistle (**Figure 9 (a)**), are exotic species.

(a)


(b)


Figure 8
The niches of the starling **(a)** and the mountain bluebird **(b)** overlap. The naturally occurring bluebird is losing its range to the invading starling.

(a)


(b)


Figure 9
Canada thistle **(a)** and purple loosestrife **(b)** are exotic species in Canada.

EXTENSION

CBC radio ONE

QUIRKS & QUARKS

Fox versus Skunk
Dr. Gary Roemer (New Mexico State University) unravels the complex interactions between foxes and skunks on the Californian island of Santa Cruz. The ecosystems had been in balance for hundreds of years, but the introduction of exotics (in the form of feral pigs) has changed everything.

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Cattle, goats, and pigs were intentionally imported to North America. Other species, such as purple loosestrife, (**Figure 9** (**b**), previous page) which was mixed in contaminated grain seeds, have entered North America accidentally. Purple loosestrife spread so quickly and is so common that early settlers believed it was an indigenous (native) plant. Since it is well-suited for marshes, purple loosestrife has choked out many species of native plants in wetlands.

WEB Activity

Case Study—The Zebra Mussel

The identification of the zebra mussel in Lake Erie in the early 1990s set off a series of alarms. Biologists believe that this tiny bivalve, a native of the Caspian Sea in western Asia, entered the Great Lakes from bilge water discharged from ships. In 1991, there were extensive colonies of zebra mussels in Lake Ontario and only small groups in Lake Huron. By 1994, the zebra mussel was common in southern Ontario's rivers and lakes. By 1995, zebra mussels had moved through the Ohio River to the Mississippi, and were found all the way to the Gulf of Mexico. In this activity, you will read and assess information on the effects of the zebra mussels on the ecosystems in these waterways. You will also conduct your own research on another exotic species that has been introduced to the Western Hemisphere.

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EXPLORE an issue

Genetically Modified Crops

Issue Checklist

- ● Issue
- ○ Resolution
- ○ Design
- ● Evidence
- ● Analysis
- ● Evaluation

In the biotechnology field called genetic engineering, scientists remove small segments of DNA from one organism and insert them into the chromosomes of another. This transfers highly desired characteristics from one species to another, unrelated organism. Organisms treated with this technology are called genetically modified (GM) organisms (GMOs). Many GMOs are crop plants. The first GM crops were planted in North America in the early 1990s. By 2000, more than 40 % of the corn, 45 % of the soybeans, and 50 % of the cotton crop were GM plants. On our grocery shelves, about 70 % of the processed foods contain some GM ingredients.

When a GMO is introduced to an ecosystem, it is new to the entire biosphere. A few of its genes are not found in related natural organisms. The competitive advantage of a GMO over a non-GMO could alter an ecosystem in ways that are difficult to predict.

Benefits of GM crops

- Decreased fertilizer use: the genes added to some GM plants allow them to produce their own nitrate or phosphate nutrients, reducing fertilizer use and saving money.
- Herbicide resistance: the genes in some GM plants make them resistant to herbicides, so the herbicide kills only the weeds. Crop yield is increased and herbicide use is reduced.
- Resistance to cold and disease-causing agents: some GM plants grow faster in cooler temperatures or are more resistant to disease than their non-GM counterparts.

Concerns about GM crops

- Allergies: GM plants could contain proteins that trigger allergies in people.
- Nutrient levels: do GM foods have the same nutritional value as non-GM foods?
- Interbreeding: can GM plants breed with non-GM plants? If so, what might result?

With your group, conduct research to find out more on the benefits and concerns of GM crop plants in Canada.

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When research is complete, use an appropriate method to communicate your ideas on the appropriate use of this technology.

SUMMARY Roles in Ecosystems

- Ecosystems contain abiotic and biotic components. The biotic components can be grouped into populations and communities.
- Ecotones, transition areas between ecosystems, often have more biodiversity than the ecosystems do themselves.
- An ecological niche refers to an organism's place within the ecosystem—its place in the food web, living quarters, breeding area, oxygen requirements, etc.
- Each species has a different niche or role to play in an ecosystem. This helps reduce competition between species for the same territory and resources.
- The introduction of a foreign species to an ecosystem is a primary cause of species depletion and extinction. The introduced species can have advantages over the native species, since natural population controls, such as predators or diseases, may be lacking in the ecosystem.

Section 4.1 Questions

1. List four biotic and four abiotic factors in:
   (a) a freshwater ecosystem, such as a lake
   (b) a terrestrial ecosystem, such as a forest
2. Predict whether you would find more species in a forest, an open field, or the forest–grassland ecotone between them. Explain your prediction.
3. **Figure 10** shows changes in the size of the populations of paramecia (single-cell organisms) placed in three different beakers.
   (a) Compare the growth of Species 1 in Beaker A with the growth of Species 2 in Beaker B.
   (b) What evidence suggests that the populations of paramecia affect each other?
   (c) Suggest a conclusion that can be drawn from the population changes in Beaker C.
4. In your own words, define the term *ecological niche*.
5. Give examples illustrating the problems that can be created when a new species is introduced into an ecosystem.
6. Describe your ecological niche. Consider your habitat and your place in food webs.
7. Human interference often causes ecosystems to change.
   (a) Provide an example of how human interference has caused an increase in the population of a species.
   (b) Provide an example of how human interference has caused a decrease in the population of a species.
   (c) Provide an example of how the rapid increase in a species has affected another species.
8. For many years, ecologists have argued about whether all niches within ecosystems are occupied. Present examples that support both sides of the argument.
9. Do lions and tigers occupy the same niche? Research and give reasons for your answer.

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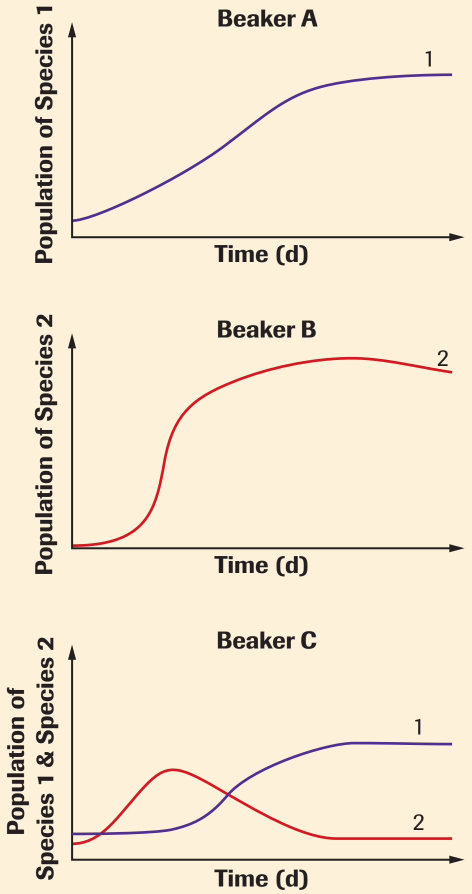


Figure 10
Graphs showing changes in populations of paramecia in three beakers

4.2 Terrestrial and Aquatic Ecosystems

Ecological systems or ecosystems are smaller regions within the biosphere. The scale and complexity of ecosystems varies, depending not only on the organisms that live in them but also on abiotic factors such as climate and local geology. By studying a variety of ecosystems and comparing the data gathered from them, ecologists can get an overall picture of the biosphere as a whole.

One way of organizing the interactions between biotic and abiotic components is to divide the biosphere into biomes. A **biome** is a large geographical region with a specific climate, and the plants and animals that are adapted to that climate. Biomes have particular dominant species, such as the coniferous trees of the taiga biome or the prairie grasses of the grassland biome. However, each biome also contains many different ecosystems, each defined by the particular local biotic and abiotic factors. Some of these ecosystems support organisms that are found nowhere else in the biosphere.

biome a large geographical region with a specific range of temperatures and precipitation, and the organisms that are adapted to those conditions of temperature and precipitation

Canada has four major terrestrial biomes (**Figure 1**). We also have contact with two major aquatic biomes: the freshwater biome composed of lake, river, and pond ecosystems, and the marine or salt water biome that contains all ocean ecosystems. In this section, you will explore some of the ecosystems that are found in Alberta's terrestrial biomes. You will also look at the aquatic ecosystems found in Alberta's lakes. In the next section, you will revisit these terrestrial and aquatic ecosystems to look more closely at the biotic and abiotic factors that define an ecosystem.

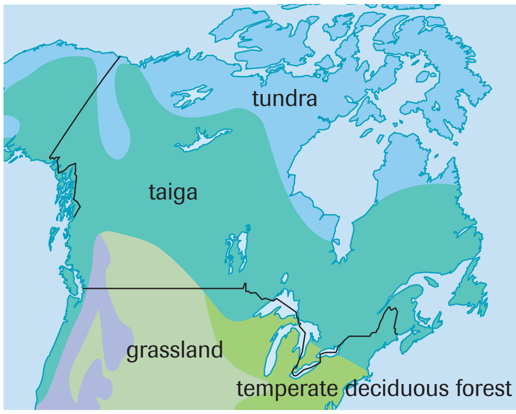
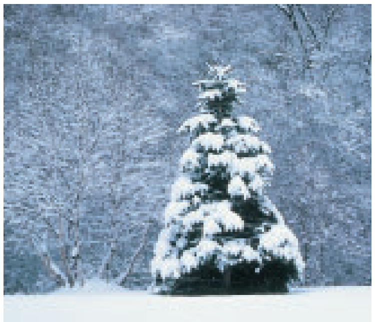


Figure 1
Canadian terrestrial ecosystems can be grouped into four main biomes: tundra, taiga, temperate deciduous forest, and grassland. Mountains are shown in purple.

(a)



(b)

Figure 2
Snow slides off conifer trees. **(a)** The flexible branches bend, causing the snow to tumble down the tapering boughs. By comparison, deciduous trees **(b)** are shaped more like an inverted cone, with many branches at the top. Although well-suited for collecting sunlight, they also easily collect snow or freezing rain.

Terrestrial Ecosystems

Terrestrial ecosystems are ecosystems that are found anywhere on Earth that is not covered by water. Alberta's terrestrial ecosystems are found within two major biomes: taiga and grassland.

Ecosystems of the Taiga Biome

Most of the taiga biome (also called the boreal forest biome) can be found throughout northern Alberta and along the Rocky Mountains. Dominated by conifers (cone-bearing trees that have needles, instead of leaves), taiga is found in every province in Canada. Approximately 80 % of all our forested regions are taiga. Conifers are especially well-adapted to the warm, moist summers and the cold, dry winters found in most parts of this biome. The thin needle-like leaves provide less surface area for water loss during winter. A thick cuticle of wax coats the needles, preventing water loss and protecting against frost damage. The pyramid shape of the tree and its flexible branches shed the crushing weight of a heavy snowfall. Unlike deciduous trees, the tiny needles trap comparatively little snow (**Figure 2**, previous page).

Although taiga forests may appear uniform from a distance, they are actually a mosaic of different ecosystems. Each ecosystem is composed of organisms with adaptations that make them suited to the *local* differences in abiotic and biotic factors that occur in different regions in the biome.

Different ecosystems can also be found in the same small geographic area. In any forest, the amount of sunlight varies depending on the height above the ground. The parts of the trees that reach up into the forest **canopy** receive the most sunlight. In taiga, these are usually mature conifer trees, such as spruces and pines. Conifers are suitable as food for only about 50 species of birds, including seed-eaters such as crossbills (**Figure 3 (a)**), which have thick, strong beaks capable of cracking the cones. Some other species, such as red and flying squirrels, can feed on pine seeds.

In contrast, the forest floor is in almost continuous shade. Little sunlight filters through the canopy. As a result, vegetation on the forest floor is restricted to shade-loving plants such as shrubs, mosses, and ferns. The primary consumers of this ecosystem, including moose, voles, and white-tailed deer, depend on these shade-loving plants for their food. The available shelter is also determined by these shade plants. Nesting sites on the forest floor are unsuitable unless the animal has effective camouflage, such as that of the spruce grouse (**Figure 3 (b)**). Predators in this type of ecosystem include black and grizzly bears, weasels, owls, and wolverines.

canopy the upper layer of vegetation in a forest

(a)

(b)

Figure 3
Birds found in taiga ecosystems: white-winged crossbill **(a)** and spruce grouse **(b)**

Muskeg Ecosystems

Climate is the average conditions of temperature and precipitation of a region, and is one of the main factors that determine biomes. Temperature and water are important factors to any ecosystem. Within the taiga biome of Alberta, there is a range of climate conditions and thus, a range of ecosystems. In areas with warmer ground temperatures, there is relatively rapid decomposition of organic matter, resulting in good soil. The decomposition of needles produces acidic soils, in which only certain plants grow, such as black spruce trees.

As you move north, Alberta's climate becomes colder. The most northern regions are sufficiently cold that there is a layer of **permafrost** beneath the soil that never melts. Rain and melted snow cannot drain away in this part of the taiga, and the water soaks the decomposing plants and peat moss. This forms **muskeg**, ground that is swampy or boggy in the summer (**Figure 4**). Muskeg supports different organisms than are found in conifer forest ecosystems.

permafrost permanently frozen soil

muskeg soil above the permafrost that is swampy or boggy in summer

Figure 4
Muskeg has proved challenging for exploration companies searching for oil. Vehicles often sink into the spongy muskeg.

Figure 5
Caribou are more commonly found in muskeg ecosystems of taiga.

Decomposition of plant and animal matter is slow in muskeg ecosystems, since the low temperatures limit the growth and reproduction of soil bacteria and fungi. This in turn limits the amount of organic matter in the soil. Since soil formation is extremely slow, any damage to the fragile ecosystem takes years to repair. The plants best adapted to this ecosystem grow close to the ground and have fibrous root systems that can anchor the plant in the shifting soil. Plants include lichens, mosses, tall grasses, small shrubs, and stunted conifers. Numerous pools provide abundant water for plants, as well as ideal breeding conditions for black flies and mosquitoes. Muskeg also provides habitat for some larger animals, such as caribou (**Figure 5**).

Ecosystems of the Grassland Biome

The black earth of grassland ecosystems is said to be the most fertile in the world. Short-lived grasses with deep roots provide a large biomass for decomposition. The warm temperatures cause rapid decay and the formation of a rich layer of humus. Not surprisingly, grass length is controlled by precipitation. Unlike forests, grassland ecosystems have only one layer in which to support the biotic community, limiting the number and diversity of organisms.

Producers in Alberta's grasslands include rough fescue, wheat grass, and spear grass. Deer, squirrels, and rabbits graze on the grasses. Birds such as the yellow-bellied sapsucker, and snakes such as the prairie rattlesnake, also live in the grassland ecosystems.

Deciduous Forest Ecosystems

At the edges of the grassland biome of Alberta, before it turns into taiga, are ecosystems dominated by trees. Aspen, balsam poplar, and birch are the most common trees in these deciduous forest ecosytems (**Figure 6**). They require lower amounts of water than coniferous trees, and are found in areas where the rainfall is intermediate between the taiga and the true grasslands. Deciduous trees can also be found near rivers (such as the Bow River in Calgary), lakes, and ponds.

Figure 6
Of all the ecosystems in Canada, deciduous forests have the greatest plant and animal diversity.

Warmer temperatures, more precipitation, and the large amount of humus from the leaves provide a rich soil in deciduous forests. In the early spring, most of the sunlight reaches the forest floor and the **understorey**. By summer, the canopy is in full leaf and only about 6 % of the sunlight that strikes the canopy reaches the understorey. However, by this time the undergrowth is well-established. The broad leaves of deciduous trees maximize light capture for photosynthesis, promoting rapid growth.

Deciduous forests support a great diversity of animals. The thick layer of leaf litter provides an ideal environment for many types of insects. Not surprisingly, insect-eating birds and mammals, such as fly-catchers and shrews, live in deciduous forest ecosystems. The rich vegetation of the understorey shrubs and the lower branches of the trees support large browsers such as deer and moose. The canopy is home to many species of birds and some climbing mammals.

Alberta has a rich diversity of terrestrial ecosystems. **Table 1** summarizes the ecosystems that have been discussed.

Table 1 Terrestrial Ecosystems in Alberta

Name	Abiotic factors	Biotic community
taiga ecosystems	• northern and central Alberta forests • changeable weather • soil contains some water and is acidic • precipitation 50-250 cm/a	black and grizzly bears wolverines weasels moose deer grouse owls spruce and pine shrubs, ferns, mosses, and lichens
muskeg ecosystems	• cold temperatures • short growing season • permafrost layer beneath soil • low precipitation: 50-150 cm/a	black bear caribou ptarmigans rapidly flowering plants moss and lichens
grassland ecosystems	• central and southern Alberta • increased sunlight and warmer temperatures than muskeg or boreal forest ecosystems • rich fertile soil • precipitation 25-100 cm/a	bison deer rabbits hawks yellow-bellied sapsuckers fescue grasses grasshoppers
deciduous forest ecosystems	• central Alberta • increased sunlight and warmer temperatures than muskeg or taiga forest ecosystems • rich fertile soil • precipitation 75-250 cm/a	black bears weasels moose deer woodpeckers deciduous trees shrubs

understorey below the canopy layer; usually shrubs and smaller trees

DID YOU KNOW ?

Fire and Deciduous Trees in Alberta

Intermittent fires once swept across the Prairies, killing any saplings, thus ensuring that trees did not encroach on the grasslands. In addition, the fires acted as decomposers, returning nutrients back to the soil faster than by bacterial decomposition. Some of the Aboriginal peoples of the Prairies recognized the importance of the fires and set fires to maintain the grassland ecosystem. Today, most grassland fires are controlled by human actions.

EXTENSION

Biogeography

Why do different types of grasses grow in different parts of the Canadian Prairie? Why does Canada have different types of forests? In this activity, you will look at various abiotic factors and how they vary in regions across Canada. You will then relate these abiotic factors to the adaptations of the biotic components of the ecosystems in those regions.

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WEB Activity

Case Study—Critical Ecoregions of the World

The Sierra Club has identified critical ecoregions in North America, and has developed strategies to restore and maintain each ecosystem. The objective of this plan is to re-establish the "web of life" on Earth. Choose an ecosystem of interest and find out the details of the plan to sustain that ecosystem, and identify underlying assumptions on which that strategy is based.

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INVESTIGATION 4.2 *Introduction*

A Forest Ecosystem

A variety of abiotic factors affect terrestrial ecosystems. Soil quality, temperature, and sunlight amounts determine which plants will populate an area. In this investigation, you will identify types of vegetation and calculate plant density in a selected study site. You will explore how environmental conditions interact with the plant community studied.

Report Checklist

- ● Purpose
- ○ Problem
- ○ Hypothesis
- ○ Prediction
- ○ Design
- ○ Materials
- ○ Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ● Synthesis

To perform this investigation, turn to page 125.

Practice

1. What is permafrost?
2. Why is soil quality poor in the muskeg ecosystem and rich in grasslands?
3. Why can a spruce tree grow in a taiga ecosystem but not in a grassland ecosystem?
4. Why do few trees grow on grasslands?

Aquatic Ecosystems

Water covers more than two-thirds of our planet. Ninety-seven percent of that water is saltwater. These great reserves of ocean water are of tremendous value to all living things. Millions of organisms live in many different ecosystems on and under the ocean's surface. In addition, the oceans control the weather patterns on our planet to a large extent. They also provide a constant supply of freshwater through evaporation. Most freshwater on Earth exists as snow and ice. However, there are still vast amounts of liquid freshwater on Earth's surface, housing millions of organisms in many different ecosystems.

Aquatic ecosystems are found in ponds, rivers, lakes, and oceans. In Alberta, the major aquatic ecosystems are freshwater ecosystems. The rest of this section will focus on lake ecosystems in particular.

Lake Ecosystems

On the surface, a lake may appear to be similar everywhere, but below the surface, the amount of light available, the water temperature, and oxygen levels can all vary. Not surprisingly, the organisms you can find in each area also differ greatly.

Figure 7 shows a cross section of a typical lake. The **littoral zone** is the area extending out from the lakeshore to the point where you can no longer find plants rooted in the bottom of the lake. Aquatic plants that grow to the surface, such as bulrushes and water lilies, take hold where the littoral zone is shallow. In slightly deeper areas, plants that are rooted to the bottom but completely submerged may thrive.

littoral zone the area from the shore of a lake or pond to the point where no more plants grow in the lake bottom

DID YOU KNOW ?

Comparing Productivity

With some important exceptions, aquatic ecosystems are less productive than terrestrial ecosystems. For example, a cubic metre of ocean water might contain 5 kg of biomass, while the same volume of fertile soil would contain about 50 kg of biomass.

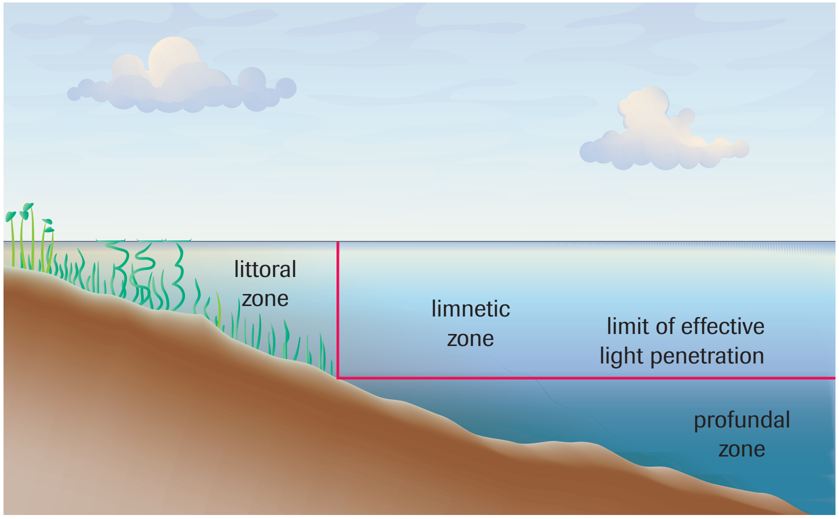

Figure 7
A cross section showing the three main zones of a lake. Note that the depth of the boundary between the limnetic zone and the profundal zone varies in each lake. Plankton and undissolved solids can block the light.

The littoral zone is the most productive part of a lake, the area where algae and plants take advantage of the sunlight to carry out photosynthesis. The size of the littoral zone is determined by the depth of a lake and the slope of its lakebed, both of which are individual to each lake.

Beyond the littoral zone is the **limnetic zone**, the area of the open lake where there is enough light for photosynthesis to occur. The most common form of organism within the limnetic zone is called plankton. The word **plankton** is used to describe both autotrophic and heterotrophic microorganisms. Heterotrophic plankton (invertebrate animals) feed on the autotrophic plankton (tiny plants and algae). Both kinds of plankton are food for consumers in the higher trophic levels, such as fish, tadpoles, and birds.

The region beneath the limnetic zone, where there is not enough light for photosynthesis to occur, is called the **profundal zone**. (This zone is not usually found in ponds.) In most lakes, the only source of nutrients in the profundal zone is the rain of dead plants and animals that falls from the limnetic zone. This detritus is slowly broken down by bacteria or consumed by other bottom-dwelling invertebrates and fish, called detritus feeders.

The decay of this falling organic matter has important consequences for the ecosystem. Bacteria use oxygen to decompose detritus, reducing the amount of oxygen available in the water. In the absence of sunlight and plants to replenish the oxygen, oxygen levels could be reduced to very low levels. The only larger organisms that survive are those that can tolerate low oxygen levels; they include some invertebrates, and a very few fish species such as carp.

limnetic zone the area of a lake or pond in which there is open water and sufficient light for photosynthesis to occur

plankton autotrophic and heterotrophic microorganisms found in the limnetic zone of a lake or pond

profundal zone the region of a lake beneath the limnetic zone, in which there is insufficient light for photosynthesis to occur

SUMMARY Terrestrial and Aquatic Ecosystems

- Alberta has two major terrestrial biomes, taiga and grassland. In these biomes, there are many different ecosystems.
- Alberta's terrestrial ecosystems experience a wide range of seasonal conditions. Organisms in these ecosystems are adapted to these conditions.
- Alberta's aquatic ecosystems are found in lakes, ponds, and rivers. Lake ecosystems vary depending on depth and the resulting amount of light available for photosynthesis.

Section 4.2 Questions

1. Hypothesize why the moose is often found in taiga and in deciduous forests but not in muskeg ecosystems.
2. What adaptations make conifers well-suited for taiga?
3. Rank the ecosystems discussed (muskeg, taiga, deciduous forest, grassland) in descending order according to each abiotic factor below. Give reasons for your rankings.
   (a) precipitation
   (b) cold temperatures
   (c) length of growing season
   (d) diversity of organisms
   (e) biomass
4. Copy **Table 2** (below) in your notes and fill in the blank cells.
5. Draw a map of Alberta, and locate regions that can be classified as muskeg, coniferous forest, deciduous forest, and grassland.
6. Identify the profundal zone, according to the data in **Table 3**.

Table 3 Abiotic Factors in a Lake

Zone	Temp. (°C)	Depth (m)	Light conditions
1	25	1	bright
2	20	5	medium
3	15	20	dim
4	10	25	dark

7. Explain why you would expect to find different organisms in the limnetic, littoral, and profundal zones of a lake. In your answer, refer to the abiotic factors in each zone.
8. Using the terms you've learned in this section, describe a local lake or pond.

Table 2 Components of Biomes

Ecosystem			Grassland	Deciduous forest
soil	acidic	permafrost		rich, fertile
biotic factor (vegetation)	spruce trees	lichens and moss		
annual mean precipitation (cm)	50-250		25-100	75-250

Factors Affecting Ecosystems 4.3

In the previous section, you looked at several terrestrial and aquatic ecosystems. Each ecosystem was defined not only by the organisms that live in it, but also by abiotic factors such as temperature, amount or type of water, and amount of light. In this section, you will take a closer look at the factors that affect ecosystems.

Factors Affecting Terrestrial Ecosystems

Despite their many differences, terrestrial regions such as coniferous forests, deserts, and grasslands are alike in one way: each region functions as a system. Within each ecosystem, the biotic and abiotic factors are interdependent. These factors can limit the size of populations and can also determine the number of species that can survive in each ecosystem.

Soil

Soil is so familiar that its importance can go unnoticed. A thin layer of soil, rarely more than two metres thick and often much thinner, provides nutrients for all plants that grow on land. The quality and amount of soil available are crucial factors in determining the size and health of the plant community, and thus, the biodiversity of the ecosystem. Entire civilizations have collapsed because the topsoil was depleted or overused (**Figure 1**).

Soil can be viewed as a series of layers, each of which can be identified by its distinct colour and texture (**Figure 2**, next page). As you move downward, deeper into the soil, less organic matter can be detected. The upper layer, known as the **litter**, is mostly made up of partially decomposed leaves or grasses. The litter acts like a blanket, limiting temperature variations in the soil and reducing water loss by evaporation.

Beneath the litter is the **topsoil** layer, made up of small particles of rock mixed with decaying plant and animal matter (**humus**). Humus is black, so topsoil is often dark. Topsoil usually contains a rich supply of minerals and other nutrients that plants require for growth. Nutrients from dead and decaying matter are recycled as new plants grow. Also present in the topsoil, in the spaces between the rock particles, are air and water. For dead material to decompose completely, oxygen is needed. This is because the microbes that cause decay use oxygen for respiration. For example, if oxygen is present in small amounts, dead plant material decays slowly and can build up into a layer of peat which is characteristic of muskeg.

Below the topsoil is the **subsoil**, a layer that usually contains more rock particles, mixed with only small amounts of organic matter. The subsoil is usually lighter in colour because of the lack of humus. Subsoil may contain relatively large amounts of minerals such as iron, aluminum, and phosphorus. Beneath the soil lies a layer of rock, the **bedrock**, which marks the end of the soil.

As you saw in Section 4.2, different ecosystems in a biome can have different types of soil. The type of soil affects the biotic components of the ecosystem. For example, taiga ecosystems with well-drained soil tend to have many white spruce and jack pine trees. Birds that feed on these trees are found more often in these ecosystems, as are the predators that depend on these birds for food. In contrast, muskeg soil in the northern taiga has relatively poor drainage and lower amounts of oxygen. As a result, muskeg ecosystems have more species that are adapted to water-soaked soil, such as black spruce and larch. The other biotic components of this ecosystem depend on the black spruce and larch for their food.

litter the upper layer of soil, composed mainly of partially decomposed leaves or grasses

topsoil the soil layer beneath the litter, composed of small particles of rock mixed with humus

humus decaying plant and animal matter

subsoil the soil layer beneath the topsoil, usually containing more rock particles and less organic matter than the topsoil

bedrock the layer beneath the soil, composed of rock

Figure 1
There are many possible explanations for the disappearance of the civilization that created these statues on Easter Island. One theory is that the islanders removed too many trees, causing the topsoil of the island to erode. With their soil depleted, the people could not grow as much food as before.

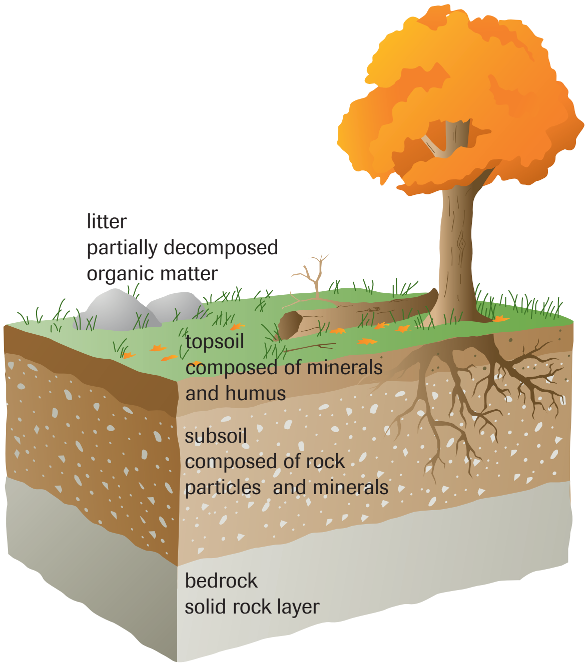

Figure 2
The soil can be divided into layers. Each layer can be identified by colour and the presence of stones. Roots from trees help break up large stones in the subsoil and the bedrock itself, helping to deepen the soil.

Soil can be acidic, neutral, or basic. Basic soils are often referred to as alkaline soils. The pH of the soil is determined by the nature of the rock from which it was formed, and by the nature of the plants that grow in it. (The decomposition of organic matter from dead plants and discarded leaves can cause the accumulation of acids in the soil.) The acidity of rain, snow, and groundwater that enters the soil, also plays a role. Humans have been contributing to higher levels of acidity in many soils by burning fossil fuels such as coal, oil, and gasoline. The burning of fossil fuels releases sulfur doxide and nitrogen oxides into the air. These gases form acidic compounds in the atmosphere, resulting in acidic rain and snow.

The pH of the soil determines which plants will grow best. For example, coniferous trees do poorly in strongly acidic soils, even though they are well adapted to mildly acidic soil. Mosses often flourish in acidic soils because of decreased competition from other plants that require more nutrients.

Available Water

The amount of available water in an ecosystem is another important abiotic factor. This factor is part of the overall climate of the region. All organisms depend on water to survive. Some organisms have adaptations that allow them to live in regions with extremely low levels of available water, such as deserts and extremely cold regions. For example, Alberta's rough fescue grass has long, thin leaves that reduce moisture loss. As a result, this organism can survive in dry areas.

groundwater water in the soil or rock below Earth's surface

The amount of available water is determined by the amount and the type of precipitation (e.g., rain or snow). The amount of available water is also affected by how long it stays in the upper layers of soil, and how much collects beneath the soil. Precipitation collects in lakes, ponds, and rivers, but it also seeps into the soil and the porous rock below the soil. Once in the soil or rock, water is called **groundwater**. The water that flows down through the soil eventually reaches a layer that is saturated with water. The boundary between this saturated layer and the unsaturated soil above it is called the water table. The depth of the water table in an area affects the organisms that grow there.

For example, if a region has little precipitation but a water table that is close to the surface, plants can reach down with their roots to obtain water, even though there is little rain or snow. If the water table is very close to the surface, the area will be marshy or swamp-like.

As water seeps downward, it dissolves organic matter and minerals from the soil and carries them deeper in a process called leaching. Leaching is a serious problem because plants require these nutrients for growth and development. In many ways, plants help to correct the problem themselves. Their branching roots extend deep into the soil and help pump minerals and other chemicals from the lower levels back to the surface.

DID YOU KNOW?

Aboriginal Technologies

Aboriginal peoples have developed many technologies to cope with abiotic factors, including temperature, in their environments. Some of these technologies, such as snowshoes, kayaks, and canoes, are still in use today.

Temperature

Like available water, temperature is part of the overall climate of a region. Temperature can vary significantly throughout the year in an ecosystem, which affects both biotic and abiotic factors. For example, organisms such as cacti are not able to survive the temperature conditions in Northern Alberta, and so do not form part of food webs in ecosystems in this region. Similarly, the rate at which water evaporates is affected by the temperature. At cooler temperatures, it takes longer for water to evaporate, and so it is available to plants with shallow roots for a longer time.

Albertan ecosystems experience extreme summer and winter conditions. However, the organisms that live here are adapted to their ecosystems, which means that either they can cope with abiotic factors such as low moisture, cold temperatures, and decreased sunlight, or they migrate from the area before winter sets in.

For example, by keeping their leaves (the needles) throughout the winter, conifers are better able to survive in regions with a short growing season. These trees do not expend large amounts of time, energy, and nutrients to grow a complete new set of leaves each year.

Grassland populations are highly adapted to winter climates. A large proportion of the grasses' biomass exists underground in their root systems (**Figure 3**). Although the above-ground grass freezes off during the winter, the roots survive to regrow in spring.

Animals adapt in several different ways to the cold winters. Some birds, such as loons, ducks, and some species of hawk, migrate to warmer climates, while some mammals, such as black bears, hibernate (become inactive). Many insects enter a state of low metabolic activity or overwinter as eggs. Other animals, however, are active throughout the winter. For example, small animals such as mice and voles dig tunnels in the snow, protecting themselves from predators and cold temperatures.

Figure 3
Most of the biomass of native prairie grasses is in the root system.

mini Investigation — How Does Temperature Affect Seed Germination?

Using the following materials, design an experiment that determines the effect of temperature on seed germination. The materials listed are per group.

Materials: 30 radish seeds, 3 Petri dishes, 3 plastic bags, paper towel, 100 mL graduated cylinder, water

(a) Construct a hypothesis for the experiment.

(b) Identify your independent and dependent variables, and which factors must be controlled.

(c) Write a procedure. Make sure you include any safety precautions and describe how you will record your data. Have your procedure checked by your teacher.

- Perform your investigation.

(d) Analyze your data and communicate your conclusions.

Sunlight

Finally, all terrestrial ecosystems are affected by the amount of sunlight they receive. In ecosystems close to the equator, the amount of sunlight received every day is more or less constant throughout the year. Regions at more southern or northern latitudes experience changes in the amount of sunlight during different times of the year. For example, in Canada, we receive fewer hours of sunlight in winter than in summer.

Ecosystems within any geographic region can also receive different amounts of sunlight. For example, an area that is shaded by a large outcrop of rock will support a different ecosystem than an area close by but in full sunlight. As plants in an ecosystem grow, they can affect the amount of sunlight received by other areas in their vicinity. For example, you saw in Section 4.2 how taller trees in a forest form a canopy blocking sunlight from shorter trees and shrubs in the understorey.

Practice

1. If you were to dig a hole in local soil, what layers would you expect to see? Explain your answer.
2. Describe two factors that would alter the amount of ground water in an area.
3. Using a diagram, explain how minerals leach from the soil and how plants help to correct this process.

Factors Affecting Aquatic Ecosystems

Like terrestrial ecosystems, aquatic ecosystems are limited by three main abiotic factors: the chemical environment, light levels, and temperature. Water pressure is a fourth abiotic factor that affects only aquatic ecosystems.

Figure 4
Aquatic ecosystems, such as this stream in the Kanaskis, will have more dissolved oxygen when the water is cold than when it is warm.

Chemical Environment

In aquatic ecosystems, the chemical environment naturally includes the type of water, whether freshwater or saltwater. Organisms that live in freshwater ecosystems can seldom survive in saltwater ecosystems, and vice versa. A second component of the chemical environment in aquatic ecosystems is the amount of oxygen that is dissolved in the water. Like terrestrial organisms, aquatic organisms require oxygen, but they must get their oxygen from the water. The amount of oxygen that is dissolved in a body of water depends on a number of factors, including temperature (**Figure 4**), pressure (determined by the depth of the water), and the amount of salt and other substances dissolved in the water. Finally, the chemical environment of aquatic ecosystems includes any other dissolved substances. For example, lake water might contain naturally occurring minerals, such as phosphorus and nitrogen, as well as organic pollutants.

Temperature and Sunlight

As in terrestrial ecosystems, the light and temperature of an aquatic ecosystem may vary over the course of a year. This is particularly true in Canada, where we have four seasons. However, in aquatic ecosystems, these factors are also affected by the depth of the water.

Ecosystems near the surface of an ocean will obtain far more light and experience warmer temperatures than ecosystems in the depths. Surprisingly, life can exist even in the dark regions of the ocean. As you learned in Chapter 2, oceanographers have discovered fascinating ecosystems existing around hydrothermal vents on the ocean floor. These ecosystems contain organisms such as tube worms, crabs, and mussels, forming food chains based on bacteria that produce food through chemosynthesis.

Water Pressure

Water pressure is another important abiotic factor in aquatic ecosystems. Plants and animals in aquatic ecosystems have adapted to conditions that are dramatically different from those on land.Water is about 800 times denser than air, making it more difficult to move through. This factor is particularly important in ocean ecosystems. Although sea animals can travel widely without obstruction, they are limited by how much they can move up and down. At a depth of 10 m, the pressure is roughly double what it is at the surface, and the pressure increases by 100 kPa for every 10 m of depth. The average depth of the ocean is about 4000 m. Very few organisms are adapted to survive both near the surface and under the crushing pressure at the ocean bottom.

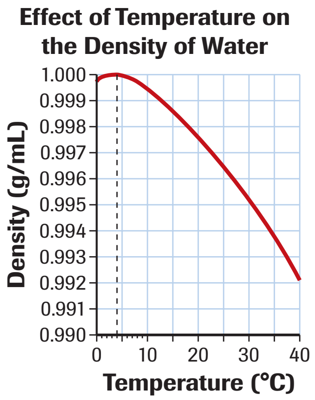

Figure 5
Unlike most substances, pure water becomes less dense as it cools below 4 °C.

Seasonal Variations in Canadian Lakes

In Canada, the changing of the seasons causes significant changes in the abiotic factors in freshwater ecosystems found in our lakes. As water cools, it becomes more dense, just like other substances. However, as water cools below 4 °C a strange thing happens—it starts becoming less dense (**Figure 5**). This is why ice floats, forming a layer on top of cold water, and why the lowest layer of water in a lake often has a temperature of 4 °C. Seasonal variations in a lake are shown in **Figure 6**.

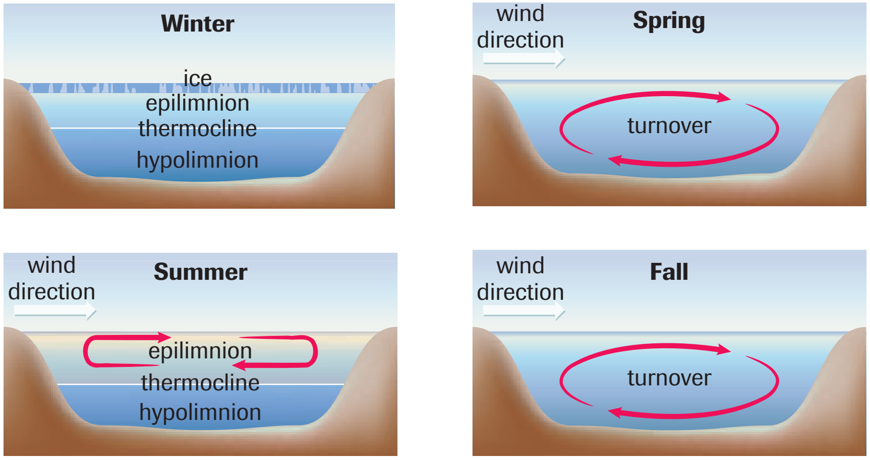

Figure 6
Temperature and the variable density of water both play important roles in seasonal changes in Canadian lakes.

Winter

During the winter, many of our lakes are covered by ice and snow. This prevents atmospheric oxygen from dissolving in the water and acts as an insulator. Under the ice the water is arranged in layers, according to its density. The least dense water, at or slightly above 0 °C, is near the surface. The densest water, at 4 °C, is found at the bottom. No matter how cold the air becomes above the ice, this structure remains the same, although the ice will get thicker if the air remains cold.

If the ice is wind-blown and transparent, light can penetrate into the water, supporting photosynthesis in the liquid water below. However, if the ice freezes to a greater thickness than normal, or is covered in thick snow, light can no longer penetrate, and the organisms under the ice are in trouble. The level of dissolved oxygen in the water may drop until it is not high enough to support some organisms. Because fish are particularly sensitive to dissolved oxygen concentrations, the result could be a massive die-off of some fish species. In shallow lakes, particularly in the Arctic, ice may form right to the bottom, virtually eliminating most life forms every winter.

+ EXTENSION

Thermal Stratification of Lakes
Listen to this Audio Clip to get a better understanding of how the properties of water relate to the process of thermal stratification. Find out how surface warming becomes an abiotic limiting factor.

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epilimnion the upper level of a lake, which warms up in summer

hypolimnion the lower level of a lake, which remains at a low temperature year round

thermocline the zone between the epilimnion and hypolimnion, in which temperature changes rapidly

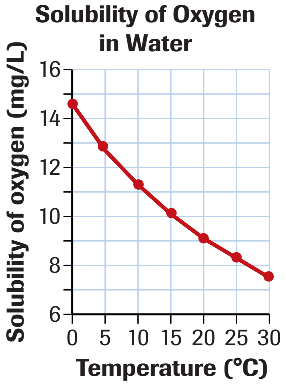


Figure 7
Solubility of oxygen in water

Spring

Spring brings storms and the melting of the ice. Oxygen can now pass from the air into the water. Wind stirs the water, creating waves that increase the surface area and so the rate at which oxygen can dissolve. As the cold surface water warms, it eventually reaches a temperature of 4 °C. At this point, it begins to sink through the less dense water beneath it, carrying its precious supply of oxygen with it. The mixing process that results is called the spring turnover.

Summer

As the surface water warms above 4 °C, it will no longer sink because it is less dense than the cooler water below. Just as in winter, layers of water are set up, with the densest water at the bottom. If you swim in a lake during summer you can experience these layers. By allowing your feet to sink slowly through the water, you will encounter colder regions.

The upper level of a lake, which warms up in summer, is called the **epilimnion**. The lower level, which remains at a low temperature, is called the **hypolimnion**. Between these two levels is the **thermocline**, a narrow zone in which the temperature drops rapidly from warm to cold.

Because the epilimnion and hypolimnion do not mix, there is little movement of oxygen from the surface to the depths during summer. Organisms living in the hypolimnion must rely on oxygen reserves brought down during the spring turnover.

The epilimnion has a different oxygen problem. The ability of water to hold dissolved gases is inversely proportional to the temperature of the water: The warmer the water, the less dissolved oxygen it can hold (**Figure 7**). During a hot spell, a lake that is fairly shallow may lose so much oxygen that some species, such as lake trout, will die.

Fall

As temperatures begin to drop in the fall, the surface water begins to cool. Once again, as the surface water reaches a temperature of 4 °C, it sinks down through the lake. This fall turnover renews oxygen levels at lower levels, and breaks up the summer thermal layers.

Practice

4. Explain why a shallow lake tends to be warmer than a deep lake in summer.

5. In your own words, describe the changes that happen in a lake from summer to winter.

mini Investigation — Measuring Undissolved Solids

Rain carries soil and other solids into surface water where they can remain suspended, creating turbidity (cloudiness or murkiness) that limits the penetration of sunlight and reduces photosynthesis. Solids that are deposited as sediment on the bottom of the body of water can also affect ecosystems. Large volumes can bury bottom-feeding animals and the eggs of fish. Large amounts of falling sediment also make life generally unpleasant for filter feeders such as clams.

(a) Using filter paper and other materials, design a procedure (including safety precautions) to determine the amount of undissolved solid material in water samples from three different sources.

- Have your materials list and procedure approved by your teacher before starting. (Shake each of the samples before each test.)

(b) Present your results (including your data) in a written report.

SUMMARY Factors Affecting Ecosystems

- The quality and amount of soil are critical factors in determining the size and health of the plant community and the biodiversity of an ecosystem.
- Terrestrial ecosystems can experience large changes in temperature and precipitation. Organisms must adapt to these changes.
- The amount of sunlight in a terrestrial ecosystem can vary with geographic location, time of year, and biotic and abiotic factors that change the amount of shade.
- Organisms in aquatic ecosystems are limited by the abiotic factors of that ecosystem: the chemical environment, light levels, and temperature.
- The solubility of oxygen in water increases as the water temperature decreases.
- The amount of sunlight and the temperature of aquatic environments are determined by the depth of the water, as well as any seasonal changes.
- Temperature and the density of water play important roles in seasonal changes in lakes in Canada. As water cools, it becomes more dense. However, below 4 °C, it becomes less dense.

Section 4.3 Questions

1. List some ways in which the amount of organic matter in an ecosystem can increase.
2. Why is it possible that two ecosystems, with identical conditions of temperature and precipitation, could support different plants?
3. Describe what you would expect to happen to oxygen levels in the hypolimnion of a lake over the summer months.
4. Cold water holds more dissolved gas than warm water. Cold water also tends to collect in the lower levels of a lake. However, in summer, oxygen levels in a lake can be highest in the warm surface water of a lake. Explain why.
5. Predict what would happen to a lake that experienced no seasonal changes in temperature. Make a diagram showing the temperature and oxygen levels in the water of the lake after many years of little change in surface air temperatures.
6. (a) Using soda pop, beakers, water, and other materials you choose, design a demonstration (including safety precautions) that shows the relationship between water temperature and the amount of dissolved gas. Have your teacher approve your materials list and design before you begin.
   (b) How did you measure the amount of dissolved gas in the soda pop?
   (c) Present your data in a graph and interpret your findings.
7. A good fisher knows where to find fish. Catfish are less active than trout. In the summer months, which of these fish would you expect to find in the hypolimnion and the epilimnion? Give your reasons.

4.4 Limits on Populations and Communities in Ecosystems

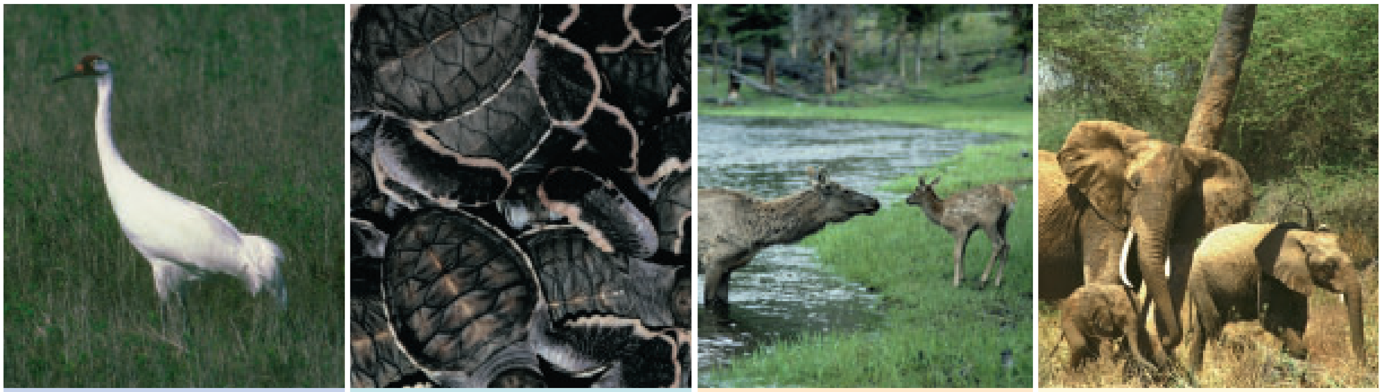
Field mice can have litters with six or more pups, and they can reproduce every six weeks. It takes only six weeks for a mouse to become sexually mature. In six months, a population of 20 mice could become a population of 5120 mice. What keeps the population of field mice under control? Predators, available amounts of food and water, disease, changing temperatures, and other factors all prevent mice populations from growing exponentially.

In the previous section, you examined specific factors that affect ecosystems. In this section, you will see how these and other factors limit populations and communities within ecosystems.

Biotic Potential

biotic potential the maximum number of offspring that a species could produce with unlimited resources

Species vary in their capacity to reproduce. **Biotic potential** is the maximum number of offspring that a species could produce if resources were unlimited. You have seen how quickly field mice reproduce, but many animals have a much lower biotic potential. For example, mature female black bears give birth to one or two cubs after a gestation period of 7.5 months. Generally, bears take at least two years to mature, during which time their mother will not give birth again. Biotic potential is regulated by four important factors, shown in **Figure 1**.



Factor: birth potential
Description: The maximum number of offspring per birth
Example: Whooping crane females lay two eggs per year, and usually only one chick survives.

Factor: capacity for survival
Description: The number of offspring that reach reproductive age
Example: The female sea turtle lays many eggs, but only a few of her offspring even reach the sea, and fewer still reach maturity.

Factor: breeding frequency
Description: The number of times that a species reproduces each year
Example: Elk mate only once per year, during the fall.

Factor: length of reproductive life
Description: The age of sexual maturity and the number of years the individual can reproduce
Example: African elephants reach sexual maturity at about 15 years of age, but may reproduce until they are 90.

Figure 1
Factors that determine biotic potential

Limiting Factors

Factors in the environment can prevent populations from attaining their biotic potential. Any resource that is in short supply is a limiting factor on a population. Food, water, territory, and the presence of pollutants and other toxic chemicals are all limiting factors, as shown in **Table 1**.

Table 1 Factors That Limit Populations

	Factors that cause a population to increase	Factors that cause a population to decrease
Abiotic	favourable light	too much or too little light
	favourable temperature	too cold or too warm
	favourable chemical environment	unfavourable chemical environment
Biotic	sufficient food	insufficient food
	low number or low effectiveness of predators	high number or high effectiveness of predators
	few or weak diseases and parasites	many or strong diseases and parasites
	ability to compete for resources	inability to compete successfully for resources

For example, a fern plant produces more than 50 000 spores in a single year (**Figure 2**). If all fern spores germinated, fern plants would cover all of North America within two generations of the first plant. This doesn't happen because of the limiting biotic and abiotic factors. If the weather is wetter than usual, the soil is moist, and many fern spores will germinate, so the fern population will increase. A return to drier weather will not only prevent spores from germinating, but will also kill plants in exposed areas, so the population declines. The presence of many grazing animals will reduce the population of ferns, and if there are few grazers the population will grow. Fluctuations like these, caused by one factor, can occur in natural ecosystems; however, most populations are affected by more than one factor at a time.

Figure 2
Abiotic and biotic factors limit the number of ferns in an ecosystem.

Carrying Capacity

Populations commonly fluctuate because of an interaction of the many biotic and abiotic limiting factors. However, communities are often stable. Stability is achieved when an ecosystem is in equilibrium, when none of the populations exceeds the carrying capacity of the ecosystem. The **carrying capacity** is the maximum number of individuals of a species that can be supported at the time by an ecosystem. The carrying capacity for any species is determined by the availability of resources, such as food and water.

carrying capacity the maximum number of individuals of a species that can be supported by an ecosystem

A population can exceed the carrying capacity of the ecosystem, but not for long. Consider the field mouse again. Imagine that the population of predators is lower than usual. Suddenly, the mouse population can grow. However, the extra mice will eat all the available food. Hungry rodents soon become sickly—making them easy prey for the hawks, owls, and foxes that are present. The mouse population will decline again, to or below the carrying capacity. Ecosystems soon re-establish equilibrium.

DID YOU KNOW?

Acting Like Lemmings?

The "lemming mass suicides" you may have seen or read about don't really happen. When Arctic lemming populations grow larger than the local carrying capacity, many of the lemmings migrate to neighbouring territories. They always try to arrive alive when they migrate.

Limits of Tolerance

You have seen that the survival and reproduction of an organism depend on the presence of nutrients and the ability of the organism to withstand the abiotic factors in the environment. Our understanding of this fact has developed over many years.

In the mid-1800s, Justus von Liebig noted that certain substances must be present if plants are to grow. If any one of these substances is present in low amounts, the growth of the plant is reduced, regardless of the quantity of other substances that are present. This observation became known as the **law of the minimum**: the nutrient in least supply is the one that limits growth.

law of the minimum states that the nutrient in the least supply is the one that limits growth

In 1913, Victor Shelford added to von Liebig's work by noting that too much of a factor can harm an organism. This principle is often called Shelford's **law of tolerance**: an organism can survive within (tolerate) a certain range of an abiotic factor; above and below the range it cannot survive. The greater this range of tolerance, the greater the organism's ability to survive.

law of tolerance states that an organism can survive within a particular range of an abiotic factor

As seen in **Figure 3**, the maximum population size is possible when the abiotic factor is at an optimum level within the range of tolerance. However, many abiotic factors act on a species at any given time. Most species have a broad range of tolerance for some factors, and a narrow range for others.

EXTENSION

Competitive Exclusion and Resource Partitioning
Listen to a discussion of competitive exclusion, resource partitioning, and Shelford's Law of Tolerance.

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Change in Population of a Fish Species with Water Temperature

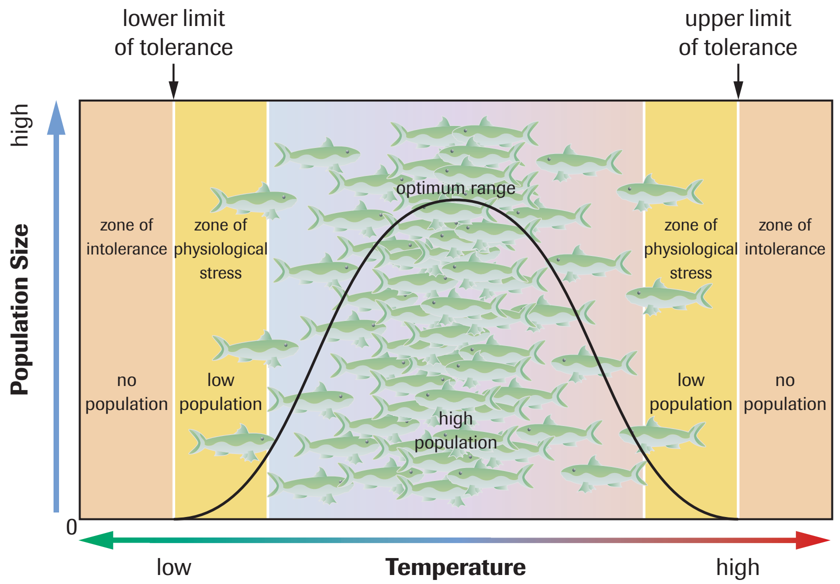

Figure 3
The population of a fish species is likely to increase as the water temperature gets closer to the optimum. None of the fish can survive if the water gets too hot or too cold.

Density-Independent and Density-Dependent Factors

The number of organisms in an ecosystem is important when considering the effects of some abiotic and biotic factors. A population is said to be dense when there is a large number of organisms in a small area.

Density-independent factors affect members of a population regardless of population density. Fire and flood are two naturally occurring events that are density-independent. They will affect a population regardless of its size.

density-independent factor a factor in an ecosystem that affects members of a population regardless of population density

density-dependent factor a factor in an ecosystem that affects members of a population because of the population density

When the density of a population increases, other factors may limit further growth or reduce population numbers. **Density-dependent factors** affect a population *because* of the density of the population. Food supply, water quality, sunlight, disease, and territory are density-dependent factors. For example, when a tree in a dense forest becomes infected with a fungal blight, the infection will spread more quickly than it would in a forest where trees are separated by larger distances.

Similarly, individuals in more densely populated areas are more prone to starvation, as food is in lower supply. Competition for food may leave animals weak and more susceptible to predation. The density-dependent factors listed in **Table 2**, on the next page, will cause higher mortality rates, lowering the population density. When the population density is reduced, the effects of the density-dependent factors are also reduced.

Table 2 Factors That Cause Changes in Populations

Density-independent factors	Density-dependent factors
• flood	• food shortage
• fire	• competition for mates, breeding areas (habitat)
• spraying with pesticides	• disease caused by a microorganism or parasite
• change in climate or temperature	• introduction of an exotic species
• destruction of habitat	• increased predation
• drought	• competition for water and other resources

SUMMARY Limits on Populations and Communities

- Biotic potential is the maximum number of offspring that a population could produce if its resources were unlimited. It is determined by birth potential, capacity for survival, breeding frequency, and length of reproductive life.
- Carrying capacity is the maximum number of individuals in a population that can be supported at the time by an ecosystem.
- Populations that temporarily exceed their carrying capacity reduce their biotic resources.
- The law of the minimum states that the factor in lowest supply is the one that limits population growth. The law of tolerance describes the minimum and maximum limits for essential factors that control the population size.
- Density-independent factors affect members of a population regardless of population density. Fire and flood are density-independent.
- Density-dependent factors affect a population because of the actual density of the population. Food supply and territory are density-dependent factors.

CAREER CONNECTION

Fish and Wildlife Officer

Wildlife management and hunting have a long association. Concerned that the populations of game species were declining, hunters lobbied governments to regulate hunting. Each year, some game animal populations produce more offspring than can survive. Populations that exceed their carrying capacity are susceptible to disease and starvation. How does game regulation assist farmers and ranchers? What role does the Fish and Wildlife division of Alberta Environment play in game regulation?

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Section 4.4 Questions

1. Four factors regulate population growth. Using an example of a nonhuman population, explain how each factor would affect the population size.
2. Cedar waxwings are one of the few birds that can withstand the cold and lack of available food during our winters. To ease the strains of winter, bird watchers in Lethbridge provide cedar waxwings with seeds during winter months.
   (a) Would the seeds alter the carrying capacity of the ecosystem? Explain.
   (b) Provide a hypothesis that explains why bird watchers have noted an increase in the falcon population in recent years.
3. A scientist studying wolves near Canmore notices a steady decline in the population of wolves for four consecutive years.
   (a) Make a prediction about how the population of wolves will affect the population of moose. Give your reasons.
   (b) Assuming that humans are not the cause of the wolf population decline, would it be reasonable to conclude that the wolf population will continue to decline until there are no more wolves left in the area? Give your reasons.
   (c) What might cause the wolf population to begin increasing again?
   (d) Using a flow chart, explain how changes in the wolf population would affect the plant community surrounding Canmore.

4. (a) Create a table like **Table 3** and classify the following information within it.
   - Larger mammals generally live longer than smaller ones.
   - Pregnant female elephants carry their young for nearly 18 months.
   - Elephants reach sexual maturity at 15 years.
   - Elephants usually produce one offspring each birth.
   - Most elephants wait more than 5 years between births.
   - Female elephants care for their young for more than 10 years.
   - Mice often produce litters of 6 or more.
   - After about 6 weeks, mice reach sexual maturity.
   - In a natural setting few mice are older than 2 years.
   - A pregnant female mouse will carry her young for 22 days.
   - Mice will breed every 6 weeks or less.

   (b) Refer to your table and write a paragraph comparing the biotic potentials of elephants and mice.

Table 3 Biotic Potential of Elephants and Mice

Biotic potential	Elephant	Mouse
birth potential		
capacity for survival		
breeding frequency		
maturity		

5. A researcher conducts a study to find a possible biological control for pine bark beetles, an insect considered a pest by the forestry industry. The researcher sets up four different studies of predators and the pine bark beetle. The populations of prey and predator are monitored over many different generations. The graphs in **Figure 4** show changes in populations over time.

   (a) Which species is most likely the best controlling agent? Give your reasons.

   (b) Sometimes the eggs of a predator are eaten by its prey. Which predator might serve as a food source for its prey? Give your reasons.

   (c) Why is the population of predator A consistently lower than that of the pine bark beetle?

   (d) Predict what would happen to the population of pine bark beetles if predator species C exceeds the carrying capacity of the environment after year 9.

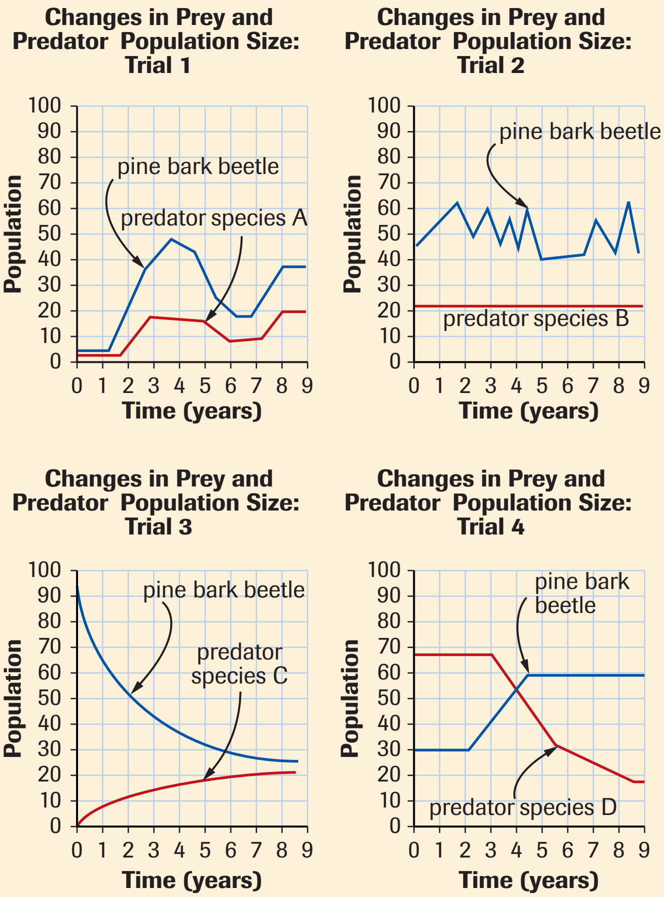

Figure 4
Changes in populations over time of pine bark beetles and four different potential control species

Changes in Ecosystems 4.5

Changes in terrestrial and aquatic ecosystems happen naturally, over time, as biotic and abiotic factors gradually shift. In addition, natural events such as floods and fires can cause sudden, dramatic changes. However, one of the most common sources of change for ecosystems is human activity. In this section, you will examine some natural and human-caused changes in terrestrial and aquatic ecosystems.

Changes in Terrestrial Ecosystems

Prior to the Industrial Revolution, there were approximately 6 billion hectares of forest on Earth. Today, an estimated 4 billion hectares remain. Approximately 33 % of Earth's forests have been cleared to make way for agricultural land or urban areas (**Figure 1**).

Figure 1
In Canada, more than 60 % of the virgin forest has been lost to logging since European settlers arrived.

Forests are important resources. They affect climate by recycling water and carbon dioxide. On a hot day, a large tree may absorb 5.5 T of water from the soil and release it into the atmosphere. Forests also affect the physical environment of ecosystems by acting as a giant sponge—controlling water runoff, holding groundwater, and preventing soil erosion. They act as shelters for wildlife, providing nesting sites and food for many different animals. According to one estimate, a typical tree provides $196 250 in long-term ecological value, compared with about $590 as timber.

Forestry Practices

In Canada, deforestation is one of the most controversial ways in which humans change ecosystems. Deforestation falls under three categories. **Slash-and-burn** is most commonly used in tropical areas to clear forests for agriculture. Bulldozers are often used to remove all existing vegetation. The debris is piled and ignited in a controlled burn to

slash-and-burn the complete clearing of a forest by felling and burning the trees

clear-cutting the removal of all trees in an area

selective cutting the harvesting of only certain trees from an area

provide soil nutrients for future crops. **Clear-cutting** involves the removal of all trees in an area for use in timber or pulp. In Canada, this practice is followed by replanting the dominant species. **Table 1** lists some effects of clear-cutting. In **selective cutting**, only certain trees are harvested from an area, leaving the others to regenerate the area.

Table 1 Effects of Clear-Cutting

Positive effects	Negative effects
• Clear-cutting is less expensive than selective cutting. This provides timber or pulp at more competitive prices. • If a site is teeming with pests, clear-cutting can eliminate the hazard without infecting surrounding areas. • Clear-cutting permits the replacement of less valuable trees with ones that are more valuable. • Some wildlife, such as moose, benefit from clear-cuts. Low vegetation, such as fruit-bearing shrubs, provide a stable food source.	• Soil erosion and runoff into the streams increase. • Nitrates and other nutrients are carried into streams and ponds, increasing algal growth. • Sediment is carried into streams, affecting fish spawning areas. • The removal of vegetation on the ground exposes dark soils and increases the warming of the area. In turn, this increases water loss from the soils. • Replanting with a monoculture decreases biodiversity in the ecosystem. • Some wildlife, such as owls, are negatively affected by clear-cuts. Nesting sites are destroyed in mature forest areas.

CAREER CONNECTION

Wildland Firefighter

A unique combination of training and mentoring equips wildland firefighters to deal safely and effectively with the dangers associated with wildfires in remote locations. Some firefighters are given specialized training, for example Helitack (helicopter attack) crews.

Alberta Environment has a specific program that handles the recruitment and training of these people. Explore the career of a wildland firefighter. How well are these jobs being filled in Canada?

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Used for pulp and paper, softwoods such as spruce and fir are often considered more valuable than hardwoods, which grow much more slowly. Two or three years after clear-cutting, herbicides are used to prevent the more valuable softwood trees from being crowded by hardwood trees (**Figure 2**). At about 10 years, the underbrush is removed. At about 35 years, the trees are checked for diseases and pests, such as the spruce bud-worm. Monocultures are much more susceptible to disease than natural forests are. After about 80 to 90 years, the softwood trees are large enough to harvest.

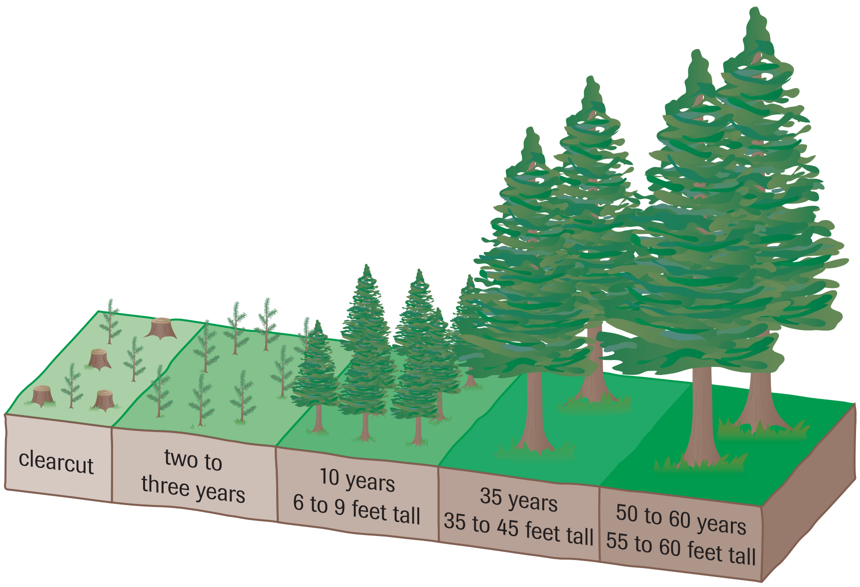

Figure 2
Forest succession after clear-cutting

The Effects of Fire

Fire is an important and often helpful cause of change in ecosystems. Elk Island National Park provides a good example of the important role fire has in ecosystems. This beautiful area in the Beaver Hills, designated as a National Park in 1906, is home to herds of free-roaming plains bison, wood bison, moose, deer, elk, and more than 250 species of birds. Located less than an hour east of Edmonton, this natural aspen parkland is one of the most endangered habitats in Canada.

Fires have occurred in the Beaver Hills for thousands of years. Fire creates and maintains a mosaic of different vegetation types, such as grassland, wetland, shrub area, and aspen parkland. Lightning causes some fires. In the past, Sarcee and Plains Cree intentionally set fires to discourage the expansion of forests and maintain a food supply for large animals like bison. More recently, settlers set fires to clear land and burn stubble.

Traditionally, all fires within the boundaries of all national parks have been suppressed. Therefore, since 1906, no fires were deliberately set in Elk Island and any wildfires were extinguished as quickly as possible. During the 1970s, however, Parks Canada realized that the absence of natural fires was upsetting the ecological integrity of the area. Park managers recognized the need for prescribed burns to maintain and enhance the Elk Island ecosystem. **Prescribed burns** are fires set intentionally in defined areas of the park (**Figure 3**). The fires are carefully controlled. Many park workers are involved and the fire is carefully put out after the prescribed area is burned.

Figure 3
A prescribed burn

prescribed burn a controlled fire set intentionally in a designated area

Practice

1. Why are forests important?
2. What are three methods used for deforestation?
3. What problems could be created by clear-cutting an old-growth forest?

Changes in Lake Ecosystems

Like terrestrial ecosystems, aquatic ecosystems are sustained by the dynamic equilibrium among biotic and abiotic factors. When one or more of these factors changes, it can have profound effects on the ecosystem as a whole.

There are two kinds of lake. **Oligotrophic** lakes are typically deep and cold. Nutrient levels are low in such lakes, limiting the size of producer populations. Because there are limited numbers of only a few kinds of organisms, the water is usually very clear. **Eutrophic** lakes are generally shallow and warmer, and have an excellent supply of nutrients. Many species of photosynthetic organisms find these abiotic conditions very favourable. As a result, the water of eutrophic lakes is often murky.

oligotrophic having low nutrient levels

eutrophic having high nutrient levels

In general, oligotrophic lakes gradually become eutrophic over time. Eutrophic lakes become increasingly shallow, eventually filling in and becoming dry land. This evolution from oligotrophic, to eutrophic, to land is called eutrophication and may take hundreds or even thousands of years. **Figure 4**, on the next page, shows the eutrophication of a lake.

Water Pollution

Humans sometimes accelerate eutrophication by adding to lakes nutrient-rich substances such as human wastes, fertilizers in the runoff from agricultural land, other household and industrial products, and thermal energy (raising the temperature).

Water pollution is any physical or chemical change in surface water or groundwater that can harm living things. Biological, chemical, and physical forms of water pollution can be grouped into five categories:

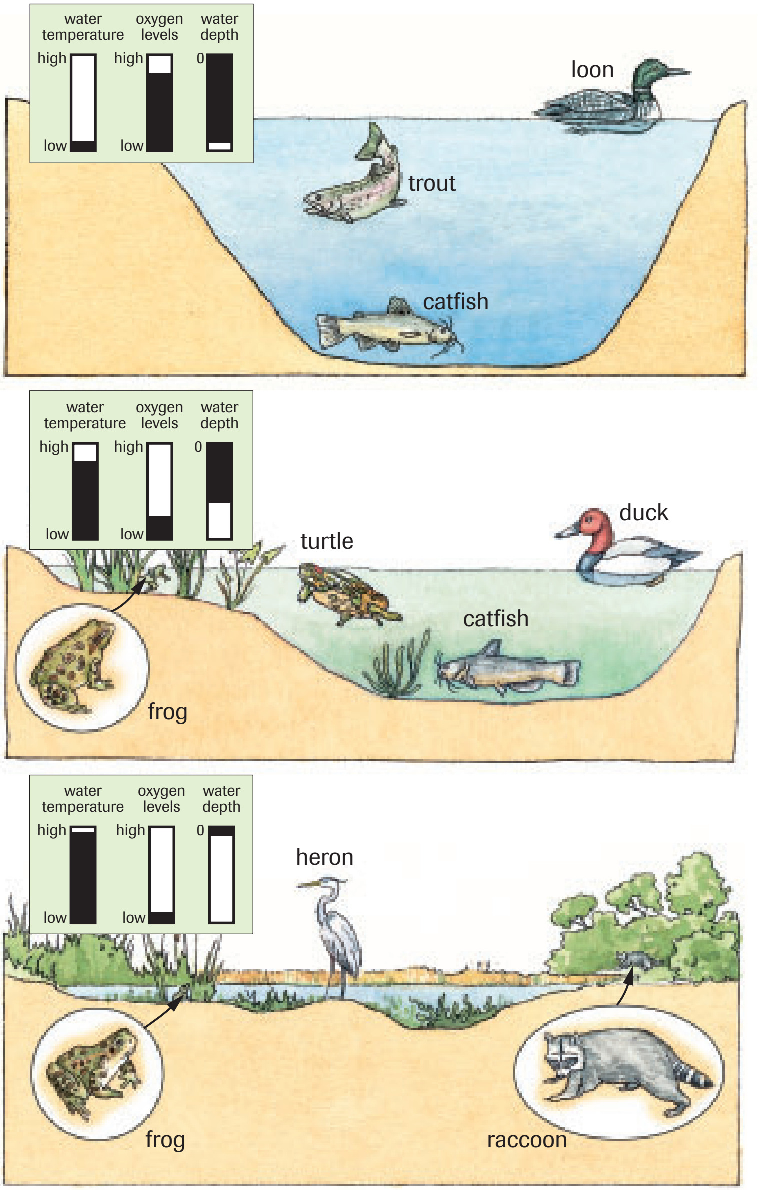

Figure 4 The eutrophication of a lake, as seen through changes in the community (summer conditions)

(a) An oligotrophic lake. Deeper lakes tend to be cooler. Cold water can hold more dissolved gases (including oxygen) than warm water.

(b) Soil sediment and organic material falling to the bottom of the lake gradually make the lake shallower. As it becomes shallower, its profundal zone slowly disappears, until eventually sunlight can reach the lakebed. Lake temperatures rise and oxygen levels drop. Organisms that require higher levels of oxygen begin to disappear.

(c) The lake continues to become shallower and warmer. Plants can grow at all levels, and the warmth encourages the growth of plankton. When the plants die, decomposers return their nutrients to the lake, using oxygen in the process. Later in the eutrophication process, the lake will become a marsh and then dry land.

- *Organic solid waste* includes sewage and waste from food processing. As this matter is decomposed by bacteria, oxygen in the water is used up.
- *Disease-causing organisms* come from sewage and animal wastes that enter aquatic ecosystems with runoff. These organisms can trigger an outbreak of a waterborne disease such as typhoid.
- *Inorganic solids and dissolved minerals* include waste from mining, fertilizers, and salts from road runoff in winter.
- *Thermal energy* comes from electricity generating plants and other industries. Heating the water in aquatic ecosystems decreases the solubility of oxygen in the water.
- *Organic compounds* include oil from roads, pesticides, and detergents (organophosphates). Road oil is toxic to fish and waterfowl. Pesticides are toxic to various organisms, and accumulate through the food chain. Phosphates promote algae growth, resulting in a loss of oxygen during decomposition.

Indicators of Water Quality

When studying water pollution, researchers classify the quality of the water according to its intended use. For example, water too polluted to drink is often considered acceptable for industrial processes or watering lawns. There are three main indicators of water quality: bacteria count, the concentration of dissolved oxygen, and the biological oxygen demand (BOD).

Bacteria

The detection of disease-causing bacteria is both difficult and expensive. However, there is an indirect way to discover if these bacteria are present in water. Detecting **coliform bacteria**, a type of bacteria that occurs naturally in the intestines of humans and many other animals, is fairly easy (**Figure 5**). The presence of coliform bacteria indicates that animal wastes are polluting the water. Since many of the dangerous disease-causing bacteria are transmitted in wastes, the presence of coliform bacteria indicates that more dangerous bacteria may also be present. Some lakeside beaches are frequently closed to swimming in summer because of high counts of coliform bacteria.

coliform bacteria a type of bacteria that occurs naturally in the intestines of humans and other animals, and indicates the presence of fecal contamination in water

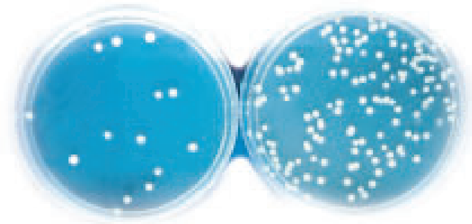

Figure 5
Agar nutrient medium, which contains minerals and a source of energy, is used to grow bacteria. Each bacterium in a water sample divides into many cells, forming colonies that can be seen on the agar plate. The greater the number of colonies, the more polluted the water sample is. Drinking water must produce no colonies of coliform bacteria per 100 mL. In contrast, swimming pools are permitted 200 colonies per 100 mL.

Dissolved Oxygen

A second indicator of water quality is dissolved oxygen. Several different solutions can be used to test for oxygen. The solutions change colour when they react with oxygen dissolved in a water sample. Lakes that are cooler and have fewer pollutants have levels of dissolved oxygen of between 8 and 14 mg/L. As dissolved oxygen begins to drop, fewer organisms can be supported.

Another way to determine dissolved oxygen levels is to examine the living things found in the water. Healthy trout indicate a high oxygen level; carp and catfish indicate a low level. A complete absence of fish may indicate that oxygen levels are very low, but it is also possible that there are toxins in the water that kill fish.

DID YOU KNOW?

River Rivals

The word *rival* comes from the Latin word *rivus* (stream). The first rivals were people who lived along the same stream—and competed for the same water.

INVESTIGATION 4.3 *Introduction*

Biological Oxygen Demand and Organic Pollutants

Thermal energy and nutrients can deplete the levels of dissolved oxygen in aquatic systems, and this can have dramatic effects on the community of organisms in an aquatic ecosystem. In this investigation, you will determine the biological oxygen demand (BOD) of an artificial aquatic ecosystem and observe how changes in thermal energy and nutrient levels affect BOD.

Report Checklist

- ○ Purpose
- ● Problem
- ● Hypothesis
- ● Prediction
- ● Design
- ○ Materials
- ○ Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ○ Synthesis

To perform this investigation, turn to page 126.

biological oxygen demand (BOD) the amount of dissolved oxygen needed by decomposers to completely break down the organic matter in a water sample at 20 °C over five days

Biological Oxygen Demand

To narrow down the causes of low dissolved oxygen levels, it is possible to test the **biological oxygen demand (BOD)**. The BOD is a measure of the amount of dissolved oxygen needed by decomposers (bacteria) to break down the organic matter in a sample of water over a five-day period at 20 °C. The BOD indicates the amount of available organic matter in a water sample. As the number of organisms in an ecosystem increases, so does the biological oxygen demand. A cold, less productive lake with fewer organisms might have a BOD near 2 mg of oxygen per litre, while a more productive lake with many living things might have a BOD as high as 20 mg/L.

It is important to note that, as the number of organisms increases and biological oxygen demand increases, more organisms use oxygen from the water. This causes the level of dissolved oxygen to decrease.

Too many nutrients can create problems for a lake. Consider the problems when cities release sewage into aquatic ecosystems without treatment. (Montreal releases untreated solid wastes into the St. Lawrence River. Victoria, St. John's, and Halifax release wastes into their harbours.) The greater the amount of decaying matter introduced into the water, the greater will be the population of decomposing bacteria. Unfortunately, both bacteria and fish use oxygen. While some species of fish have greater oxygen requirements than others, all fish eventually die if oxygen levels drop too low. Moreover, the death of fish adds detritus to the ecosystem. That detritus further promotes growth of the bacterial population. In turn, this causes oxygen levels to drop even more. To make matters even worse, human wastes act much like fertilizers by introducing nitrogen and phosphates into the ecosystem. The added nutrients promote the growth of plants and algae, which will eventually die and be decomposed. Each time organic matter is returned or added to an aquatic ecosystem, oxygen levels are further reduced.

CAREER CONNECTION

Environmental Education Specialist

Environmental education specialists encourage others to make responsible decisions about our environment by designing and delivering educational programs. They may be employed as guides and naturalists by both public and private sector organizations.

Do your personal characteristics match those of an environmental education specialist?

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INVESTIGATION 4.4 *Introduction*

Biological Indicators of Pollution in Streams

Ecologists use "indicator species" to determine the health of a stream. In this activity, you will collect organisms from a stream to provide indirect evidence of pollution.

Report Checklist

○ Purpose	○ Design	● Analysis
○ Problem	○ Materials	● Evaluation
○ Hypothesis	● Procedure	○ Synthesis
● Prediction	● Evidence	

To perform this investigation, turn to page 127.

Practice

4. List types of pollution that cause reduced levels of dissolved oxygen in aquatic ecosystems. For each type of pollution, explain in your own words how dissolved oxygen is affected.
5. Which would show a higher biological oxygen demand: a sample of water from a cold lake or a sample of water from a warm lake? Explain your answer.
6. Describe two ways in which phosphates can get into surface water.

Figure 6
Muriel Lake

Changes in Alberta Lakes

Cottage owners throughout Alberta have become aware that some shorelines are receding at an alarming rate. One of Alberta's receding lakes is Muriel Lake (**Figure 6**), located just south of Bonnyville in north-central Alberta. The water level has dropped more than 3 m between 1975 and 2005 (**Figure 7**, next page). At the same time, the salt content

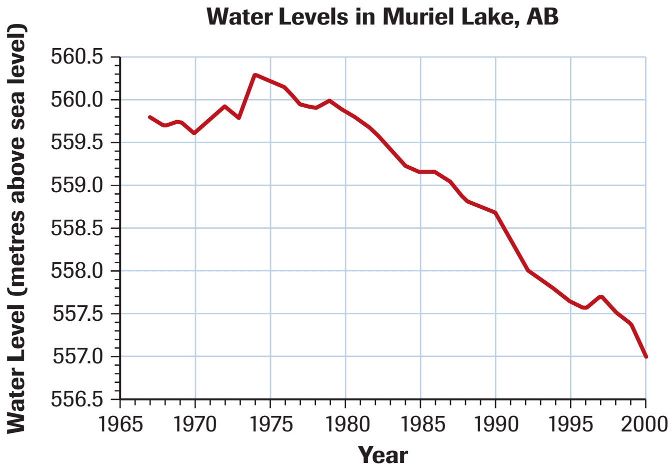

Figure 7
Muriel Lake's water level has steadily declined.

("salinity") has increased and the lake is now classified as slightly saline. As the concentration of dissolved solids has increased, oxygen levels have fallen.

The area of land that drains toward a lake is called the lake's **watershed**. Over time, a waterfront environment develops a natural balance among biotic and abiotic factors along the shoreline. This delicate equilibrium can easily be disrupted. Cottage dwellers have altered shorelines in many ways. Making a sandy beach increases erosion, while planting lawns increases nitrogen and phosphate runoff from fertilizers.

watershed the land that drains toward a lake or other body of water

Even removing shoreline plants profoundly affects the aquatic environment. These plants act as a filtering system by slowing the movement of potentially harmful chemicals from the land into the lake. Soil bacteria have more time to break down these chemicals, and the roots of many aquatic plants absorb them. In addition, shoreline plants provide shade, which keeps the water cooler, allowing it to hold more oxygen gas. Because shorelines are so vital to the existence of a lake, they remain crown land around most lakes. In Alberta, you need a permit to build a pier on a shore bed or alter the shoreline for most lakes.

One of the most serious problems presented by cottages is caused by sewage from outhouses seeping into lakes. The high levels of nutrients that are released cause eutrophication of the lake and declining dissolved oxygen levels (**Figure 8**).

DID YOU KNOW?

Water and Farmland

Human activities have caused soil to deteriorate and deserts to expand. Globally, about 21 million hectares of farmland are lost every year. According to Bill Rees, a resource ecologist at the University of British Columbia, we produced 14 % less grain per capita in 1990 than we did in 1984.

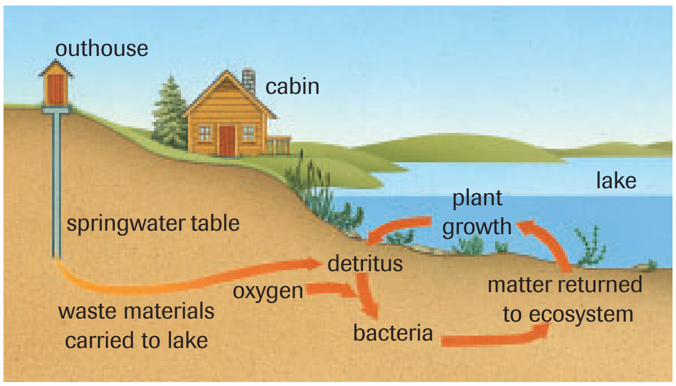

Figure 8
Human wastes are broken down by bacteria, which function as decomposers in the lake's ecosystem.

Increased erosion and the accelerated flow of nutrients into lakes speed the aging process of lakes. Enhanced plant growth along the shoreline can produce dense mats of organic matter that decompose during hot summer days. The decomposing plants release distinctive odours and change the taste of the water.

DID YOU KNOW?

Alberta's Fish Populations

Alberta has very few fish-bearing lakes (800) compared with lakes in many other provinces. Only 2.5 % of the province is covered by water. By comparison, Ontario has 250 000 fish-bearing lakes, while Saskatchewan has 94 000.

Changes in Alberta's lakes have also been linked to climate change. Higher temperatures increase evaporation rates but do not increase precipitation. This lowers water levels and raises lake temperatures, creating problems for coldwater fish. Trout, for example, lose parts of their habitat and are replaced by fish such as perch, which can withstand warmer temperatures. As the global temperature increases, droughts will become more frequent and river and stream flows will slow down. As a result, the movement of water into and out of lakes will decrease. Minerals in lakes will have time to settle, and the concentration of sodium and chloride ions in lakes will increase. Nitrogen and phosphorus concentrations will also increase.

Practice

7. Indicate some factors that would cause a dramatic change in the shoreline of a lake.
8. How could the removal of plants from along the shoreline have a negative impact upon a lake?
9. Drilling companies pump water into oil wells to increase oil extraction. Because the oil is less dense than fresh water, the oil is pushed closer to the surface, making extraction less expensive. Indicate both positive and potentially negative impacts of this practice.
10. Alberta's lakes are a valuable recreational resource. Should the number of cottages built along the shoreline be restricted?

WWW WEB Activity

Web Quest—Whose Lake Is It?

Alberta's natural resources are highly valued by many different stakeholders. Have you ever thought about all of the different ways that people see resources such as lakes and rivers? This Web Quest explores issues surrounding Sylvan Lake. You will research how one lake can be so many different things to so many different people. You will then take a stand and participate in a town hall meeting concerning Sylvan Lake.

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EXPLORE an issue

Selling Water

Issue Checklist

- ● Issue
- ● Resolution
- ○ Design
- ● Evidence
- ● Analysis
- ● Evaluation

Have you ever thought of water as money? In many respects it may become our most precious natural resource. Water is essential to human life, both for drinking and in the production of our food. In 1960, the world's human population was only 3 billion. Today, it is over 6 billion. By 2030 it will increase to 8 billion and by 2200 to 10 billion. The world faces major food shortages, as more than 800 million people remain hungry around the world. Food production must be increased.

One technological solution involves diverting fresh water from remote northern lakes and rivers to the parched farmlands and cities of the south. The Republic of Uzbekistan was the first to employ giant engineering schemes that changed the pathways of rivers and created new lakes. With 75 % of its population living in the southwest but more than 80 % of its rivers draining into less populated regions of the Arctic, a plan was devised to distribute water to greater advantage. Irrigation systems supported by the diverted water sources changed millions of hectares of marginal land into farms. Unfortunately, the increase in productive land has not been without problems. For example, two large rivers were diverted away from the Aral Sea, once the world's fourth largest body of inland water. Deprived of this water, the Aral Sea has shrunk dramatically. Experts predict it will disappear altogether by 2010. The last fish was caught in 1983.

To make matters worse, the irrigation techniques have gradually made the soil salty. More than 26 000 km^2 are no longer arable. Crop production increased dramatically after the irrigation systems were built, but since then it has has fallen sharply.

Two similar projects have been proposed for North America. The GRAND project would dam James Bay, slowly converting it into a large freshwater lake. The water would be diverted southward to the Great Lakes where it could be exported south of the border. The second proposal, referred to as NAWAPA, is even more grandiose. The scheme would divert water from the Mackenzie River basin southward, flooding a trench along the Rocky Mountains. The huge freshwater canal would carry water to the vegetable farmers and vine growers of California. **Figure 9** outlines the two proposed projects.

Figure 9
Several huge projects have been proposed to divert water southward.

The Benefits

Opinion of a taxpayer and concerned citizen: Fresh water could be diverted to the rich farmlands of the Midwest and the expanding cities of the United States. This would provide Canada with many economic benefits. We sell other resources such as oil and coal, so why not water?

Opinion of California vegetable grower: Canada and the United States are part of a free-trade agreement that is designed to benefit both countries. Resources must be looked at beyond that of boundaries. Having water carry fish to the Arctic will not help feed people. Water must be diverted to where it can do the most good.

The Risks

Wildlife biologist: Projects like GRAND will have a major impact on wildlife. Many species of marine organisms will be destroyed. In addition, the channel between the new lake and the Great Lakes will serve as a highway for many new predators and parasites. This could change the food chain in the Great Lakes and cause the destruction of certain fish stocks.

Climatologist: Water from southern rivers warms the Arctic Ocean. Diverting these waters southward would change Canada's climate. Removal of this important heat source would mean longer winters and shorter growing seasons in the north. There is no telling what the impact would be.

1. How would irrigation of farmlands benefit consumers?
2. Why have water diversion projects been proposed?
3. What are the two main proposals for diverting water?
4. Should large-scale irrigation projects be initiated?
5. Should Canada consider selling water?

SUMMARY Changes in Ecosystems

- Forests affect climate by recycling water (by transpiration) and carbon dioxide and help to control water runoff, hold groundwater, and prevent soil erosion. Old-growth forests contain many fallen trees that slowly decompose, providing a constant source of nutrients for the soil.
- Three methods of deforestation are slash and burn, clear-cutting, and selective cutting. Each has positive and negative environmental effects.
- Fires help maintain and rejuvenate forest and grassland ecosystems.
- Oligotrophic lakes are usually cold and have low nutrient levels. Eutrophic lakes tend to be warmer and have higher nutrient levels. Oligotrophic lakes often become eutrophic as they age and warm.
- Five categories of water pollution are organic solid waste, disease-causing organisms, inorganic solids wastes and dissolved minerals, thermal energy, and organic chemicals.

- High bacteria counts and falling oxygen levels indicate water pollution.
- Biological oxygen demand (BOD) is a measure of the amount of dissolved oxygen needed by decomposers to break down the organic matter in a sample of water over a five-day period at 20 °C. As the amount of organic matter increases, so does the BOD.

Section 4.5 Questions

1. Perform a risk–benefit analysis report for clear-cutting.
2. In British Columbia alone, more than twice as many trees are harvested than from all U.S. national forests. During a protest staged against the clear-cutting of an old-growth forest in the Clayoquot Sound area on Vancouver Island, environmentalists blocked a logging road. Do you believe that such protests are justified? Give your reasons.
3. By law, national parks in Canada are areas that are protected for public understanding, appreciation, and enjoyment.
   (a) Identify specific regulations that pertain to national parks.
   (b) Discuss why these regulations need to be in place.
   (c) Propose a regulation that you think would protect national parks even more than they are protected today.
   (d) Make a list of things that you need to take into consideration when you go to a national park.

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4. Use **Figure 4**, on page 116, to answer the following questions.
   (a) What happens to the depth of a lake over time?
   (b) Explain how the mean water temperature is related to the depth of the lake.
   (c) How would a change in lake temperature affect the types and numbers of plants found in the area?
   (d) Describe the changes in the species and populations of fish you would expect to find in a lake that progresses through the three stages of eutrophication.
   (e) Explain why turtles might be found in the second stage but not the first.
5. After complaints were received from fishers on a river (**Figure 10**), the data in **Figure 11** were collected from three sites.
   (a) What is the source of nitrates and phosphates?
   (b) In which area of the river would you find the highest level of eutrophication? Explain your answer.
   (c) Why does the BOD increase from site A to site B?
   (d) Why does the BOD decrease from site B to site C?
   (e) Sewage treatment plants are supposed to remove organic waste. Is the plant doing a good job?
6. Design and conduct an investigation to determine how water temperature affects algal growth. Based on your results, how would you expect surface thermal pollution to affect dissolved oxygen levels in the epilimnion and hypolimnion of a lake? Draw diagrams illustrating your hypothesis.

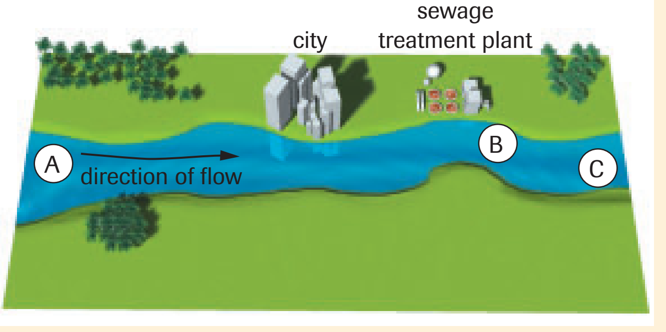


Figure 10
A polluted river with test sites

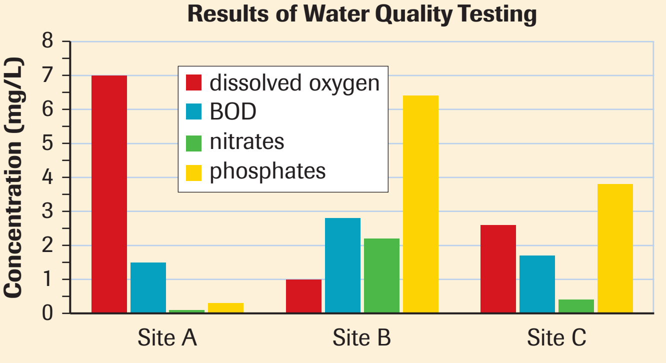


Figure 11

7. (a) Identify aquatic systems in your own area that you would expect to contain high levels of phosphates. Explain your prediction.
   (b) Take water samples from the identified systems and test for phosphates. Evaluate your prediction.
8. Small communities often discharge sewage into fields. Bacteria break down the organic wastes, releasing nutrients such as phosphates and nitrogen. Plants growing in the fields absorb the nutrients.
   (a) What advice would you give a small community investigating this approach to waste treatment?
   (b) Identify potential problems if the field is located in a valley that floods every spring.

INVESTIGATION 4.1

A Schoolyard Ecosystem

Report Checklist

○ Purpose	○ Design	● Analysis
○ Problem	○ Materials	● Evaluation
○ Hypothesis	○ Procedure	● Synthesis
● Prediction	● Evidence	

To gain a better understanding of the impact of environmental change on living things within ecosystems, you do not have to go far. You can begin by investigating your schoolyard, and how living things there respond to local biotic and abiotic factors. A weed is classified as any plant the human caretaker does not want. Location can affect the distribution of common weeds.

Problem

To determine how abiotic factors affect the distribution of plants commonly considered weeds

Prediction

Abiotic factors play an important role in determining which plants can succeed in a given area. In this investigation you will study sites on the north and south sides of your school building.

(a) Predict which site will contain the most weeds. Explain your prediction.

Materials

string	protractor
8 craft sticks	metre stick or measuring tape
tape	plastic bottle cap
table-tennis ball	light meter
field guides for common weeds	thermometer
	thread

Procedure

1. Set up equal study sites on the north and south sides of the school. Using string and 4 sticks mark off each study site as shown in **Figure 1**. Make sure you push the sticks completely into the ground. Calculate and record the area of each study site.

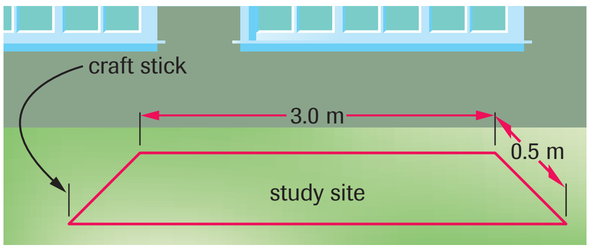


Figure 1

2. Toss a plastic bottle cap into a study site. Using the light meter, determine the amount of light reaching the soil next to the bottle cap. Repeat the procedure at least twice more. Record your observations in a table similar to **Table 1**.

Table 1 Light Readings

Measurement	North study site (lux)	South study site (lux)
1		
2		
3		
mean		

(b) Why was the bottle cap tossed before light readings were taken?

3. Repeat the light measurements in the second study area. Calculate the mean for each set of measurements.
4. Using a thermometer, measure the soil surface temperature in the north and south study sites. Throw the bottle cap, as in step 5, to choose measurement locations. Record your observations in a table.
5. Construct an anemometer (a device to measure wind speed), as shown in **Figure 2**.

Figure 2
An anemometer

6. Make sure you are not blocking the wind. Point the thin edge of the anemometer into the wind. To measure wind speed, record how many degrees from vertical the thread is at the edge of the protractor. Take three readings in each study site and record them in a table. Record the time of day.
7. Using the conversion scale in **Table 2**, convert the degree readings to wind speeds.

Table 2 Conversion from Degrees to Wind Speed

Angle (°)	90	85	80	75	70	65	60
Wind speed (km/h)	0	9	13	16	19	21	24
Angle (°)	55	50	45	40	35	30	25
Wind speed (km/h)	26	29	32	35	38	42	46

8. Survey each study site by counting and recording the number and type of weeds in each site. Use the field guide to identify and name the species.
9. Within each of the study sites, record the coverage by each type of weed. Use a measuring tape or a metre stick to measure the diameter of each of the larger weeds in the study area.
10. Calculate the area covered by each weed using the formula

$$\text{area} = \frac{\pi d^2}{4}$$

For small weeds such as wild oats, you can measure the entire area covered by a grouping of weeds rather than the area covered by each individual plant.

Analysis and Evaluation

(c) Calculate the density of each kind of weed in the north and south study sites using the following formula:

$$\text{density} = \frac{\text{number of weeds}}{\text{area of the study side}}$$

(d) Determine the total number of weeds in each study site. Calculate the area covered by weeds in each study site.

(e) Comment on the accuracy of each instrument you used to take measurements. In each case, did the accuracy affect the reliability of your data? Explain.

(f) Was your prediction correct? Explain why or why not, based on your observations.

(g) Which abiotic factor do you think is most important for the growth of dandelions? Use your observations to create a hypothesis, and design an experiment that would allow you to test your hypothesis.

Synthesis

(h) You may have noticed that there are more weeds close to a building than in the open field. How would wind help explain that difference?

(i) How would the light meter help explain differences in weed distribution between the two study areas? Based on this investigation, could you tell if light or soil temperature is more important?

(j) Explain why unfavourable growing conditions for grass could increase the number of weeds in a study area.

(k) In which of the two study sites would you expect to find a larger animal population? Explain your answer.

(l) How do humans affect the distribution of weeds in your study areas?

(m) Examine a map of a new housing development. Provide some reasons that help explain the difference in selling price between two lots that are the same size but on different sides of the street.

(n) One biotic factor that affects distribution of plants is competition between plants. Design an experiment that would determine how competition from other plants affects the area covered by dandelions.

(o) You made several measurements and calculations in this investigation, including the density of each type of weed. Why would it be important for an ecologist to calculate the density of plants in an ecosystem?

INVESTIGATION 4.2

Report Checklist

- ● Purpose
- ○ Problem
- ○ Hypothesis
- ○ Prediction
- ○ Design
- ○ Materials
- ○ Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ● Synthesis

A Forest Ecosystem

Soil quality, air temperature, and amount of sunlight determine which plants will populate a region. Similarly, environmental conditions are affected by the distribution of plant life in an ecosystem. For example, soil quality affects the type and number of trees growing in a forest. However, the trees also affect the soil quality. The more leaves in an area, the greater the amount of decomposing organic matter and the better the soil quality. The number of trees also affects wind and shade, which in turn affect soil quality and the growth of smaller plants on the forest floor.

Purpose

To identify trees in a study site, and determine the relationships between environmental conditions and the plant community and between the plants and the physical factors in the site

Materials

4 craft sticks	felt pen
graph paper	notebook
light meter	string
measuring tape	thermometer

Procedure

1. Tie four 10 m sections of string between craft sticks. Put the craft sticks in the ground to make a study area as shown in **Figure 1**.

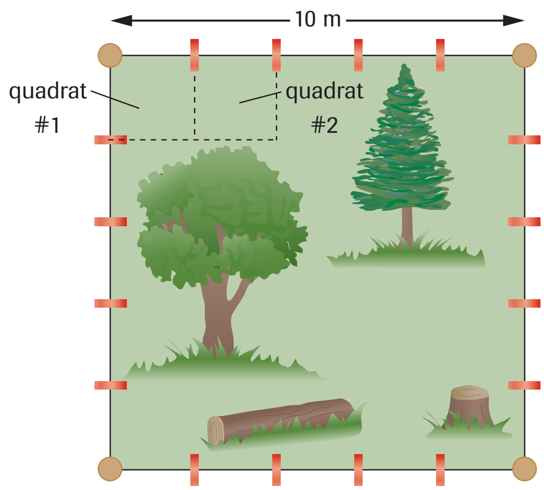


Figure 1

2. Using a measuring tape and felt pen, make a mark every 2 m along the strings. Use these marks to divide the study site into sections or quadrats. Record the number of quadrats in your study site.

(a) Make a map of the study area on graph paper. Use the quadrats to help you draw the map. Indicate the dominant plant or plants found in each quadrat. Locate the positions of trees, shrubs, paths, fences, and other objects. Include a legend, such as the legend shown in **Table 1**.

Table 1 Legend for Study Site

Letter symbol	Description of vegetation	Map symbol
D	deciduous trees such as maple, aspen, and poplar	D
C	coniferous trees such as spruce, pine, hemlock, cedar, and fir	C
S	shrubs such as pin cherry, dogwood, and willow. These woody plants grow under the canopy of the trees.	S
G	wild grasses, such as crab grass	G
W	non-grass weeds, such as ragweed, thistle, dandelions, and stink weed	W
L	leaves, moss, lichens, and other litter	L

3. Count and record the number of large (over 3 m tall) deciduous trees, large (over 3 m tall) coniferous trees, and shrubs in the study area.

(b) Use plant guidebooks to determine the types of trees, shrubs, and smaller plants in the study area.

4. With a measuring tape, determine the amount of shade provided by each tree. Take and record measurements on at least two sides of the tree.

(c) On your map, indicate the shade provided by each large tree.

5. Take soil temperature readings at 0 m, 2 m, 4 m, 6 m, 8 m, and 10 m in your study area, by placing the bulb

INVESTIGATION 4.2 *continued*

of the thermometer on the surface of the forest floor. Do not hold the bulb of the thermometer with your fingers.

(d) Record the soil temperatures on your map, at the exact locations.

Analysis

(e) Calculate the area of the study site.

(f) Determine the density of deciduous trees, coniferous trees, and shrubs in the study site, using the following formula.

$$\text{density} = \frac{\text{number of trees}}{\text{area used in the study}}$$

(g) Using the quadrats on your map to help, estimate the percentage of your study site that is shaded by the trees.

(h) Present your temperature data in table format.

Evaluation

(i) In step 5, you were instructed not to hold the bulb of the thermometer. Explain why this instruction was given.

(j) Did you find a greater number of shrubs and weeds in the shaded areas or the open areas of your study site? Provide a theory that helps explain your observation.

Synthesis

(k) Why do dense forests usually have moist soil?

(l) How do dead leaves on the forest floor help increase soil moisture?

(m) Why are the shrubs and small plants of dense forests less affected by wind than the grasses of the open prairies?

(n) Describe how sunlight affects soil temperature and soil moisture.

INVESTIGATION 4.3

Biological Oxygen Demand and Organic Pollutants

As you have seen, thermal energy and nutrients can deplete dissolved oxygen in aquatic ecosystems. As oxygen levels drop, the community that can survive in the ecosystem changes. In this investigation, you will use methylene blue indicator to detect a change in oxygen levels. The indicator turns from blue to colourless when the oxygen content of the sample drops below a threshold level. The time taken for this colour change indicates the BOD.

The biological oxygen demand (BOD) is the amount of dissolved oxygen needed by decomposers to break down organic matter in the water. If more organic matter is introduced into an ecosystem, the population of decomposing bacteria will increase. This large population of bacteria requires more oxygen.

Purpose

To determine how nutrients and heat affect dissolved oxygen

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	● Synthesis
● Prediction	● Evidence	

Prediction

(a) Predict which sample will have the greatest BOD.

Always handle hot plates and heated items with care.

Materials

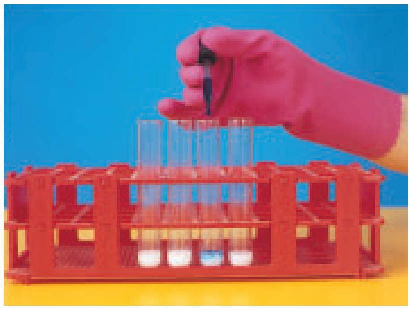
safety goggles
safety apron
water
500 mL beaker
hot plate
thermometer
brewer's yeast
mass balance
10 mL graduated cylinder
two 50 mL flasks
stirring rod
waterproof marker
11 mL homogenized milk
four 20 mL test tubes
test-tube rack
medicine dropper
methylene blue indicator
timing device
beaker clamp

INVESTIGATION 4.3 *continued*

Procedure

1. Make a hot-water bath by pouring about 400 mL of water into a 500 mL beaker and placing the beaker on a hot plate. Heat the water until the temperature reaches 40 °C . Using a thermometer, periodically check that the water temperature is maintained near 40 °C.
2. While the water is heating, measure 5 g of brewer's yeast with a mass balance. Pour 20 mL of water into a 50 mL flask, then add the yeast. Gently stir until the yeast dissolves. Label the flask "yeast."
3. Prepare a 25 % milk solution: mix 5 mL of milk and 15 mL of water in a 50 mL flask. Label the flask "25 % milk solution."
4. Label four test tubes 1, 2, 3, or 4 and put them in the test-tube rack. Add 3 mL of 100 % milk to test tubes 1 and 2. Add 3 mL of 25 % milk solution to test tubes 3 and 4.
5. When the temperature of the hot-water bath reaches 40 °C, add two drops of methylene blue indicator to each of the test tubes (**Figure 1**).

Figure 1



6. Rinse the graduated cylinder with tap water. Add 2 mL of the yeast solution to each of the test tubes. Place test tubes 1 and 3 in the hot-water bath and leave test tubes 2 and 4 in the test-tube rack. Record the time at which you put the tubes in the bath as time 0. Note the time when the methylene blue indicator turns colourless in each tube.

Analysis and Evaluation

(b) What was the source of organic matter used in this investigation?

(c) Yeast is a living organism. What purpose did the yeast serve in this investigation?

(d) A control was not used for the effect of nutrients on BOD levels. Devise such a control.

(e) Suggest some sources of error that might affect the outcome of this investigation.

(f) How does the concentration of nutrients affect the BOD?

(g) How does water temperature affect the BOD?

INVESTIGATION 4.4

Biological Indicators of Pollution in Streams

Report Checklist

○ Purpose	○ Design	● Analysis
○ Problem	○ Materials	● Evaluation
○ Hypothesis	● Procedure	○ Synthesis
● Prediction	● Evidence	

Many different pollutants can affect water quality. No single test can be used to assess water quality; however, an examination of the plants and animals found in the system can be used as a useful indicator of pollution in streams. Species that are active, such as trout, have high oxygen demands, while those that are less active, such as slugworms, need much less oxygen.

When aquatic ecosystems contain high levels of oxygen, the active species gain the advantage in the competition for food and territory. When oxygen levels are low, however, less active species gain the advantage. **Table 1**, on the next page, correlates oxygen level with species expected in freshwater systems.

INVESTIGATION 4.4 *continued*

Table 1 Oxygen Levels and Species

Oxygen level (mg/L)	Description	Species present
8 and above	high level of dissolved oxygen is positive for most species, resulting in high biodiversity	Fish: trout, jackfish, whitefish Invertebrates: mayfly larvae, caddis fly larvae, beetles, waterboatman
6 and above	level of dissolved oxygen sufficient for most species, although presence of active fish such as trout is less likely	Fish: perch, bottom feeders such as catfish Invertebrates: few mayfly larvae, some beetles, more worms (including leeches), slugworms.
4 and below	critical level for most fish; invertebrate populations increase	Fish: few Invertebrates: freshwater shrimp, many midge larvae, slugworms, leeches
2 and below	too low for fish	Invertebrates: some midge larvae, some slugworms, many small protozoans (amoebae)

It is important to note that the presence of a species usually identified with low levels of oxygen, such as the slugworm, does not mean that the water is polluted or even that oxygen levels are low. Slugworms can be found in well-oxygenated waters; however, their numbers tend to be lower.

Prediction

If a stream contains only organisms that do well when dissolved oxygen content is low, then the amount of dissolved oxygen in the stream will be low.

(a) Examine the stream you will investigate and the territory it flows through. Predict whether dissolved oxygen levels in the water will be high or low.

Materials

field guides to birds, fish, and invertebrates
high boots
plankton net
hand lens
bottom dredger
shovel
pan
bucket with lid
forceps
dissolved oxygen kit

Procedure

1. Before entering the stream, watch for fish and birds such as ducks and wading birds. Identify those you see, or record their colouring and shape for later identification.
2. Use a plankton net to take samples from the surface water. Examine the plankton with a hand lens. Record the type and population of the organisms you find.
3. Using a bottom dredger and a shovel, collect a sample from the streambed (**Figure 1**). Place the sample in a large pan and examine the organisms using the forceps and a hand lens. Be careful not to injure any organisms. Record your observations. Return the sample to the stream.

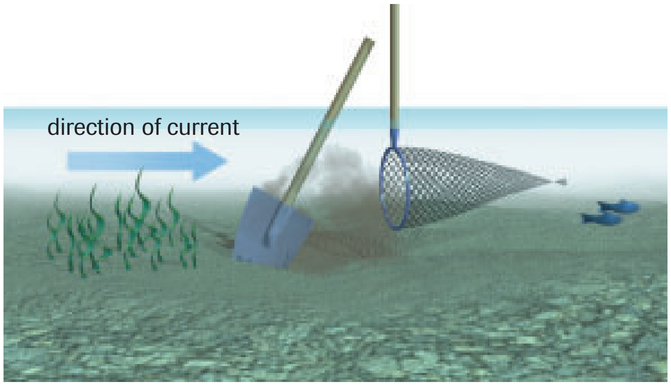


Figure 1

4. Use a bucket to collect a water sample from the stream. Using a dissolved oxygen kit, measure the amount of oxygen in the water.

Analysis and Evaluation

(b) Was your prediction correct? How do you account for any discrepancy between your observations and your prediction?

(c) Identify potential sources of pollution for this ecosystem.

(d) Suggest a method for determining the amount of plankton collected. How could one test site be compared with another?

(e) Using **Table 1** and your observations, rate the effects of pollution on the ecosystem you analyzed.

(f) Make a food web of the organisms you found.

(g) Make a pyramid of numbers for the organisms you found in the stream according to the following classification: producers; primary consumers; secondary consumers; decomposers.

Chapter 4 SUMMARY

Outcomes

Knowledge

- define and explain the interrelationship among species, population, community, and ecosystem (4.1)
- explain how a terrestrial and an aquatic ecosystem supports a diversity of organisms through a variety of habitats and niches (4.1, 4.2)
- identify biotic and abiotic characteristics and explain their influence in an aquatic and a terrestrial ecosystem in a local region (4.1, 4.2, 4.3, 4.5)
- explain how limiting factors influence organism distribution and range (4.4)

STS

- explain that science and technology have both intended and unintended consequences for humans and the environment (4.1, 4.5)

Skills

- ask questions by hypothesizing the ecological role of biotic and abiotic factors (4.1, 4.2, 4.3, 4.4)
- conduct investigations and gather and record data and information by: performing a field study to measure, quantitatively, abiotic characteristics of ecosystems and to gather evidence for analysis of the diversity of life of the ecosystem(s) studied (4.1, 4.2)
- analyze data and apply mathematical and conceptual models by: analyzing the interrelationship of biotic and abiotic characteristics that make up the ecosystem(s) studied in the field (4.1, 4.2) and; evaluating the accuracy and reliability of instruments used for measurement and identifying the degree of error in the field study data (4.1, 4.2, 4.5)
- work as members of a team and apply the skills and conventions of science (all)

Key Terms

4.1

ecology
abiotic factor
biotic factor
ecotone
artificial ecosystem
natural ecosystem
ecological niche

4.2

biome
canopy
permafrost
muskeg
understorey
littoral zone
limnetic zone
plankton
profundal zone

4.3

litter
topsoil
humus
subsoil
bedrock
groundwater
epilimnion
hypolimnion
thermocline

4.4

biotic potential
carrying capacity
law of the minimum
law of tolerance
density-independent factor
density-dependent factor

4.5

slash-and-burn
clear-cutting
selective cutting
prescribed burn
oligotrophic
eutrophic
coliform bacteria
biological oxygen demand (BOD)
watershed

MAKE a summary

1. Use as many key words as possible in the chapter to complete a fish bone diagram.
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

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The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 4
- additional Diploma Exam-style Review Questions
- Illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

Chapter 4 REVIEW

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. Write the numbers for the four factors that can cause a population to increase. (Record all four digits of your answer in lowest-to-highest numerical order.) NR
1. low reproductive rate
2. ability to adapt to change
3. favourable light
4. highly specific niche
5. generalized niche
6. ability to compete

Use the following information to answer questions 2 and 3.

Yellow-headed blackbirds are typically found in marshes from the Great Lakes to the Pacific Ocean. Their population size is influenced by water levels and vegetation density. **Table 1** shows the yellow-headed blackbird population and the amount of rainfall from 1992 to 1999 in a marsh area.

Table 1 Yellow-headed Blackbird Populations and Amount of Rainfall

Year	Number of birds, site 1	Number of birds, site 2	Amount of rainfall (cm)
1992	24	28	13
1993	80	88	38
1994	75	86	35
1995	55	74	30
1996	70	98	43
1997	105	186	62
1998	90	130	50
1999	21	22	16

2. According to the data, what is the relationship between water level and population?
A. As water levels decrease, the bird population declines.
B. As water levels increase, the bird population declines.
C. As water levels decrease, the bird population increases.
D. There is no relationship between water levels and the bird population.

3. According to the data in **Table 1**, which statement is correct?
A. Site 1 had the greater number of birds, due to the area being protected from predators.
B. Site 1 had the greater number of birds, due to the area having more water.
C. Site 2 had the greater number of birds, due to the area being protected from predators.
D. Site 2 had the greater number of birds, due to the area having more water.

Use the following information to answer questions 4 to 6.

The temperatures of the air, in the litter (dead leaves on the ground), in the humus (topsoil 10 cm below the surface) and in the mineral layer (30 cm below the surface) were monitored in a deciduous forest throughout a day. The data appear in **Figure 1**.

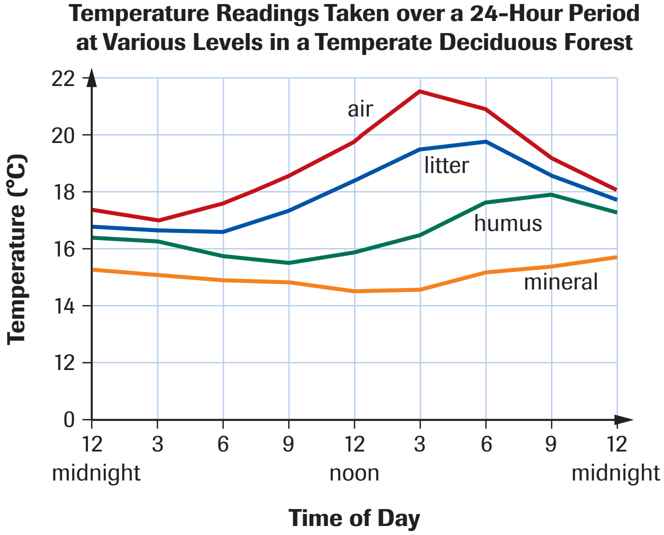


Figure 1

4. In which area of the forest did the greatest variation in temperature occur?
A. air
B. litter
C. humus
D. mineral

5. Which abiotic factor would account for the greatest difference in temperature readings in the litter?
A. wind
B. exposure to sunlight
C. soil moisture
D. thickness of litter

6. For the experiment described above, the dependent variable (responding variable) and independent variable (manipulated variable) are, respectively:
A. temperature and type of soil
B. type of soil and time
C. temperature and time
D. time and temperature

7. Forest fires have a beneficial role in ecosystems because they
   - A. clear the ground so water can be absorbed into the soil.
   - B. enrich the soil by returning nutrients.
   - C. drive exotic plants out of ecosystems where they don't belong.
   - D. reduce the number of predators in an area by destroying their homes.

8. Increased algae growth in a lake can occur because of
   - A. decreased pH
   - B. decreased water temperatures
   - C. increased carbon levels
   - D. increased nitrogen or phosphate levels

Part 2

Use the following information to answer questions 9 to 12.

Figure 2 is a Venn diagram showing species overlapping between a pond and a grassland.

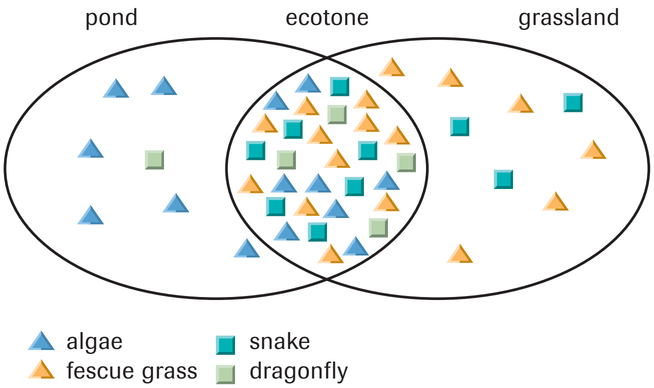


Figure 2

9. **Identify** producers within the ecosystem.
DE
10. **Describe** the abiotic conditions that are likely in the ecotone between the pond and the grassland. DE
11. **Why** is the greatest number of species found in the ecotone? DE
12. **Predict** how pollution of the ecotone might affect the grassland and pond ecosystems. DE

---

13. Using the field mouse or the lemming as an example, **explain** the limits on the size of a population.
14. **Describe** the evidence you have gathered in this chapter that supports the statement that ecosystems must change to remain stable.
15. **Identify** the factors affect the distribution of small shrubs in a dense forest.
16. Using a chart, **compare** the abiotic factors in oligotrophic and eutrophic lakes.
17. **Compare** dissolved oxygen levels and light intensity in the epilimnion and hypolimnion of eutrophic and oligotrophic lakes.
18. (a) **Describe** the spring and fall turnovers as they occur in most Canadian lakes.
    (b) Costa Rica is a Central American country that is much closer to the equator than Canada. **Explain** how the process of turnover in a deep lake in Costa Rica might differ from that in a deep lake in Canada.
19. **Sketch** food webs in a lake as the lake changes from oligotrophic to eutrophic.
20. When the population of white-tailed deer becomes large, they destroy the vegetation, drastically altering the entire ecosystem and placing other populations, both plants and animals, in peril. Once food supplies decline, the deer herd becomes more prone to disease and starvation. This problem is developing in the foothills of Alberta. Controlled hunting has been proposed as a solution. There are several different opinions on whether hunting of white-tailed deer should be allowed in the foothills.
    (a) **Identify** the perspective for each of the statements below.
    (b) Do you agree with each statement? **Explain** your reasons for agreeing or disagreeing.
    - Once deer populations increase beyond the food supply, the herd will become ill. Some will die, and others will be taken by predators, removing the weak from the population. This will eventually strengthen the herd—only the strong remain. Generally, hunters shoot only the largest and healthiest animals. Hunting will weaken the deer.
    - The Alberta foothills are visited regularly by the general public, and camping is allowed in some campgrounds. Hunting might create dangers for tourists.
    - If deer eat too much of the local vegetation, there will be no more food left and they will begin to starve. It is more humane to allow hunting than to allow the deer to starve.
21. In an attempt to compare the amount of undissolved solids at two different sites in a lake, the following procedure is followed at each site.

    Procedure
    - The mass of a cheesecloth is measured using a triple-beam balance.
    - The cheesecloth is placed over the opening of a kitchen sieve.
    - The sieve is moved back and forth in water for 5 minutes.
    - The cheesecloth is removed from the sieve and the mass of the cheesecloth is measured using the triple-beam balance.

    (a) **Identify** potential sources of error in the procedure described above.
    (b) **Describe** how the procedure might be improved.

chapter

5 Evolution

In this chapter

- Exploration: Curiosity Generates Questions
- Chemistry Connection: Classifying Chemicals
- Mini Investigation: Classifying Organisms
- Investigation 5.1: Using a Classification Key
- Mini Investigation: Puzzling over Evidence
- Web Activity: Finding Fossils and Famous Footprints
- Mini Investigation: Variations on a Theme
- Lab Exercise 5.A Evidence from Genetics
- Web Activity: Were Neanderthals Humans?
- Mini Investigation: Genetic Shuffle
- Investigation 5.2: Measuring Inherited Variation
- Web Activity: Lactose Intolerance and Evolution
- Web Activity: Natural Selection
- Career Connections: Paleontologist; Breeder

Black widow spider females (**Figure 1**) often consume their partners during mating. How can such unusual behaviour be explained? To answer this question, biologists have to understand and apply of the theory of evolution.

Researcher Dr. Maydianne Andrade believes she has found the answer. Some male black widow spiders intentionally offer their abdomens as food to the females. The females normally mate with several males, store their sperm, and use it to fertilize as many as 3000 eggs. Males who do not sacrifice themselves rarely mate with more than one female. Males who volunteer their bodies as food during mating extend their mating time and transfer more sperm to the female, increasing their chances of fertilizing eggs. Thus, males who are eaten have more offspring than those who are not. These findings support the conclusion that the volunteering-for-cannibalism behaviour has evolved because it increases the reproductive success of males who perform such behaviour.

Evolution is a compelling scientific theory that explains not only how organisms change over time, but also the diversity of species. To appreciate and judge the significance and validity of this theory, it is important to examine the evidence and to review the nature of science as a way of gaining knowledge. As you will learn, evolutionary biology is a modern science that provides answers about the past and has present-day applications in many fields of study, from medicine to conservation biology.

STARTING Points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. Domesticated animals such as dogs, cats, horses, and cattle are descended from wild animals. Why do many different domesticated breeds now exist? How could breeders have produced animals with traits that their wild ancestors did not have?
2. Penguins, ostriches, and eagles share many similar features, while fish, antelopes, and bats do not. Offer an explanation for such findings.
3. Why are some bacteria becoming immune to antibiotics?
4. The vast majority of fossil species are no longer alive today, and many species that are alive today are not found as fossils. Why?

Figure 1
A male of the black widow spider increases his reproductive success when he allows the female, shown here, to consume his body during mating.

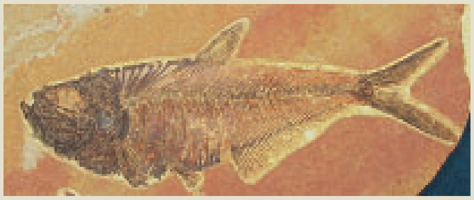
Exploration — *Curiosity Generates Questions*

Most humans are curious by nature, and scientists particularly so. Whenever someone witnesses an unusual event or discovers an unusual object, questions immediately arise. What caused the event? Where did the object originate? When we try to answer such questions, we start with the knowledge and beliefs we already have.

Carefully examine the puzzling images in **Figure 2**.

(a) Generate two questions about each image.
(b) Based on background knowledge and understanding you already have, write short answers to your own questions.
(c) Exchange your question set with a fellow student. Record and respond to his or her questions.
(d) Was it difficult to generate questions about the images in **Figure 2**?
(e) Was it difficult to answer the questions? How confident do you feel about the accuracy of your answers?
(f) What specific steps would you take to better answer these questions?
(g) Would you describe your approach as a "scientific method?" Why?

(a)


(b)


(c)

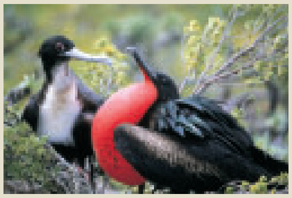

(d)


Figure 2

5.1 Classification of Organisms

CHEMISTRY CONNECTION

Classifying Chemicals

Classification also plays an important role in chemistry. For example, scientists can predict the behaviour of elements in chemical reactions based on their position in the Periodic Table. Your chemistry textbook has more information on the use of classification in chemistry.

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Scientists estimate that there are at least 10 million different species alive today. However, this number is only a small part of the hundreds of millions of species that have existed on Earth over time. Understanding the dramatic history of Earth's changing biological diversity is the goal of evolutionary biology. Before studying how populations change over time (evolve), it is useful to understand Earth's current biological diversity. Biological diversity is usually a sign of a healthy ecosystem. When an ecosystem is biologically diverse, there is a higher chance that some organisms will survive changes in the ecosystem that arise.

There are two levels of biological diversity: (1) species diversity, which describes the number of different species; and (2) genetic diversity, which refers to the amount of variation in inherited traits between individuals of the same species. In this section, you will consider species diversity, by looking at how scientists use a classification system to understand the similarities and differences between species.

mini Investigation — Classifying Organisms

It is not always easy to classify an organism. To decide, a scientist makes careful observations. Clues are compiled based on organizing similarities and differences. Eventually, the clues can be linked and a conclusion can be drawn. Scientists then look for ways of testing their conclusions.

Examine the organisms in **Figures 1** to **6**.

(a) Speculate about which organisms are plants and which are animals. Give your reasons. *Hint:* recall the cellular differences between plants and animals.

(b) What test would you conduct on each of these organisms to determine whether they are plants, animals, or something else?

Figure 1
Fucus, a seaweed

Figure 2
Sponge

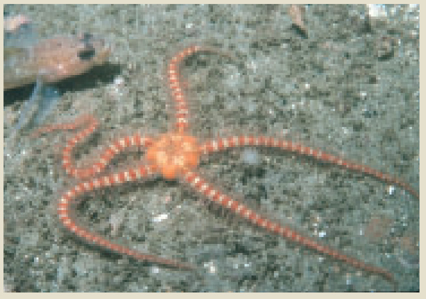

Figure 3
Brittle star

Figure 4
Coralina, a red alga

Figure 5
Sea anemone

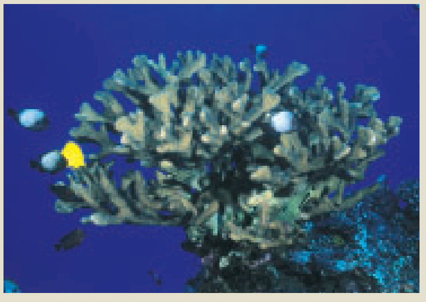

Figure 6
Coral

Taxonomic Systems

Estimates of the number of living plant and animal species range somewhere between 2 and 4.5 million. Bacteria and other microorganisms add several more million species to this total. Many scientists believe that there may be up to four times this number, including many species that are now extinct. Is it any wonder, given the numbers and diversity of living things on this planet, that classification is a major field of biology? The science of classifying organisms is called **taxonomy**. Scientists who carry out this work are called *taxonomists*.

taxonomy the science of classification according to the inferred (presumed) relationships among organisms

Biological classification systems have two main purposes: identifying organisms and providing a basis for recognizing natural groupings of living things. However, classification systems are artificial. They are developed by scientists to help deal with the diversity of life and to represent relationships among organisms.

Our present biological system of classification was developed from the system created by Swedish botanist Carl Linnaeus (1707–1778). His system was based on an organism's physical and structural features, and operated on the idea that the more features organisms have in common, the closer their relationship.

Linnaeus created rules for assigning names to plants and animals. He was the first to use **binomial nomenclature**, which assigns each organism a two-part scientific name using Latin words. Latin (and sometimes Greek) is still used today for naming organisms, and provides a common language for all scientists. A scientific name is often based on some characteristic such as colour or habitat; an example is *Castor canadensis* (*Castor* meaning "beaver," and *canadensis* meaning "from Canada"). The first part of any scientific name is called the **genus** (plural: genera). Its first letter is always capitalized and can be written alone; for example, the *Acer* genus refers to maple trees. The second part is called the **species** and is never used alone; for example, *Acer rubrum* refers to the red maple. Living organisms within a species can usually only breed with members of their own species to produce fertile offspring.

binomial nomenclature a method of naming organisms by using two names—the genus name and the species name. Scientific names are italicized.

genus the first part of a binomial name; a genus includes several species

species a group of organisms that look alike and can interbreed under natural conditions to produce fertile offspring

The two-name system provides an added advantage by indicating similarities in anatomy, embryology, and evolutionary ancestry. For example, binomial nomenclature suggests that the North American black bear (*Ursus americanus*) and the grizzly bear (*Ursus horribilis*) are closely related. Similar organisms are grouped into the same genus. The giant Alaskan brown bear (*Ursus arctos*) and the polar bear (*Ursus maritimus*) are other relatives belonging to the same genus. By contrast, the koala bear and the panda do not belong to the genus *Ursus* and are not considered true bears.

In our present classification system, there are seven main levels or **taxa** (singular: taxon), as shown in **Table 1**.

taxa categories used to classify organisms

Table 1 Levels of Classification

Levels of classification	Dandelion	Housefly	Human
kingdom	Plantae	Animalia	Animalia
phylum	Tracheophyta	Arthropoda	Chordata
class	Angiospermae	Insecta	Mammalia
order	Asterates	Diptera	Primates
family	Compositae	Muscidae	Hominidae
genus	*Taraxacum*	*Musca*	*Homo*
species	*officinale*	*domestica*	*sapiens*

EXTENSION

Comparing Plants and Animals at the Cellular Level

Listen to a comparison of the structural and functional characteristics of plants and animals at the level of their cells.

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Protista a kingdom originally proposed for all unicellular organisms such as the amoeba. More recently, multicellular algae have been added to the kingdom.

Monera in a five-kingdom system, a kingdom that includes organisms that lack a true nucleus

Archaebacteria in a six-kingdom system, a kingdom consisting of prokaryotic microorganisms distinct from eubacteria that possess a cell wall not containing peptidoglycan and that live in harsh environments such as salt lakes and thermal vents

Eubacteria in a six-kingdom system, a kingdom consisting of prokaryotic microorganisms that possess a peptidoglycan cell wall

DID YOU KNOW?

Most Highly Evolved

Many scientists point out that humans may not be the most highly evolved creatures on the planet. The placement of humans at the top of the ladder is highly subjective.

Originally, the first level consisted of only two kingdoms: plants and animals. Later, single-celled organisms that displayed both plant and animal traits were discovered. To recognize this unique group, scientists created a third kingdom: **Protista**. However, shortly after the introduction of the protist kingdom, it was noted that certain microorganisms within this group shared an additional distinct feature. Bacteria and cyanobacteria, unlike protists, lack a true nucleus. This distinction resulted in the establishment of a fourth kingdom: **Monera**. The monerans are referred to as prokaryotes since the cells lack a true nucleus. All other groups of living organisms are known as eukaryotes. Later, taxonomists acknowledged that mushrooms and moulds are sufficiently different from plants and thus placed them in a separate kingdom called Fungi. This five-kingdom classification system, which includes Animalia, Plantae, Fungi, Protista, and Monera, was originally proposed by Robert Whittaker in 1969. It enjoyed wide acceptance until recently.

In the 1970s, microbiologist Carl Woese and other researchers at the University of Illinois conducted studies indicating that a group of prokaryotic microorganisms called **Archaebacteria** are sufficiently distinct from bacteria and other monerans that they constitute their own kingdom. Archaebacteria have been known for a long time. They thrive in harsh habitats such as salt lakes, hot springs, and the stomach chambers of cattle and other ruminants. Archaebacteria possess cell walls and ribosome components that are very different from those in **Eubacteria**. Eubacteria are prokaryotes that possess a rigid cell wall composed of peptidoglycan, a three-dimensional polymer containing carbohydrate and protein subunits. Thus, Woese and his colleagues proposed that the kingdom Monera be divided into two kingdoms, Archaebacteria and Eubacteria (true bacteria). The resulting six-kingdom system includes Animalia, Plantae, Fungi, Protista, Eubacteria, and Archaebacteria. **Table 2** on the next page summarizes a six-kingdom system of classification.

DNA sequencing studies conducted by Carol Bult and Carl Woese in 1996 revealed that some of the genes in archaebacteria are more closely related to the genes of humans and other eukaryotes than to those of eubacteria. Woese proposed that archaebacteria are so different from other prokaryotes that their name should not contain the term bacteria. He suggested the name *Archaea* for this group. While the six-kingdom system grows in popularity among biologists in general, many microbiologists feel that all traditional kingdom systems should be replaced with a system that better reflects the evolutionary history of life. This has led to a three-domain classification system (**Figure 7**). Scientists continue to update evolutionary history and classification schemes as more DNA evidence is collected and analyzed.

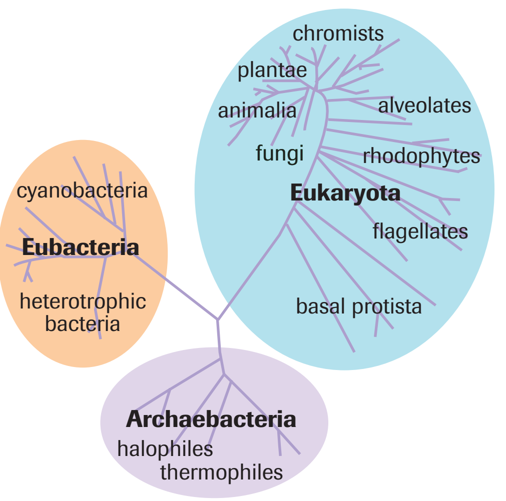
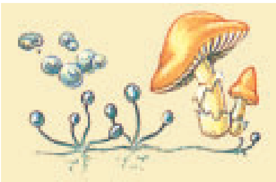
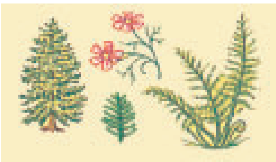


Figure 7
A three-domain system of classification

Table 2 A Six-Kingdom System of Classification

	Kingdom	General characteristics	Cell wall	Representative organisms
	1. Eubacteria	• simple organisms lacking nuclei (prokaryotic) • either heterotrophs or autotrophs • all can reproduce asexually • live nearly everywhere	often present (contains peptidoglycan)	bacteria, cyanobacteria
	2. Archaebacteria	• prokaryotic • heterotrophs • live in salt lakes, hot springs, animal guts	present (does not contain peptidoglycan)	methanogens, extreme thermophiles, extreme halophiles
	3. Protista	• most are single-celled; some are multicellular organisms; eukaryotic • some are autotrophs, some heterotrophs, some both • reproduce sexually and asexually • live in aquatic or moist habitats	absent	algae, protozoa
	4. Fungi	• most are multicellular • all are heterotrophs • reproduce sexually and asexually • most are terrestrial	present	mushrooms, yeasts, bread moulds
	5. Plantae	• all are multicellular • all are autotrophs • reproduce sexually and asexually • most are terrestrial	present	mosses, ferns, conifers, flowering plants
	6. Animalia	• all are multicellular • all are heterotrophs • most reproduce sexually • live in terrestrial and aquatic habitats	absent	sponges, worms, lobsters, starfish, fish, reptiles, birds, mammals

Practice

1. Describe a situation in which classification affects your life.
2. What is meant by the term *binomial nomenclature*?
3. Indicate the advantage of using a Latin name over a common (e.g., English) name. Provide at least one example.
4. List, in order, the major levels of classification, starting with kingdom.

phylogeny the history of the evolution of a species or a group of organisms

Today, most scientists believe that organisms have changed over time. The history of the evolution of organisms is called **phylogeny**. Relationships are often shown in a type of diagram called a phylogenetic tree, where the tree starts from the most ancestral form and includes branchings that lead to all of its descendants. **Figure 8** shows an overall picture of the relationships, but more specific diagrams are possible.

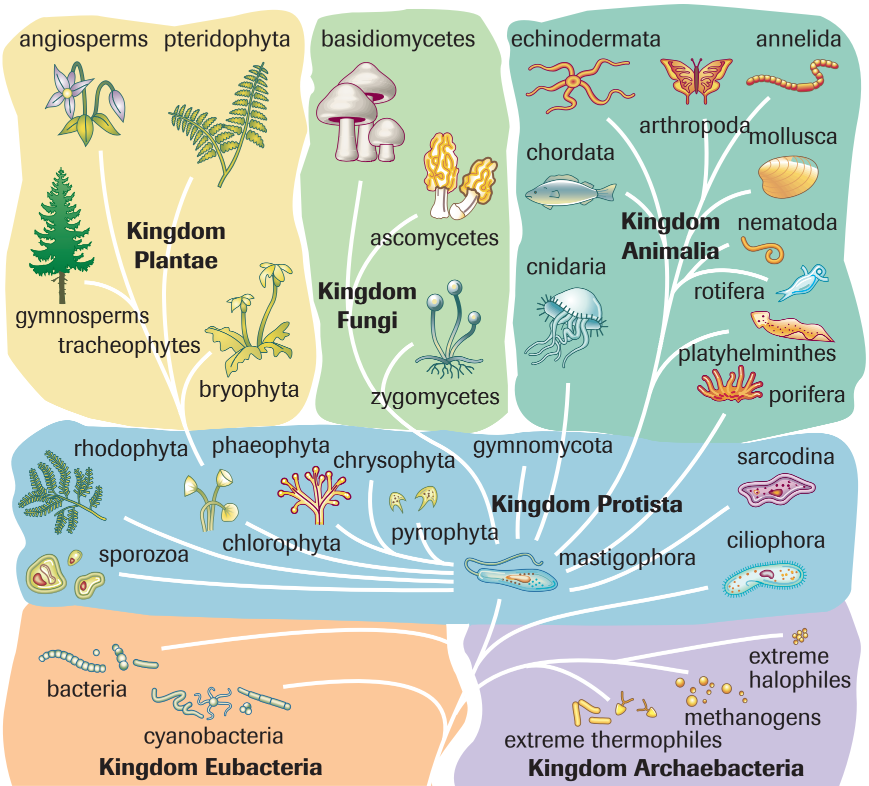


Figure 8
This phylogenetic tree shows relationships within the six kingdoms.

dichotomous key a two-part key used to identify living things. *Di* means "two."

Many scientists regularly use classification manuals to conduct their identification work. Usually it involves the use of a **dichotomous key**. The key is constructed so that a series of choices must be made, and each choice leads to a new branch of the key. If choices are made accurately, the end result is the name of the organism being identified.

INVESTIGATION 5.1 ***Introduction***

Using a Classification Key

Whale species are quite variable. For example, some whales are as small as 3.5 m in length, whereas others can reach 25 m or more. Nevertheless, whales can be classified into two general groups. In this investigation, you will use a classification key to group different whales into species.

To perform this investigation, turn to page 162.

Report Checklist

- ● Purpose
- ● Problem
- ○ Hypothesis
- ● Prediction
- ● Design
- ○ Materials
- ● Procedure
- ● Evidence
- ● Analysis
- ○ Evaluation
- ● Synthesis

SUMMARY Classification of Organisms

- Taxonomy is used to help biologists identify organisms and recognize natural groupings of living things.
- Different organisms have different scientific names, which consist of a genus name and a species name.
- In taxonomy, there are seven main taxa arranged in order: kingdom, phylum, class, order, family, genus, and species. The taxa are used to group organisms by their similarities according to structure and/or evolutionary history.

Section 5.1 Questions

1. What is a phylogenetic tree?

2. Why is the classification of organisms important?

3. Discuss the importance of the use of scientific names in the study of biology.

4. Why is phylogeny sometimes called the foundation of taxonomy?

5. Which of the kingdoms is at the bottom of a phylogenetic tree? Why is it placed there?

6. The following is a list of some Latin (Lat.) and Greek (Gr.) words and their English definitions:
- alopekos (Gr.): fox
- felis (Lat.): cat
- articus (Lat.): arctic
- pous (Gr.): foot
- canis (Lat.): dog
- alpinous (Lat.): mountain
- lagos (Lat.) or lepus (Gr.): rabbit
- aquaticus (Lat.): found in water
- mephitis (Lat.): bad odour
- rufus (Lat.): reddish

Match each scientific name with the correct common name.

(a) *Felis concolor*
(b) *Sorex arcticus*
(c) *Canis rufus*
(d) *Mephitis mephitis*
(e) *Alopex lagopus*
(f) *Eutamias alpinus*
(g) *Sciurus arizonensis*
(h) *Sylvilagus aquaticus*

(i) arctic shrew
(ii) swamp rabbit
(iii) skunk
(iv) red wolf
(v) alpine chipmunk
(vi) arctic fox
(vii) mountain lion
(viii) Arizona grey squirrel

7. Use the information in **Table 3** to answer the following questions.
(a) Which of the species are the most closely related? Explain.
(b) Is the river otter more closely related to the muskrat or the weasel? Why?
(c) Is the groundhog more closely related to the chipmunk or the ferret? Why?
(d) Which of the species is (are) the closest relative(s) of the squirrel? Explain.

Table 3 Names of Some Common Mammals

Common name	Scientific name	Family
red squirrel	*Tamiasciurus hudsonicus*	Sciuridae
shorttail weasel	*Mustela erminea*	Mustelidae
groundhog	*Marmota monax*	Sciuridae
mink	*Mustela vison*	Mustelidae
eastern chipmunk	*Tamias striatus*	Sciuridae
river otter	*Lutra canadensis*	Mustelidae
fisher	*Martes pennanti*	Mustelidae
muskrat	*Ondatra zibethica*	Cricetidae
black-footed ferret	*Mustela nigripes*	Mustelidae

5.2 Evidence of a Changing Earth

As you saw earlier, the populations in an ecosystem change in response to changes in the environment. The introduction of a new species or a shift in the amount of nutrients can dramatically affect the equilibrium of the ecosystem. In fact, it is predicted that within your lifetime, changes to Earth's ecosystems will cause the extinction of many species. Have changes in the populations of organisms always occurred? How have these affected living species? Although it is impossible to directly observe what Earth was like millions of years ago, indirect evidence suggests that the types of organisms that lived in the past were very different from those of today. This evidence suggests that modern species evolved from ancestral ones.

Evidence for evolution comes from many lines of investigation. Some evidence comes from direct observation and experiment, while other evidence is more indirect. In the following sections, we examine scientific evidence gathered from the fossil record, the geographic distribution of species, comparative anatomy and embryology, behaviour, plant and animal breeding, and biochemistry and genetics.

DID YOU KNOW?

The Scientific Method

Francis Bacon (1561–1626) first proposed the scientific method, one way of finding out about the world around us. Bacon devised a method of testing a hypothesis using a controlled experiment. At about the same time, Galileo was using a telescope to provide compelling evidence that Earth was not the centre of the universe—a finding that contradicted the teachings of the church at the time.

paleontology the study of fossils

Evidence from Fossils

Strong evidence of a changing Earth can be seen from a careful examination of fossils. **Paleontology** (the study of fossils) has a central position in the study of evolution. Scientists have discovered approximately 250 000 fossil species, a number thought to represent only a fraction of the species that have lived on Earth. Burrows, footprints, and even chemical remains can fossilize. A complete set of fossils of all previous existing life forms will never be uncovered, since most organisms leave no evidence of their existence. However, fossilized remains, impressions, and traces of organisms from past geological ages provide scientists with direct physical evidence of past life. What patterns have been found in this album in rock?

+ EXTENSION

Fossil Formation

Fossils are commonly formed when the bodies of organisms become trapped in sediments. In this extension activity, you will find out how this process occurs.

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mini Investigation — Puzzling over Evidence

Biologists investigate the natural world through methodical observation and experimentation. As they accumulate evidence, they continually form and test tentative hypotheses toward the development of a theory. In this activity, you model this process by gathering and interpreting evidence, in order to develop and test hypotheses.

- Remove eight puzzle pieces at random from your group's "Evidence" envelope.
- Arrange the pieces on your desk. Discuss the evidence and make predictions about the missing puzzle pieces. Record the predictions in your notebook as your group's first tentative hypotheses.
- Remove two more puzzle pieces from the "Evidence" envelope.
- Add to and modify your original arrangement of puzzle pieces. Comment on the validity of your original hypotheses. Make and record a second set of hypotheses.
- Repeat the above process of obtaining new evidence and modifying your previous hypotheses. At some point you may wish to propose a theory—a tentative explanation that accounts for all the evidence.

(a) In what way do the puzzle pieces model evidence in science?

(b) What scientific processes were you modelling when you arranged your puzzle pieces?

(c) How did you test your hypotheses? How do scientists test hypotheses?

(d) Do you think it is possible to make valid predictions and develop valid theories even when you don't have all the evidence? Explain your reasoning.

(e) How does the "accumulation" of more and more evidence influence your ability to make predictions and/or formulate and test a theory?

1. Different species lived on Earth at various times in the past. Very few of today's species were alive even 1 million years ago, and almost all of the species that have lived are now extinct.
2. The complexity of living organisms generally increases from the most distant past to the present. When fossil deposits are arranged from most ancient to most recent, there is an obvious and systematic progression from only very simple organisms to species of ever-increasing complexity.
3. Living species and their most closely matching fossils are typically located in the same geographic region. For example, all fossils of ancient sloths are found in Central and South America, the only region in which modern, but smaller and very different, species of sloth live today (**Figure 1**).

Figure 1
(a) sloth skeleton **(b)** living sloth

Dating the Past

By the early 1800s, evidence from geology strongly suggested that Earth might be hundreds of millions of years old, much older than the thousands of years assumed at the time. In his 1830 book, *Principles of Geology*, Sir Charles Lyell revolutionized geology with his argument that most geological change was slow and gradual and had been going on over vast expanses of time. Lyell based his theories on his observations of fossil deposits and of geological processes such as erosion and sedimentation.

However, Lyell's conclusions were not widely accepted and were severely attacked by Lord Kelvin, the most respected physicist of the day. Kelvin estimated that Earth was 15 to 20 million years old, based on rigorous mathematical and scientific calculations that assumed that Earth was gradually cooling down. Even though his estimate conflicted with the geological evidence, it agreed with the most widely held beliefs of the time.

In 1903, radioactivity was discovered, a source of heat energy. Kelvin's model had grossly underestimated the age of Earth because it had failed to account for the heat that is continuously generated within Earth by radioactive decay. Radioactive decay also provides a form of geologic clock, giving scientists a means to determine the absolute age of the Earth with great precision.

Radioactive decay changes a particular atom (parent isotope) into a daughter isotope of the same or a different element. For example, radioactive potassium 40 decays to become argon 40 or calcium 40, while uranium 238 decays into lead 206. Physicists measure these decay rates in units called half-lives, the amount of time it takes for half of a sample of the isotope to decay and become stable. They have determined that the

DID YOU KNOW?

The Burgess Shale

Fossil beds in the Burgess Shale in British Columbia likely formed through a series of mudslides, which buried living organisms in moving sediment. The resulting fossils are superbly preserved (**Figure 2**). Many of the animals had unusual body forms not found in present-day animals. Discovered in 1909 by Charles D. Walcott of the Smithsonian Institute, it was immediately declared the most important geological find in the world. The Burgess Shale fossil beds became a UNESCO World Heritage Site in 1981.

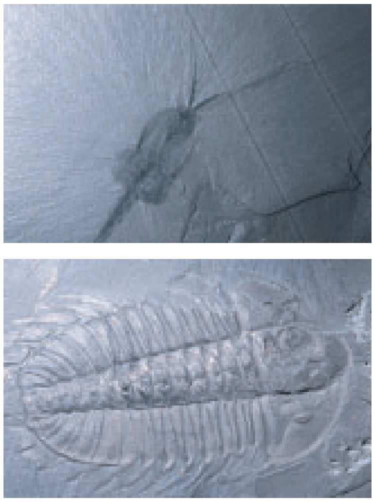

Figure 2

CAREER CONNECTION

Paleontologist

Paleontologists work with fossils to explore the organisms found in various regions over Earth's history. Most paleontologists are college or university professors, but some also work for museums or for petroleum and mining companies. Find out what qualifications are needed for a career in paleontology.

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half-life for any particular isotope is a constant; it is not affected by temperature, moisture, or other environmental conditions. With constant half-lives, isotopes can be used as naturally occurring and extremely precise radiometric clocks.

By measuring the age of rock through these **radiometric dating** techniques, modern paleontologists can estimate accurate ages for fossils. Radiometric dating using a single isotope is not perfect, but when data from a variety of isotopes are combined, scientists can provide age estimates with a very small margin of error. The oldest fossils of living things discovered thus far date to approximately 3.8 billion years.

radiometric dating a technique used to determine the age of a rock or fossil

EXTENSION

Radiometric Dating

View this animation of dating a fossilized mollusc by radiometric dating.

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Practice

1. Offer an explanation for the observation that fossils of birds are rare, while fossils of clams are extremely common.
2. What is radiometric dating and of what value is it to paleontologists?

WEB Activity

Case Study—Finding Fossils and Famous Footprints

In 1976, some famous fossils dating from more than 3.6 million years ago were discovered in Tanzania (**Figure 3**). They represent some of the oldest fossil evidence for upright, bipedal, walking—a milestone in human evolution. Complete this online activity to find out more about these fossils and be introduced to Lucy!

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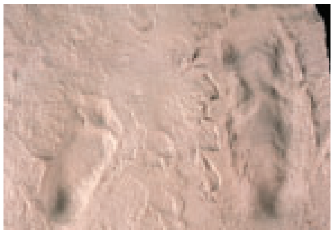

Figure 3

Evidence from Biogeography

Biogeography explores the variation and distribution of life over Earth's surface, both today and in the past. Patterns of geographic distribution provide important clues to the history of life on Earth.

Over long periods of time, Earth's landmasses have undergone dramatic changes by the process of continental drift. About 225 million years ago, Earth's continents were part of one landmass. The slow drift of Earth's tectonic plates eventually separated the ancient landmasses into the continents we see today. As a result, fossils of some species that date to 150 million years ago and older were once in the same geographic region, but are now distributed on different continents (**Figure 4**, next page). After the continents separated, most species younger than about 150 million years were restricted to separate continents. Most recent fossils of the same species are not found on these different continents. This strongly suggests they evolved *after* the breakup of the continents.

Islands that are far removed from landmasses are also of great interest to evolutionary biologists. Many of these islands are products of volcanic activity, and were barren ash and rock when they first were formed. Remote islands are homes to unique species, many of which are **endemic** (found nowhere else). This suggests that these species have evolved in isolation. Scientists hypothesize that the ancestors of endemic species came from other landmasses. But how? Any ancestors would have had to cross great distances of open ocean, and so most likely were animals capable of flight (birds and insects) and seeds carried by the wind or the sea. Other species may have travelled on rafts of vegetation or ice floes. Is there any evidence to support these conclusions?

biogeography the study of the geographic distribution of life on Earth

endemic a term used to describe a species that is found in one location only

DID YOU KNOW?

The Royal Tyrrell Museum

The Royal Tyrrell Museum opened in 1985, commemorating Joseph Burr Tyrrell, the man credited with finding the first dinosaur fossils in the Drumheller Valley, Alberta, in 1884. You can view the museum's fabulous fossil collection or find out about its many active programs in person or online.

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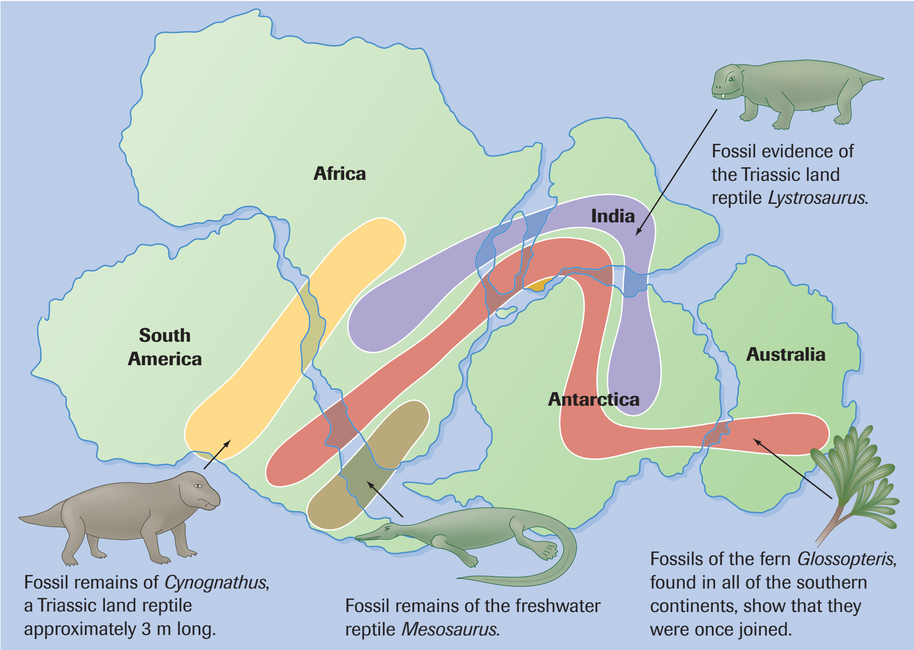

Figure 4
Fossil remains of species that lived more than 150 million years ago can be found on many continents. Fossils of more recent species (not shown) are found on separate continents.

> **DID YOU KNOW?**
> **Flightless Birds**
> Virtually all of the world's large remote islands are home to unique species of flightless, ground-nesting birds. Even when very similar islands are separated by only short distances of open ocean, distinct species occur.

There is. The native species on remote islands are invariably and exclusively birds, insects, and other potentially mobile organisms. For example, the Hawaiian Islands are located in the Pacific Ocean, 3200 km from any continent. Species native to these islands include 0 native reptiles or amphibians, 2 native mammals—the monk seal and the hoary bat, 96 species of birds, and many, many insect species. Additionally, genetic testing of Hawaiian plants strongly suggests that the 1729 native species and varieties known today all descended from only 272 founding species.

SUMMARY Evidence of a Changing Earth

- Fossil evidence reveals that species living today are different from those living in the past.
- Fossils reveal a progression of different species on Earth over time, from simple forms in the most distant past to increasingly complex forms.
- Radiometric dating allows scientists to accurately determine the ages of rocks and fossils.
- Evidence from biogeography suggests that different species evolved independently in isolated parts of the world.

Section 5.2 Questions

1. Explain how the following patterns of fossils offer compelling evidence for evolution:
   (a) the relationship between the age of fossils and the kinds and complexity of fossils
   (b) the relationship between the geographical location of both fossils and living species
2. Would you expect to find more unique species on remote islands, such as Iceland, or islands that are close to a large landmass, such as the Queen Charlotte Islands? Give reasons for your answer.
3. Brainstorm a list of living plants and animals that you think might be able to reach the Hawaiian Islands from the coast of British Columbia. Be prepared to defend your choices.

Extension

4. Research carbon 14 (^{14}C) dating techniques, including why the percentage of ^{14}C begins to change after an organism dies. Report your findings to your class.

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5.3 Evidence of Evolution from Biology

homologous features features with similar structures but different functions

analogous features features that are similar in appearance and function, but do not appear to have the same evolutionary origin

A comparison of the physical anatomy and genetic makeup of organisms also provides evidence to support the theory that modern species evolved from ancestral species. Some of this evidence will be presented in this section.

Evidence from Anatomy

The forelimbs of a bird, whale, horse, and human all share very similar bone arrangements, even though they serve very different functions (**Figure 1**). These observations strongly suggest that an ancestral forelimb evolved modifications that better served new functions. Such features, with similar structure but different functions, are called **homologous features**. In contrast, **analogous features** are similar in appearance and in function, but do not appear to have the same evolutionary origin, such as a bird's wing and an insect's wing.

An evolutionary relationship among species is also evidenced in embryonic development (**Figure 2**). In the early weeks of development, human embryos possess a tail and gill slits, similar to those in chicken and fish embryos. The embryonic tail serves no function in humans and later forms a rudimentary tailbone. The gill slits become modified in both humans and birds to form various internal structures, including bones of the inner ear.

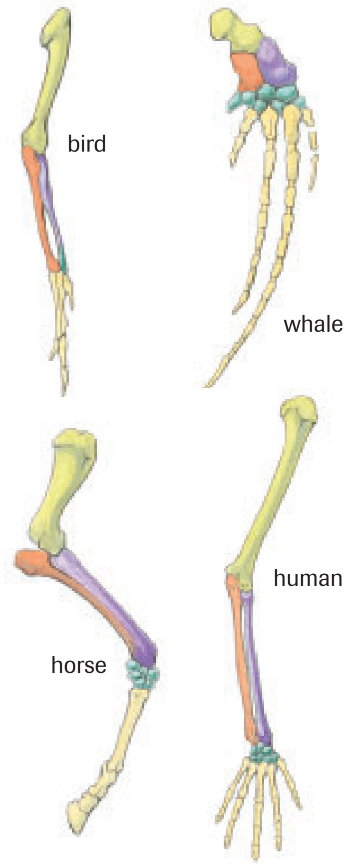

Figure 1
The forelimbs of each of these organisms are adapted to carry out very different functions, yet they all possess very similar bone structure.

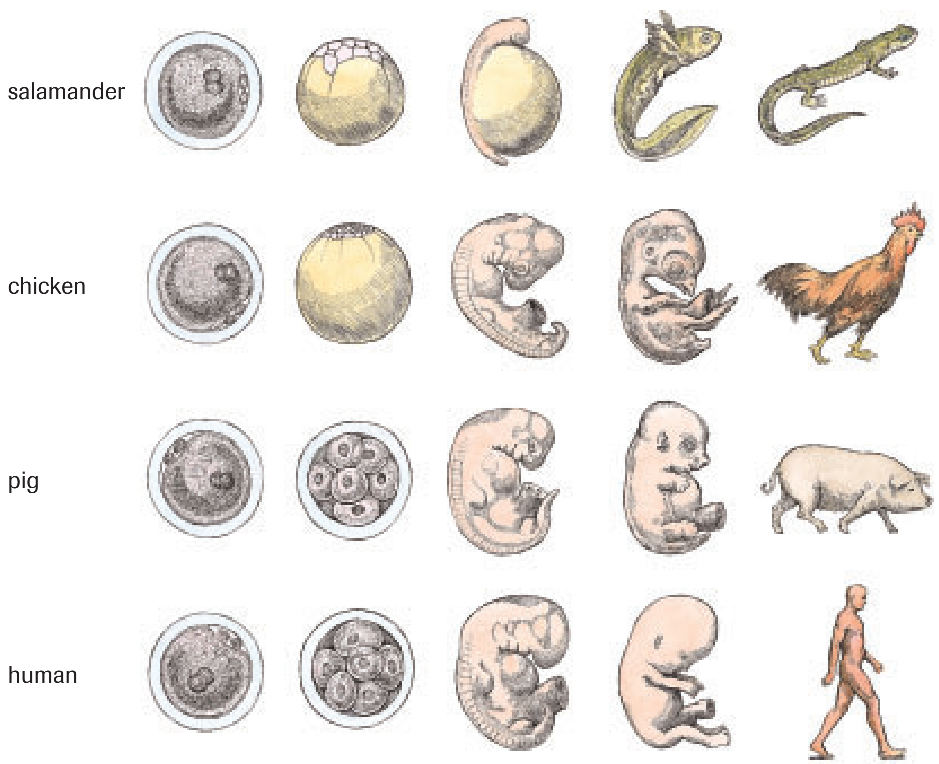

Figure 2
Homologous features such as tailbones are clearly evident in the embryos of these organisms.

Vestigial Features and Anatomical Oddities

Vestigial features are rudimentary structures that serve no useful function. Such features are present in virtually all species and provide perhaps the most compelling evidence for evolution. A reasonable explanation for vestigial features is that they once served some function in an ancient ancestor. Some modern species of whales and snakes have vestigial hip and leg bones—evidence that suggests they evolved from ancestors that walked on four limbs (**Figure 3**). Similarly, many mammals have vestigial toe bones elevated above the ground (**Figure 4**). Some beetles even have fully developed wings, trapped beneath fused covers. Blind cave salamanders have empty eye sockets, suggesting that they evolved from salamanders with fully functioning eyes.

vestigial features rudimentary structures with no useful function

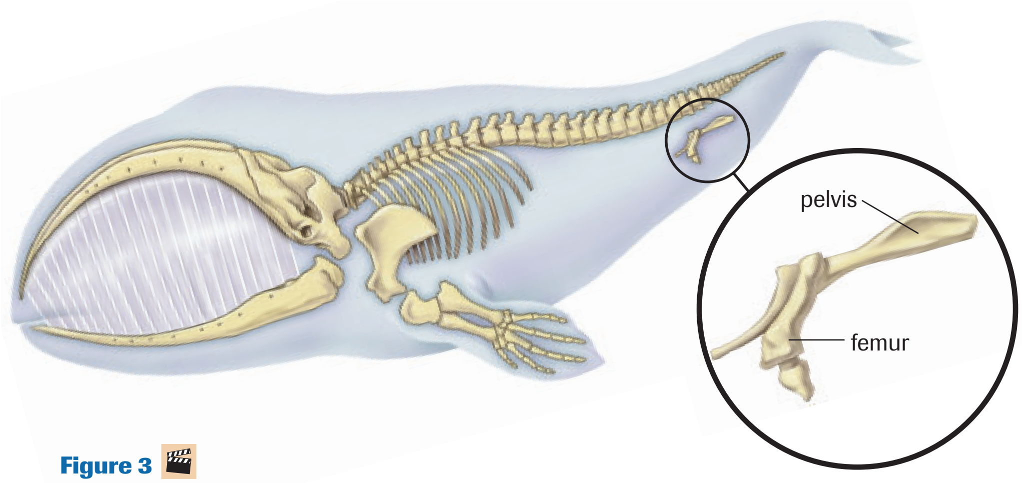

Figure 3
Whale skeletons have vestigial hip and leg bones.

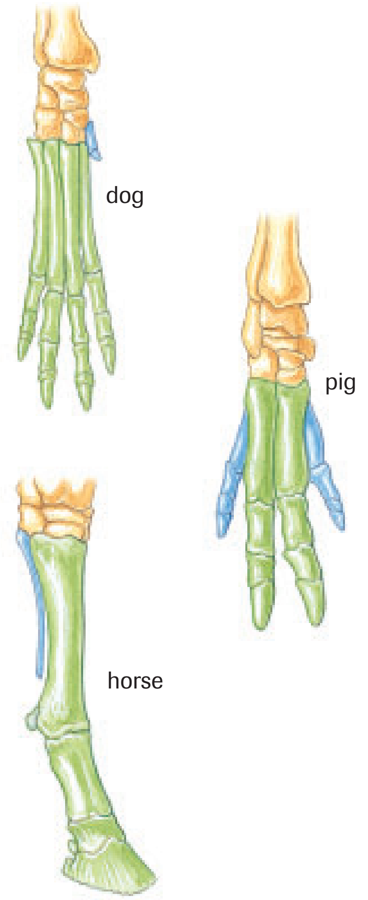

Figure 4
Dogs, pigs, and horses have at least one vestigial toe (blue). Although the bones remain, these digits no longer serve a purpose.

Practice

1. The shells of crabs and turtles serve a similar purpose. Are they homologous or analogous traits? What evidence did you use to reach your conclusion?
2. Would you consider human body hair to be a vestigial feature? Support your answer.

mini *Investigation* — *Variations on a Theme*

The forelimbs of different vertebrates are well adapted to serve specific functions. However, hypothesizing the potential adaptive advantage of such homologous features is not always easy. **Table 1** lists bird species with very different bills.

- Use print and Internet resources to explore the bill shapes of six of these species. Choose four species that are living (extant) and two that are extinct.

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(a) How does the shape of each bill contribute to the species' success?
(b) Write a hypothesis that explains the adaptive significance of each bill shape.

Table 1 Birds with Unique Bill Shapes

Extant	Extinct
pelican	dodo
nighthawk	diatryma
falcon	gastornis
bittern	
toucan	
hummingbird	
flamingo	
skimmer	
spoonbill	

Evidence from Biochemistry

Evidence for evolution has also been found by comparing biochemical characteristics of different species. Proteins are molecules that make up many structures in organisms, such as muscle cells and skin cells. Proteins are made up of long chains of amino acids, and each type of protein has a unique number and sequence of amino acids. Many species possess similar proteins. Studies suggest that, over time, similar proteins in different species become increasingly different in terms of their amino acid sequences. For example, hemoglobin is an oxygen-carrying protein present in all vertebrates. When scientists determined the amino-acid sequence of hemoglobin from different species, they found that the sequence varied. The differences were greater between species that were less similar overall, such as a macaque and a lamprey (**Figure 5**). This is evidence that, over time, the hemoglobin molecules evolved to have different characteristics.

EXTENSION

Nucleotide Sequences and Amino Acids

This Audio Clip describes how the sequence of nucleotides found in the genes determines which amino acids make up each protein. If the DNA is changed through a mutation, this can change the final protein product.

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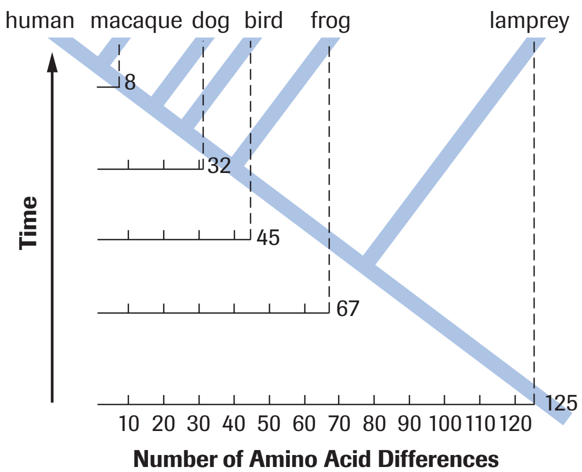

Figure 5
Differences in amino acid sequences in a portion of the hemoglobin protein reflect the degree of similarity among different species.

DNA the molecule that makes up genetic material

gene a segment of DNA that performs a specific function, such as coding for a particular protein

Scientists have also found evidence for evolution in DNA sequences. **DNA** (deoxyribose nucleic acid) is the hereditary material that determines which characteristics are passed on to the next generation. Every organism has a particular set of characteristics, or traits, that are inherited, such as eye colour in humans. Each DNA molecule contains many different **genes** that provide the instructions for these traits. Genes determine the particular traits of an individual, such as brown eye colour or green eye colour.

DNA is composed of four chemicals called nucleotide bases, or simply bases, arranged in different sequences (**Figure 6**). The four bases in DNA are adenine (A), thymine (T), cytosine (C), and guanine (G). DNA sequences from different species that code for the same protein vary in the number and order of the nucleotides.

cow AGTCCCCAAAGTGAAGGAGA CTATGGTTCCTAAGCACAAG GAAATGCCCTTCCCTAAATA

Figure 6
This is a segment of DNA from cows that codes for a milk protein.

Just as early biologists discovered homologous and vestigial *anatomical* features, geneticists have found large numbers of both homologous and vestigial *genes* in the DNA of virtually all species. For example, humans possess a set of defective genes that would allow us to make our own vitamin C. We have lost both the ability and the need to make vitamin C but still possess the useless genetic instructions to do so.

LAB EXERCISE 5.A

Report Checklist

- ○ Purpose
- ○ Problem
- ○ Hypothesis
- ○ Prediction
- ○ Design
- ○ Materials
- ○ Procedure
- ● Evidence
- ● Analysis
- ○ Evaluation
- ○ Synthesis

Evidence from Genetics

DNA fingerprinting is now used widely in criminal investigations. With this technique, forensic scientists can determine the probability that a DNA sample is from a particular individual or a close relative, with an unprecedented degree of certainty. DNA samples obtained from closely related individuals have more of the same DNA sequences; samples from the same individual are identical. This same principle applies to the DNA sequences from different species. More closely related species are more likely to have more similarities in the sequence of their DNA. In this activity, you will compare sequences of DNA from different species to infer their phylogeny, or kinship.

The Closest of Kin

The sequences of real data in **Figure 7** represent a segment of DNA that codes for the same milk protein in six different species. Each letter represents one nucleotide base in the DNA segment. The letters have been vertically aligned and colour coded to highlight similarities and differences between the species. Use the following guidelines to assist you in analyzing this DNA information:

- Only a shared difference offers evidence of evolutionary kinship. It suggests species may have inherited the difference from a common ancestor.
- The more base differences species have in common, the more likely they are to be closely related.
- Base sequences common to all species offer no useful information about relationships.
- A difference exhibited by only one species offers no information about kinship.

Evidence

(a) Design and construct a data table or spreadsheet that can be used to tabulate the numbers of shared differences between each possible pair of species.

(b) Tabulate your data.

Analysis

(c) Which pair of species had the greatest number of shared differences in their bases?

(d) Based on this evidence, what species is most closely related to the

(i) deer (ii) peccary (iii) whale?

(e) What evidence suggests that whales may be more closely related to cows than they are to pigs?

	143	162 166	182
	▼ ▼▼	▼ ▼▼ ▼ ▼▼	▼ ▼
cow	AGTCCCCAAAGTGAAGGAGA	CTATGGTTCCTAAGCACAAG	GAAATGCCCTTCCCTAAATA
deer	AGTCTCCGAAGTGXAGGAGA	CTATGGTTCCTAAGCACGAA	GAAATGCCCTTCCCTAAATA
whale	AGTCCCCAXAGCTAAGGAGA	CTATCCTTCCTAAGCATAAA	GAAATGCGCTTCCCTAAATC
hippopotamus	AGTCCCCAAAGCAAAGGAGA	CTATCCTTCCTAAGCATAAA	GAAATGCCCTTCTCTAAATC
pig	AGATTCCAAAGCTAAGGAGA	CCATTGTTCCCAAGCGTAAA	GGAATGCCCTTCCCTAAATC
peccary	AGACCCCAAACCTAAGGAGA	CCGTTGTTCACAAGCGTAAA	GGAATGTCCTCCCCTAAATC

Figure 7
These base sequences include positions 141–200 of a portion of the DNA molecules encoding a milk protein in six mammal species. Coloured bases indicate genetic changes shared by more than one species. The “X” denotes a base for which the original DNA sequencing data were inconclusive.

Evidence from Artificial Selection

Since the beginning of agriculture, humans have used artificial selection to alter the appearance, behaviour, and even chemical makeup of plants and animals. They select the individuals with the desired traits, breed them, and then pick the best offspring to breed again. Today's domestic animals and crop plants have been artificially selected over many hundreds of generations. **Artificial selection** is another word for plant and animal breeding, in which people breed individuals with desired characteristics in order to get offspring with those same characteristics.

artificial selection the process of humans selecting and breeding individuals with the desired traits

As an example, did you know that cabbage, broccoli, cauliflower, and ornamental kale are all the same plant species? Over the centuries, farmers and plant breeders selected characteristics of a single plant species, the sea cabbage, to produce a range of edible and ornamental varieties (**Figure 8**). The fact that humans can use artificial selection to produce such dramatic changes in species over relatively short periods of time provides compelling evidence that similar and even more dramatic changes occur in nature over millions of years and countless generations.

CAREER CONNECTION

Breeder

Plant and animal breeders use artificial selection to modify crops and livestock to have traits that are useful for humans. Breeders may work at universities, colleges, corporations, or directly in agricultural production.

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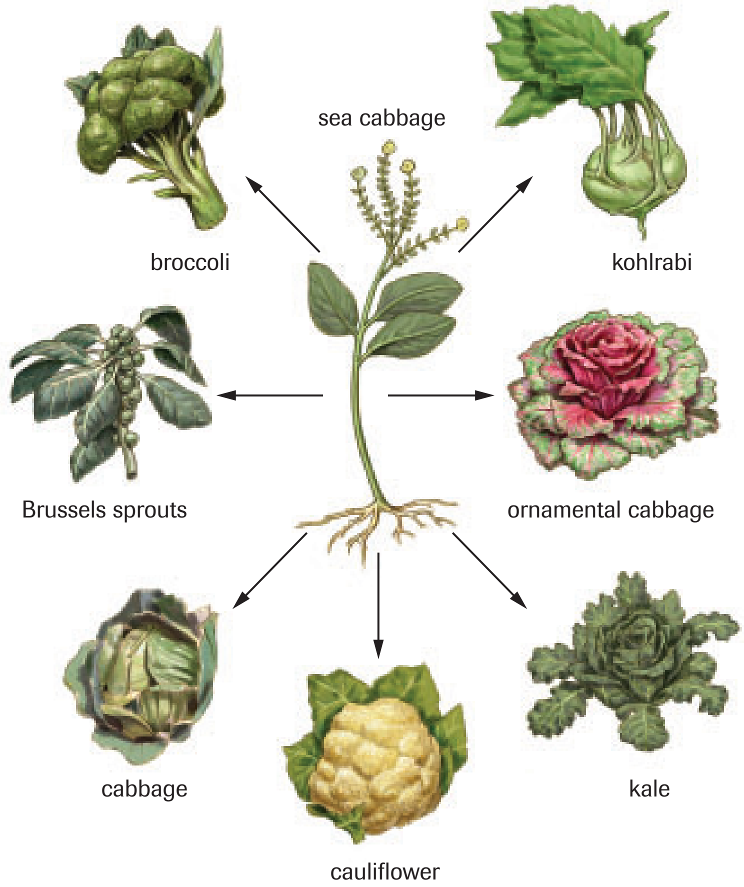

Figure 8
Artificial selection over many generations produced a range of useful varieties from sea cabbage.

WEB Activity

Case Study—Were Neanderthals Humans?

In the late 1990s, several samples of DNA were successfully extracted from the teeth of well-preserved Neanderthal fossils. The DNA was then copied and sequenced.

In this activity, you will go online to compare the actual DNA sequences of ancient Neanderthals, modern humans, and chimpanzees. Note that this research involved the analysis of mtDNA, DNA that is present within the mitochondria of all cells.

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SUMMARY *Evidence of Evolution from Biology*

- Multiple lines of evidence suggest species have a shared ancestry.
- Homologous and vestigial features provide evidence of specific changes.
- DNA analysis can be used to reveal phylogenetic relationships between different species or groups.

Section 5.3 Questions

1. For each of the following vestigial features, write a hypothesis for its ancient function and indicate a change that may have led to the loss of this function. Show your answer in a graphic organizer.
   (a) pelvic (hip) bones in some whales
   (b) elevated toe on hind leg of deer
   (c) human "goosebumps"
   (d) human muscles for moving the outer ear
   (e) rudimentary wings in flightless insects, such as earwigs
2. Dolphin flippers contain a wrist and set of digit bones and associated muscles. Explain how this provides evidence that cats and dolphins share a common evolutionary origin.

Extension

3. Examine **Figure 9**. Each of these series of letters represents the partial sequence of amino acids for the same type of protein in each of six different species. Each letter represents a specific kind of amino acid. Highlighted letters show differences in the sequence as compared to that of the chicken. The order and type of each amino acid is coded by inherited genetic information. Therefore, based on evolutionary theory, we would expect more closely related species to have more similar sequences.

Species: tuna, turtle, dog, screwworm fly, penguin.

chicken	GDIEKGKKIFVQGKCSQCH
________	GDVEKGKKIFVQGRCAQCH
________	GDIEKGKKIFVQGKCSOCH
________	GDVAKGKKTFVQGKCAQCH
________	GDVEKGKKIFVQGKCAQCH
________	GDVEKGKKIFVQGKCAQCH

Figure 9

Based on this evidence, compare each sequence to that of the chicken, and match each species with its most probable sequence.

4. New Zealand scientist David Lambert collected DNA samples from 7000-year-old nesting grounds of the Adélie penguin in Antarctica. He collected wonderfully preserved DNA samples from ancient frozen bones in layers of ice directly beneath the present-day nesting colonies. Use the Internet to learn his findings. What does Lambert's evidence suggest about the rate of evolutionary change in this species of penguin?

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5.4 The Making of a Theory—Accounting for the Evidence

Figure 1
Charles Darwin

A scientific theory is a model that accounts for all of the known scientific evidence as completely as possible. It provides a plausible explanation of how things in nature are related and enables scientists to make testable predictions. As evidence accumulates, scientists alter or modify a theory to fit the new data.

Before the 18th century, it was widely believed that living things were "fixed" and that they retained the same form from when they first appeared on Earth. During the second half of the 18th century, a number of scholars began to speculate and speak out on the issue of evolution. Georges-Louis Leclerc de Buffon, a leading naturalist, proposed that species could change over time and that these changes could lead to new organisms. Similar views were put forth in 1760 by Carl Linnaeus, the founder of biological nomenclature, and in 1794 by Erasmus Darwin, the grandfather of Charles Darwin (**Figure 1**). Linnaeus proposed that the few species at creation had become hybrids, which had then formed many new species. Erasmus Darwin presented a strong case for the idea that all life had developed from a single source. Such ideas were not widely accepted.

spontaneous generation the belief that living things arose from non-living matter

inheritance of acquired characteristics the false concept of inheritance of features acquired during the life of an individual

Lamarck's Theory

In the early 1800s, a student of Buffon, Jean-Baptiste Pierre Antoine de Monet Chevalier de Lamarck, presented the first theory of evolution that included a *mechanism*. Lamarck believed that new, very simple species were continually being created by **spontaneous generation** (by arising spontaneously from non-living matter), and then gradually became more complex. He believed that organisms had a "force" or "desire" that led them to change for the better, and that organisms must be able to produce new parts to satisfy these needs and become better adapted to their environment. Lamarck reasoned that the use and disuse of certain structures could be passed on to the offspring. For example, Lamarck proposed that one generation of giraffe might have had to obtain food that was higher in trees. The continual stretching of the neck would lead to a slight elongation of the neck over a lifetime. Lamarck postulated that this acquired trait, a slightly longer neck, would be inherited by offspring. This pattern of inheritance over many generations eventually led to the very long necks now found in the giraffe (**Figure 2**). Today the term "Lamarckism" is used to describe the concept of **inheritance of acquired characteristics**. We now know that acquired traits cannot be inherited, but Lamarck did recognize that the environment played a role in driving evolutionary change.

Figure 2
Lamarck believed that the long neck of a giraffe came from generations spent reaching for food.

Practice

1. Make a two-column chart with the headings "Inherited traits" and "Acquired traits."
   (a) In each column, write examples of your own traits (these can be physical or behavioural).
   (b) Which, if any, of your inherited traits could be altered during your life? How?
   (c) Which, if any, of your acquired traits can be passed on to your offspring? How?

Darwin's Theory

In 1831, Charles Darwin set sail on HMS *Beagle* to travel around the world. He returned in 1836 filled with enthusiasm and questions about what he had seen and experienced. The following list highlights some of the now famous evidence Darwin gathered while on his voyage and the inferences he would later draw from them:

1. In South America, Darwin observed unusual fossil species that resembled giant variations of the sloths and armadillos living in the same region. He suspected that the living forms might have descended from the fossilized species.
2. He noted that species living in the South American tropics did not resemble those living in the African tropics. Instead, they were more like the species living in cooler parts of South America. He inferred that each such landmass might have acted like an isolated nursery, in which sets of species had evolved independently.
3. The harsh landscape of the Galapagos Islands was home to 13 very similar species of finches (**Figure 3**). Found nowhere else on Earth, these birds most closely resembled species living in a very different habitat on the coast of South America, 1000 km to the east. Darwin speculated that they had all evolved from a single species that had arrived in the Galapagos from South America.
4. Darwin observed fossil deposits of corals at an elevation of 3000 m in the Andes Mountains. After experiencing a severe earthquake that lifted portions of the coastline 3 m upward, Darwin became convinced that such geological forces, given vast expanses of time, could account for the location of the fossils and the mountains.

Long after his voyage, Darwin continued to gather evidence, performing thousands of experiments and bombarding experts in every field of biology with questions. He became keenly interested in artificial selection, soon recognizing that all species possessed inherited variations that could be selected to change the traits of a species in desirable ways. Darwin reasoned that if people could alter the appearance and behaviour of species through artificial selection, then the environment could have a similar selective effect on wild species.

Darwin found the final piece of his puzzle in a mathematics paper written in 1778 by Thomas Malthus, *Essay on the Principle of Population*. Malthus showed that all species produce far more offspring than are able to survive. Darwin realized that, since so many offspring were being born, there must be intense competition among them for suvival. Darwin then put together a workable theory of evolution by **natural selection**. By June of 1858, he had written a quarter of a million words toward a major treatise, when he received a letter from Alfred Russell Wallace, a brilliant naturalist working in Malaysia. Wallace had independently arrived at the same conclusions as Darwin and described his own theory in the letter. Learning of the situation, Darwin's colleagues convinced him to submit a paper along with Wallace's at a meeting on July 1, 1858. A year and a half later, Darwin published *On the Origin of Species by Means of Natural Selection or The Preservation of Favoured Races in the Struggle for Life*. It sold out on the first day. **Table 1** summarizes Darwin and Wallace's Theory of Evolution by Natural Selection.

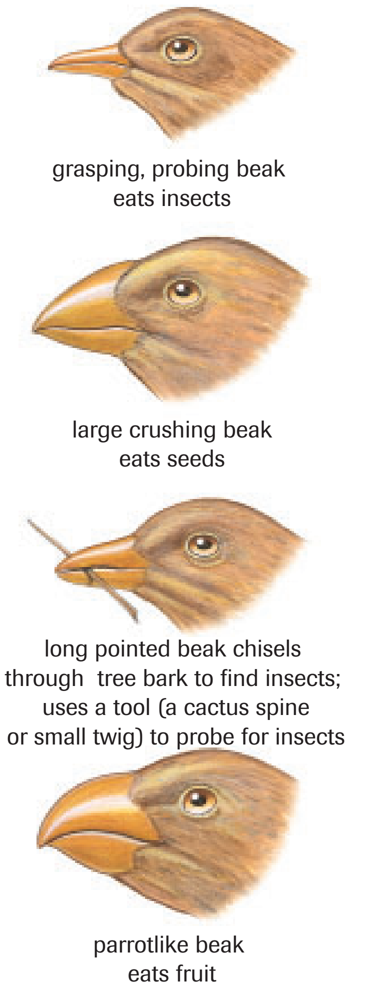

Figure 3
Some of the beak modifications that Darwin noted among the 13 similar species of finches on the Galapagos Islands

Table 1 The Theory of Evolution by Natural Selection

Observation 1	Individuals within any species exhibit many inherited variations.
Observation 2	Every generation produces far more offspring than can survive to reproduce.
Observation 3	Populations of species tend to remain stable in size.
Inference 1	Individuals of the same species are in a constant struggle for survival.
Inference 2	Individuals with more favourable variations are more likely to survive and pass these variations on. Survival is not random. *This* is natural selection.
Inference 3	Since individuals with more favourable variations contribute proportionately more offspring to succeeding generations, their favourable inherited variations will become more common. *This* is evolution.

natural selection the result of differential reproductive success of individuals caused by variations in their inherited characteristics.

Practice

2. After returning from his famous voyage, Darwin began to believe that species could change. What steps did he take to gather evidence to support this possibility?
3. Describe the impact that the principles in Malthus's essay had on Darwin's thinking.

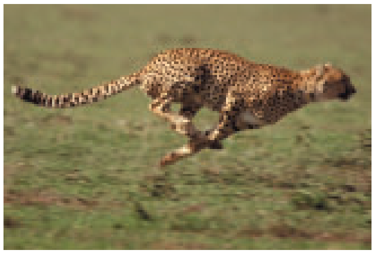

Figure 4
Cheetahs rely on their speed to help them catch their prey.

Natural Selection

How does this process of natural selection operate in nature? Imagine an ancient population of cheetahs with different running speeds. The faster cheetahs probably caught prey more easily and stayed healthier. Such fit individuals might have been better able to compete for mates, provide better nourishment and protection for their young, and lead longer reproductive lives. Natural selection would favour the reproductive success of the faster individuals. Natural selection may therefore account for the running speed in modern-day cheetahs (**Figure 4**).

Darwin's theory is based on a very simple set of observations and logical reasoning. He observed that all species exhibited inherited variations. He reasoned that, because of those differences, some individuals are better adapted to survive and reproduce than others are. Over time, the inherited traits that provided the survival advantage would become more common in the population. The population would have evolved.

Even without evidence from chemistry and genetics, scientists had accumulated sufficient evidence for general agreement that Earth's populations had a history of change by the mid-1800s. This evidence from paleontology, geology, biogeography, anatomy, and artificial selection is consistent with this idea. However, it was not until the early 1900s that scientists formulated a reasonable explanation, or theory, that could explain *how* such change occurred—the *mechanism* of evolution. As you will read in the next section, this was not possible until scientists began to understand how traits are inherited from parent to offspring.

EXTENSION

The Peppered Moth
One example of natural selection at work is the changes in the peppered moth that occured during the Industrial Revolution. You can explore these changes by viewing an animation and then carrying out this extension activity.

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SUMMARY The Making of a Theory—Accounting for the Evidence

- Buffon, Linnaeus, and Erasmus Darwin were among the first prominent scientists to suggest that species could change over time.
- Lamarck was the first to recognize that the environment played a central role in directing adaptation, and to develop a plausible theory of how evolution might occur—by the inheritance of acquired characteristics.
- Charles Darwin based his theory of evolution by natural selection on evidence from many sources, including his five-year voyage on the *Beagle*.
- Darwin and Wallace's theory of natural selection states that evolution occurs because those individuals best suited for survival contribute a greater proportion of offspring with similar traits to the next generation.

Section 5.4 Questions

1. In some wild deer populations, selection by humans favours the survival of smaller males, since large bucks are preferentially hunted.
   (a) What would you expect to happen to the genetic makeup of this population over time?
   (b) In these populations, will mutations for "small size" occur more often than for "large size"? Explain.
2. Create a table to compare and contrast Lamarck's and Darwin's explanations of the mechanism of evolution.
3. Sir Isaac Newton credited the work of Galileo and others for his own successes, declaring that: "If I have been able to see further, it was only because I stood on the shoulders of giants." Describe the contributions of four scientists on whose work Darwin relied for his achievement.

Sources of Inherited Variation 5.5

Recall that Darwin's theory of natural selection states that individuals that are better adapted to their environment will contribute more offspring to the next generation. These offspring have traits similar to their parents, and so will in turn be better adapted. Over time, natural selection leads to a change in the traits of the species as a whole—that is, to evolution. However, natural selection can only occur when there was variation in the traits of the individuals that make up a species. Where does this variation come from? When Darwin published *On the Origin of Species*, scientists were not able to answer this question. It took until the 1930s until biologists understood enough about genes and their role in inheritance to start to answer this question. Variability in a species may arise from two biological processes: mutations and sexual reproduction.

Mutations

DNA, the hereditary material, is found in the chromosomes of a cell (**Figure 1**). DNA is composed of long sequences of the four nucleotide bases—adenine (A), thymine (T), cytosine (C), and guanine (G). The sequence of these bases forms a code which, when translated by the cell, gives an organism specific inherited traits. Genes are segments of DNA that code for specific traits. Each gene has a specific DNA sequence. DNA is therefore like a blueprint for a particular individual organism.

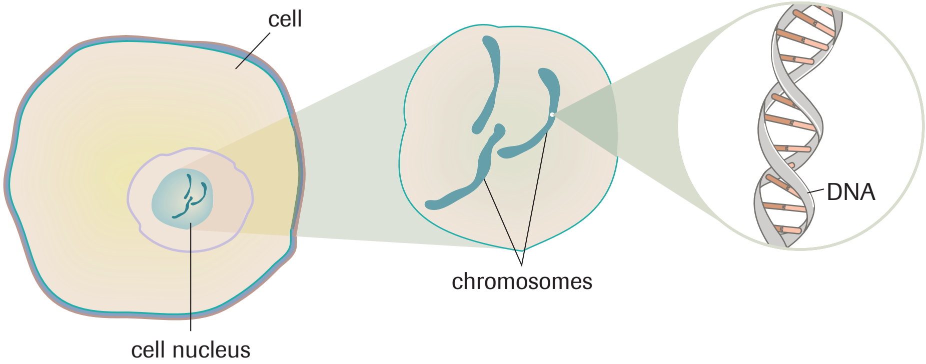

Figure 1
DNA, the genetic material, is packaged in chromosomes in the cell. The DNA molecule is composed of two strands of nucleotide bases.

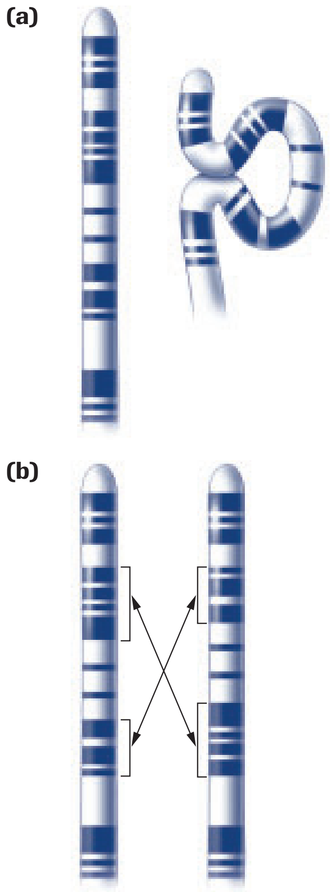

Figure 2
Some mutations result in the reversal of banding patterns along chromosomes. In **(a)**, the chromosome on the right undergoes a mutation in which the looped section breaks and re-attaches in the opposite "flipped" orientation **(b)**.

In most cases, the DNA of an organism will remain the same throughout its life. Sometimes, however, DNA changes occur, and entirely new genetic information can arise. **Mutations** are random changes in the DNA itself, and they provide a continuous supply of new genetic information. Mutations can be caused by environmental factors such as chemicals or radiation, or from errors that arise when cells use or make copies of the DNA molecules. There are many types of mutations. Some involve the loss or duplication of entire sections of DNA, while others may be simple changes to the DNA sequence (**Figure 2**). Mutations are relatively rare in individuals—roughly about one new mutation per sex cell. In large populations reproducing over many generations, however, the number of mutations is substantial.

mutation a change in the DNA sequence in a chromosome

neutral mutation a mutation that has no effect on the organism

fitness an organism's reproductive success

harmful mutation a mutation that reduces an organism's fitness

beneficial mutation a mutation that enhances an organism's fitness

The effects of a mutation depend on what DNA sequence is altered and how it is affected. A **neutral mutation** has no immediate effect on an individual's **fitness**, or reproductive success. A **harmful mutation** reduces an individual's fitness. A **beneficial mutation** gives an individual a selective advantage. Most mutations are neutral or harmful in nature.

There are three common misconceptions about how mutations contribute to evolution. These misconceptions are given in **Table 1**, along with the accepted understanding based on observations.

Table 1 Mutation Misconceptions

Misconception	Accepted Understanding
Mutations occur when "needed," in response to environmental challenges.	Mutations occur at random, with harmful mutations being more common than beneficial mutations. There is no design to it.
Since harmful mutations are more common than beneficial mutations, they can accumulate and the species will steadily degrade.	Harmful mutations are *selected against* and therefore do not accumulate over the generations. The environment favours the fittest organisms. Harmful mutations can reduce or even eliminate the individual's chance of reproductive success.
Since mutations are random or chance events, then evolution is just pure chance.	Although beneficial mutations are rare, they are *selected for* and may accumulate over the generations. Beneficial mutations often give individuals improved survival and reproductive success.

EXTENSION

Mutations and Changes in Proteins

Listen to a discussion of how mutations can cause proteins to change, which might then affect the survival of an organism.

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Practice

1. In your own words, explain the role, if any, that neutral, harmful, and beneficial mutations each play in evolution.

Sexual Reproduction and Variability

asexual reproduction the production of offspring from a single parent; offspring inherit the genes of that parent only

siblings offspring from the same parent (in asexual reproduction) or parents (in sexual reproduction)

sexual reproduction the production of offspring by the union of sex cells from two different parents; the offspring inherit a combination of genes from both parents

In species that undergo **asexual reproduction**, such as bacteria, an individual reproduces without a mate. The offspring receives an identical copy of its parent's DNA. As a result, the offspring has identical traits to its parent and to any other offspring from that parent (**siblings**). The exception to this occurs if there is a mutation in the DNA. As you have read, mutations are relatively rare. As a result, there is very little inherited variability in asexually-reproducing species and very few traits that can be selected by natural selection.

In contrast, there is a great amount of inherited variability in species that undergo **sexual reproduction**. For example, think of the variation among just the people you know. Most plants and animals reproduce sexually. In sexual reproduction, the offspring are never identical to the parents or to other siblings (except for identical twins). Sexually reproducing species therefore have many traits on which natural selection can act.

Why are sexually-reproducing species so variable? There are three reasons.

1. Sexually-reproducing species have two copies of each gene. Each copy of the gene may be identical or different. In sexual reproduction, there are two parents. Both parents contribute one copy of each gene to the offspring. An offspring therefore inherits one copy of each gene from one parent and one copy from the other parent. The offspring therefore has a different combination of genes than either parent, and therefore will have its own unique set of traits.

2. The assortment of genes that an offspring inherits from either parent is determined randomly. Each sibling therefore has a unique combination of genes, and so siblings from sexual reproduction are not identical to each other. (Identical twins are an exception to this.) To illustrate, let's say that a large, black male dog is crossed with a small, brown female dog. A puppy from this cross might inherit any combination of these traits. For example, one puppy might be a large, brown female while another might be a small, black male. (There are other combinations as well.) The greater the number of genes a species has, the larger the number of combinations and the greater the genetic variability of the species as a whole.
3. Sexually reproducing species choose different mates. This process is not always random, but each combination of parents will give rise to different combinations of genes and traits in the next generation. In a small population of 1000 males and 1000 females, there are 1 million different possible mating pairs.

Table 2 connects genetics and Darwin's theory of natural selection.

Table 2 Genetic Mechanisms and Darwin's Theory

Darwinian evolution	Genetic mechanisms
inherited characteristics	Inherited characteristics are determined by genes. Organisms typically possess thousands of different genes.
population variability	Individuals of the same species differ from one another, in part because they possess different combinations of genes. The genetic makeup of all individuals within a population is called the population's **gene pool**.
source of new variations	New traits can arise when genes become mutated.
natural selection	Some genes determine traits that make the individual better suited for survival and reproductive success. Individuals with these traits will produce more offspring, some of which will inherit these advantageous genes.
evolutionary change	Over many generations, individuals carrying the genes that determine the most favourable traits for survival and reproductive success will become more common in the population. Evolution is this change in the population's gene pool.

DID YOU KNOW?

Thomas Kuhn

A well-known philosophy of scientific thought put forward by Thomas Kuhn in a book published in 1962 proposes that scientific knowledge advances by gradual study and research, interspersed with abrupt jumps forward, known as "paradigm shifts." How might the theory of evolution help to back up Kuhn's philosophy?

gene pool all the genes in a certain population

mini Investigation: Genetic Shuffle

In this activity, you will model the amount of possible variation for different numbers of traits in a sexually-reproducing species, using a deck of playing cards. Each card represents the gene for a particular trait. The suits represent the different forms of a gene. Since there are four suits in a deck of card, there are four possible forms for each gene in this model.

Materials: playing cards

- Obtain all four suits for any four different playing cards. Divide them into two sets to represent the genetic makeup of two parents. For example:

  Father: 3 of spades and 3 of clubs;
  8 of spades and 8 of clubs;
  Jack of spades and Jack of clubs;
  King of spades and King of clubs

  Mother: 3 of hearts and 3 of diamonds;
  8 of hearts and 8 of diamonds;
  Jack of hearts and Jack of diamonds;
  King of hearts and King of diamonds

- Using your cards, determine the number of all possible different genetic combinations from the two parents for one of the traits. Record your results in a table or spreadsheet.
- Repeat the procedure for two, three, and then four traits. You may wish to devise a method of organizing your different genetic combinations.

(a) What did you notice about the number of possible combinations as the number of traits increased?

(b) Humans possess genes for over 30 000 different genetic traits. With the exception of identical twins, is it surprising that no two siblings are alike? Explain.

INVESTIGATION 5.2 *Introduction*

Measuring Inherited Variation

In this investigation, you will design and conduct experiments to quantify inherited variations in living populations of a very successful species, *Homo sapiens.* You will then design and carry out your own investigation into the amount of variation in an inherited trait of a species of your choice.

Report Checklist

- ○ Purpose
- ○ Problem
- ● Hypothesis
- ● Prediction
- ● Design
- ● Materials
- ● Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ● Synthesis

To perform this investigation, turn to page 164.

SUMMARY *Sources of Inherited Variation*

- Inherited variations are determined by differences in genes between individuals.
- The study of genetics redefined evolution as a change in the genetic makeup of a population over time.
- Since genes recombine during sexual reproduction, this process contributes to individual variability in populations.
- Mutations are the only source of new genetic material. Mutations may be neutral, harmful, or beneficial.
- Beneficial mutations may increase the fitness and reproductive success of an individual and therefore may become more common in a population. Harmful mutations decrease fitness and reproductive success and do not tend to accumulate.

Section 5.5 Questions

1. What key information regarding variation was missing in Darwin's explanation of the evolution of species?
2. Compare and contrast the contributions of sexual reproduction and mutation in producing variation within populations. Consider both short- and long-term influences.
3. Following their initial contact with non-indigenous people, many populations of indigenous peoples suffered devastating losses from previously unknown diseases. How might evolutionary biology account for their low resistance to these diseases?
4. Examine the collection of sea urchins in **Figure 3**. Prepare a design statement for an investigation to compare the inherited variation in these species.

Extension

5. Research Richard Dawkins's theory about "selfish genes." Prepare arguments and counter-arguments for a class debate on his theory.

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Figure 3
Sea urchin exoskeletons

Speciation and Evolution 5.6

Natural selection provides an explanation of how species become better adapted to their environment. Does it also account for the formation of new species (**speciation**) and, from there, entire new groups of living organisms? A species can be thought of as a population of individuals who are reproductively isolated—they are not capable of breeding with individuals of other species under natural conditions. Most new species are believed to arise by a three-step process called **allopatric speciation**.

1. A physical barrier separates a single interbreeding population into two or more groups that are isolated from each other. Any mutations that occur in one of these isolated groups are not shared with the other population(s) (**Figure 1**).
2. Natural selection works on the separated groups independently, resulting in inherited differences in the two populations. In other words, the populations evolve independently. Differences in selective pressures will be greater if the populations experience pronounced differences in their environments.
3. In time, accumulated physical and/or behavioural differences between the populations become so pronounced that the groups, should they be reunited, would no longer be sexually compatible. At this point, they have formed two or more distinct species (**Figure 2**).

Physical barriers range in size from entire mountain ranges and oceans to river channels and canyons. On a smaller scale, human constructions such as dams and canals may produce insurmountable physical barriers to small organisms.

Speciation can also occur when a single population splits into distinct breeding populations when occupying a single geographic region (**Figure 3**). This process can be sudden. One form occurs when a mutation results in individuals with double or more the normal number of chromosomes. These individuals may be healthy and vigorous but reproductively isolated from the rest of the population. They are only able to mate with other similar polyploids. Many plant species are thought to have evolved by this mechanism.

speciation the formation of new species

allopatric speciation speciation by reproductive isolation

Figure 1
Wood bison **(a)** and plains bison **(b)** are reproductively isolated. Wood bison live in northern wooded areas in Canada, while plains bison live on the Prairies in both Canada and the United States.

Figure 2
This black-and-white lemur of Madagascar island is an example of allopatric speciation. Separated from the continent of Africa for over 1 million years, Madagascar now hosts some 8000 plant species and 1200 animal species found nowhere else.

Figure 3
Genetic evidence strongly suggests that a number of different species of sticklebacks living in some lakes in British Columbia evolved as a result of mutations that produced sudden changes in chromosome numbers.

WEB Activity

Case Study—Lactose Intolerance and Evolution

Lactose intolerance is the inability to digest lactose (milk sugar). Interestingly, certain groups of people, including First Nations people and those of African descent, are more likely to suffer from this condition. How does the theory of evolution account for these findings? Can we make and test predictions regarding the evolution of this condition? Working in a small group, investigate these questions by completing this Web Activity.

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The Rate of Evolution

theory of gradualism the idea that speciation takes place slowly

theory of punctuated equilibrium the idea that species evolve rapidly, followed by a period of little or no change

Until the mid-20th century, most biologists thought that changes to species occurred at a slow, steady pace. By this **theory of gradualism**, we would expect to find many fossils that showed small changes in species over time. Instead, distinct species often appear abruptly in the fossil record, and then little further change is seen over very long periods of time. In 1972, Niles Eldridge of the American Museum of Natural History and Stephen Jay Gould of Harvard University proposed **the theory of punctuated equilibrium** to account for these patterns in the fossil record. This theory has three main assertions:

- many species evolve very rapidly in evolutionary time
- speciation usually occurs in small isolated populations, so intermediate fossils are very rare
- after an initial burst of evolution, species are well adapted to their environment and so do not change significantly over long periods of time

These contrasting theories about the rate of evolution are shown in **Figure 4**. To some extent, the differences between them are a matter of perspective. To paleontologists, a sudden or "rapid" change might mean the appearance of a new species in the fossil record within 100 000 years. In fact, both theories are needed to understand the fossil record while remaining compatible with many other forms of evidence.

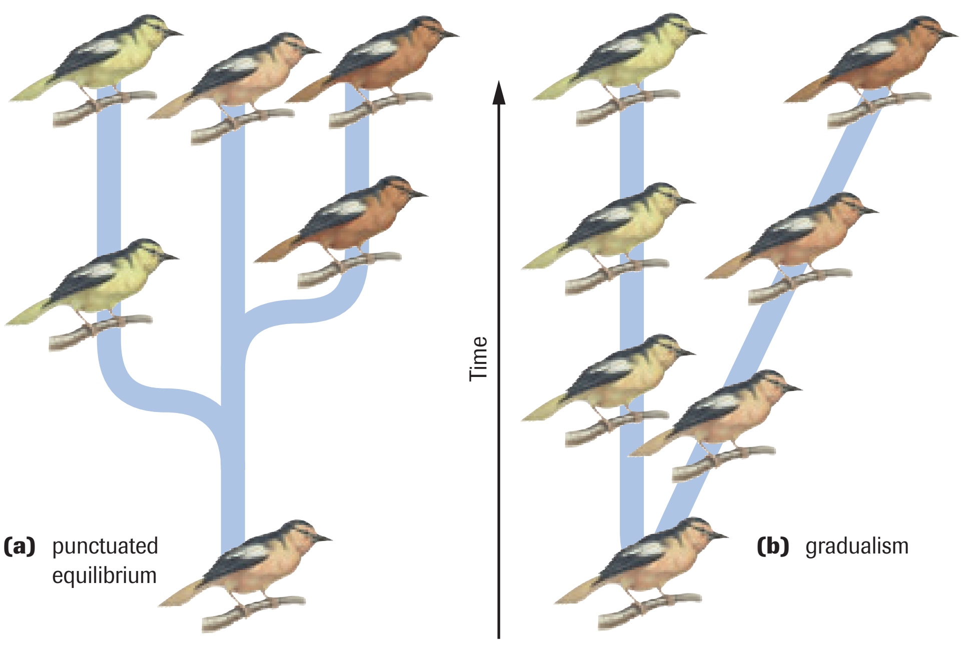

Figure 4
Two theories of the rate of evolution

Macroevolution: Diversification and Extinction

Figure 5, on the next page, shows the geological time scale and summarizes significant events in Earth's evolutionary history. Since life began, Earth has experienced an increase in diversity of living things. However, this trend has been interrupted by several major "extinction events," each identified by a thick red line in **Figure 5**. The Paleozoic era, for example, began with a rapid increase in the number of species, referred to as the Cambrian explosion, and ended 245 mya (million years ago) with the dramatic Permian extinction.

There is extensive fossil evidence for the Cambrian explosion. One of the most important fossil discoveries in the world, the Burgess Shale in Canada's Rocky Mountains, contains beautifully preserved 515-million-year-old fossils of marine life. The great diversity—more than 120 species—is evidence of **divergent evolution**, when species rapidly evolved into many different species during the early Cambrian period.

divergent evolution evolution into many different species

At the end of the Paleozoic era, between 240 and 225 mya, a series of cataclysmic events eradicated more than 90 % of the known marine species. The causes of this Permian extinction are unknown, but many scientists suspect tectonic movements. The Mesozoic era, well known for its dinosaurs, also came to a sudden end about 65 mya, when the remaining dinosaurs and many other species suddenly disappear from the fossil record. Considerable evidence supports the hypothesis that an asteroid impact caused this best-known mass extinction. The Chicxulub Crater, almost 10 km deep and 200 km in diameter at the edge of the Yucatán Peninsula (**Figure 6**), is thought to have been the impact site. The debris and energy released in the resulting fireball—equivalent to 100 million nuclear bombs—would have killed most of the plants and animals in North and South America within minutes. Tsunamis 120 m high would have devastated coastlines around the world, and atmospheric debris would have blocked out much of the sunlight for months or even years.

Figure 6
A computer-generated image of the moment of impact that created the 200-km-wide Chicxulub Crater, in the ocean floor at the edge of the Yucatán Peninsula.

While the mass extinctions that ended the Permian and the Mesozoic eras are dramatic, it is important to keep in mind that most extinctions of species result from the ongoing evolutionary forces of competition and environmental change. This "background" rate of extinction is slow—the average species exists for about a million years.

Putting the Theory of Evolution to Work: Predictions

All scientific theories are judged on their ability to (1) account for old and new evidence and (2) make testable predictions. How does the theory of evolution stand up to this judgement? As you have learned, the theory of evolution is clearly able to account for a wide range of evidence, but can it be used to make testable predictions?

Because evolution is usually a very slow process, it is difficult to witness evolutionary change directly, making it difficult to test predictions about the future evolution of a species. Predicting future *events,* however, provides an equally rigorous method of testing a theory. The following example illustrates such a test.

Prediction: Because they are not mobile, plants will have evolved toxic and bitter-tasting compounds to deter predators. These compounds are likely to be concentrated in their delicate leaves.

Evidence: Most plant tissues, and particularly leaf tissues, are far more toxic than animal tissues.

EXTENSION

Measuring Time
This video discusses evidence of changes in Earth's history resulting from the asteroid that hit the Yucatán Peninsula.

www.science.nelson.com GO

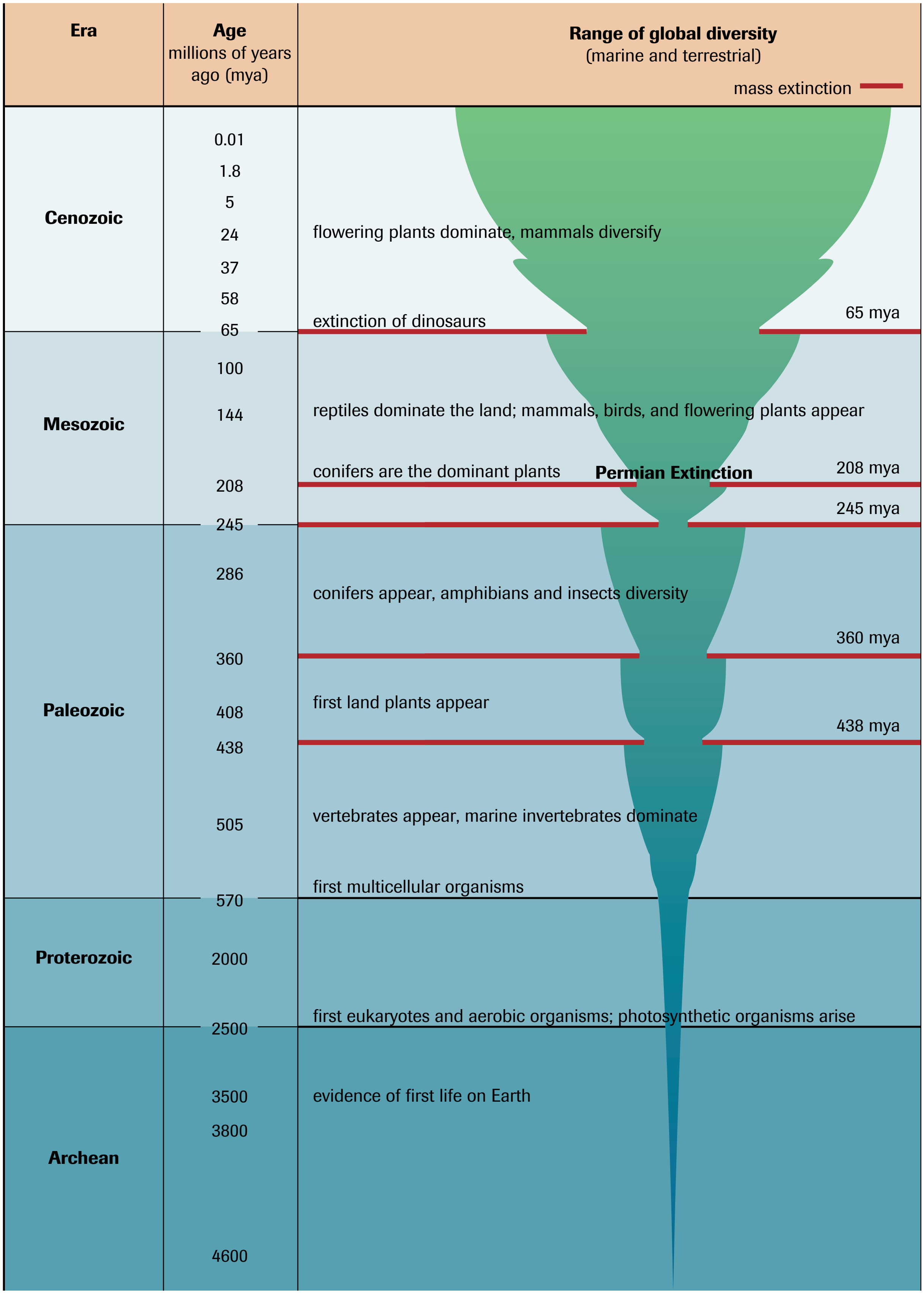

Figure 5
Major events of life on Earth

WEB Activity

Simulation—Natural Selection

The reproductive success of the peppered moth has been observed to be related to its colouring. In this online investigation, you will observe the effects of a change in the colour of environment on a population of virtual creatures of variable coloration. Will the simulation model the real-life observations with peppered moths?

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SUMMARY Speciation and Evolution

- New species have evolved when two or more populations become reproductively isolated from each other.
- Geographic isolation may be the most common cause of populations evolving into separate species (allopatry).
- The pace, or rate, of evolution is variable—the theories of gradualism and punctuated equilibrium account for various patterns seen in the fossil record.
- Earth has experienced periods of rapid diversification of living things—divergent evolution—as well as episodes of mass extinction.

Section 5.6 Questions

1. Outline the steps involved in allopatric speciation.
2. Living in the same region, the almost identical species of tree frog, *Hyla veriscolor* (**Figure 7 (a)**) and *Hyla chrysoscelis* (**Figure 7 (b)**) are distinguished only by their vocal calls and their DNA. *H. veriscolor* has exactly twice the number of chromosomes as *H. chrysoscelis.* How might *H. versicolor* have evolved?

(a) **(b)**

Figure 7

3. Construction of a canal through Panama has affected marine and terrestrial species. Consult an atlas to see the extent of the canal.
   (a) Comment on effects on the evolution and speciation of Atlantic and Pacific marine organisms in the vicinity of the Panama Canal.
   (b) How might the construction of the Panama Canal have influenced the evolution of terrestrial species?
4. What aspect of the fossil record suggests that evolution may occur rapidly?
5. Compare and contrast the theories of punctuated equilibrium and gradualism.
6. Evolutionists have concluded that mammals evolved from a group of reptiles. Based on your understanding of fossil formation and evolution, make a testable prediction about the fossil records of mammals and reptiles. Conduct literature and Internet research to see if your prediction was valid.

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INVESTIGATION 5.1

Report Checklist

● Purpose	● Design	● Analysis
● Problem	○ Materials	○ Evaluation
○ Hypothesis	● Procedure	● Synthesis
● Prediction	● Evidence	

Using a Classification Key

Whales are often grouped as either toothed or baleen whales. Baleen whales have a series of vertical plates that branch and crisscross at the opening of the mouth. Each plate acts as a filter, straining small marine life from the seawater.

Purpose

To identify various species of whales using a dichotomous key

Procedure

1. Use **Figure 1** to help you identify the whale's body structures referred to in the key.

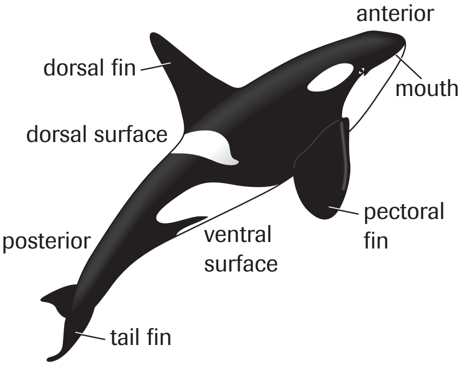


Figure 1

2. To identify each whale in **Figures 2** to **8**, start by reading part 1(a) and (b) of The Key (below). Then follow the "Go to" direction at the end of the appropriate sentence until the whale has been properly classified.

Analysis

(a) What are four characteristics used to classify whales?

(b) Why might biologists use a key?

(c) Provide an example of when a biologist might use a key to classify whales.

(d) Make a list of other characteristics that could be used to classify whales.

Evaluation and Synthesis

(e) Research to find out more about whales, for example, their distribution ranges and whether a species is threatened or endangered.

(f) Identify eight different trees or shrubs native to your locale and make a dichotomous key that allows others to identify them.

The Key	
1. (a) baleen plates (b) teeth	Go to 2. Go to 4.
2. (a) dorsal fin (b) no dorsal fin	Go to 3. bowhead whale (*Balaena mysticetus*)
3. (a) long pectoral fin (b) short pectoral fin	humpback whale (*Megaptera novaeangline*) blue whale (*Balaenoptera musculus*)
4. (a) no dorsal fin (b) large dorsal fin	Go to 5. killer whale (*Orincus orca*)
5. (a) small nose (b) large projection from nose	Go to 6. narwhal (*Mondon monoceros*)
6. (a) mouth on ventral surface (underside) of head (b) mouth at the front of head	sperm whale (*Physeter macrocephalus*) beluga (*Delphinapterus leucas*)

INVESTIGATION 5.1 *continued*

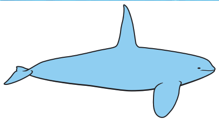


Figure 2
- teeth
- adult length: 6.0 m (females), 6.7 m (males)
- adult mass: 7.4 tonnes (t) (females), 10.5 t (males)

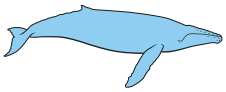
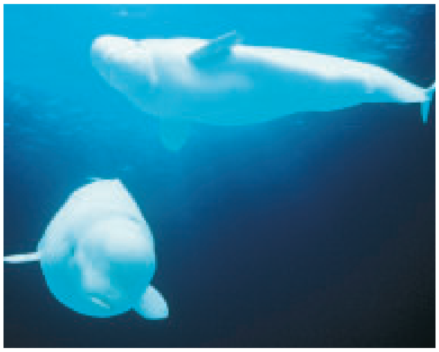


Figure 3
- baleen plates
- adult length: 13.7 m (females), 12.9 m (males)
- adult mass: 25 t–30 t



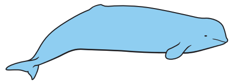
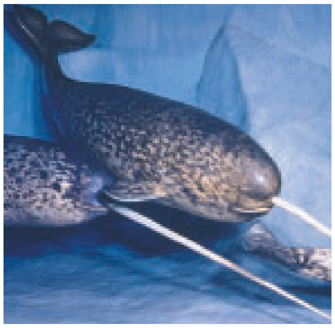


Figure 4
- teeth
- adult length: 3.5 m (females), 4.5 m (males)
- adult mass: 1.0 t (females), 1.2 t (males)



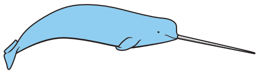


Figure 5
- teeth
- adult length: 4.2 m (females), 4.7 m (males)
- adult mass: 900 kg (females), 1.6 t (males)

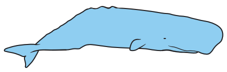


Figure 6
- teeth
- adult length: 11 m (females), 15 m (males)
- adult mass: 20 t (females), 45 t (males)

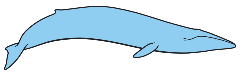


Figure 7
- baleen plates
- adult length: 26.5 m (females), 25 m (males)
- adult mass: 200 t (females), 100 t (males)

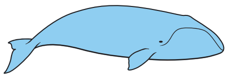


Figure 8
- baleen plates
- adult length: 14 m–15 m
- adult mass: 50 t–60 t

INVESTIGATION 5.2

Measuring Inherited Variation

Report Checklist

- ○ Purpose
- ○ Problem
- ● Hypothesis
- ● Prediction
- ● Design
- ● Materials
- ● Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ● Synthesis

If, as Darwin asserted, natural selection is occurring throughout the living world, then all species of organisms must possess inherited variations. In this investigation, you will design and conduct experiments to quantify inherited variations in living populations.

Part 1: Human Variability

Humans are the only exclusively bipedal mammals—that is, we walk upright on two feet. This characteristic is clearly inherited. In this investigation, you will quantify variation in the length of the human foot and investigate whether such variation is inherited. Before beginning your investigation, generate one or more testable hypotheses regarding both variability and inheritability of human foot length.

Design Suggestions

1. Devise a method to accurately measure human foot length.
2. Consider using commercial shoe sizes for your data. How might this influence the accuracy and objectivity of the data? Would this be offset by the ability to obtain more data?
3. Gather and tabulate inheritance evidence as a set of ordered pairs. Each data set should include foot length of an offspring paired with the foot length of the biological parent of the same gender (boys with their father, girls with their mother).
4. Take into account the influence of student age in your investigation.
5. Use histograms to display sample variation and (x,y) coordinate graphs to display inheritability. **Figure 1** shows an example of each.

Analysis

(a) Comment on the degree of variation you observed in human foot length. Describe any patterns in the data.

(b) Did the range of male foot length differ from that in females?

(c) What was the mean foot length among the males and the females you studied?

(d) Were some foot lengths obviously more common? Were the more common foot length(s) closer to the mean of foot length or to one of the extremes?

(e) Describe any evidence you found that foot length is an inherited trait.

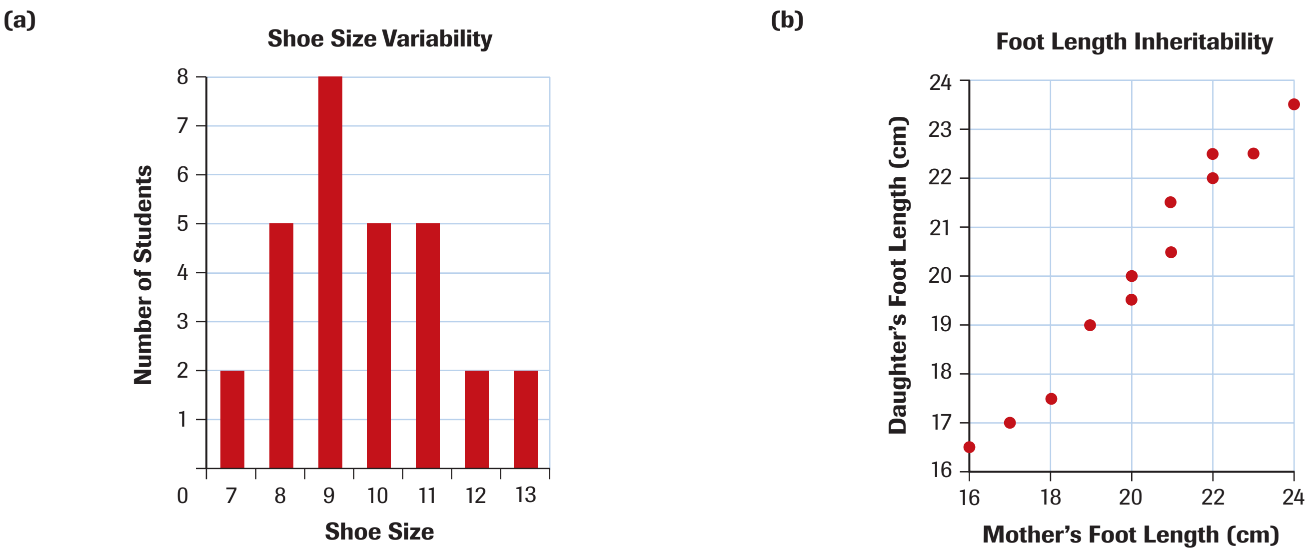


Figure 1
(a) histogram of number of male students versus shoe size
(b) daughter's foot length (cm) (*y*-axis) versus mother's foot length (cm) (*x*-axis)

INVESTIGATION 5.2 *continued*

(f) Does the evidence suggest that foot length is an inherited trait that remains unchanged between a child and the parent of the same gender? Explain.

Evaluation

(g) Do the sample data in **Figure 1 (b)** appear realistic? Do you think they represent actual data? Explain.

(h) How might the age of the offspring have influenced the results of your investigation?

(i) Do you think the age of the parents influenced your results? Why?

(j) What could you do differently to eliminate or reduce the influence of offspring age?

(k) How could you modify the experimental design to determine whether both parents influence foot length?

Synthesis

(l) Foot length was chosen for this investigation because it was suspected of being an inherited trait, at least in part. What environmental factors could be partly responsible for human foot length?

(m) What physical human characteristics are variable but are not inherited?

(n) What role might sexual reproduction have played in influencing the variability and inheritability of foot length in this investigation?

Part 2: Variations in Nature

Design and conduct an investigation similar to Part 1, using a quantifiable characteristic of an animal or plant species. For example, you might investigate the number of seeds per fruit or seed germination time; or adult height of cats or dogs. Select a characteristic that you know or can assume is inherited. The evidence you collect must either support or refute the following hypothesis: All species exhibit variations in inherited traits.

Analysis

(o) Based on the findings of your investigation, as well as the investigations of your classmates, what general conclusions can you draw about the variability within species?

Evaluation

(p) What role does the variability of a trait have in influencing its evolution? Is variation necessary for evolution? Explain.

(q) How might the length or size of the following anatomical structures have proven advantageous for these animals?

- (i) neck of a swan
- (ii) an elephant's trunk
- (iii) moose or elk antlers
- (iv) long legs of herons
- (v) rattlesnake fangs

Synthesis

(r) The results of a scientific study often lead to new questions which become the topic of future investigations. Generate three new questions that arise from your findings that could be the basis of additional investigations.

Chapter 5 SUMMARY

Outcomes

Knowledge

- explain the fundamental principles of taxonomy, i.e., domains, kingdoms, and binomial nomenclature (5.1)
- explain that variability in a species results from heritable mutations and that some mutations may have selective advantage(s), i.e., fossil record, Earth's history, embryology, biogeography, homologous and analogous structures, and biochemistry (5.5)
- discuss the significance of sexual reproduction to individual variation in populations and to the process of evolution (5.5)
- compare Lamarckian and Darwinian explanations of evolutionary change (5.4)
- summarize and describe lines of evidence to support the evolution of modern species from ancestral forms (5.2, 5.3, 5.6)
- explain speciation and the conditions required for this process (5.6)
- describe modern evolutionary theories, i.e., punctuated equilibrium versus gradualism (5.6)

STS

- explain that conventions of mathematics, nomenclature, and notation provide a basis for organizing and communicating scientific theory, relationships, and concepts (5.1)
- explain that scientific knowledge and theories develop through hypotheses, the collection of evidence, observation, and the ability to provide explanations (5.2, 5.3, 5.6)

Skills

- ask questions about observed relationships and plan investigations by designing an investigation to measure or describe an inherited variation in a plant or animal population (5.5); and hypothesizing the adaptive significance of the variations in a range of homologous structures in extant and extinct organisms (5.2, 5.3)
- conduct investigations and use a broad range of tools and techniques (all)
- analyze data and apply mathematical and conceptual models by: applying classification and binomial nomenclature systems in a field study (5.1), and analyzing data, actual or simulated, on plants and animals to demonstrate how morphology changes over time (5.3, 5.4, 5.5, 5.6)
- work as members of a team and apply the skills and conventions of science (all)

Key Terms

5.1

taxonomy
binomial nomenclature
genus
species
taxon (pl. taxa)
Protista
Monera
Archaebacteria
Eubacteria
phylogeny
dichotomous key

5.2

paleontology
radiometric dating
biogeography
endemic

5.3

homologous features
analogous features
vestigial features
DNA
gene
artificial selection

5.4

spontaneous generation
inheritance of acquired characteristics
natural selection

5.5

mutation
neutral mutation
fitness
harmful mutation
beneficial mutation
asexual reproduction
siblings
sexual reproduction
gene pool

5.6

speciation
allopatric speciation
theory of gradualism
theory of punctuated equilibrium
divergent evolution

MAKE a summary

1. Our current understanding of the evolution of life on Earth was gained using methods of scientific inquiry. We have used these methods to gather evidence and understand both the processes and the products of evolution. Design and construct a concept map that depicts these key elements. Your concept map should make creative use of information and communication technologies. You might construct a Web page concept map with hyperlinks to Web sites, information, or image files. Alternatively, you may want to make use of digital technology.
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

Go To

www.science.nelson.com GO

The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 5
- additional Diploma Exam-style Review Questions
- Illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

EXTENSION

Little People of Flores
The remains of three-foot-tall humans are discovered on a remote Indonesian Island. How have scientists interpreted these skeletons? This is a *NOVA* video.

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EXTENSION

CBC radioONE QUIRKS & QUARKS

Newts and Garter Snakes
Dr. Butch Brodie, (professor of biology at Indiana University) describes natural selection and the amazing predator-prey interactions of the toxic rough-skinned newt and the garter snake. A genetic mutation allows the snake to eat this highly poisonous prey. The newt's toxin is so strong it can quickly kill humans, yet the snake has managed to adapt to the toxin.

www.science.nelson.com GO

EXTENSION

T. rex
An astonishing adolescent growth spurt accounts for T. rex's enormous size. Scientists were able to make conclusions about the life span of this huge dinosaur by comparing fossilized bones to homologous bones in modern alligators. This is a *NOVA* video.

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UNIT 20 B PERFORMANCE TASK

The Sixth Extinction

In this Performance Task, you will use the knowledge and skills you have gained in this unit to compare past and current extinctions. Go to the Unit 20 B Performance Task link on the Nelson Web site and complete the task.

www.science.nelson.com GO

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. Radiometric dating provided scientists with
- A. a method for determining the exact age of sedimentary deposits
- B. a method for determining the age of a fossil by measuring its radioactivity
- C. a method of dating that is not accurate for objects only a few thousand years old
- D. a method for accurately dating igneous rock and for estimating the age of Earth

2. The theory of evolution by acquired characteristics did not include which of the following ideas:
- A. strenuous activities can change organisms
- B. organisms can change during their own lifetime
- C. physical characteristics cannot be passed to offspring
- D. the environment plays a role in selecting favourable characteristics

3. Jean-Baptiste Lamarck is important to the study of evolution because he
- A. conducted genetic experiments with garden peas
- B. proposed a theory of evolution called adaptations
- C. proposed a theory of evolution called natural selection
- D. proposed that the environment could drive evolutionary change

Use the following information to answer questions 4 to 6.

Darwin's voyage allowed him to observe species with distinct inherited variations. Based on the work of Malthus, Darwin realized that all populations produce far more offspring than can survive long enough to reproduce. From this, Darwin developed the concept of natural selection.

4. Malthus's work was important to Darwin's theory of evolution because it led him to conclude that
- A. all species show inherited variation
- B. there is competition among individuals of the same species
- C. all populations can be expected to increase in size over time
- D. the individuals with the best traits will be more likely to survive and reproduce

5. Since he found inherited variations in all species, Darwin concluded that
- A. variations between individuals were random
- B. the environment did not influence the characteristics of individuals
- C. variation did not play a significant role in the mechanism of evolution
- D. some individuals might be better suited to the environment than others

6. According to Darwin's theory of natural selection, a struggle for survival is a result of
- A. the occurrence of mutations
- B. many species competing with one another
- C. the variation of traits among individuals of a species
- D. the large number of offspring born in each generation

7. A species of flying squirrel inhabited an island. Ten thousand years ago, ashes from a nearby volcano killed most of the vegetation, including all the trees. A few flying squirrels survived. Today, squirrels are abundant, living among the rocks and shrubs that now cover the island. In the present population, the "flight membranes" are mostly too small to be functional. The most probable explanation for this change is that
- A. all the squirrels that could fly left the island
- B. a new type of squirrel was introduced to the island
- C. natural selection no longer favoured those that could fly
- D. young squirrels were not taught to fly by their parents, so the membranes did not develop

8. NR Many poisonous frogs are brightly coloured (**Figure 1**). This adaptation is thought to protect the frog by warning off potential predators. Assume that each of the following steps occurred in the evolution of the warning coloration. Place them in chronological order from the earliest to the most recent. (Record all four digits of your answer.)
1. Predators associated the foul-tasting frogs with their coloration and stopped feeding on them.
2. Some frogs within the population had mutations that made them more brightly coloured.
3. Some frogs within the population had mutations that made them toxic to some predators.
4. These frogs were more likely to survive than others, and this trait became established among all the frogs of this species.

Figure 1

9. Examine and compare the following samples of DNA. Using this evidence, place species 1, 2, 3, and 4 in order from *most* closely related to *least* closely related to species X.

species X AATCCGAGGTATAGCTACCAGAATCCGGG

A. species 1 AATCGGAGGTATAGCTACCAGAATCCGGG
B. species 2 AATCCGAGCTATAGCCACCAGAATCCAGG
C. species 3 ATTTCTAGGTATAGGGACCAGCATCCTGG
D. species 4 AATCCGAGGTATAGCTACCAGAATCCCGG

10. NR Each of the following individuals had ideas about the evolution of life on Earth. Place their names in chronological order from the earliest to the most recent. (Record all four digits of your answer.)
1. Buffon
2. Darwin
3. Wallace
4. Lamarck

Part 2

11. When Europeans arrived in Hawaii, they introduced rats, cats, dogs, and other predators. As a direct consequence, 61 of Hawaii's 96 species of native birds have already gone extinct. **Relate** this set of events to the theory of evolution by describing how natural selection influenced Hawaii's bird species before and after the arrival of Europeans.

Use the following information to answer questions 12 to 16.

The computer simulation entitled "Methinks It Is Like a Weasel" uses the analogy of a monkey typing randomly at a keyboard to compare pure chance with natural selection. After reading the online introduction and background information, run the simulation several times, noting both the ongoing processes and the end results.

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12. DE **Describe** what in the natural environment is being modelled by the phrase "Methinks it is like a weasel".

13. DE **Identify** the process that leads to changes in the alleles of both the monkey at the keyboard and cumulative selection.

14. DE **Why** don't the beneficial mutations that arise in the monkey at the keyboard accumulate?

15. DE **Describe** what happens to harmful changes in the cumulative selection simulation.

16. DE Could the monkey at the keyboard actually generate the phrase "Methinks it is like a weasel?" **Explain**.

17. It is thought that a billion prairie dogs once populated an area of over 100 million ha. Their current territory has been reduced and fragmented to less than 1 % of this original space. **Predict** the impacts from these changes in habitat on the prairie dog gene pool, as well as on the evolution and survival of the species.

Use the following information to answer questions 18 to 21.

A fascinating evolutionary relationship exists between the genetic disorder sickle cell anemia and the infectious disease malaria. View the online video that describes this relationship and answer the questions.

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18. DE **Conclude** whether sickle cell anemia is a serious disorder.

19. DE **Conclude** whether malaria is a serious disorder.

20. DE **Conclude** whether it is always a disadvantage to have the sickle cell trait.

21. DE **Describe** how your geographic location influences whether the mutation that causes sickle cell anemia is harmful or beneficial.

Use the following information to answer questions 22 to 24.

Recent genetic analysis of purebred dogs, published in the journal *Science,* suggests that dog breeds can be distinguished with great accuracy by comparing their DNA. According to research scientist Elaine Ostrander, "At a DNA level, breeds are a very real concept. Every poodle is more closely related to a poodle than it is to a dog of any other breed."

22. DE **Describe** how this evidence supports the assertion that selection can lead to changes in the genetic makeup of a population.

23. DE **Describe** what this evidence suggests about the use of DNA analysis as a tool for evolutionary biologists.

24. DE **Describe** some possible advantages and disadvantages to comparing breeds or species based on their DNA as opposed to their physical or behavioural characteristics.

25. Some prions (infectious proteins) that cause diseases such as bovine spongiform encephalopathy (mad cow disease) and the inherited form of human spongiform encephalopathy (Creudtzfeldt-Jacob disease) result from single genetic mutations. Research the genetics of these diseases. **Explain** how they are transmitted and **why** they are not eliminated by natural selection.

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Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. All of the deer in a forest area of 100 km^2 can be described as a
A. deer community
B. deer population
C. deer biome
D. deer species

2. The cougar, African lion, and common house cat are all types of cats. They share all of the same taxonomic categories except
A. family
B. class
C. genus
D. order

3. In which taxonomic group do the members have the greatest number of similarities?
A. kingdom
B. family
C. genus
D. phylum

4. A niche is best described as
A. biological components of an ecosystem
B. abiotic factors of an ecosystem
C. a population of a species of animals that occupies an area
D. roles and interactions of a species within its community

5. A community includes
A. the physical area where an organism lives
B. all members of a certain species in a defined area
C. the populations of all organisms that occupy a defined area
D. all organisms in a population regardless of area

6. The addition of nutrients to a stream will immediately cause
A. bacteria to increase, which will increase the level of dissolved oxygen in the stream
B. bacteria to increase, which will decrease the level of dissolved oxygen in the stream
C. bacteria to decrease, which will increase the level of dissolved oxygen in the stream
D. bacteria to decrease, which will decrease the level of dissolved oxygen in the stream

7. Data were collected from three different sites along the North Saskatchewan River, and used to draw the graph in **Figure 1**. If a biologist took water samples from the river and measured the dissolved oxygen levels, she would find that dissolved oxygen is lowest at point
A. W
B. X
C. Y
D. Z

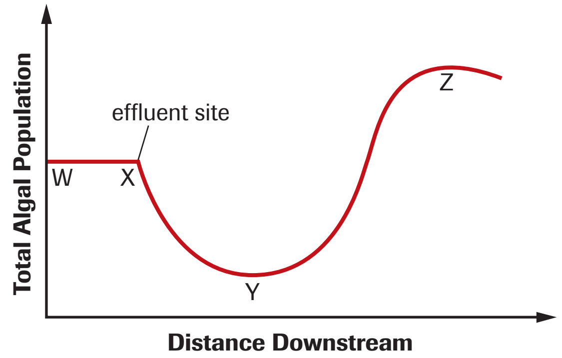

Figure 1

8. Which of the following statements is false?
A. The littoral zone of a lake is farthest from the shore.
B. The limnetic zone has more light than the profundal zone.
C. The littoral zone is closer to the surface than the profundal zone.
D. Aquatic plants do not usually grow in the profundal zone.

Use the following information to answer questions 9 to11.

Ecologists measured the amount of melted snow entering a river from April 1 to May 15. They also recorded the pH of the river. Their results are presented in **Figure 2**.

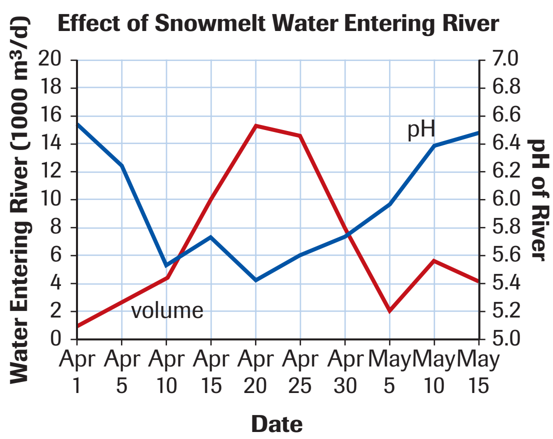

Figure 2

9. According to the data collected from the graph, as the snowmelt increases,
   A. the volume of water in the river increases and the pH becomes more acidic.
   B. the volume of water in the river decreases and the pH becomes more acidic.
   C. the volume of water in the river increases and the pH becomes more basic.
   D. the volume of water in the river decreases and the pH becomes more basic.

10. On which date was the water most acidic?
   A. April 1
   B. April 15
   C. April 20
   D. May 10

11. Which factor could account for the drop in pH during mid-April?
   A. increased photosynthesis during mid-April
   B. acid deposition enters the river with melting snow
   C. alkaline (basic) minerals in the soil are carried into the river with melting snow
   D. the increased volume of water entering the river dilutes the concentration of acids found in the river

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12. Which of the following is not an acquired trait?
   A. the ability to read
   B. a suntan
   C. a tattoo
   D. sense of smell

13. NR Through natural selection, individuals with adaptations that increase their chances of survival will produce more offspring. As a result, those adaptations will become more common in the species over time and the species evolves. Sometimes, new adaptations in one species affect the evolution of an adaptation in another species. Consider the following pairs of adaptations. For each of the four pairs, record the number of the adaptation that is most likely to have evolved first. (Record all four digits of your answer from lowest-to-highest numerical order.)
   1. insect-pollinated flowers OR 2. sacks on the legs of honeybees that hold pollen
   3. the flying ability of insects OR 4. spider webs
   5. a brightly coloured butterfly species OR 6. the same species is poisonous
   7. certain mammals have forepaws that can grasp things OR 8. certain mammals begin living in trees

14. NR Place the following discoveries/theories in chronological order from earliest to most recent. (Record all four digits of your answer.)
   1. Wallace develops a theory of evolution by natural selection.
   2. First fossils are discovered.
   3. Darwin goes on a voyage on HMS *Beagle*.
   4. Lamarck hypothesizes the evolution of acquired characteristics.

Part 2

Use the following information to answer questions 15 to 18.

In an attempt to increase the local food supply for people, humans introduced 26 caribou (24 females and 2 males) to an island off the coast of Alaska in 1910. **Figure 3** shows how the reindeer population changed after the introduction.

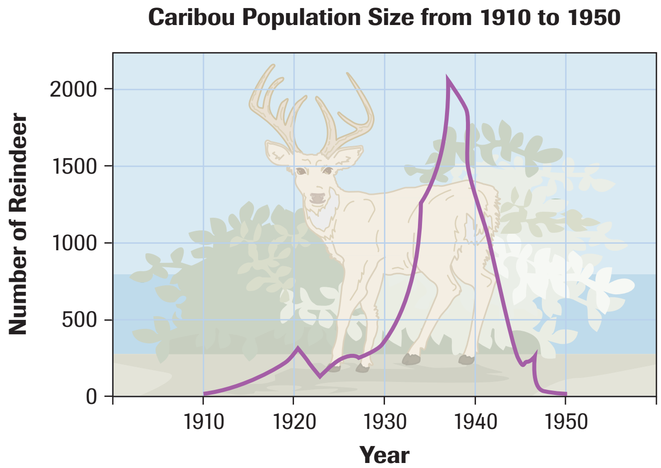

Figure 3

15. DE **Why** were more females introduced than male?

16. DE By 1937, the caribou population had soared to 2000. **Describe** the evidence that supports the hypothesis that the carrying capacity for reindeer had been exceeded.

17. DE Caribou feed on slow-growing lichens and moss. Would you expect to find more food for caribou on the island in 1931, 1935, or 1950? **Explain** your answer.

18. DE The introduction of a new species can cause major changes in an ecosystem. Should the caribou have been put on the island? **Explain** your position.

Use the following information to answer questions 19 to 25.

Scientists examined the aging of a lake over time. **Table 1** shows the data they collected from historical records. **Table 2**, on the next page, gives standard data on the change in solubility of carbon dioxide and oxygen with temperature. The scientists also collected historical data on fish populations in the lake over the same time period (**Table 3**).

Table 1 Recorded Lake Depth and Temperature

Year	Water depth (m)	Surface temp. (°C)	Bottom temp. (°C)
1885	25	25	10
1955	20	29	20
2000	14	30	25

Table 2 Solubility of Carbon Dioxide and Oxygen

Temp. (°C)	CO_2 solubility (ppm)	O_2 solubility (ppm)
0	1.00	14.6
5	0.83	12.7
10	0.70	11.3
15	0.59	10.1
20	0.51	9.1
25	0.43	8.3
30	0.38	7.5

Table 3 Fish Populations over Time

Year	Population of trout (per km^3)	Population of perch (per km^3)	Population of catfish (per km^3)
1885	12	22	14
1955	7	23	15
2000	1	12	16

19. **Describe** what happened to the lake as it aged, according to the data in **Table 1**. DE

20. **Outline** in a list factors that might explain why the lake became shallower as it aged. DE

21. **Graphically** represent the solubility of oxygen from the data in **Table 2**. DE

22. From the data from **Table 2**, **predict** the long-term consequences of prolonged warming. DE

23. **Explain** why the levels of carbon dioxide in many Canadian lakes increase during winter. DE

24. **Explain** the changes in fish populations over time shown by the data in **Table 3**. DE

25. **Identify** two human activities that may have accelerated the aging of the lake. For each of the activities, **describe** the negative environmental consequences and **explain** how those consequences can be minimized. DE

26. The removal of all trees from a forest is called clear-cutting. After cutting, different trees are separated and processed to make different products. Many of the products are sold to other countries, such as the United States. Write a unified response addressing the following aspects of clear-cutting. DE
    - **Why** is clear-cutting promoted by many businesses?
    - **Identify** some of the ecological problems associated with clear-cutting.
    - **Identify** and **explain** the roles of industry, government, and individuals to prevent the negative impact of uncontrolled clear-cutting of forests.

27. The Gaia Hypothesis proposes that Earth is alive. It suggests that our planet functions as a single organism that maintains conditions necessary for its survival. Although not accepted by all scientists, this theory provides many useful lessons about the interaction of physical, chemical, geological, and biological processes on Earth. Write a unified response that addresses the following aspects of the Gaia Hypothesis.
    - Based on your understanding of the biosphere, **outline** in a list, ways in which Earth is similar to an organism.
    - **Describe** one way that the Gaia Hypothesis might change the way scientists think about ecosystems.

Use the following information to answer questions 28 to 35.

Levels of nutrients, algae, and light penetration were measured throughout the year in the limnetic zone of a northern Alberta lake, producing the patterns shown in **Figure 4**.

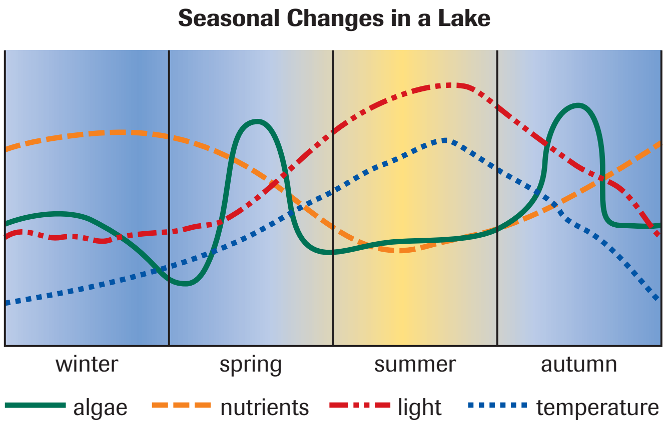

Figure 4

28. **Determine** from **Figure 4** at which times of the year the population of algae is highest. DE

29. **Explain** the changes in algae population. DE

30. **Explain** the changes in temperature. DE

31. **Why** do nutrient levels in the lake rise in winter but fall in summer? DE

32. **Explain** the fluctuations in light penetration. DE

33. Using **Figure 4** as a model, show **graphically** the changes you would expect to see in dissolved oxygen in the same lake. DE

34. Using **Figure 4** as a model, show **graphically** the changes you would expect to see in BOD in the same lake. DE

35. **Explain** how the patterns would change if sewage began to be dumped into the lake. DE

36. **Compare** (point out similarities and differences) how the theories of Lamarck and Darwin would explain each of the following:
(a) **how** the giraffe evolved a long neck
(b) **how** the cheetah became an extremely fast runner

37. Mutations are very rare events.
(a) **Explain** if you agree with the above statement, if it were referring to an individual organism.
(b) **How** would your answer differ if you were referring to mutation events in an entire population over long periods of time?
(c) Would your answer to part (b) differ if you were referring to an elephant population? to a bacterial population? **Explain**.

38. **Describe** a testable hypothesis for Lamarck's theory of inheritable acquired traits. **Describe** an experimental design that would test your hypothesis.

39. **Relate** the variability of a species to its mode of reproduction (i.e., asexual or sexual).

40. DE Darwin recognized that natural selection by the environment could produce change in a way similar to the artificial selection used by plant and animal breeders. Write a unified response that addresses the following aspects of these two processes.
- **Compare** the sources of new variation in each process. **Illustrate** your answer with an example.
- **Describe** any role of selection for certain characteristics in each process. **Illustrate** your answer with an example.
- **Describe** any role of selection against certain characteristics in each process. **Illustrate** your answer with an example.
- **Compare** the length of time needed before noticeable differences can be seen. **Illustrate** your answer with an example.

41. DE As a result of human activity, extensive forests are becoming fragmented into small forest islands. Write a unified response that addresses the following aspects of forest fragmentation:
- **How** might the increasing isolation of populations in these forests influence their success and evolution?
- **How** might the effects differ for a large mammal species, such as the lynx, compared to an insect species, such as a beetle?

42. Evolutionary biologists have hypothesized that many epidemics—widespread diseases that usually kill their hosts, such as smallpox or plague—could only have evolved in large human populations. Further, they hypothesize that these diseases originated in mammals that were domesticated. Consider these hypotheses in relation to contact between European explorers and indigenous peoples, such as the Arawak, Aztec, Maya, Inca, Aboriginal peoples in North America, Aborigines in Australia, and Maori in New Zealand. Research the exchange of diseases between Europeans and any two of the indigenous peoples listed above. Look for evidence that supports one or both of these hypotheses. **Describe** your findings in a presentation to your class.

Use the following information to answer questions 43 to 47.

A study by Environment Canada showed variations in the number of prairie ponds in the 30 years from 1955 to 1984 (**Figure 5**). Graph A shows the number of ponds found in each year of the study. Graph B shows the total population of ducks each year. Scientists conducting the study suggest that the decline was caused by draining ponds to expand agricultural land.

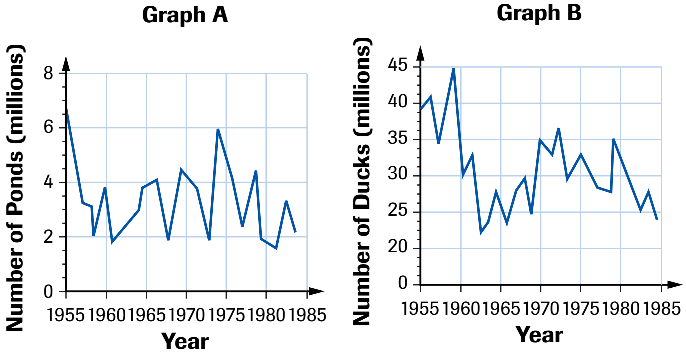

Figure 5

43. DE Farming is not the only cause of changes in the number of ponds. **Hypothesize** what abiotic factor might cause the number of ponds to fluctuate from year to year.

44. DE **Determine** the year in which the fewest number of ponds were found.

45. DE A hunters' group says that prairie ponds should be protected, to increase the number of ducks. Restate the hunters' position as a hypothesis, and **explain** whether the evidence in **Figure 5** support the hypothesis.

46. DE If the number of ducks declines, **predict** what other populations might be affected? **Explain** your answer.

47. DE Protecting ponds makes both aquatic and ecotone habitats available for wildlife but reduces the area of land on which a farmer can grow crops. Write a letter to a grain farmer, expressing your opinion about whether ponds on farmland should be protected or filled in. **Justify** your opinion.

48. Review the focusing questions on page 80. Using the knowledge you have gained from this unit, briefly **outline** a response to each of these questions.