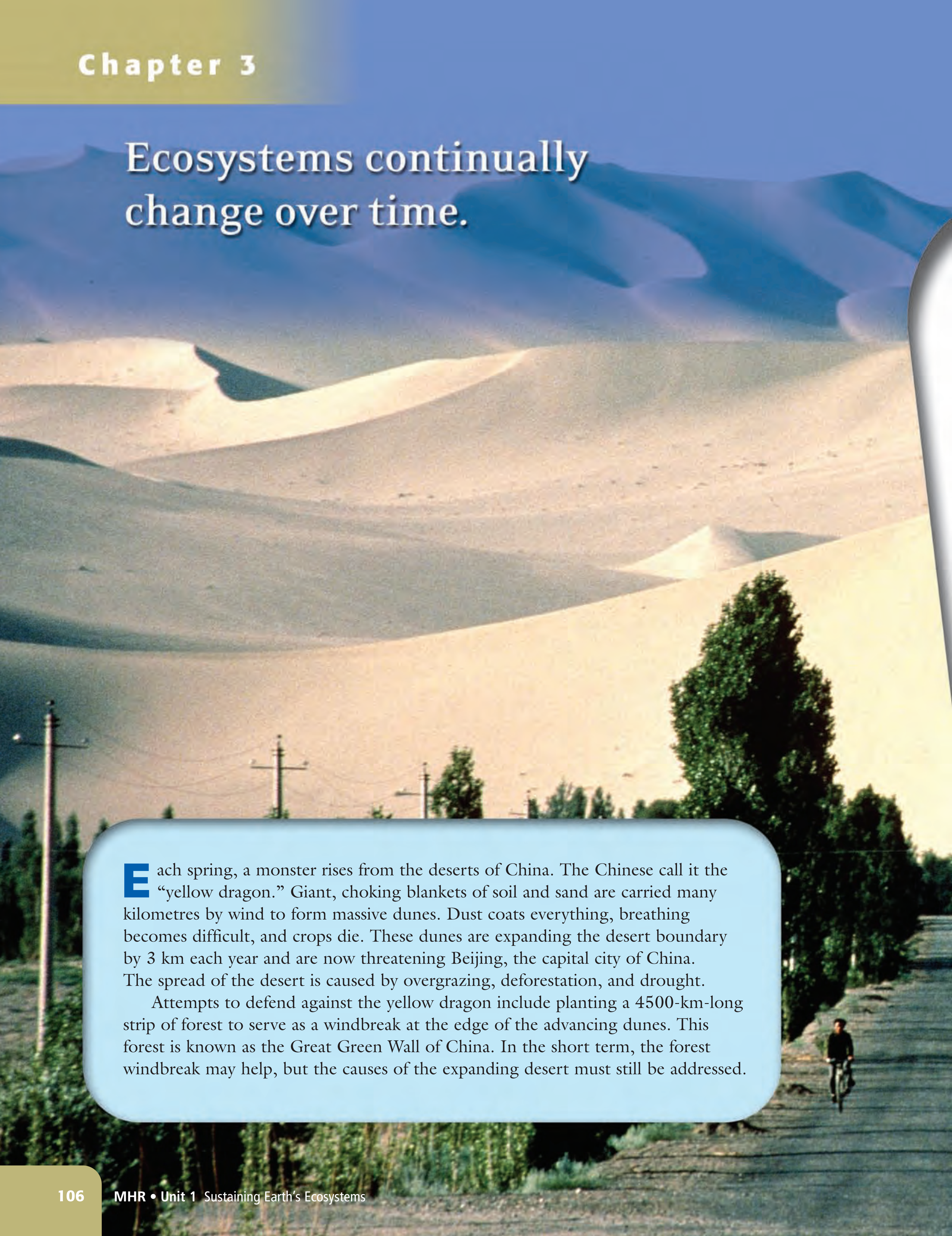
Ecosystems continually change over time.



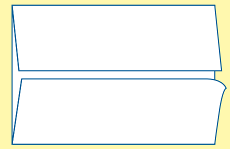
Each spring, a monster rises from the deserts of China. The Chinese call it the "yellow dragon." Giant, choking blankets of soil and sand are carried many kilometres by wind to form massive dunes. Dust coats everything, breathing becomes difficult, and crops die. These dunes are expanding the desert boundary by 3 km each year and are now threatening Beijing, the capital city of China. The spread of the desert is caused by overgrazing, deforestation, and drought.

Attempts to defend against the yellow dragon include planting a 4500-km-long strip of forest to serve as a windbreak at the edge of the advancing dunes. This forest is known as the Great Green Wall of China. In the short term, the forest windbreak may help, but the causes of the expanding desert must still be addressed.

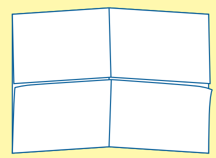
FOLDABLES™
Reading & Study Skills

Make the following Foldable and use it to take notes on what you learn in Chapter 3.

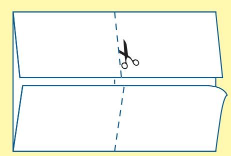
STEP 1 **Make** a shutterfold using one sheet of paper.



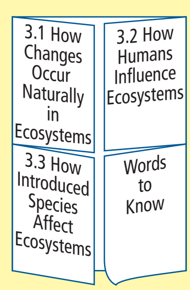
STEP 2 **Fold** the shutterfold in half like a hamburger. **Crease** well.



STEP 3 **Open** the project and **cut** the small, side tabs in half. These cuts will form four doors on the front of the project.



STEP 4 **Label** three of the four doors with the three section titles as shown, and label the remaining door with "Words to Know." As you read through the chapter, **record** main ideas and information beneath the tabs. **List** and **define** key terms from all three sections under the fourth tab.



What You Will Learn

In this chapter, you will
- **explain** how species adapt to changes in their environments
- **explain** how ecosystems naturally change over time
- **describe** how the impact of natural phenomena can alter ecosystems
- **explain** how human activities affect and change ecosystems
- **demonstrate** an understanding of how introduced species can alter ecosystems

Why It Is Important

Changes in biotic and abiotic factors as a result of natural events and human activities occur continually in ecosystems. Knowing how these changes affect ecological processes is important to understanding how we can maintain or increase the sustainability of an ecosystem.

Skills You Will Use

In this chapter, you will
- **model** ecological succession
- **communicate** your understanding of how ecosystems change naturally
- **identify** issues that affect the environment and make informed evaluations

3.1 How Changes Occur Naturally in Ecosystems

Over time, living organisms have changed as the abiotic and biotic factors in their environments have changed. The process that makes change in living things possible is called natural selection. In natural selection, the best-adapted members of a species will survive and reproduce. Changes also take place in ecosystems. Ecological succession refers to changes that take place over time in the types of organisms inhabiting an area. There are two types of ecological succession: primary succession and secondary succession.

Words to Know

adaptive radiation
climax community
ecological succession
natural selection

Before the last ice age ended, three-spine sticklebacks (Figure 3.1) swam, fed, and reproduced in the oceans of the northern hemisphere. Their sharp spines and the tough armour-like plates along the sides of their bodies protected them from being eaten by many marine animals. When the glaciers retreated from coastal areas of British Columbia, about 13 000 years ago, ocean levels changed and lakes were formed. Some marine sticklebacks were trapped in these lakes, which eventually changed from salt water to fresh water. The marine sticklebacks adapted to their freshwater environments, and new species of freshwater sticklebacks developed. The formation of these species occurred quite rapidly, and several of the new species are quite different from the ancestral marine sticklebacks.

In six shallow lakes in British Columbia (four on Texada Island, one on Lasqueti Island, and one on Vancouver Island), pairs of stickleback species developed (Figure 3.2). Each species in the pair is adapted for survival in a different part of the lakes. One species feeds near the lake bottom on prey such as snails, clams, and dragonfly nymphs. Bottom-feeding sticklebacks have chunky bodies and wide mouths. They also have little armour and fewer spines than their stickleback ancestors. Open-water

Figure 3.1 The marine three-spine stickleback

Figure 3.2 The bottom-feeding stickleback (top) and the open-water stickleback (bottom)

sticklebacks have slender bodies and narrow mouths. They have retained more of the spines and the armoured side plates of ocean sticklebacks. They are also lighter in colour than bottom-feeding sticklebacks, which allows them to blend into the lighter background of surface waters. The two types of sticklebacks have different diets and reproduce only with members of their own species, so they do not compete with each other and are able to share their habitat.

Did You Know?

In the mid-1990s, the stickleback pairs in Hadley Lake on Lasqueti Island disappeared. Humans caused their disappearance by introducing catfish into the lake. The catfish became a major predator that reduced the stickleback populations so they could no longer reproduce in adequate numbers to sustain themselves.

3-1A Adaptations to Aquatic Environments

Find Out ACTIVITY

Adaptations enable species to survive in a particular environment. These characteristics have resulted from changes that occur in species over time. In this activity, you will identify the advantages that certain structural adaptations provide, and describe the niches of given fish species.

What to Do

1. Study the structural adaptations in the table below. (Refer to page 18 to review information on structural adaptations.)
2. For each structure, match the adaptations to the appropriate advantages.

What Did You Find Out?

1. Your teacher will give you illustrations of seven different fish. Based on what you have learned in this activity, describe the role of each fish by answering these questions.
   (a) What type of feeding behaviour does the fish have? Explain.
   (b) Would the fish be a fast swimmer or a slow swimmer? Explain.
   (c) Would the fish live in deep water, shallow water, or at the bottom? Explain.

Structure	Structural Adaptations	Advantages to the Organism
Body	1. Round 2. Torpedo-shaped 3. Flat from side to side 4. Flat from top to bottom	(a) Hides on the bottom (b) Swims at high speed (c) Is difficult to swallow (d) Is almost invisible from front and rear
Mouth	1. No teeth 2. Strong jaws; has teeth 3. Mouth angled downward; longer upper jaw 4. Mouth angled upward; longer lower jaw 5. Whisker-like structures called barbels (like those on a catfish) 6. Sucker-shaped mouth that acts like a vacuum	(a) Eats small plants and animals (b) Feeds on bottom; senses food in murky water (c) Feeds on prey that live above it at the surface (d) Eats easily swallowed micro-organisms (e) Preys on other fish (f) Feeds on prey that live below it on the bottom
Eyes	1. Large eyes 2. Both eyes on same side of head 3. Small eyes	(a) Lives in shallow water (b) Lives in deep water (c) Lies flat on the bottom

How Organisms Adapt to Change

Living organisms change as the abiotic and biotic components in their environment change. The process that makes change possible in living things is called **natural selection**. In natural selection, members of a species having certain characteristics that give them an advantage over other members of that species will be in better condition to mate. These individuals then may pass these favourable characteristics on to their offspring. For example, the slimmer, streamlined shape of the open-water stickleback is more efficient for escaping predators.

One of the most famous examples of natural selection is the Galapagos finches. Biologists believe that all 13 species of finches that now inhabit the Galapagos Islands developed from a single species from the mainland of South America. Scientists use the term **adaptive radiation** to describe the change from a common ancestor into a number of different species that "radiate out" to inhabit different niches. Each species of Galapagos finch is adapted to a particular niche on the ground or in the trees, and each species gathers and eats a different type of food. Finches that are seed eaters (Figure 3.3), cactus eaters, fruit eaters, and insect eaters have different beak sizes and shapes, which are adapted for different food sources.

Figure 3.3 The large ground finch (A) is an expert at cracking open big, hard seeds with its large beak. The small ground finch (B), with its smaller beak, eats smaller, softer seeds.

Another example of adaptive radiation is the cichlid fish of Lake Victoria in Africa (Figure 3.4). More than 300 species of cichlid once lived in this lake. Scientists have researched these species extensively and have determined that they also developed from a single species. The development of different species of sticklebacks is also an example of adaptive radiation, as new species of sticklebacks in North America developed from an ancestral species.

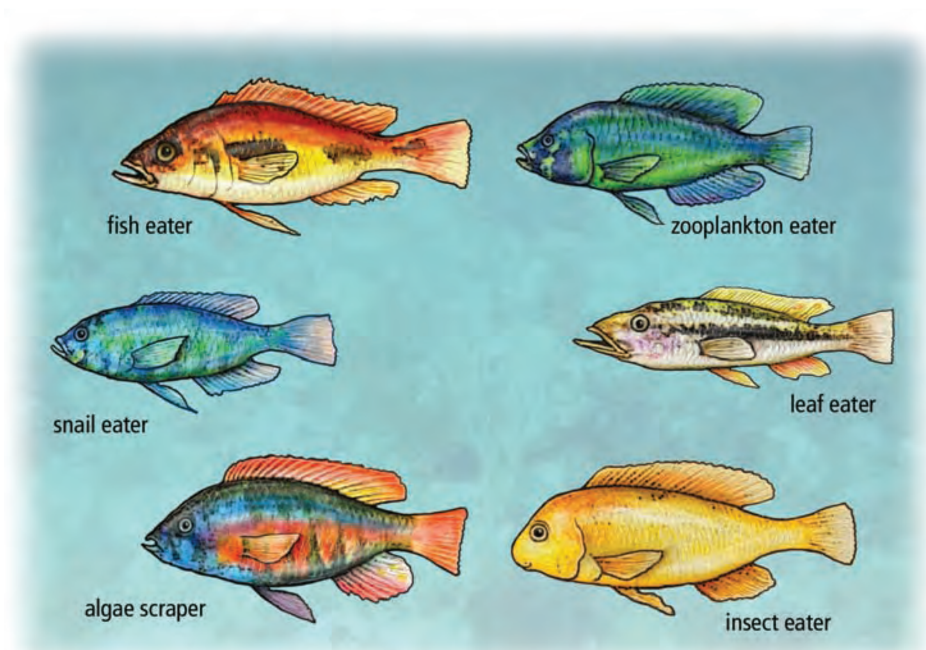


Figure 3.4 Six of the cichlid species living in Lake Victoria

Reading Check

1. What is natural selection?
2. What is adaptive radiation?
3. Give an example of adaptive radiation.

Figure 3.5 Gradually, other types of plants replaced the lawn that once grew here.

How Ecosystems Change Over Time

Ecosystems are continually changing. The types of species that live in an ecosystem change as the abiotic factors in the ecosystem change. In your neighbourhood, you may have observed how the grass on an abandoned property gets longer and longer. You may also have observed how other species of plants start to grow there (Figure 3.5). Over time, even trees may develop on the site. **Ecological succession** is the term scientists use to refer to changes that take place over time in the types of organisms that live in an area. There are two types of ecological succession: primary succession and secondary succession.

Primary succession

Primary succession occurs in an area where no soil exists, such as on bare rock. Natural events such as retreating glaciers can scrape existing rock bare, or new rock can form when lava cools after a volcanic eruption. Wind and rain carry the spores of organisms such as lichens to these rocks. Earlier in this unit, you learned that a lichen is an organism that consists of a fungus and an alga. You also learned that lichens obtain nutrients from rock by secreting chemicals that break down the rock. The weathering caused by lichens and by processes such as wind, rain, and freezing begin the formation of soil. As dead lichens decay, they also add organic matter to the developing soil. In time, soil slowly accumulates, a process that may take hundreds of years in some locations.

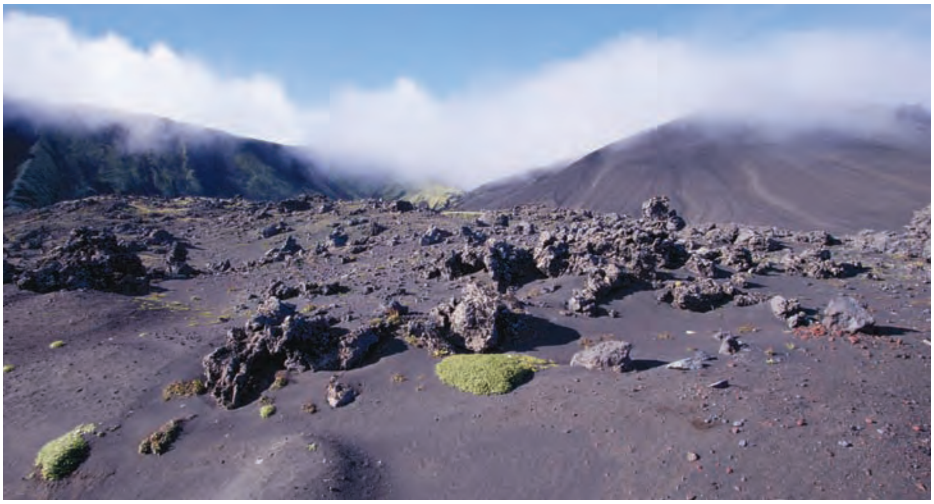


Figure 3.6 The moss growing on the rock in the middle of this volcanic landscape indicates that primary succession is occurring.

Figure 3.7 Grasses and wild strawberries are beginning to take over from the lichens and mosses growing on this rock.

Plants such as mosses, whose spores have also been deposited by wind, begin to grow (Figure 3.6 on the previous page). Many of these species are adapted to grow in harsh and often nutrient-poor conditions. **Pioneer species** is the term scientists use to describe the lichens and other plants that are the first organisms to survive and reproduce in an area.

Pioneer species change the biotic and abiotic environment in a variety of ways. They decay and create more soil. They also make the soil more fertile and increase its ability to hold moisture. Pioneer species provide food for insects and other organisms, introducing animals into the community. Figure 3.7 shows some pioneer species.

Each stage in primary succession is gradual and introduces different populations of micro-organisms, plants, and animals that compete for nutrients, moisture, and sunlight. As each generation of plants and animals dies off,

Figure 3.8 A general model of primary succession. Abiotic factors such as the amount of soil, light, moisture, or nutrients limit the kinds of species that can survive.

Lichens begin to grow and release chemicals that slowly start to break down rock. This begins the process of soil formation. Decaying dead lichens add nutrients to this new soil.

Plants such as mosses also begin to grow. They die and decay, adding more nutrients to the soil. Insects, micro-organisms, and other organisms move in.

they decompose and contribute more organic matter to an increasing soil layer. Eventually, the seeds of trees, which have been transported by animals or carried by wind or water, will germinate. The first trees to grow usually require a lot of light, such as deciduous trees in a boreal forest. The shade they cast will change the abiotic conditions again because the soil will become cooler and moister beneath them. Only shade-tolerant plants will then be able to survive on the forest floor. Figure 3.8 shows a general model of how primary succession occurs. As more niches are created, there is greater variety, or diversity, in animals, micro-organisms, fungi, and bacteria. This diversity creates more complex food webs.

Although the types of species differ even in similar zones, scientists have found that primary succession occurs in much the same way in different parts of the world. For example, coniferous forests eventually form in northern latitudes, deciduous forests form in temperate zones, and tropical forests form in tropical zones.

Did You Know?

In 1883, the volcanic island of Krakatau exploded with tremendous power and was heard over 3000 km away in Australia. The explosion generated giant 40 m waves that circled Earth four times. Every living thing on the island was destroyed. Today, the island is once again a tropical rainforest with a rich diversity of plant and animal species, which were naturally transported by wind, water, and animals across the ocean from Java and Sumatra.

As decomposing materials build up, the soil holds more water. Grasses, wildflowers, and shrubs begin to grow. More types of insects, micro-organisms, and other organisms move in.

Tree seeds are transported to the area by animals. Sun-tolerant trees such as deciduous trees begin to grow. Plants that cannot tolerate the shade of the trees are replaced by shade-tolerant plants. A greater diversity of species occurs.

Trees such as coniferous trees germinate and begin to grow in the shade. Eventually, the conifers shade out the deciduous trees. A mature community develops.


Figure 3.9 A boreal forest is a mature community.

Mature communities

The process of primary succession leads to the development of a mature community, which is sometimes called a **climax community**. Boreal forests, tropical rainforests, grasslands, and deserts are examples of climax communities (Figure 3.9). Previously, ecologists thought that climax communities would remain unchanged indefinitely. Ecologists now realize that climates naturally change over time. Therefore, so do the abiotic and biotic factors in an ecosystem. A climax community may appear unchanged, but there are always changes occurring because of small disturbances. For example, in a boreal forest, alder may begin to grow again in the open space created by fallen white spruce because sunlight can once again reach the forest floor. Today, many scientists prefer to use the term mature community or mature forest instead of climax community. These terms reflect the idea that, although certain species of plants and animals are present in a mature forest community, the forest itself is constantly changing.


Figure 3.10 After a recent fire, new growth is already appearing in this forest.


Figure 3.11 Grass and dandelions can rapidly reproduce after a disturbance.

Secondary succession

After a forest fire, not much is left except ash and the burnt trees. When a house is demolished, all that seems to remain is bare soil. But neither of these places will remain lifeless for long because the soil that has been exposed contains micro-organisms, worms, insects, and the seeds of wildflowers, weeds, grasses, and trees. Other seeds may blow in or be carried by animals returning to these areas. In both places, a process called **secondary succession** will soon begin (Figure 3.10). Secondary succession occurs as a result of a disturbance to an area that already has soil and was once the home of living organisms.

Secondary succession occurs much faster than primary succession because soil and nutrients already exist. While primary succession may take hundreds of years to result in a mature community, secondary succession may take only decades. Secondary succession often depends on the recovery of existing plants, such as trees, and on species that can rapidly reproduce in new conditions of increased sunlight and open areas (Figure 3.11).

Reading Check

1. What is ecological succession?
2. Briefly describe the process of primary succession.
3. What is a mature community?
4. How does secondary succession occur?

Suggested Activity

Conduct an Investigation 3-1B on page 118

How Natural Events Affect Ecosystems

As you have just learned, large disturbances such as forest fires have an impact on mature communities and result in secondary succession. Other large disturbances such as flooding, drought, tsunamis, and insect infestations can also greatly affect mature communities.

Flooding

Flooding occurs in coastal areas, rivers, and lakes, when the volume of water exceeds the ability of the water body to contain it. Flooding can be part of a normal cycle or the result of heavy rainfall, increased run-off from melting snow, or an extreme natural event such as a tsunami. Flooding can result in soil erosion and soil pollution if toxic chemicals are present in floodwaters. Flooding can also cause widespread disease among humans when toxins or harmful bacteria from untreated sewage enter drinking water supplies (Figure 3.12). Climate change may be causing an increase in flooding in some parts of the world, such as West Africa, where heavier annual rains are occurring.

Figure 3.12 Flooding can cause soil erosion and wash away nutrients (A). Flooding can also cause the spread of disease in human populations when bacteria and other toxins pollute drinking water supplies (B).

Tsunamis

Figure 3.13 shows the impact of a tsunami on an ecosystem. Tsunami is the term used to describe a huge, rapidly moving ocean wave. Tsunamis are usually caused by large earthquakes or underwater volcanic eruptions. On land, the force of the huge wave carries away or destroys plants and animals, disrupting habitats and food webs. The large volume of salt water that is carried onto the shore can also change the composition of the soil. As a result, plants that cannot survive in a salty environment are unable to grow.

Figure 3.13 The coastline of southwest Thailand before a devastating tsunami in 2004 (A). The same coastline after the tsunami (B). The lighter-coloured areas were previously covered with lush vegetation.

Figure 3.14 The effects of drought in northeast Kenya, Africa

Drought

Drought is a recurring event in many parts of the world. Drought usually occurs when there is a below-average amount of precipitation in an area over a period of many months or years. Most often, an ecosystem can recover from drought once normal precipitation patterns are re-established. However, the effects of prolonged drought can destroy habitats when water becomes scarce and plants and animals die. Drought can result in crop failures and livestock deaths. Many parts of the world, such as Australia, western Europe, and Africa south of the Sahara Desert, have recently experienced drought conditions (Figure 3.14). These droughts may also have been made worse by climate change.

Insect infestations

Insects play a major role in the natural succession of a forest. In a mature coniferous forest, for example, the mountain pine beetle destroys older, weaker pines. The dead trees provide food and shelter for some species, and eventually the nutrients of the tree are recycled in the soil. Spruce, fir, and younger pines, which are unaffected by the beetles, thrive in the openings left by dead, fallen trees. The beetle is also an important food source for other insects, birds such as woodpeckers and nuthatches, and for some mammals.

Younger, healthy trees are better able to defend against beetle infestations by producing resin. Resin traps and flushes the adult beetles out of the tree, which is effective when only a few beetles attack a tree. However, if many insects attack, or if the tree is stressed from overcrowding, drought, or grazing by animals, resin flow is reduced. The pine beetle has evolved a symbiotic relationship with the blue stain fungus (Figure 3.15). The beetle carries the fungus from tree to tree in its mouthparts. The fungus destroys plant tissue and prevents the host tree from using resin to sweep away both invaders.

Explore More

The extent of the pine beetle infestation in western Canada is the largest ever recorded. Find out more about how the beetle epidemic has dramatically changed the biodiversity of the lodgepole forest for the next few decades and the steps being taken to control it. Start your search at **www.bcscience10.ca**.

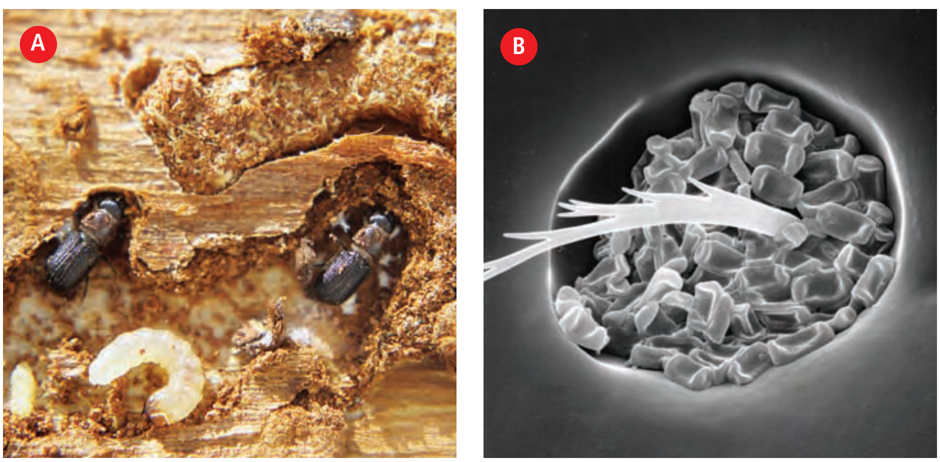


Figure 3.15 The mountain pine beetle (A) has a symbiotic relationship with the blue stain fungus (B).

Events that would keep the mountain pine beetle population in check, such as cold winters, are no longer occurring. With the warming trend in the climate, British Columbia's forests are no longer exposed to sustained periods with temperatures below –30°C, which would be required to kill the beetle larvae. Human suppression of forest fires has resulted in the retention of large numbers of host trees for the beetles. Because of their large populations, the pine beetles are now attacking younger trees as well. Since mountain pine beetle populations are no longer in check, their impact on lodgepole pine forests is devastating (Figure 3.16). With large losses to the forest canopy, many bird and mammal nests have been lost. The economies of many forest-dependent communities have also been affected.

Figure 3.16 The effect of the mountain pine beetle on lodgepole pines

3-1B Modelling Succession in Ecosystems

SkillCheck
- Predicting
- Communicating
- Modelling
- Explaining systems

Materials
- blank paper
- paper squares or self-adhesive removable notes
- coloured pencils
- stapler

You have learned that primary succession occurs in an area when lichens start to grow on bare rock. You also know that secondary succession occurs following a disturbance in an established ecosystem. In this activity, you will model primary and secondary succession in either a pond or an ocean sand dune ecosystem.

Question
How are the stages of primary and secondary succession similar and how are they different?

Procedure

Part 1 Modelling Primary Succession

1. Below are lists of the stages of succession in pond and ocean sand dune ecosystems. Put each list in order.

Pond Succession	Ocean Sand Dune Succession
Micro-organisms die and form a layer of muck on the pond bottom.	A forest of white spruce eventually grows.
Fish and other animals carried by streams, birds, or other animals move in.	Soil can hold water, so other organisms such as lichens and mosses begin to grow.
Pond lilies and cattails die off, creating more organic material on the pond bottom.	Nutrients are obtained from decaying seaweed.
Micro-organisms carried by wind and insects are deposited in the water.	Shrubs can grow because of the increased amount of soil.
Water plant fragments transported by birds and wind take root in the muck.	Grasses that can tolerate salt spray from the ocean begin to grow.
The increased decay of organisms provides more organic matter on the pond bottom, in which pond lilies and cattails can take root.	Decaying vegetation creates soil.
Water becomes shallower. Grasses and small shrubs move in.	Grasses help anchor the soil.

2. Select either the pond ecosystem or ocean sand dune ecosystem to illustrate succession. Create a seven-panel storyboard to show succession.

Part 2 Modelling Secondary Succession

3. Imagine that one of the following natural events occurs in the climax community of your ecosystem: flood, tsunami, severe drought, insect invasion, landslide, or hurricane.
4. Draw three small sketches to illustrate the stages of secondary succession following the natural event. The first sketch should be a simple drawing following the event. The second sketch should be a scene 100 years later. The third sketch should be a scene 500 years later.

Analyze

1. Write a paragraph to describe how your ecosystem progressed through the stages of primary succession. Include the following terms in your response as you discuss changes in the plant and animal community: pioneer organisms, changes, replaces, community, least biodiversity, most biodiversity, and mature community.

Conclude and Apply

1. Compare the biotic and abiotic changes that occurred in primary succession and secondary succession in your ecosystem. How are they similar? How are they different?

The Fire Survivors

Thick bark protects trees from fire, and new seedlings spring up quickly.

Wildfire! The word sets off alarm bells as we picture valuable forest and grassland habitats going up in smoke. But fires have always been a part of nature, and many plants and animals have evolved adaptations to cope with them. Some even depend on fires for survival.

In grasslands, plant roots can extend as much as 3 m below the surface, well below the flames. In forests, ponderosa pine, Douglas fir, longleaf pine, and many oak species have thick bark that acts as insulation against the heat. Some trees have a self-pruning mechanism to avoid ground fire. The ponderosa pine, for example, sheds its lower branches as it matures. Ice plants and sage have fire-resistant foliage.

Some species of plants, such as fireweed, also have the ability to rapidly reproduce following a fire. The fire actually helps second-growth plants become established by recycling nutrients in the ecosystem. As plants turn to ash, the nitrates and phosphorus trapped inside them are recycled back into the soil. Carbon stored in the plants is released during combustion as carbon dioxide gas, making it available again for photosynthesis. To take advantage of the new nutrient-rich soil, aspen and many shrubs have heat-resistant roots that send up new shoots soon after a fire. Birch and aspen produce thousands of wind-borne seeds in neighbouring unburned stands and are the usual colonizers after a fire.

When a fire occurs, plants that once grew in an area and have adaptations that suit them to increased sunlight take over. For example, fast-growing grasses and bushes that require lots of light now thrive in these open spaces. The growth of these plants often reduces the number of species that were previously most numerous. As time passes, more slowly growing, shade-tolerant species crowd out the sun-tolerant plants.

Animals also have behavioural adaptations that enable them to survive a fire. Most animals are not harmed in a fire, but many lose their homes. Deer and bears are able to escape by running. Mice, snakes, and lizards burrow to save themselves. Mature birds can fly away, but young nestling birds die. While some organisms that inhabit the forest litter may decrease in number after a fire, many decomposer micro-organisms such as bacteria and fungi survive and multiply quickly.

Soon after a fire, the burned timber will attract insects, and these in turn will attract woodpeckers and omnivores such as bears and foxes. As secondary succession advances, the tender new grasses, seedling shrubs, and trees that re-establish in burned areas provide an ideal environment for small seed-eating mammals and birds, voles, deer, and moose.

Questions

1. List three adaptations that enable plants to survive fires.
2. Explain how three animal species escape fires.
3. How does a forest fire result in secondary succession?

Check Your Understanding

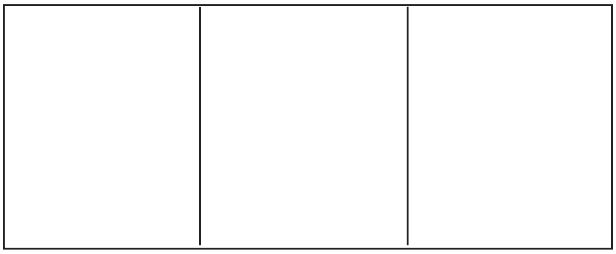
Checking Concepts

1. What caused the development of two species of stickleback in the same lake?
2. What is the role of a pioneer species in an ecosystem?
3. Why are lichens considered to be pioneer species?
4. How is new soil created in primary succession?
5. Put the following stages of primary succession in order.
   (a) Animals move in after the plants they require for survival have become established.
   (b) New species of plants become established after pioneer species have altered the abiotic conditions.
   (c) A community with a wide variety of species and more complex food webs develops.
   (d) Pioneer species become established in an area.
6. Will primary succession or secondary succession occur after the event shown in the photograph below? Explain how you know.

7. The mountain pine beetle has devastated British Columbia's lodgepole pine forests.
   (a) How do lodgepole pine trees naturally defend themselves against the beetle?
   (b) Explain why the mountain pine beetle has had such a devastating impact on lodgepole pine forests.
8. Are there more types of species in a mature forest or in a forest undergoing succession? Explain.

Understanding Key Ideas

9. How do the Galapagos finches illustrate both natural selection and adaptive radiation?
10. In a flowchart, show succession from bare rock to coniferous forest.
11. State how primary succession compares to secondary succession in terms of the following.
    (a) the amount of soil available
    (b) the amount of nutrients available
    (c) the rate of succession
12. Does secondary succession directly follow primary succession? Explain.
13. Draw three boxes like the ones below, and label them as shown. Sketch what might happen over time if the grass on a soccer field were not cut.



14. Use three different examples to explain how natural events affect ecosystems.

Pause and Reflect

Climate change is a natural event, but it is happening more rapidly because of human activities. Scientists are concerned that the current rate of climate change is harmful to ecosystems and is threatening biodiversity. Explain why scientists are concerned.