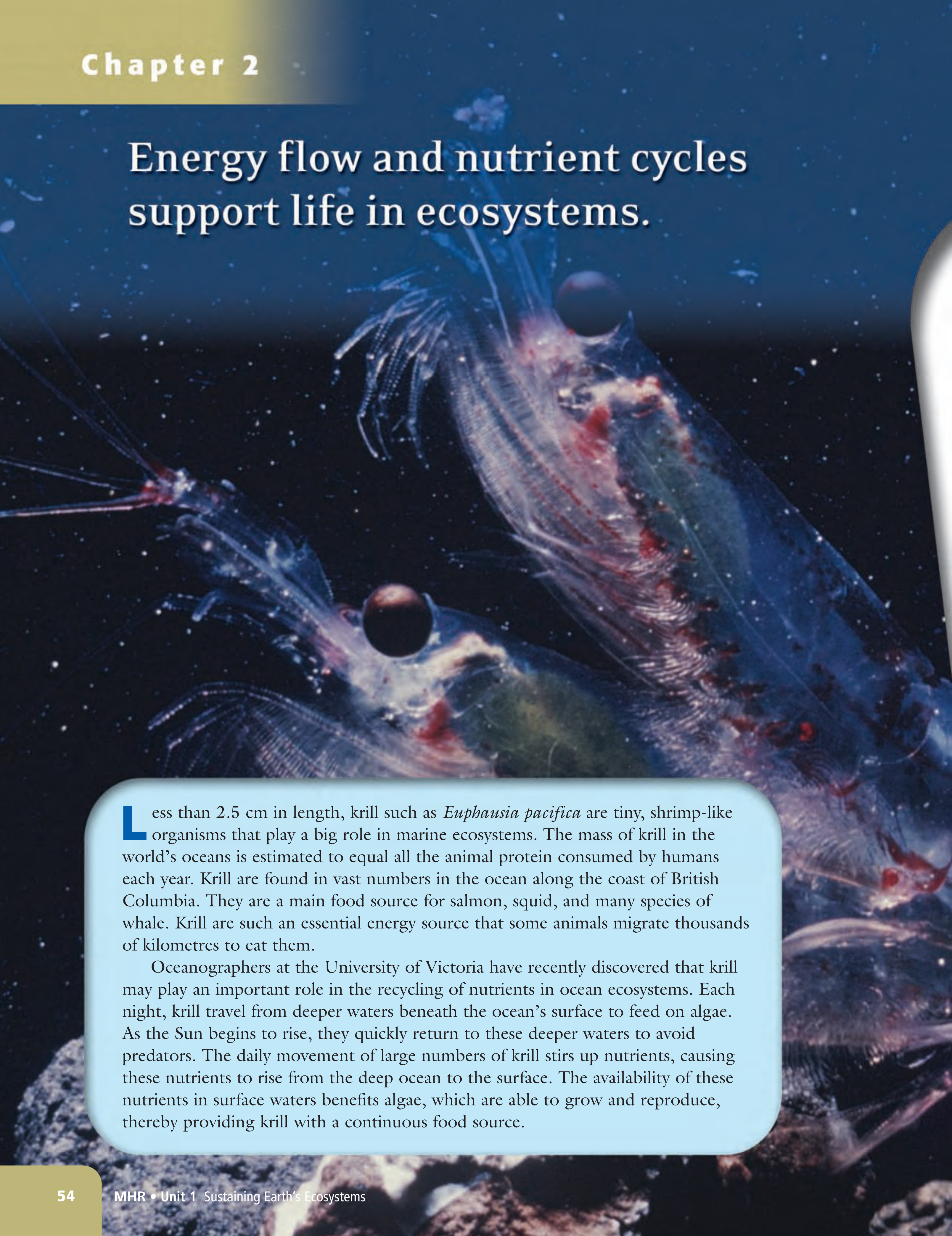
Chapter 2

Energy flow and nutrient cycles support life in ecosystems.



Less than 2.5 cm in length, krill such as *Euphausia pacifica* are tiny, shrimp-like organisms that play a big role in marine ecosystems. The mass of krill in the world's oceans is estimated to equal all the animal protein consumed by humans each year. Krill are found in vast numbers in the ocean along the coast of British Columbia. They are a main food source for salmon, squid, and many species of whale. Krill are such an essential energy source that some animals migrate thousands of kilometres to eat them.

Oceanographers at the University of Victoria have recently discovered that krill may play an important role in the recycling of nutrients in ocean ecosystems. Each night, krill travel from deeper waters beneath the ocean's surface to feed on algae. As the Sun begins to rise, they quickly return to these deeper waters to avoid predators. The daily movement of large numbers of krill stirs up nutrients, causing these nutrients to rise from the deep ocean to the surface. The availability of these nutrients in surface waters benefits algae, which are able to grow and reproduce, thereby providing krill with a continuous food source.

What You Will Learn

In this chapter, you will
- **explain** how energy flows through food chains, food webs, and food pyramids
- **describe** how nutrients are cycled in an ecosystem
- **explain** how chemicals can accumulate and cause harm to organisms in ecosystems
- **demonstrate** an understanding of how human activities affect biodiversity

Why It Is Important

Knowledge of energy flows and nutrient cycles can help us appreciate how our activities affect ecosystems and the organisms living in them. The more we learn about these effects, the better prepared we are to attempt to prevent environmental damage before it occurs. Scientific knowledge is leading to new technologies that will help us restore ecosystems and protect biodiversity.

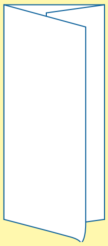
Skills You Will Use

In this chapter, you will
- **construct** energy pyramid models
- **simulate** the cycling of nutrients
- **analyze** the effects of altering the amount of nutrients in an ecosystem
- **model** the effects of human activities on ecosystems

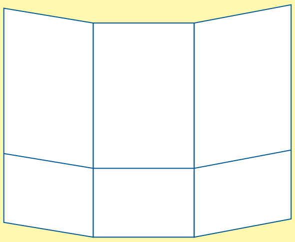
FOLDABLES™ Reading & Study Skills

Make the following Foldable to take notes on what you will learn in Chapter 2.

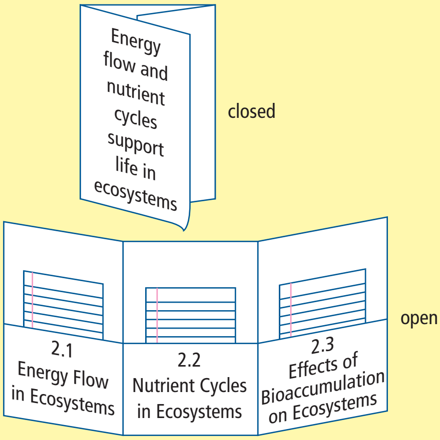
STEP 1 **Fold** a horizontal sheet of 28 cm by 43 cm paper into thirds. **Crease** well, and **open** the paper.



STEP 2 **Fold** the bottom edge up 5 cm, and **crease** well. **Glue** the outer edges of the 5 cm tab to create three pockets.



STEP 3 **Label** the exterior with the chapter title. **Label** each of the three pockets with the section titles.



Use index cards or quarter sheets of paper to record information, define terms, provide examples, and draw diagrams of cycles, food chains, and processes. Store your notes in the appropriate pockets.

2.1 Energy Flow in Ecosystems

In an ecosystem, energy flows from producers (plants) to primary consumers (herbivores) to secondary and tertiary consumers (carnivores). Food chains and food webs model this energy flow and these feeding relationships. Each step in a food chain is called a trophic level. Food pyramids model how energy is lost at each trophic level in an ecosystem.

Words to Know

biodegradation
consumers
decomposers
food chain
food pyramid
food web
producers
trophic level

Figure 2.1 The skeleton of a decomposed leaf

The eerie-looking skeleton of a leaf (Figure 2.1) reveals a canal system that once delivered water and minerals from the stem to the leaf. It also carried sugars made in the leaf to other parts of the tree. But how did the leaf tissue disappear, and where did it go? During photosynthesis, green leaves produce carbohydrates, which are an important energy source for plants and animals. Leaf litter (fallen leaves) forms an important energy source for organisms on the forest floor. Chemicals such as cellulose found in plant cell walls cannot be easily digested by most animals. However, fungi have finger-like projections that invade leaf tissue (Figure 2.2 on the next page). The fungi secrete enzymes that break down leaf tissue and cellulose into smaller nutrients. These nutrients can then be absorbed by the fungi. Some fungi secrete enzymes that change leaf litter into a food source for invertebrates such as beetles.

Scientists estimate that each year 28 billion tonnes of cellulose are produced in new leaves and each year fungi convert 80 percent of this cellulose back into usable nutrients.

This vast amount of leaf material forms part of the mass of all living organisms in the biosphere. To understand how much organic mass is produced in different parts of the biosphere, scientists estimate biomass. **Biomass** refers to the total mass of living plants, animals, fungi, and bacteria in a given area. Biomass can also refer to the mass of particular types of organic matter such as trees, plant crops, manures, and other organic materials that may be used to manufacture biofuels such as biogas. Estimates of biomass are usually expressed in grams or kilograms per square metre.

Did You Know?

The biomass of plants on Earth is over 100 times greater than the biomass of animals.

Figure 2.2 Star fungi growing on leaf litter break down the dead leaves into usable nutrients.

2-1A Raking in Profits from Leaf Biomass

Think About It

Each year, millions of leaves may fall in your neighbourhood. A single oak tree alone may drop 200 000 leaves. A British Columbia company that manufactures fertilizers made from organic materials is researching ways to turn the biomass of fallen leaves into a fertilizer. You have been asked to join the research team. Your team knows that decayed leaves are a good source of nutrients for other plants, but the natural process of leaf decay is slow. In this activity, you will investigate possible factors that may increase the rate of leaf decay.

What to Do

1. Working with your team, brainstorm a list of factors that you predict may increase the rate of leaf decay. (**Hint**: Think about what abiotic factors change during the fall.)
2. Choose one factor from your list that you think is worth investigating further.
3. Design an experiment that tests whether or not your prediction is correct. To help you design your experiment, consider the following questions.
   - What materials and equipment would you use to test your prediction?
   - What steps would you follow to carry out your experiment?
   - What type of data would you collect?
   - How would you measure and record the data?
   - How would you know if the factor you are investigating is increasing leaf decay?

What Did You Find Out?

1. If possible, compare your experiment's design to that of another team that investigated the same factor. Are there improvements that you could make to your design?

How Energy Flows in Ecosystems

In section 1.2, you learned that organisms have special roles, or niches, in the ecosystems in which they live. They compete for food and other resources or may be part of a predator-prey relationship. Within its niche, every organism in an ecosystem interacts with that ecosystem in two ways: (1) the organism obtains food energy from the ecosystem, and (2) the organism contributes energy to the ecosystem. The flow of energy from an ecosystem to an organism and from one organism to another is called **energy flow**. You are part of this flow of energy when you eat the food energy stored in plants and animals (Figure 2.3).

Figure 2.3 Plants in the form of grains, fruits, and vegetables provide you with energy in the form of carbohydrates.

Plants are called **producers** because they "produce" food in the form of carbohydrates during photosynthesis. Carbohydrates stored in plants become an energy source for other life forms. An insect such as a bee that feeds on a plant such as a sunflower is called a **consumer** (Figure 2.4A and Figure 2.4B). A consumer may also become an energy source if eaten by another consumer (Figure 2.4C).

Figure 2.4 Plants such as sunflowers are producers (A). Consumers such as bees obtain nutrients from sunflowers (B), and bees are an energy source for other consumers such as this crab spider (C).

Organisms continue to contribute to the energy flow in an ecosystem even after they die, in a process called decomposition. **Decomposition** is the breaking down of organic wastes and dead organisms. The action of living organisms such as bacteria to break down dead organic matter is called **biodegradation**. Organisms such as bacteria (Figure 2.5) and fungi are called decomposers. **Decomposers** change wastes and dead organisms into usable nutrients. The nutrients are then made available to other organisms in soil and water and link the biotic and abiotic components of an ecosystem.

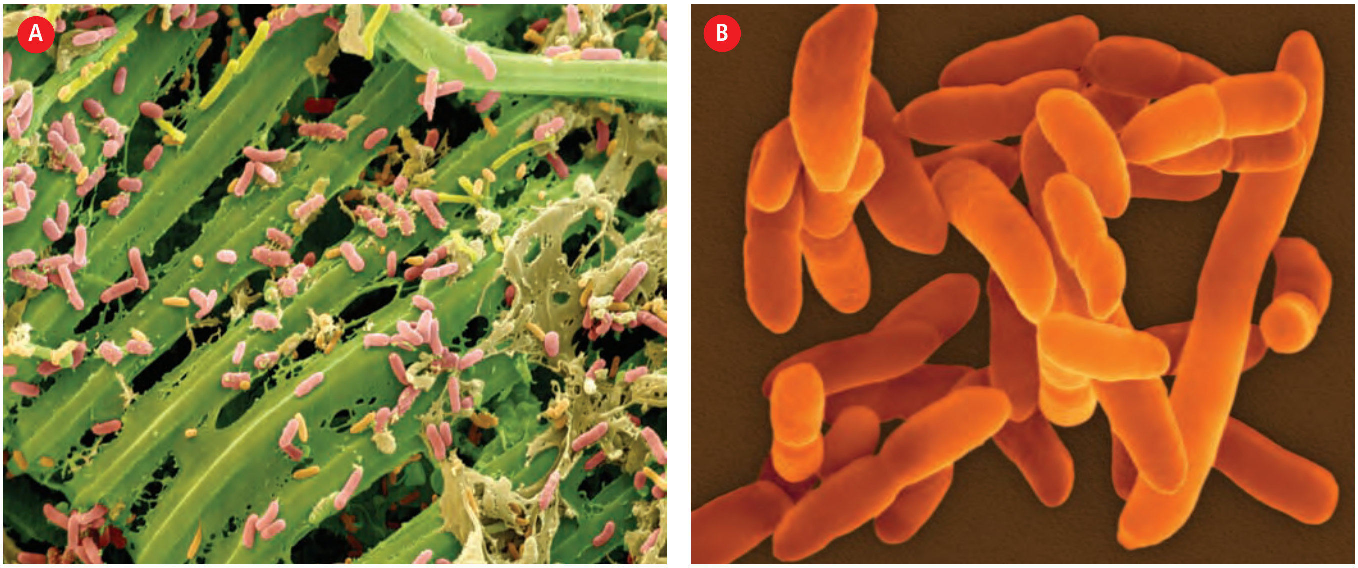


Figure 2.5 Bacteria on a decomposing cucumber (A). *Anthrobacter* is a type of decomposer bacteria (B).

Reading Check

1. What is biomass?
2. Why are plants called producers?
3. What is a consumer?
4. What is biodegradation?
5. What role do decomposers have in ecosystems?

Energy Flow and Energy Loss in Ecosystems

Scientists use different models to help them understand how energy flows through or is lost in an ecosystem. These models are food chains, food webs, and food pyramids. Each of these models reflects the feeding relationships of organisms within ecosystems.

Food chains and food webs

Food chains are models that show the flow of energy from plant to animal and from animal to animal (Figure 2.6). Each step in a food chain is called a **trophic level**. Trophic levels in a food chain show the feeding and niche relationships among organisms. Since plants and phytoplankton such as algae are the producers, they are at the first trophic level and are referred to as **primary producers**.

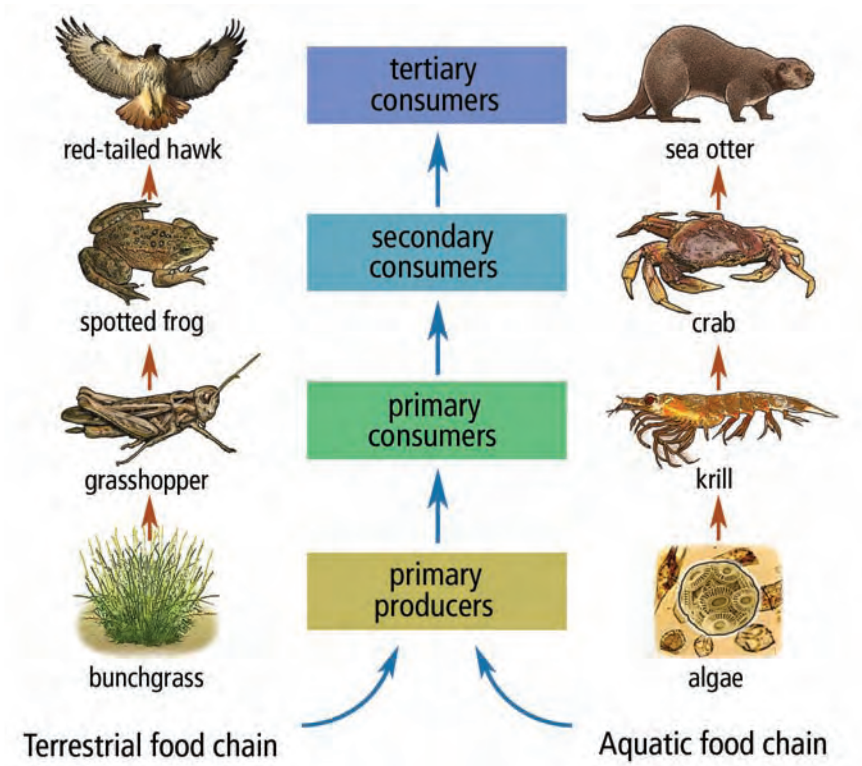


Figure 2.6 A terrestrial food chain and an aquatic food chain show the flow of energy up the trophic levels.

Figure 2.7 Detrivores in this forest ecosystem include carpenter ants, pill bugs, snails, and mites. Unseen are decomposer bacteria that vastly outnumber these detrivores.

In Figure 2.6, you can see that **primary consumers** such as grasshoppers and zooplankton (microscopic aquatic animals) are in the second trophic level. They obtain their energy by eating primary producers. **Secondary consumers** such as frogs and crabs are in the third trophic level and obtain their energy by eating primary consumers. In the fourth trophic level are **tertiary consumers** such as hawks and sea otters that feed on secondary consumers to obtain energy.

When ecologists discuss the diet or behaviour of organisms in a food chain, they often use the terms detrivores, herbivores, and carnivores. In terrestrial ecosystems, detrivores include small insects, earthworms, bacteria, and fungi (Figure 2.7).

Detrivores are consumers that obtain their energy and nutrients by eating the bodies of small dead animals, dead plant matter, and animal wastes. Detrivores feed at every trophic level (Figure 2.8) and make up their own important food chains. In fact, food chains based on dead plant and animal matter actually outnumber food chains based on living plants and animals. Detrivores such as earthworms and beetles are also an important energy source for consumers such as birds.

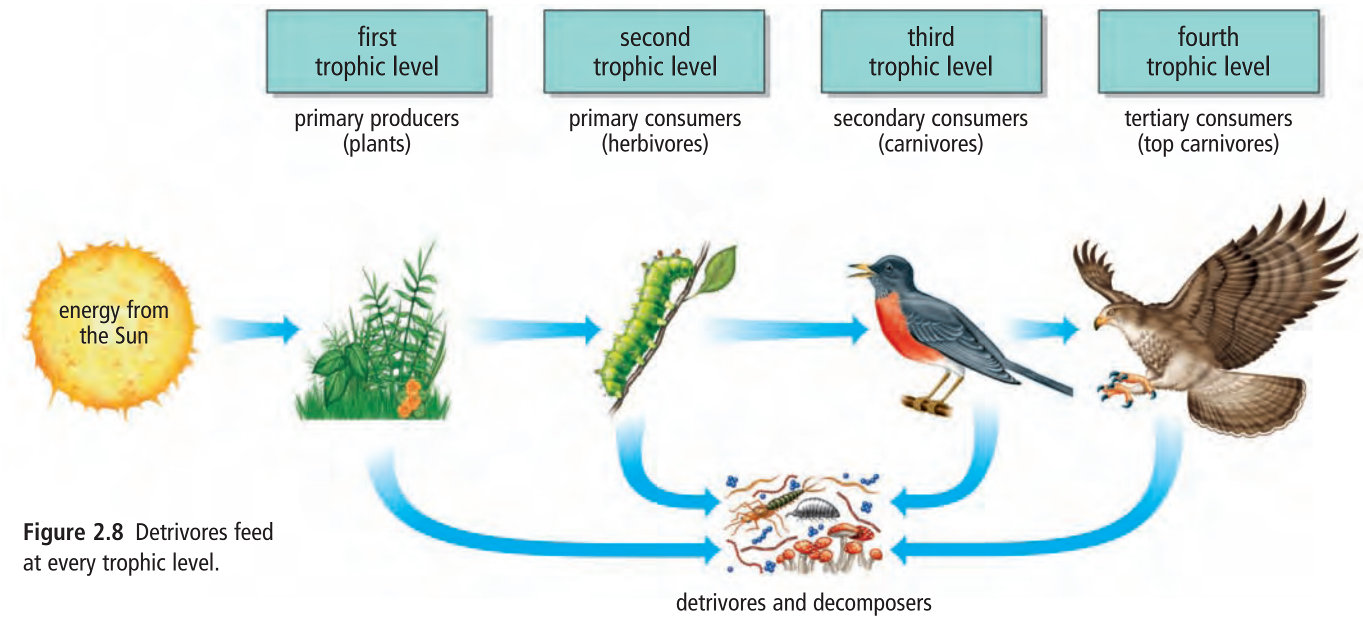


Figure 2.8 Detrivores feed at every trophic level.

Herbivores, such as grasshoppers, are primary consumers that eat plants. **Carnivores**, such as spotted frogs, are secondary consumers that eat primary consumers. Carnivores also eat other secondary consumers and are often at the tertiary level of a food chain. Carnivores at this level are often referred to as top carnivores, top consumers, or top predators. Figure 2.9 and Figure 2.10 on the next page show more examples of herbivores and carnivores.

Figure 2.9 Bighorn sheep (A) and western tiger swallowtail butterflies (B) are herbivores.

Figure 2.10 Grey wolves (A) and hobo spiders (B) are carnivores.

Many animals are part of more than one food chain and eat more than one kind of food in order to meet their energy requirements. For example, squirrels are primary consumers when they eat seeds or fruits. When they eat insects or young birds, squirrels are secondary or tertiary consumers. Consumers that eat both plants and animals are called **omnivores**. Interconnected food chains form a food web. **Food webs** are models of the feeding relationships within an ecosystem (Figure 2.11).

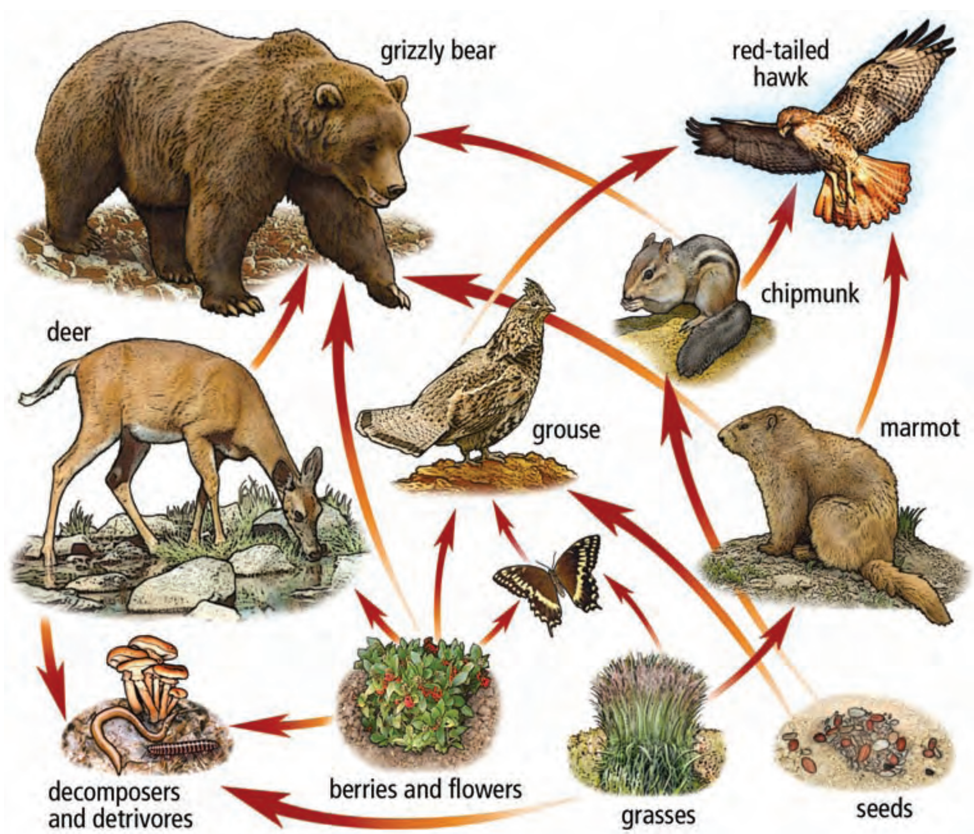


Figure 2.11 A food web in a terrestrial ecosystem

Food pyramids

When an insect eats leaves, energy stored in the leaves is transferred to the insect. When a bird eats the insect, energy stored in the insect is transferred to the bird. The same transfer of energy also occurs when killer whales eat salmon and when you eat meat, vegetables, and fruit. However, not all of the energy that organisms obtain by eating other organisms is stored (Figure 2.12). Food energy is used as you and all other living things work to obtain and digest food, repair damaged tissues, and move. Food energy is also lost when some food remains undigested and is excreted as feces. Between 80 and 90 percent of the food energy taken in by you and other organisms is used for chemical reactions in the body and eventually is lost to the ecosystem as heat. Very little food energy is used for growth or to increase biomass.

Did You Know?

Mammals and birds require a lot more food energy than most other animals to keep their body temperatures high and relatively stable.

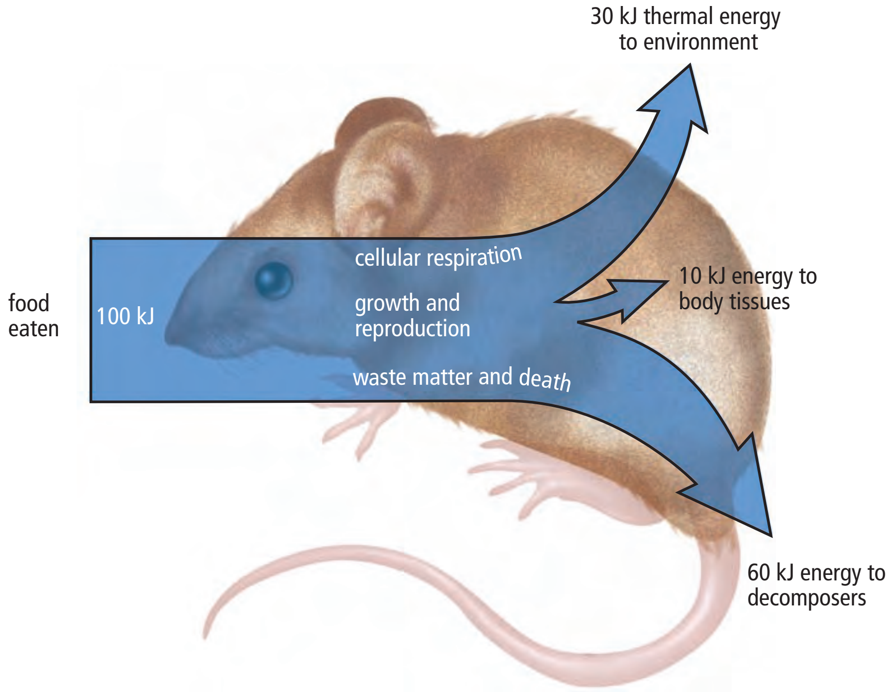


Figure 2.12 Ninety percent of the food energy taken in by this mouse is used to maintain its life functions.

A **food pyramid** is a model that shows the loss of energy from one trophic level to another (Figure 2.13 on the next page). Food pyramids are often referred to as ecological pyramids. There are several of types of **ecological pyramids** such as pyramids of biomass, numbers, and energy (see page 66). The amount of life that an ecosystem can support is determined by the amount of energy captured by producers. A desert or tundra ecosystem with little vegetation cannot support many organisms.

Explore More

In aquatic food chains, algae are primary producers that support marine life. Algae also produce 70 to 80 percent of Earth's oxygen and may be future producers of biofuels. Find out more about marine algae. Begin your search at **www.bcscience10.ca**.

Because of the 90 percent decrease in energy from trophic level to trophic level, an ecosystem supports fewer organisms at the higher trophic levels. Therefore, the lower the trophic level, the higher the number of organisms that can be supported by the ecosystem. Healthy grassland ecosystems can support many herbivores such as mice and jackrabbits, which, in turn can support large numbers of carnivores such as coyotes.

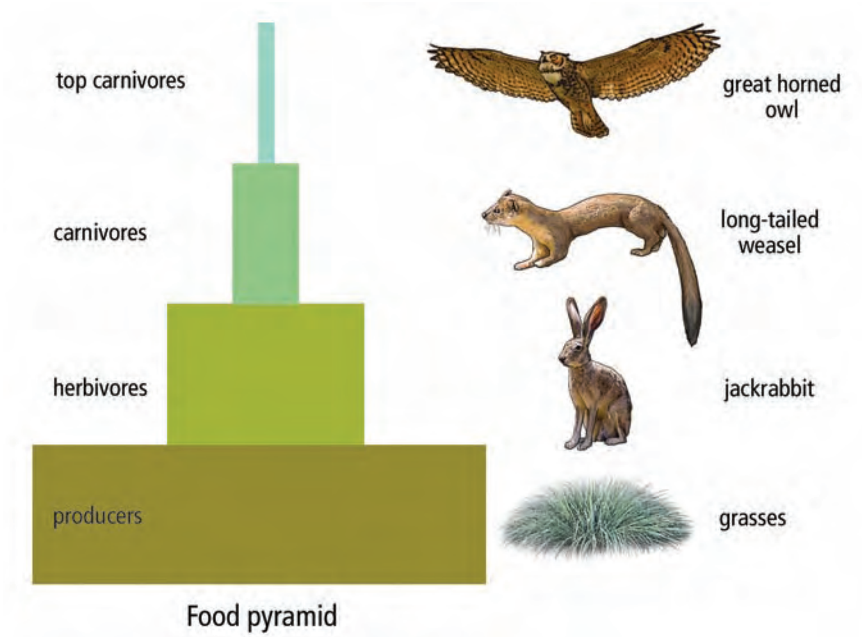


Figure 2.13 A food pyramid shows the loss of energy from one trophic level to another. This is represented by the decreasing size of the block at each level. Producers such as plants store the most energy. Carnivores such as great horned owls store the least.

Food pyramids illustrate that most of the Sun's energy that is trapped by plants flows out of an ecosystem. Food pyramids also show how important plant life is for making energy available in ecosystems. Maintaining the biodiversity of plants in an ecosystem is essential for maintaining viable food webs.

Reading Check

1. What is a food chain?
2. What is a trophic level?
3. What role do herbivores have in a food pyramid?
4. What happens to the food energy taken in by an organism?
5. What is the purpose of a food pyramid?

2-1B Comparing Available Energy

Find Out ACTIVITY

Burning firewood for heat is one of the oldest forms of using biomass energy. A temperate deciduous forest populated by trees such as maple, birch, and oak produces about 8000 kilocalories per square metre per year (kcal/m^2/y). A coniferous forest of evergreen trees such as pine, spruce, and hemlock produces about 3000 kcal/m^2/y. In this activity, you will construct two pyramids to compare the energy available in a coniferous forest and a deciduous forest.

Materials

- blank sheet of looseleaf paper
- calculator
- eight 2 cm wide strips of coloured paper
- ruler
- glue

What to Do

1. To construct a pyramid to illustrate the energy in a deciduous forest, you must use a scale for your model so that the pyramid will fit on half a sheet of looseleaf paper. Use a scale of 10 mm equals 400 kcal/m^2 to represent the amount of energy captured in a year by 1 m^2 of deciduous forest.
2. Copy the table into your notebook. In the Temperate Deciduous Forest Energy Pyramid section of your table, record 8000 kcal/m^2 of energy present for producers. Calculate how many millimetres in length a coloured strip of paper needs to be to represent 8000 kcal/m^2. Record this number in the appropriate column of your table.
3. Only 10 percent of the energy present in the biomass of the producers is converted into animal biomass. Calculate the amount of energy available to primary consumers, secondary consumers, and tertiary consumers in a deciduous forest. Record these amounts in your table.
4. Calculate how many millimetres in length a coloured strip of paper needs to be to represent each level of consumer in step 2. Record the data in your table.
5. Calculate and record the amount of energy lost at each trophic level.
6. Cut a strip of coloured paper to the correct length for plants and label it "Producers."
7. Cut a strip of coloured paper to the correct length and label it "Primary Consumers." Cut two more strips to the correct lengths and label them "Secondary Consumers" and "Tertiary Consumers."
8. Using the top half of the sheet of paper, glue the cut strips horizontally in a pyramid (the longest strip at the bottom of the pyramid, the shorter strips centred in a stack above it).
9. Repeat the above steps for the coniferous forest. Use the same scale (10 mm equals 400 kcal/m^2), and glue the pyramid to the bottom half of the sheet of paper.
10. Give each pyramid an appropriate title, and label each level in both pyramids.

Pyramids of Energy

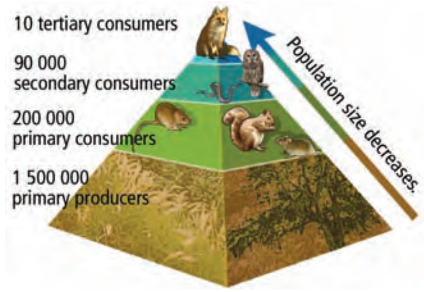
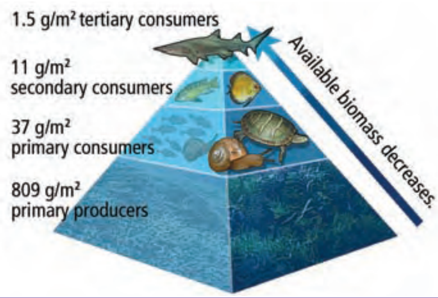
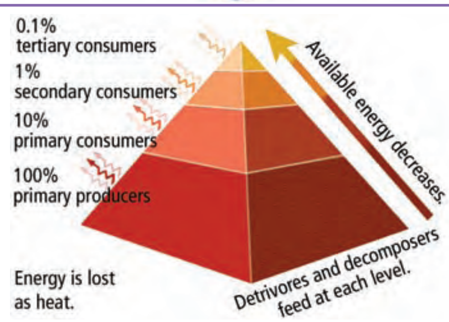
Temperate Deciduous Forest Energy Pyramid	Energy Present (kcal/m^2)	Length of Paper Strip (mm)	Energy Lost as Heat (kcal/m^2)
Producers			None
Primary consumers			
Secondary consumers			
Tertiary consumers			
Coniferous Forest Energy Pyramid	**Energy Present (kcal/m^2)**	**Length of Paper Strip (mm)**	**Energy Lost as Heat (kcal/m^2)**
Producers			None
Primary consumers			
Secondary consumers			
Tertiary consumers			

What Did You Find Out?

1. Which type of forest can support more primary consumers? More tertiary consumers?
2. Explain what happens to the energy that is not transferred at each trophic level.
3. Explain why the energy that is not transferred at each trophic level cannot be picked up by plants and cycled back through the system.

Science Math connect

Comparing Ecological Pyramids

<table>
<tr><th>Type of Ecological Pyramid</th><th>Diagram</th><th>Limitations</th></tr>
<tr><td>A pyramid of numbers shows the number of organisms at each trophic level.</td><td>
</td><td>The sizes of individual organisms vary greatly, therefore their energy needs vary greatly. The range of numbers from the producers to the tertiary consumers may be so great that it is impossible to represent the scale of the pyramid accurately.</td></tr>
<tr><td>A pyramid of biomass shows the number of organisms at each trophic level multiplied by their mass, which compensates for differences in size among organisms.</td><td>
</td><td>In some ecosystems, the biomass of lower trophic levels can be less than that of higher trophic levels. For example, in aquatic ecosystems, pyramids of biomass may be inverted because of the rapid reproduction rates of primary producers such as algae.</td></tr>
<tr><td>A pyramid of energy shows the amount of energy that is available at each trophic level.</td><td>
</td><td>It is difficult to obtain exact values of available energy in an ecosystem.</td></tr>
</table>

Questions

1. Data for ocean food chains are given in the table. Use graph paper and the data to construct:

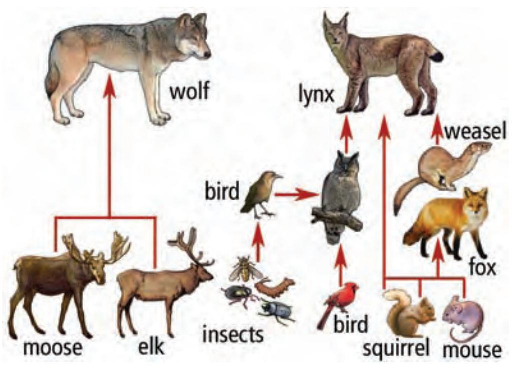
(a) a pyramid of numbers
(b) a pyramid of biomass
(c) a pyramid of energy

2. Are the pyramids you constructed for question 1 identical in appearance? Explain.

Trophic Level	Number of Organisms	Mass (g/m^2)	Energy ($kcal/m^2$)
Primary producers (phytoplankton)	4 000 000 000	807	36 380
Primary consumers	11	37	596
Secondary consumers	1	11	48

Checking Concepts

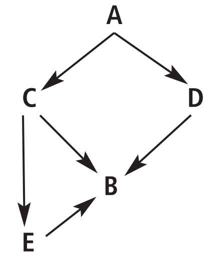
1. How do fungi decompose leaves?
2. What is decomposition?
3. Explain why plants are called primary producers.
4. Put the following organisms in order from lowest trophic level to highest trophic level.
   (a) snake (c) grass
   (b) eagle (d) mouse
5. (a) Are herbivores primary consumers? Explain why or why not.
   (b) Are carnivores primary consumers? Explain why or why not.
   (c) What is an omnivore?
6. Give an example of each of the following.
   (a) a secondary consumer
   (b) a tertiary consumer
   (c) an omnivore
7. How much energy is lost from producers to secondary consumers?
8. In the diagram below, identify each of the following.
   (a) producers
   (b) primary consumers
   (c) secondary consumers
   (d) tertiary consumers



9. Give an example of a food chain in a pond ecosystem.
10. What is the main difference between food chains and food webs?
11. Do detrivores return energy to an ecosystem? Explain.

Understanding Key Ideas

12. In the following diagram of a food web, identify which letter represents a species that:
    (a) is the producer
    (b) has the greatest biomass
    (c) has the smallest biomass
    (d) could be a caterpillar
    (e) could be a decomposer



13. If there are 1 000 000 kcal/m^2 in the producer level of a food pyramid, how many kilocalories will be incorporated into the bodies of the following, if there is a 90 percent energy loss at each level?
    (a) primary consumers
    (b) secondary consumers
    (c) tertiary consumers
14. (a) Describe a four-organism food chain that might be found in a desert community.
    (b) Identify the trophic level of each organism.
15. Explain why you do not gain weight every time you eat.
16. Explain why there cannot be an unlimited number of trophic levels.

Pause and Reflect

What would be the impact on life on Earth if less and less solar energy were able to reach Earth's surface?

The Cycling of Nutrients in the Biosphere

Nutrients are chemicals that are required for plant and animal growth and other life processes. Nutrients are accumulated for short or long periods of time in Earth's atmosphere, oceans, and land masses. Scientists refer to these accumulations as **stores** (Figure 2.15).

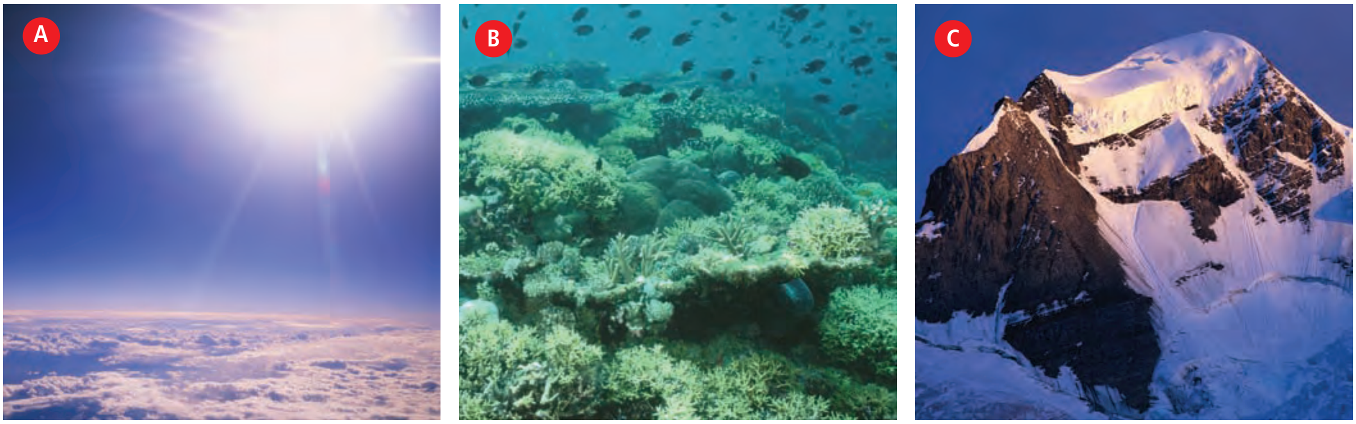


Figure 2.15 The atmosphere (A), oceans (B), and land masses (C) are stores for nutrients that are essential for life.

Biotic processes such as decomposition and abiotic processes such as river run-off can cause nutrients to flow in and out of stores. Taken together, these continuous flows of nutrients in and out of stores are called **nutrient cycles** (Figure 2.16). (These flows are sometimes referred to as exchanges.) Nutrient cycles are nearly in balance because, without human interference, the amounts of nutrients flowing into the stores are nearly the same as the amounts flowing out of the stores.

Word Connect

You may see the terms "gigatonne" and "megatonne" used in diagrams of nutrient cycles. Gigatonne is a metric measurement meaning 1 billion tonnes. The prefix "giga-" comes from the Greek word *gigas*, which means giant. Megatonne is a metric measurement meaning 1 million tonnes. The prefix "mega-" comes from the Greek word *megas*, which means great or mighty.

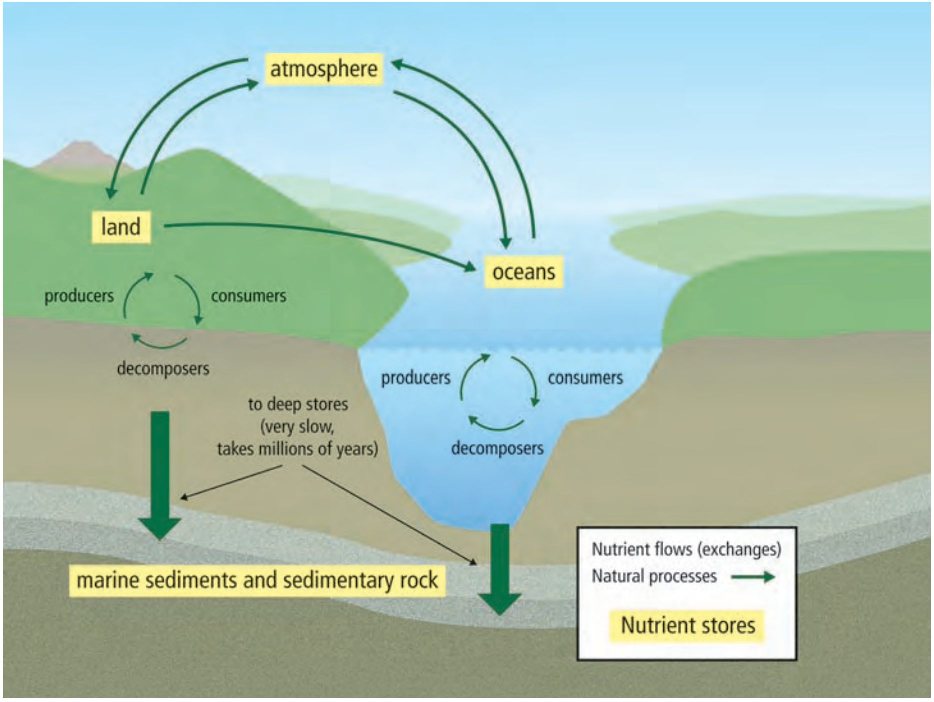


Figure 2.16 A general model of a nutrient cycle

2-2A Understanding Nutrient Cycles

Think About It

Figure 2.16 on page 69 represents a model of a nutrient cycle that takes place without human interference. In this activity, you will study this model to become familiar with the different parts of a nutrient cycle.

What to Do

1. Work with a partner and study Figure 2.16 closely. (Keep one of your textbooks open to page 69.)
2. Identify where nutrients are stored.
3. Identify the nutrient flows. Describe any patterns that you see.
4. Infer the way in which nutrients travel from land to oceans.
5. Identify the state in which nutrients enter the atmosphere (e.g., as liquids, solids, or gases).
6. State where the fastest exchange of nutrients takes place.
7. State how producers might contribute to nutrient cycles.
8. Hypothesize how human activities might alter a nutrient cycle.

What Did You Find Out?

1. Explain why the arrows are drawn in different sizes.
2. What conclusion can you make about nutrient stores in marine sediments and sedimentary rocks?
3. (a) What biotic processes may take place in a nutrient cycle?
   (b) What abiotic processes may take place?
4. Do nutrients leave the biosphere? Explain.

Word Connect

Scientists also use the term "biogeochemical cycles" when referring to nutrient cycles. "Bio" means life, "geo" means earth, and "chem" refers to chemistry. As this term implies, biogeochemical cycles involve interactions between the biotic and abiotic components of the biosphere.

The Effect of Human Activities on Nutrient Cycles

Human activities such as land clearing, agriculture, urban expansion, mining, industry, and motorized transportation can affect a nutrient cycle by increasing the amounts of nutrients in the cycle faster than natural biotic and abiotic processes can move them back to the stores (Figure 2.17). Over time, as a result of these activities, increased amounts of nutrients in the atmosphere, in the oceans, and on land can have significant effects on the environment.

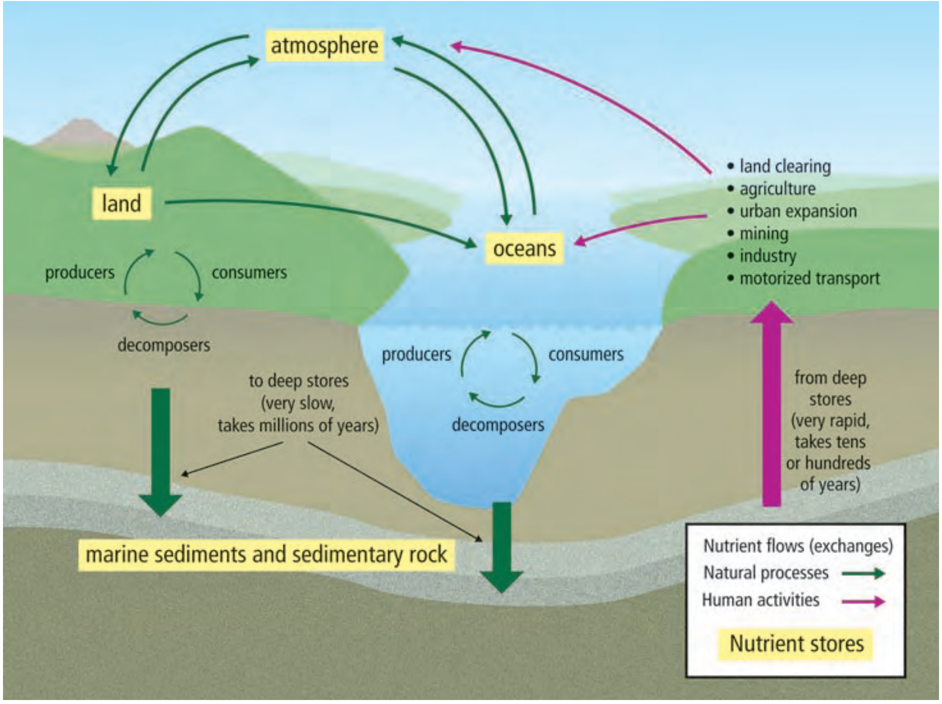


Figure 2.17 A nutrient cycle including human activities

Reading Check

1. What is the importance of nutrients?
2. What is a nutrient store?
3. Explain the term "nutrient cycle."
4. How can human activities affect a nutrient cycle?

The Carbon, Nitrogen, and Phosphorus Cycles

There are five chemical elements (also known as chemical nutrients) that limit the amount and types of life possible in an ecosystem: carbon, hydrogen, oxygen, nitrogen, and phosphorus. Carbon, hydrogen, oxygen, and nitrogen atoms are cycled between living organisms and the atmosphere. Phosphorus atoms enter the environment from sedimentary rock. Carbon, hydrogen, and oxygen make up molecules, such as deoxyribonucleic acid (DNA), carbohydrates, and proteins that are found in every living organism. Nitrogen is found in proteins and DNA. The health of an ecosystem depends on a balance of these five nutrients. In this section, you will look at three important nutrient cycles that move these nutrients through terrestrial and aquatic ecosystems. These cycles are the **carbon cycle**, the **nitrogen cycle**, and the **phosphorus cycle**.

Did You Know?

Every living thing on Earth contains billions of atoms of carbon, yet carbon makes up only 0.032 percent of Earth's crust.

The Carbon Cycle

All living things contain billions of carbon atoms in their cells (Figure 2.18). Carbon is an essential component in the chemical reactions that sustain life, such as cellular respiration, which you will learn about on page 74.

Figure 2.18 Every cell in your body contains carbon (A). Carbon plays an important role in plant growth (B).

Figure 2.19 Short-term stores of carbon are found both on land and in the upper parts of the ocean. Longer-term stores of carbon are found in intermediate and deep waters.

How carbon is stored

Short-term stores of carbon are found in vegetation on land, in plants in oceans, in land-based and marine animals, and in decaying organic matter in soil. Carbon is also found in the atmosphere as carbon dioxide gas (CO_2) and is stored, in its dissolved form, in the top layers of the ocean (Figure 2.19). Longer-term stores of carbon are found in intermediate (middle) and deep ocean waters as dissolved carbon dioxide. In cold ocean waters, this carbon will sink to the ocean floor and remain for 500 years. Eventually, it may be used by bacteria and released again.

On land, long-term stores of carbon are found in coal deposits (Figure 2.20) and in oil and gas deposits, which formed million of years ago. Coal, oil, and natural gas are fossil fuels that are formed from dead plants and animals. The largest long-term stores of carbon are found in marine sediments and sedimentary rock.

Sedimentation is the process that contributes to the formation of sedimentary rock. During sedimentation, soil particles and decaying and dead organic matter accumulate in layers on the ground or at the bottom of oceans and other large bodies of water. These layers are turned into rock by slow geological processes that take place over long periods of time. Some marine sediments and sedimentary rock form from the shells of marine organisms such as coral and clams. These shells contain calcium carbonate ($CaCO_3$). **Carbonate** is a combination of carbon and oxygen (CO_3^{2-}) that is dissolved in ocean water. Figure 2.21 shows other marine organisms that have shells containing calcium carbonate. The shells accumulate on the ocean floor when the organisms die and form carbonate-rich deposits. In time, the carbonate is changed into limestone, which is a sedimentary rock.

Figure 2.20 Coal seam on a hillside. Fossil fuels such as coal are long-term stores of carbon.

Figure 2.21 Calcium carbonate in the shells of mussels and acorn barnacles will, over a very long time, form sedimentary rock—a long-term store of carbon.

Table 2.1 shows that the largest carbon store on Earth is in marine sediments and sedimentary rock. (Carbon stores are also referred to as carbon sinks.)

Table 2.1 Estimated Major Stores of Carbon on Earth

Store	Amount of Carbon in Gigatonnes
Marine sediments and sedimentary rock	68 000 000 to 100 000 000
Oceans (intermediate and deep water)	38 000 to 40 000
Coal deposits	3 000
Soil and organic matter	1 500 to 1 600
Atmosphere	750
Terrestrial vegetation	540 to 610
Oil and gas deposits	300

Data current as of 2008

Did You Know?

The intermediate and deep waters of the world's oceans are vast stores of carbon. They store 50 times as much carbon dioxide as the atmosphere.

How carbon is cycled through ecosystems

A variety of natural processes move carbon through ecosystems. These include photosynthesis, respiration, decomposition, ocean processes, and events such as volcanic eruptions and large-scale forest fires.

Photosynthesis

Photosynthesis is an important process in which carbon and oxygen are cycled through ecosystems. **Photosynthesis** is a chemical reaction that converts solar energy into chemical energy. During photosynthesis, carbon, in the form of carbon dioxide in the atmosphere, enters through the leaves of plants and reacts with water in the presence of sunlight to produce energy-rich sugars (carbohydrates) and oxygen (Figure 2.22). Photosynthesis can be represented by this equation:

$$\text{energy (sunlight)} + 6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$$

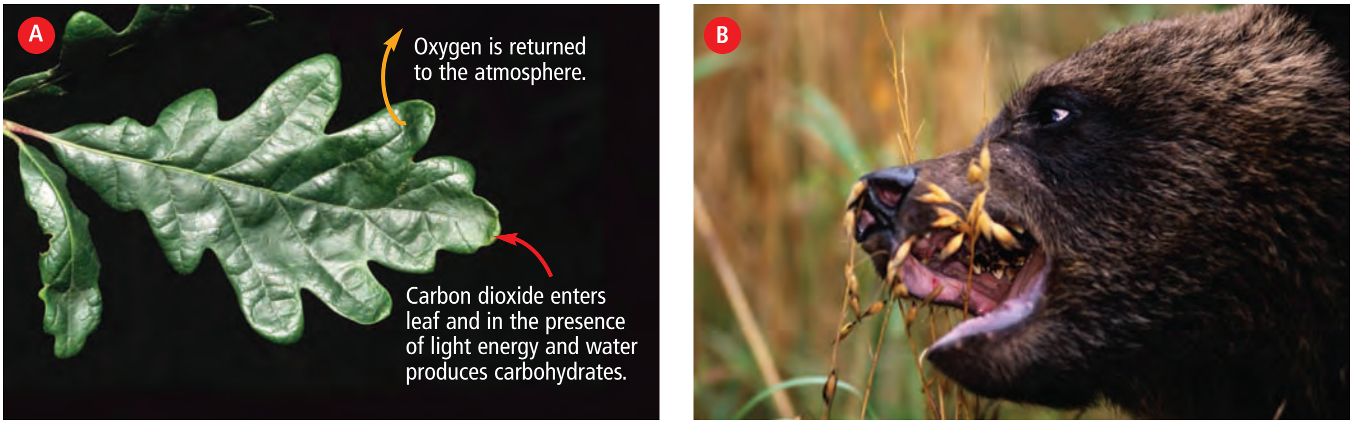


Figure 2.22 Producers remove carbon dioxide from the atmosphere during photosynthesis and produce oxygen, which is returned to the atmosphere (A). Consumers eat producers and obtain energy from them in the form of carbohydrates (B).

Photosynthesis also occurs in some micro-organisms, such as cyanobacteria, which are important biotic components of aquatic ecosystems (Figure 2.23). Photosynthesis makes usable energy for producers in the form of carbohydrates. By eating plants, consumers obtain energy and take carbon into their cells. The food pyramids you studied in section 2.1 showed how this energy was obtained.

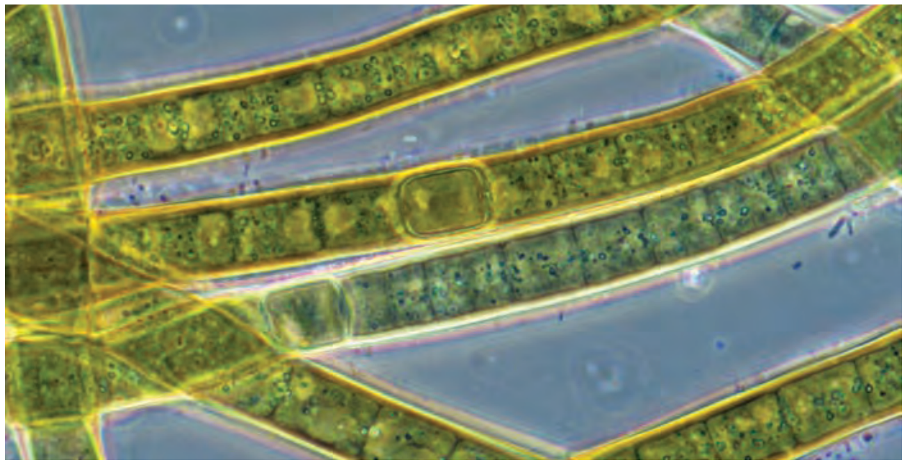


Figure 2.23 Microscopic cyanobacteria

Cellular respiration

Cellular respiration is the process in which both plants and animals release carbon dioxide back into the atmosphere by converting carbohydrates and oxygen into carbon dioxide and water (Figure 2.24). During cellular respiration, energy is released within the cells of organisms and made available for growth, repair, and reproduction. Carbon dioxide gas is released as a waste product. Cellular respiration can be represented by this equation:

$$C_6H_{12}O_6 \text{ (carbohydrates)} + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + \text{energy}$$

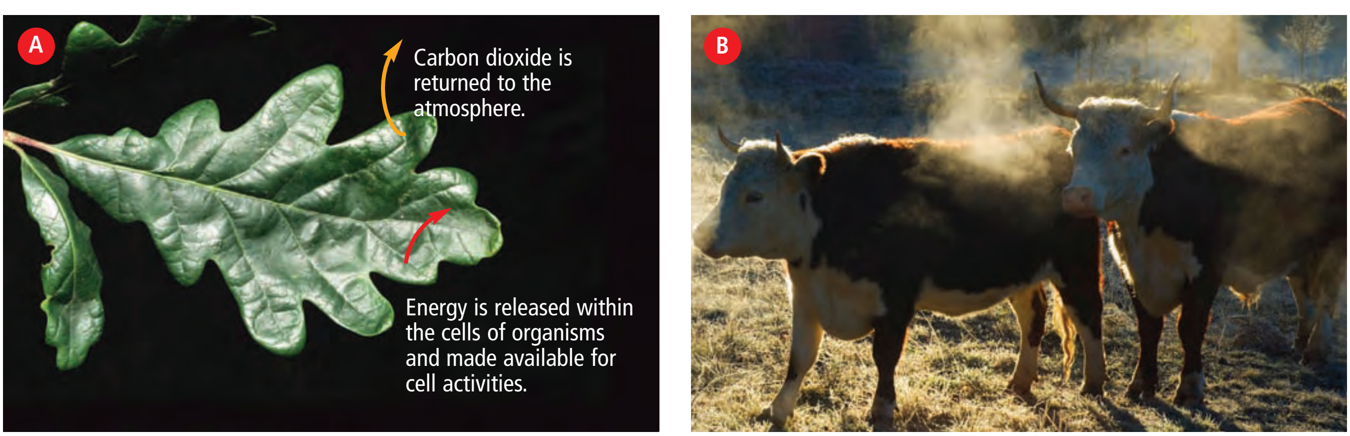


Figure 2.24 Producers release carbon dioxide back into the atmosphere (in the absence of sunlight) during cellular respiration (A). Consumers also release carbon dioxide when they exhale (B).

Decomposition

As you read in section 2.1, decomposition refers to the breaking down of dead organic matter. Decomposers such as bacteria and fungi convert organic molecules such as cellulose (a type of carbohydrate found in plants) back into carbon dioxide, which is released into the atmosphere.

Reading Check

1. Where is carbon stored on Earth?
2. Describe the chemical reaction of photosynthesis.
3. What is cellular respiration?
4. What is the importance of decomposition to the carbon cycle?

Other ways carbon is cycled through ecosystems

Processes that occur in oceans and as a result of geologic or natural events are also part of the carbon cycle. For example, the process of ocean mixing moves carbon throughout the world's oceans and pumps more carbon into the oceans than is released back into the atmosphere (Figure 2.25). In this process, carbon dioxide dissolves in the cold ocean waters found at high latitudes. The cold water sinks and moves slowly in deep ocean currents toward the tropics. In the warm tropics, the water rises as it is warmed, mixing with water at intermediate levels and at the surface. Some carbon dioxide is released to the tropical atmosphere as ocean currents carry the warmed water back toward polar areas.

Did You Know?

Some scientists estimate that the movement of krill helps cycle carbon in oceans. Krill may be responsible for one third of the ocean mixing of nutrients and gases.

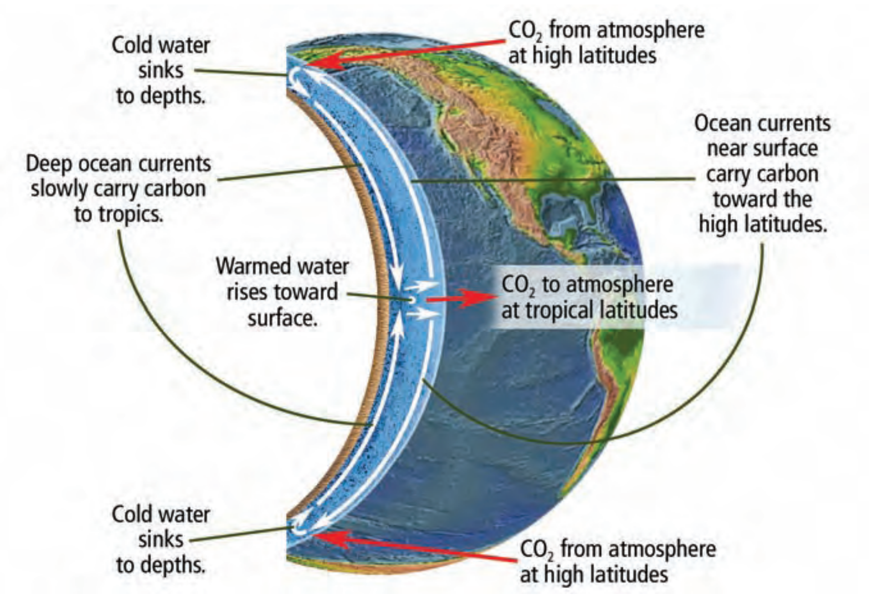


Figure 2.25 Ocean mixing

Connection

Section 12.2 has more information about subduction and tectonic plates.

Occasionally, some carbon dioxide is released from volcanoes (Figure 2.26A) following the subduction and melting of sedimentary rock in tectonic plates. Some carbon dioxide is also slowly released from decomposing trees (Figure 2.26B), and some carbon dioxide is rapidly released during forest fires (Figure 2.26C). Figure 2.27 shows how the different parts of the carbon cycle function together.

Figure 2.26 Volcanic eruptions (A), decomposing trees (B), and forest fires (C) also contribute carbon dioxide to the atmosphere.

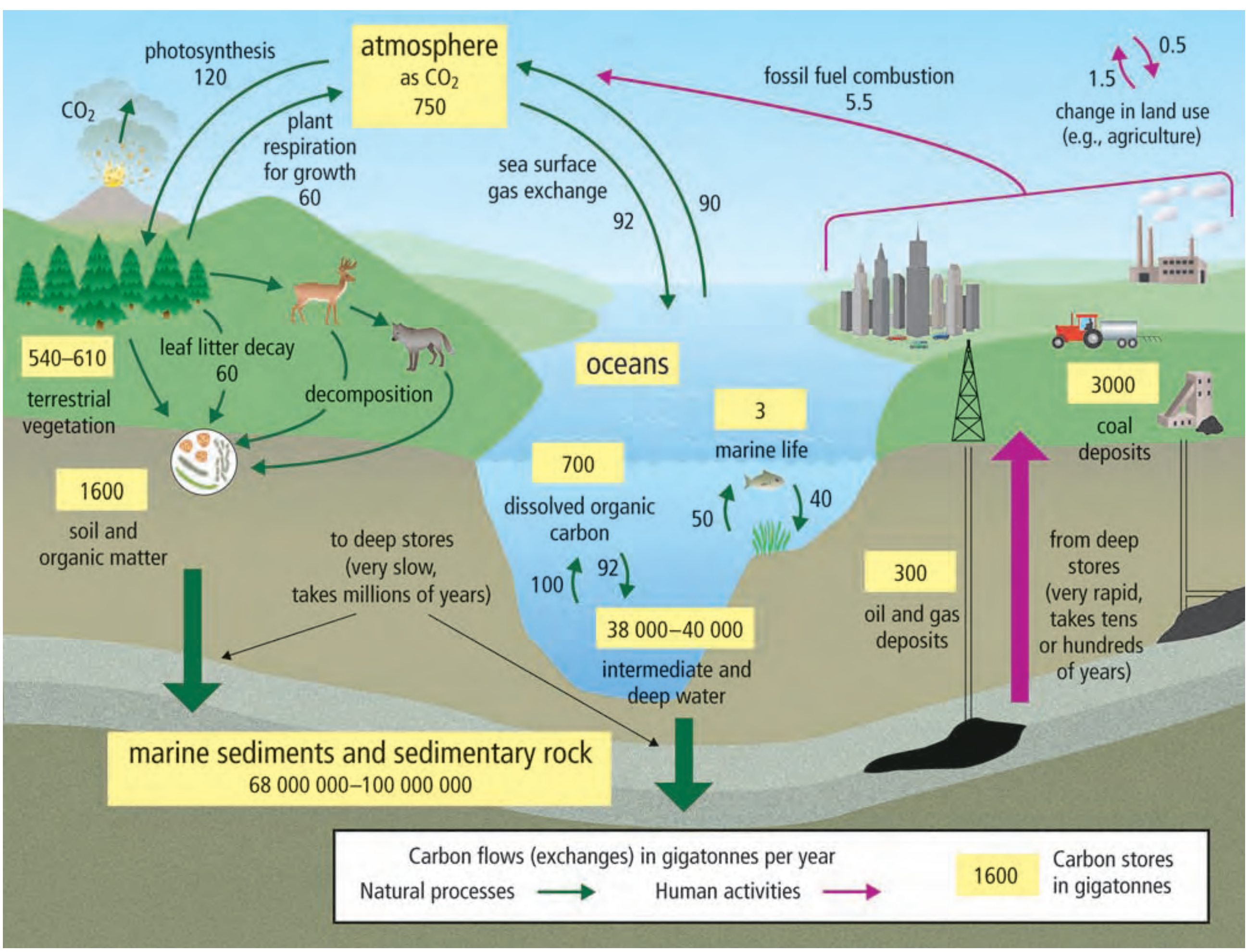


Figure 2.27 The carbon cycle

Data current as of 2008

Human Activities and the Carbon Cycle

Human activities such as industry and motorized transportation, land clearing, agriculture, and urban expansion have changed the natural carbon cycle. Since the Industrial Revolution, which began around 1850, the amount of carbon dioxide gas in the atmosphere has increased over 30 percent. Scientists have found that, for the previous 160 000 years, the increase in the amount of carbon dioxide was only 1 percent to 3 percent. Human activities that involve burning fossil fuels have reintroduced carbon into the cycle that was removed from it long ago and stored deep within the Earth (Figure 2.28). So much carbon is released so quickly into the atmosphere from these activities that the natural carbon cycle can no longer move all of it to other stores. Scientists estimate that, depending on choices made in the coming years, carbon stores in the atmosphere will rise by at least one third and perhaps as much as 3.4 times by the end of the century. This is important because carbon dioxide, the main form of carbon stored in the atmosphere, is a greenhouse gas. Greenhouse gases contribute to global climate change.

Connection

Section 11.2 has more information on greenhouse gases and climate change.

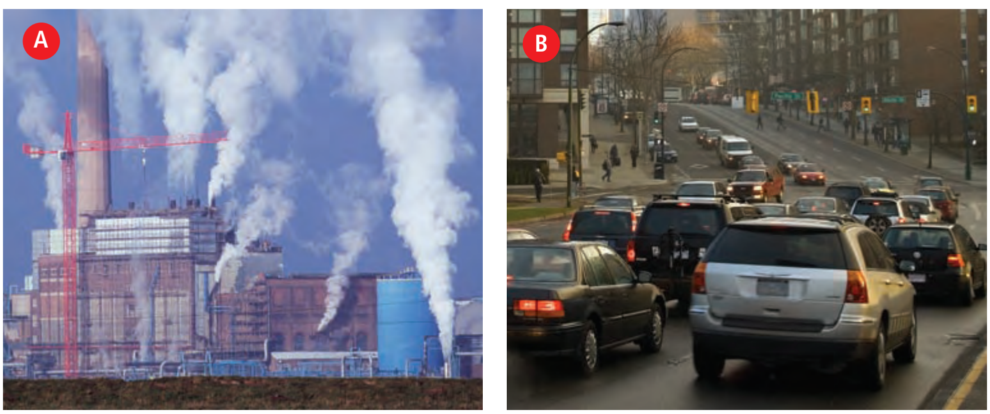


Figure 2.28 The burning of fossil fuels for industry (A) and for driving cars and trucks (B) contributes huge amounts of carbon dioxide to the atmosphere.

Other human activities also place additional carbon into the atmosphere. Clearing land for agriculture and the expansion of cities reduces the total amount of carbon taken from the atmosphere by plants during photosynthesis (Figure 2.29). Although farmed plants do remove some carbon from the atmosphere through photosynthesis, they usually remove less carbon dioxide than did the natural vegetation.

Figure 2.29 Changes in land use, such as clearing land for agriculture (A) and urban expansion (B), contribute carbon dioxide to the atmosphere.

Reading Check

1. How is carbon cycled from intermediate ocean depths?
2. Name two other ways in which carbon is cycled through ecosystems.
3. How has burning fossil fuels changed the natural carbon cycle?
4. What other human activities have an impact on the carbon cycle?

Figure 2.30 Nitrogen is found in the proteins that are required for this skateboarder's muscles to function (A). Crops require adequate amounts of nitrogen to thrive (B).

The Nitrogen Cycle

Nitrogen is an important component of DNA and proteins, which are essential for the life processes that take place inside cells. For animals, proteins are essential for muscle function (Figure 2.30A) and many other life functions. For plants, nitrogen is important for growth (Figure 2.30B).

How nitrogen is stored

The largest store of nitrogen is the atmosphere, where it exists as nitrogen gas (N_2). Other major stores of nitrogen include oceans and organic matter in soil. In terrestrial ecosystems, living organisms, lakes, and marshes also store nitrogen, but in much smaller amounts.

How nitrogen is cycled through ecosystems

Although 78 percent of Earth's atmosphere is nitrogen gas (N_2), most organisms cannot use this form of nitrogen. Therefore, much of the nitrogen cycle involves processes that make nitrogen available to plants and, eventually, to animals. Three of these processes are nitrogen fixation, nitrification, and uptake.

Nitrogen fixation

Nitrogen fixation is the process in which nitrogen gas (N_2) is converted into compounds that contain nitrate (NO_3^-) or ammonium (NH_4^+). Both of these compounds are usable by plants. Nitrogen fixation occurs in three ways: in the atmosphere, in the soil, and in water bodies.

Figure 2.31 Lightning fixes nitrogen in the atmosphere.

Atmospheric nitrogen fixation occurs when nitrogen gas (N_2) is converted into nitrate (NO_3^-) and other nitrogen-containing compounds by lightning (Figure 2.31). Lightning is an electrical discharge of static electricity in the atmosphere. It provides the energy that is necessary for nitrogen to react with oxygen to form these compounds. Nitrate and other nitrogen-containing compounds enter terrestrial and aquatic ecosystems in rain. Only a small amount of nitrogen-containing compounds are fixed in the atmosphere as a result of this process.

Nitrogen fixation in the soil occurs when nitrogen gas (N_2) is converted into ammonium (NH_4^+) by bacteria during the decomposition process. Certain species of bacteria, called **nitrogen-fixing bacteria**, play a significant role in nitrogen fixation. For example, *Rhizobium* is a species of nitrogen-fixing bacteria that lives in the root nodules of legumes and some other plants (Figure 2.32). Legumes are pod-producing plants such as peas, beans, clover, and alfalfa. These plants supply nitrogen-fixing bacteria with sugars, and the bacteria supply the host plants with nitrogen in the form of ammonium (NH_4^+). Other plants, such as red alder trees, are also important to nitrogen fixation. Red alder trees live in association with nitrogen-fixing bacteria and are an important tree in forest ecosystems in British Columbia (Figure 2.33).

Figure 2.32 *Rhizobium*, a species of nitrogen-fixing bacteria, on the roots of a bean plant

Figure 2.33 The Douglas fir trees shown in (A) grow in an area that is also planted with red alder trees. These fir trees are much larger in size than the Douglas fir trees shown in (B), which are growing in an area where red alder trees are not planted.

Certain species of cyanobacteria in aquatic ecosystems also fix nitrogen into ammonium (NH_4^+). Cyanobacteria, as you have learned, are blue-green bacteria that manufacture their own food during photosynthesis. Nitrogen-fixing cyanobacteria make these nitrogen compounds available to plants in the surface waters of oceans, wetlands, and lakes (Figure 2.34).

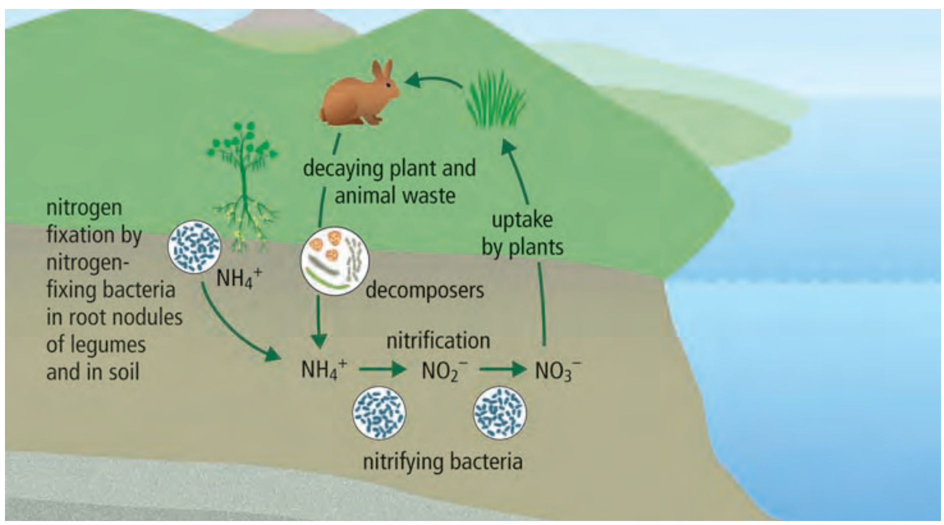
Figure 2.34 Nitrogen-fixing cyanobacteria provide nitrogen to ocean plants such as kelp.

Nitrification and uptake

Since not all plants live in association with nitrogen-fixing bacteria, they must obtain nitrogen in another form. In a process called **nitrification**, ammonium (NH_4^+) is converted into nitrate (NO_3^-). Nitrification takes place in two stages and involves certain soil bacteria known as **nitrifying bacteria**. In the first stage of nitrification, certain species of nitrifying bacteria convert ammonium (NH_4^+) into nitrite (NO_2^-). In the second stage, different species of nitrifying bacteria convert nitrite (NO_2^-) into nitrate (NO_3^-).

Once nitrates are made available by nitrifying bacteria, nitrates can enter plant roots and eventually be incorporated into plant proteins. The uptake of nitrates is important not only for plants but also for other organisms. When herbivores and omnivores eat plants, they incorporate nitrogen into the proteins in their tissues. Figure 2.35 shows the nitrification process, which occurs in both terrestrial and aquatic ecosystems.

Figure 2.35 The process of nitrification



Other types of decomposer bacteria and fungi are able to take the nitrogen trapped in the proteins and DNA of dead organisms and convert it back to ammonium (NH_4^+). Some bacteria species decompose urea (a waste product) that is excreted by animals and then convert it into ammonium (NH_4^+). Plants can use the ammonium form of nitrogen to make proteins for life functions.

Reading Check

1. What is nitrogen fixation?
2. Where does nitrogen fixation take place?
3. Name one organism that is important to nitrogen fixation.
4. What occurs during nitrification?
5. How does the uptake of nitrates by plants benefit animals?

How nitrogen is returned to the atmosphere

Nitrogen is returned to the atmosphere in a process called **denitrification**. Denitrification in terrestrial and aquatic ecosystems involves certain bacteria known as **denitrifying bacteria**. In a series of chemical reactions, denitrifying bacteria convert nitrate (NO_3^-) back into nitrogen gas. In a balanced ecosystem, the amount of fixed nitrogen equals the amount of nitrogen returned to the atmosphere through denitrification. Nitrogen is also returned to the atmosphere as ammonia (NH_3) in volcanic ash and nitrogen oxide gases such as nitrogen oxide and nitrogen dioxide.

Figure 2.36 Streams carry nitrogen compounds that have not been absorbed by plants.

How nitrogen is removed from ecosystems

Excess nitrate (NO_3^-) and ammonium (NH_4^+) that are not taken up by plants mix with rainwater and are washed from the soil into ground water and streams (Figure 2.36). This unused nitrogen may settle to ocean, lake, or river bottoms in sediments. Eventually, these sediments will form rock and the nitrogen will not be available. Only after centuries of weathering will the nitrogen be released into the water.

Figure 2.37 shows how the different parts of the nitrogen cycle function together.

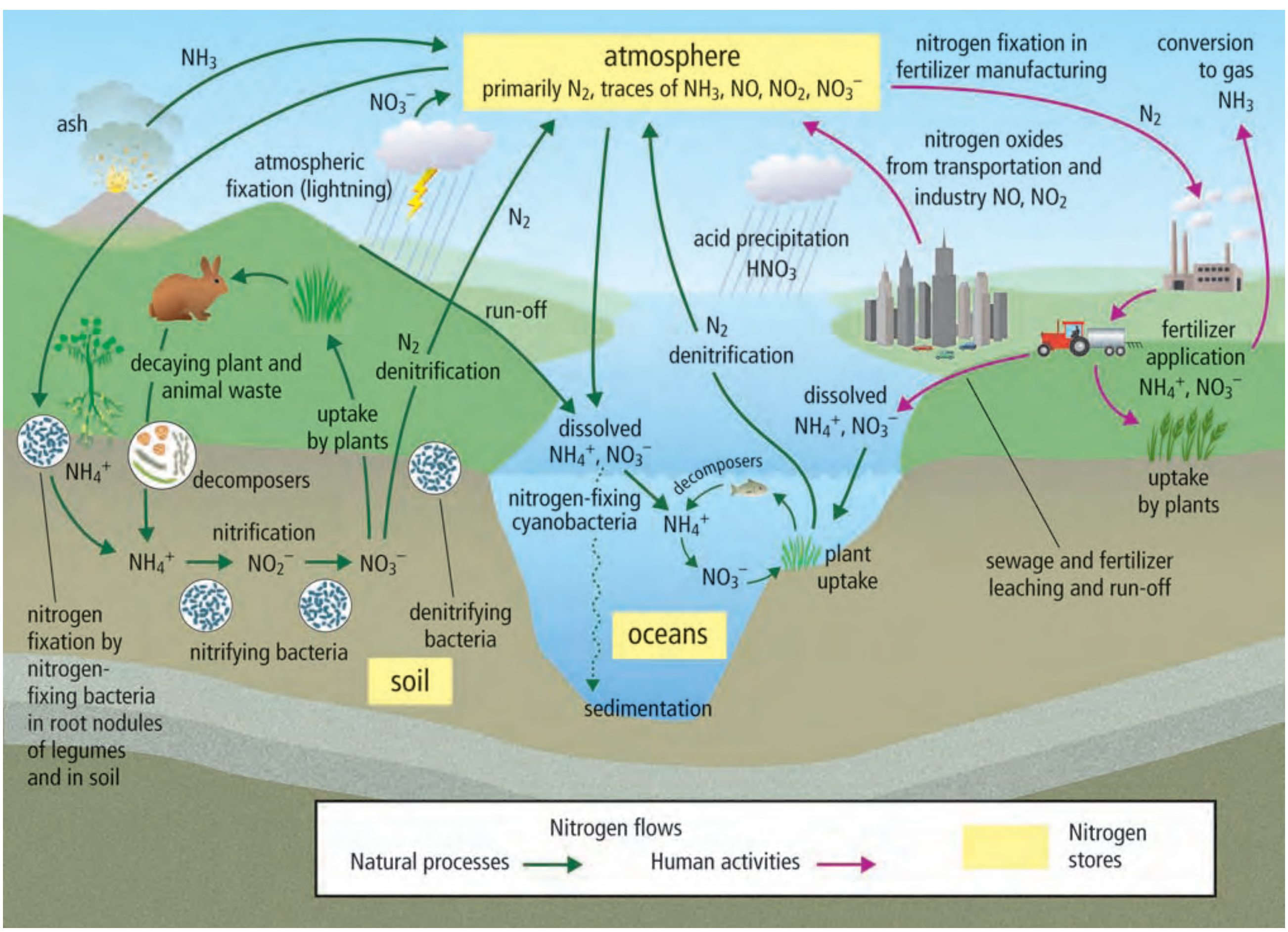


Figure 2.37 The nitrogen cycle

Human Activities and the Nitrogen Cycle

Connection

Section 5.2 has more information about the formation and effects of acid precipitation.

Human activities have doubled the available nitrogen in the biosphere in the past 50 years. Millions of tonnes of nitrogen are added to the atmosphere annually in the form of nitrogen oxide (NO) and nitrogen dioxide (NO_2) as a result of fossil fuel combustion in power plants and processes such as sewage treatment. Nitrogen is also released during the burning of fossil fuels in cars, trucks, and other motorized forms of transportation.

Clearing forests and grasslands by burning also releases trapped nitrogen into the atmosphere. These compounds eventually return to terrestrial and aquatic ecosystems as acid precipitation (Figure 2.38). Acid precipitation (or acid rain) is formed from dissolved nitrogen compounds in the moisture in clouds and falls back to Earth as nitric acid (HNO_3).

Suggested Activity

Conduct an Investigation 2-2C on page 88

Figure 2.38 These trees were destroyed by the effects of acid precipitation.

Figure 2.39 Chemical fertilizer application

The use of chemical fertilizers began in the 1800s, expanded in the 1940s, and has grown rapidly since to meet the demands of an increasing human population (Figure 2.39). Chemical fertilizers are made through industrial processes that fix atmospheric nitrogen (N_2) into nitrogen compounds that crops can assimilate. However, crops do not assimilate all of the fertilizer they receive. As a result, excess nitrogen in the form of ammonium (NH_4^+) and nitrate (NO_3^-) can escape back into the atmosphere as ammonia (NH_3) or can be washed or leached from the soil by rain or irrigation water. (**Leaching** is removal by water of substances that have dissolved in moist soil.) Ground water run-off containing these compounds enters lakes and streams. This increased amount of dissolved nitrogen causes eutrophication in aquatic ecosystems. **Eutrophication** is the process by which excess nutrients result in increased plant production and decay. Run-off from acid precipitation also contributes to eutrophication.

In a nitrogen-rich, or eutrophic, environment, algae grow very quickly. Excessive algae growth (Figure 2.40) deprives other aquatic plants of sunlight and of oxygen as algae undergo cellular respiration. When the algae die, the oxygen used in decomposition also deprives aquatic animals of oxygen and can lead to the death of all fish in a lake. Some algae blooms produce neurotoxins that are transferred through the food web to shellfish, seabirds, marine mammals, and humans.

In addition to using fertilizers globally, humans are planting large areas to grow single crops of soybeans, peas, alfalfa, and rice. Since these crops fix atmospheric nitrogen, they greatly increase the rate of nitrogen fixation in these areas.

Figure 2.40 Algae blooms can be extremely harmful to other forms of aquatic life.

Reading Check

1. What is denitrification?
2. What human activities contribute excess nitrogen to ecosystems?
3. What is acid precipitation?
4. How does excess nitrogen enter waterways?
5. What is eutrophication?

The Phosphorus Cycle

Phosphorus is essential for a variety of life processes in plants and animals. For example, phosphorus is an essential element in the molecule that carries energy to plant cells and animal cells. In plants, phosphorus contributes to root development, stem strength, and seed production (Figure 2.41). In humans, a large amount of phosphorus is found in bones (Figure 2.42). Here phosphorus works with calcium in the development of strong bone tissue.

Figure 2.41 Phosphorus is important to healthy seed development.

Figure 2.42 An X ray of healthy foot bones. About 85 percent of phosphorus in the human body is found in bones.

How phosphorus is stored

Unlike carbon, oxygen, and nitrogen, phosphorus is not stored in the atmosphere as a gas. Instead, phosphorus is trapped in phosphate (PO_4^{3-}, HPO_4^{2-}, and $H_2PO_4^{-}$) that makes up phosphate rock and the sediments of ocean floors.

How phosphorus is cycled through ecosystems

Weathering releases phosphate into the soil. **Weathering** is the process of breaking down rock into smaller fragments (Figure 2.43). Chemical weathering and physical weathering are two types of weathering involved in the phosphorus cycle. In chemical weathering, a chemical reaction causes phosphate rocks to break down and release phosphate into soil. Acid precipitation and the chemicals released by lichens can cause chemical weathering. In physical weathering, processes such as wind, rain, and freezing release particles of rock and phosphate into soil.

On land, plants quickly take up phosphate through their roots and animals obtain phosphate by eating the plants. The action of decomposers breaks down animal waste and dead organisms, which returns phosphorus to the soil to become available for producers again. Phosphate enters aquatic ecosystems as a result of erosion, leaching, and run-off (Figure 2.44). Water plants take up some dissolved phosphate and pass it through the aquatic food chain (Figure 2.45).

However, most phosphate in run-off settles on lake and ocean bottoms and will not enter the biotic community unless the sediment is disturbed. The sediment will eventually form sedimentary rock, and the phosphorus will remain trapped for millions of years. Only when the rock layers are exposed through a process called geologic uplift will phosphorus be made available, and then the cycle of weathering can begin again. **Geologic uplift** refers to the process of mountain building in which Earth's crust folds, and deeply buried rock layers rise and are exposed.

Figure 2.46 on the next page shows how the different parts of the phosphorus cycle function together.

Figure 2.43 Both the lichens on the rocks and the snow and ice on the mountain can cause weathering that will release phosphate.

Figure 2.44 Run-off carries dissolved phosphate into aquatic ecosystems.

Connection

Section 12.1 and Section 12.2 have more information about the processes that build mountains.

Figure 2.45 Underwater plants (producers) provide phosphorus to the aquatic organisms (consumers) that feed on them (A). Carnivores, in turn, obtain phosphorus from eating other consumers (B).

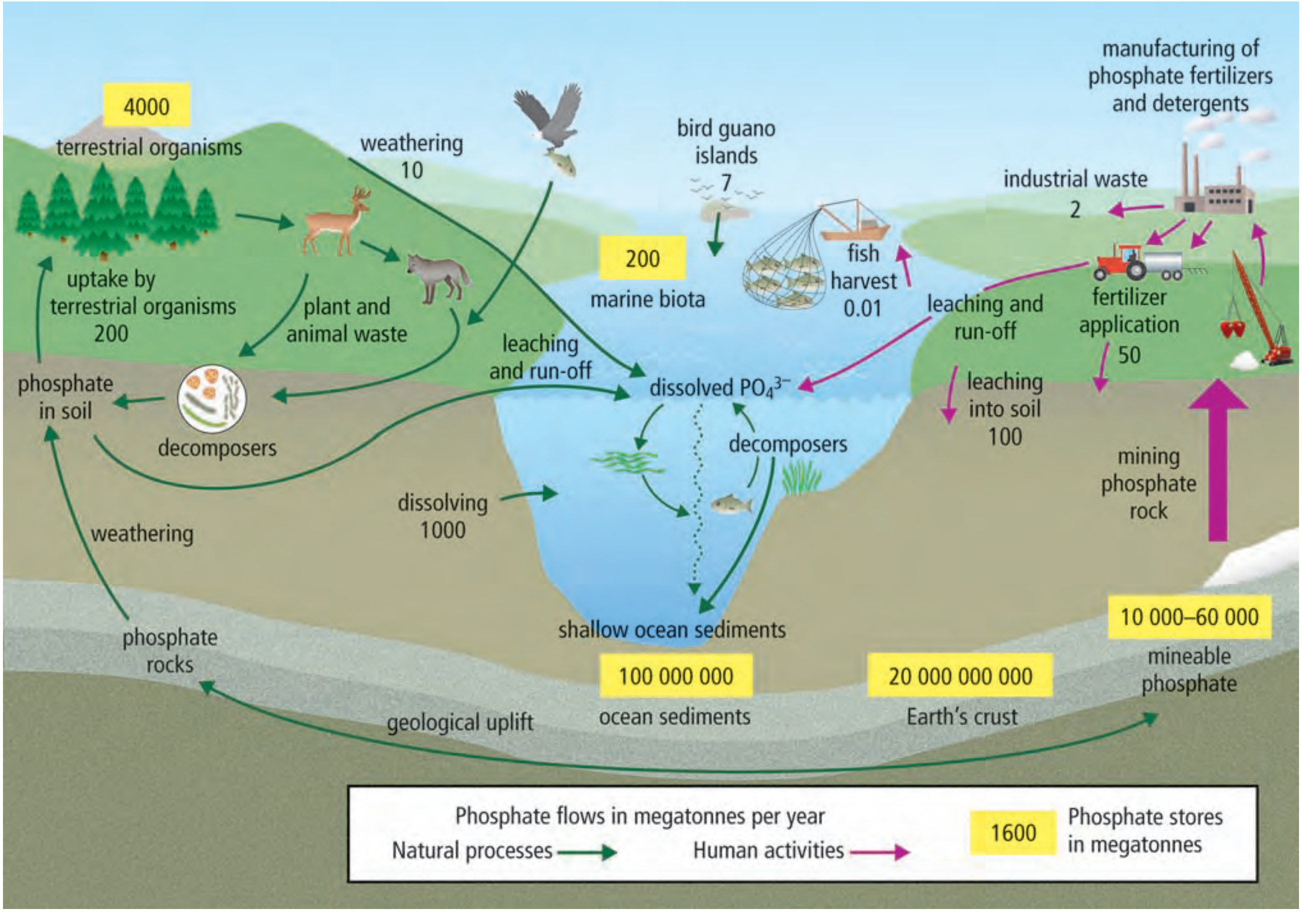


Figure 2.46 The phosphorus cycle

Data current as of 2008

Human Activities and the Phosphorus Cycle

In North America, phosphate rock is mined primarily to make commercial fertilizers and detergents such as those used in dishwashers (Figure 2.47). On some islands in the South Pacific, guano (bird droppings) is still being mined as a natural fertilizer. Guano is a rich source of phosphate, nitrogen, and potassium. (Potassium is another essential element that living organisms need for growth.) Commercial fertilizers, phosphate-containing detergents, animal wastes from large-scale livestock farming, some industrial waste, and untreated human sewage all enter waterways through run-off and leaching, thereby contributing additional phosphate to the phosphorus cycle.

Just as too much nitrogen in an ecosystem results in eutrophication and algae blooms, too much phosphorus can negatively affect species that are sensitive to an overload of this nutrient. For example, too much phosphorus can cause fish death.

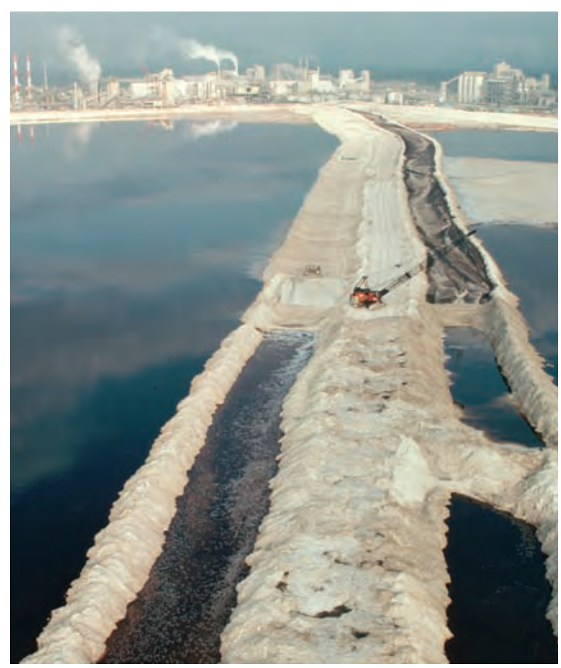


Figure 2.47 Phosphate mining operation east of Tampa, Florida. Florida provides a large percentage of the world's phosphate supply.

Figure 2.48 The conversion of a forest in Brazil into farmland using the slash-and-burn method

Human activities can also reduce phosphorus supplies. The clearing of forests by the slash-and-burn method (Figure 2.48) releases the phosphates contained in trees in the form of ash, which accumulates in soil. Phosphate leaches from the ash and runs off into the water supply to settle on the bottom of water bodies such as lakes and oceans, where it becomes unavailable to organisms.

Reading Check

1. How is phosphorus stored in ecosystems?
2. What is weathering?
3. How does phosphorus enter ecosystems?
4. What human activities contribute excess phosphate to ecosystems?

How Changes in Nutrient Cycles Affect Biodiversity

In this section, you have seen how producers cycle carbon and oxygen. You have also learned how bacteria fix nitrogen in the atmosphere, and how certain species of bacteria convert this nitrogen into a usable form for plants. Changes in carbon, nitrogen, and phosphorus cycles can affect the health and variety of organisms that live in an ecosystem. An excess of nutrients or a lack of nutrients can alter the biotic and abiotic conditions necessary for supporting biodiversity.

For example, changes in the carbon cycle are contributing to climate change. Changes in temperature, rainfall, and wind patterns may have serious effects on biodiversity if some plants and animals can no longer survive in their altered habitats. In British Columbia, long-term changes in river temperature may have a serious impact on Fraser River sockeye populations over time (Figure 2.49). Sockeye are particularly sensitive to temperature changes. Warmer than normal river temperatures can reduce the ability of sockeye to swim and can result in their death if temperatures remain warm for several days. A reduction in sockeye populations can affect the food chain in the Fraser River and thus affect biodiversity. For example, fewer salmon may reduce the numbers of bears and eagles that prey on them, and the number of smaller water organisms that are preyed on by salmon may increase.

Figure 2.49 Sockeye run in the Fraser River

Increased levels of nitrogen can seriously affect plant biodiversity in both terrestrial and aquatic ecosystems. Plant species that are adapted to increased nitrogen levels can outcompete species that cannot tolerate increased nitrogen levels. For example, grasses thrive in high nitrogen environments and grow quickly to outcompete tree seedlings (Figure 2.50).

Decreased levels of phosphorus caused by the introduction of non-native plant species have reduced algae production in some lakes in central Ontario. Since algae are an important food source for herbivores, the lack of algae has resulted in the decline of herbivore species. Loss of a producer such as algae can be harmful to all the consumers in an aquatic food web.

Figure 2.50 This grass may eventually outcompete this oak tree seedling.

Explore More

Climate change is starting to affect species in different ecosystems. For example, the quaking aspen, *Populus tremuloides*, blooms almost one month earlier than it did 100 years ago. Find out more about the effects of climate change on species and what can be done to lessen these effects. Start your search at **www.bcscience10.ca**.

2-2B The Amazing Nutrient Cycle Race

Anchor Activity

Find Out ACTIVITY

Nitrogen, carbon, and phosphorus have eventful journeys cycling through ecosystems, leaving and entering soil, air, and water. In this activity, you will travel through an ecosystem as a carbon atom, a nitrogen atom, and a phosphorus atom.

Materials

- ecosystem passport
- store station stamp
- glue stick
- 1 die
- travel log

What to Do

1. Obtain an ecosystem passport from your teacher, and begin your journey at an assigned carbon store station. Obtain a store station stamp, and glue it into your passport.
2. Toss the die provided to determine the location of your next ecosystem destination. Briefly record in your travel log what happens to you as you travel between stations, as shown in the example in your passport.
3. In your travel log, write entries at each station to describe your journey around the ecosystem. Describe where you went and how you travelled to each destination.
4. Construct a travel log flowchart in your notebook to track your journey through the carbon cycle. Use Figure 2.27 on page 76 to help you construct your chart.
5. Repeat steps 1 to 4 as a nitrogen atom. Use Figure 2.37 on page 81 to help you construct your flowchart.
6. Repeat steps 1 to 4 as a phosphorus atom. Use Figure 2.46 on page 85 to help you construct your flowchart.

What Did You Find Out?

1. Compare your ecosystem passport for carbon, nitrogen, and phosphorus to that of a classmate. How were your experiences different?
2. If all class members had started their journeys at the rainwater station, would their experiences have been more similar? Explain.
3. As you travelled through the ecosystem, you paired up with other atoms and took on new identities. Refer to the appropriate nutrient cycle figures mentioned above to determine what passport name you travelled under between each store station. Make a list of passport names you travelled under as a carbon atom, a nitrogen atom, and a phosphorus atom.
4. Does your journey as a nutrient atom ever end? Explain.

2-2C A Case Study of Nitrogen Loading

SkillCheck
- Observing
- Graphing
- Evaluating information

British Columbia's Lower Fraser Valley is an important agricultural region that produces meat, dairy products, berries, vegetables, fruit, and mushrooms. The area is unique because it has a high rate of agricultural production even though its farms are about 10 percent the size of typical farms in the province. However, run-off from agriculture and lawn fertilizers and leaching from septic systems are placing excess nitrogen into the environment. This is referred to as nitrogen loading. In this activity, you will investigate the sources of nitrogen and the trends in nitrogen loading in a Fraser Valley study area. You will then make recommendations to reduce nitrogen loading in this area.

Question

How can the excess levels of nitrogen be reduced in the Fraser Valley?

Procedure

1. Table A shows the number of kilograms of nutrients required by corn and grass crops for each hectare planted each year. Table B shows the number of kilograms of nutrients from manure and chemical fertilizer applied to each hectare of these crops every year. Study these tables, and then answer the questions in parts (a) and (b) on the next page.

Table A Nutrients Required for Corn and Grass Crops

Crop	Amount of Nutrients Required per Hectare		
	Nitrogen (kg)	Phosphorus (kg)	Potassium (kg)
Corn	140	40	79
Grass	230	22	50

Table B Nutrients Applied to Corn and Grass Crops

Application Method	Amount of Nutrients Applied per Hectare		
	Nitrogen (kg)	Phosphorus (kg)	Potassium (kg)
Fertilizer	68	17	34
Manure	205	67	131
Total	273	84	165

(a) Which crop requires less nitrogen per year?

(b) In a 1 ha cornfield that has had nutrients applied, how many kilograms of applied nitrogen, phosphorus, and potassium will not be assimilated by the corn? (**Note**: The SI symbol "ha" means hectare.)

2. Using Tables C and D, construct a bar graph to show trends in the amount of crops grown and excess nitrogen in the Fraser Valley study area.

Science Skills

Go to Science Skill 5 for information on how to construct a bar graph.

Table C Trends in the Amount of Crops Grown

Year	Grass (ha)	Corn/Grain (ha)	Small Fruit (ha)
1971	2418	290	588
1981	1455	136	1259
1991	1038	25	1651

Table D Estimated Excess Nitrogen in the Study Area

Year	Nitrogen (kg/ha)
1971	134
1981	185
1991	245

Table E Trends in the Number of Livestock Raised

Year	Pigs	Dairy/Beef Cattle	Chickens
1971	444	5049	212 200
1981	9508	4276	Not available
1991	6015	2199	1 346 600

3. Looking at your bar graph, what relationships do you see between the crops grown and excess nitrogen in the study area?

4. Analyze Table E, and then answer the questions below.

(a) What changes have occurred from 1971 to 1991 in the numbers of livestock raised?

(b) How might these changes affect the level of excess nitrogen?

(c) Concentrated animal protein is used to feed chickens on poultry farms to make them grow quickly. How might this type of food add to excess nitrogen?

(d) The human population in the area is also growing rapidly. How could rapid population growth lead to excess nitrogen?

Analyze

1. On a copy of the nitrogen cycle provided by your teacher, indicate how human activity in the Fraser Valley has affected the nitrogen cycle.

2. A farmer in the Fraser Valley is concerned about nutrient overloading in the area. Design an experiment to determine how much nitrogen the farmer will need to grow healthy raspberry plants without producing an overload of nitrogen.

Conclude and Apply

1. You are part of an assessment team asked to make recommendations to the government of British Columbia and to farmers in the region on how the area can provide food for the province and protect the environment. Analyze the additional data collected in the Fraser Valley study shown in the handout your teacher will give you. Create a list of recommendations.

2. Is it possible for humans to avoid disrupting nutrient cycles? Explain.

Science Watch

Altering Human Impact One Duck at a Time

Since the establishment of early civilizations, humans have changed the biotic and abiotic parts of ecosystems by affecting the cycling and stores of nutrients. As you may have experienced in your own life, many human activities can have negative effects on ecosystems. However, humans have also made efforts to lessen these negative effects. The more we learn about the complex interactions in ecosystems and the effects our activities are having, the more knowledge we have for developing approaches that are less harmful.

For example, the rice paddies of Asia produce more than 90 percent of the world's rice. Many of these paddies are developed by clearing and flooding land and then adding large amounts of fertilizer. In Japan, Vietnam, India, and Africa, some farmers are taking a different approach and are using the waste products of ducks and small fish to fertilize the rice paddies. The ducks also eat weeds and insect pests.

At the end of the growing season, the farmers harvest the rice and eat the fish and ducks. After the rice is harvested, the land can be reused to grow vegetables such as potatoes, onions, and tomatoes. Additional land does not have to be cleared as the same area can be used to grow multiple crops. Less nitrogen is added to the nitrogen cycle as fertilizer is not required. Pesticides and herbicides are not used as the ducks eat the weeds and other pests.

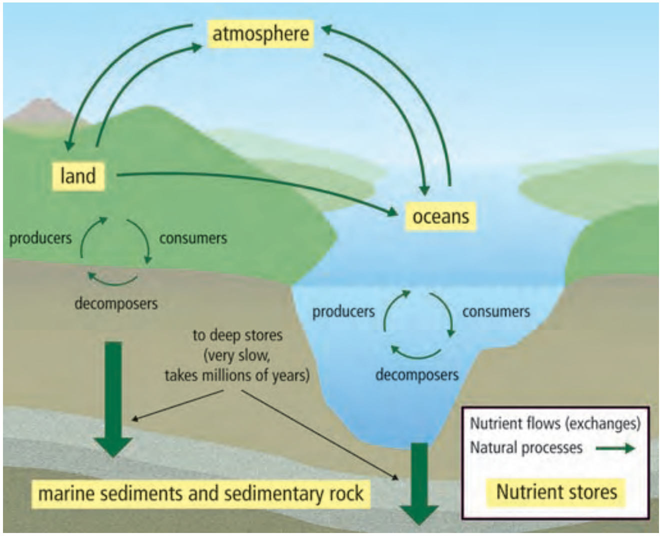
Questions

1. How are rice paddies usually developed and fertilized?
2. What alternative method are some farmers using to fertilize their rice paddies?
3. What are some advantages of this alternative method of fertilization?

Check Your Understanding

Checking Concepts

1. Use the following nutrient cycle diagram to answer questions (a) to (d).



   (a) Identify the abiotic components.
   (b) Identify the biotic components.
   (c) Why are some arrows thicker than others?
   (d) What would you add to this diagram to show the processes by which nutrients naturally leave stores in rock?
2. Describe the importance to living organisms of each of the following.
   (a) carbon (b) nitrogen (c) phosphorus
3. Explain how each of the following is stored in the biosphere.
   (a) carbon (b) nitrogen (c) phosphorus
4. In what form is carbon stored in the ocean?
5. Explain how human activities have influenced:
   (a) the carbon cycle
   (b) the nitrogen cycle
   (c) the phosphorus cycle
6. How does geologic uplift contribute to the phosphorus cycle?
7. The following processes circulate carbon in an ecosystem. Identify which processes circulate carbon rapidly and which processes circulate carbon very slowly.
   (a) photosynthesis
   (b) volcanic activity
   (c) sedimentation and rock formation
   (d) respiration
8. Explain the term "leaching."
9. List three ways in which plants influence the cycling of nutrients.
10. Match the following processes with the descriptions in (i) to (iii).
   (a) nitrogen fixation
   (b) nitrification
   (c) denitrification
   (i) Nitrate is converted to nitrogen gas.
   (ii) Ammonium is converted to nitrate.
   (iii) Nitrogen gas is converted to ammonium.
11. Explain the relationship between *Rhizobium* bacteria and plants.
12. How can lightning benefit an ecosystem?

Understanding Key Ideas

13. How do animals take up each of the following?
   (a) carbon (b) nitrogen (c) phosphorus
14. Within Biosphere II, scientists found that the carbon dioxide levels decreased each day and increased each night.
   (a) What would account for these changes?
   (b) Why do carbon dioxide levels not fluctuate daily in Earth's atmosphere?
15. Create separate flowcharts to explain each of the following nutrient cycles.
   (a) carbon (b) nitrogen (c) phosphorus
16. State what evidence shows that human activities are affecting the reproduction of:
   (a) animals (b) plants
17. What are the sources of increased nitrogen levels on agricultural land?
18. What makes agricultural land a major source of nitrogen fixation?
19. Summarize the effects of human interference in each of the following nutrient cycles.
   (a) carbon (b) nitrogen (c) phosphorus

Pause and Reflect

Some human activities, such as burning wood from trees, move carbon already in short-term stores. Other activities, such as burning fossil fuels, bring back carbon stored long ago. Can planting trees make up for the carbon emissions of either or both of these types of human activities?

2.3 Effects of Bioaccumulation on Ecosystems

Synthetic chemicals enter the environment in air, water, and soil. Plants take up some of these chemicals, and the chemicals bioaccumulate in the fat tissue of herbivores and carnivores. Synthetic chemicals become biomagnified in food pyramids and harm organisms. Heavy metals such as lead, cadmium, and mercury also bioaccumulate in the environment and negatively affect organisms. Scientists are working to find ways to remove harmful environmental chemicals. Methods include bioremediation in which organisms are used to help clean up chemical pollution.

Words to Know

bioaccumulation
bioremediation
heavy metals
keystone species
parts per million
PCBs

Figure 2.51 Malformations in frogs have greatly increased since 1980. This frog has three hind legs.

Did You Know?

A major cause of frog malformations is the flatworm *Ribeiroia*. This parasite can spend part of its life cycle in snails and then move into tadpoles, hindering their development. Epidemics of this parasite may be caused by fertilizer run-off and the presence of cattle manure near water habitats. These pollutants produce large algae blooms that feed the snail hosts, increasing their numbers.

Amphibians, such as frogs, are vertebrates that can live in two different environments. As larvae, they live in water and breathe by means of gills. As adults, they move onto land and breathe with lungs. Because amphibians live both in water and on land, they are useful to scientists as indicators of the health of an ecosystem.

In the water phase of their life cycle, amphibians are sensitive to the effects of chemical run-off and other pollutants in the environment. Their egg casings are permeable and can be penetrated by harmful chemicals. Their skin, which is a partial breathing organ, also makes them more sensitive to toxic substances. Scientists believe that factors harming amphibians today are also harming other species.

Since the 1980s, the number of amphibians in the world has fallen dramatically. Of the more than 5700 known species of amphibians, currently 43 percent are declining in number, 32 percent are threatened, and 168 species are thought to be extinct. At the same time, scientists have found that malformations in frogs, such as missing or additional legs, have greatly increased (Figure 2.51 on the previous page). In some locations, up to 50 percent of the frogs are malformed. Similar deformities have been reported for salamanders and toads.

Scientists have confirmed several causes of the amphibian loss, such as prolonged drought and increased ultraviolet radiation due to depletion of the ozone layer. Other causes include habitat loss, pollution, overhunting, parasites, and diseases caused by viruses and fungi. Researchers have found that tadpoles exposed to increased doses of ultraviolet radiation die or develop incorrectly, gaining extra limbs or eyes. Exposure to certain pesticides also interferes with tadpole development. **Pesticides** are chemicals used to eliminate pests, such as insecticides that kill insects and herbicides that kill weeds.

2-3A Simulating Toxic Effects in an Ocean Ecosystem

Find Out ACTIVITY

Pesticides are one group of compounds that may harm many different organisms. The negative impact of an accidental spill of pesticides can be felt in ocean ecosystems. In this activity, you will simulate these effects.

Safety

- Do not eat any food in the laboratory.

Materials

- 0.5 kg of coloured candies
- 1 killer whale name tag
- 3 seal name tags
- 5 large fish name tags
- 6 small fish name tags
- 15 krill name tags
- 15 small bags or containers

What to Do

1. You will select or be assigned a role in an ocean ecosystem as a killer whale, seal, big fish, small fish, or krill. Determine your role in the food chain.
2. If you are a krill, you will simulate feeding on zooplankton and phytoplankton by gathering the candies distributed in the classroom. Put your collected candy in the container provided. You have 15 seconds to "feed" (do not eat the candy). At the end of 15 seconds, you must stay where you are.
3. Students representing the next members of the food chain continue the simulation by tapping the prey on the elbow and obtaining all the candy from the prey. At the end of 15 seconds, the eaten prey must stay where they are, as they are now dead. The simulation is complete when the killer whale has eaten.
4. Your teacher will tell you which candy colours represent food contaminated by pesticide. If red and orange candies contain the pesticide, determine the percentage of toxic candies "eaten" by each member of the food chain:
$$\frac{\text{red candies} + \text{orange candies}}{\text{total candies} \times 100}$$
5. If there are any krill still alive who consumed any red or orange candy, they are now dead. If there are any small fish still alive that consumed 20 percent or more red or orange candy, they are now dead. If any higher carnivores consumed 20 percent or more red or orange candy, they are now sick. If they consumed 30 percent or more, they are now dead.
6. Determine how many organisms are still alive.

What Did You Find Out?

1. What effect did the pesticide have on the ecosystem?
2. What effect would a pesticide have on an ecosystem if it remained in the ecosystem for 50 years instead of degrading rapidly?

Figure 2.52 Pollution entering a lake from a steel mill (A). Pollution entering a stream from an abandoned car (B)

How Pollutants Climb the Food Chain

Human activities can make natural disturbances such as forest fires and insect infestations much worse. Over the past century, human activity has resulted in many new disturbances. Rapid changes have been very stressful for many organisms. Some organisms have died, and in some cases complete extinction of a species has occurred. One of the biggest changes has been the introduction into the environment of synthetic (human-made) chemicals (Figure 2.52).

Bioaccumulation

Synthetic and organic chemicals build up in the environment when decomposers cannot break them down through the biodegradation process. **Bioaccumulation** is the gradual build-up of these chemicals in living organisms (Figure 2.53). A chemical will accumulate if it is taken up and stored faster than it is broken down and excreted. Chemicals enter organisms through food intake, skin contact, or respiration. If the accumulation of a substance is too high, it can be harmful. Some chemicals are temporarily stored in fat tissue but are released from storage when fat is burned for energy. These chemicals can be harmful to the animal if they are not metabolized (chemically changed) or are not excreted in the feces or urine.

Synthetic and organic chemicals can affect the nervous, immune, and reproductive systems of animals. Bioaccumulation of these chemicals can cause birth defects in offspring or a complete failure to reproduce. These chemicals affect not only individual organisms but also entire ecosystems when keystone species are affected. **Keystone species** are species that can greatly affect population numbers and the health of an ecosystem. Salmon are a keystone species in many British Columbia forest ecosystems. In fall, salmon are an important food source for bears, wolves, eagles, and otters. Salmon alter the ecosystem as their decaying bodies become a rich source of nutrients such as nitrogen for trees. Salmon can also retain harmful chemicals in their body fat and transfer these chemicals to other organisms.

Biomagnification is the process in which chemicals not only accumulate but become more concentrated at each trophic level. Chemicals bioaccumulate and become biomagnified when pollutants are stored in plant tissue and in the fat tissue of animals. Chemicals remain trapped in plants and animals until they are eaten and the tissues and fats are broken down for energy.

As you learned in section 2.1, herbivores eat large quantities of plants and carnivores eat many times their body weight of prey during their lifetimes. For this reason, even small concentrations of chemicals in producers and primary and secondary consumers can build up to cause problems at higher trophic levels. For example, a red tide is caused by an algae bloom in which the algae become so numerous that they can turn coastal seawaters red. Red tides produce toxic organic chemicals that can affect organisms such as clams, mussels, and oysters. As the shellfish eat the algae, the toxins bioaccumulate to a level that is poisonous to other organisms such as fish, humans, and other mammals. If eaten, these shellfish can cause paralytic shellfish poisoning, which can result in serious illness or death.

Suggested Activity

Conduct an Investigation 2-3B on page 100

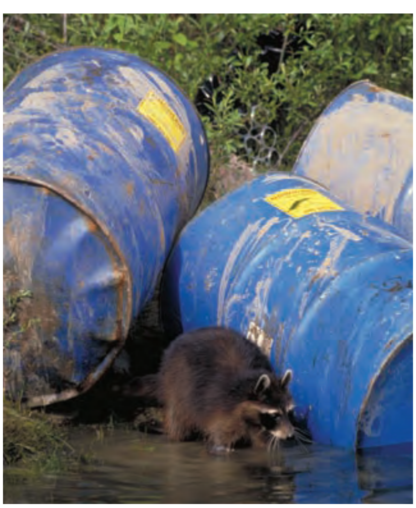


Figure 2.53 Organisms are frequently exposed to chemicals that can build up in their bodies.

PCBs and the Orca

The significance of bioaccumulation is seen in the way PCBs affect orcas (killer whales). **PCBs** (polychlorinated biphenyls) are synthetic chemicals that were widely used from the 1930s to the 1970s in industrial products such as heat exchange fluids, paints, plastics, and lubricants for electrical transformers. In 1977, they were banned in North America as concerns grew about their impact on the environment and human health. Many synthetic chemicals such as PCBs that bioaccumulate and biomagnify also have a long half-life. **Half-life** is the time it takes for the amount of a substance to decrease by half. PCBs stay in organisms and the environment a very long time, suppress the immune system, and probably cause cancer in humans. Aquatic ecosystems and species that feed on aquatic organisms are especially sensitive to the effect of PCBs.

Hardest hit of all are orcas (Figure 2.54). One study found that PCBs will interfere with the reproductive success of British Columbia's resident orcas until at least 2030. Even though these chemicals have been banned for decades, orcas retain high levels of PCBs, especially the calves.

Figure 2.55 shows how biomagnification occurs in an orca. Even if the PCBs enter the food chain at a relatively low level, by the time they get to the orca, they are highly concentrated in the blubber. When salmon stocks are low, magnification is increased, since blubber is then burned for energy. The PCBs are released into the orca's bloodstream where they interfere with immune function, making the orca more susceptible to disease.

Figure 2.54 A newborn orca calf has the same PCB level as its mother and then receives more through its mother's fat-rich milk.

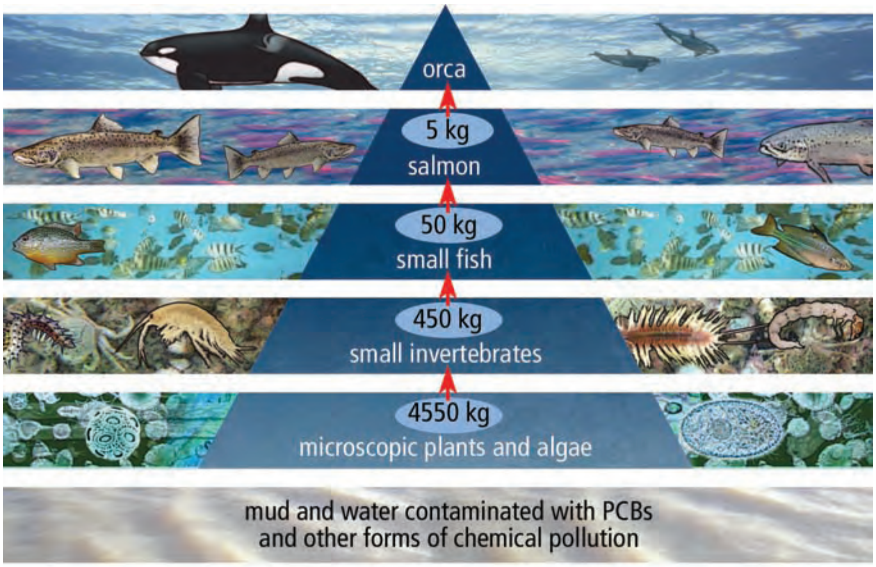


Figure 2.55 The PCB load of orcas is much higher than that of any other animal in the world. When an orca eats 5 kg of salmon, it is ingesting PCBs and other pollutants from about 4550 kg of microscopic plants and algae.

Persistent Organic Pollutants

PCBs belong to a class of compounds called **persistent organic pollutants** or POPs. POPs are carbon-containing compounds that remain in water and soil for many years. Many POPs enter ecosystems in the form of insecticide sprays (Figure 2.56).

Figure 2.56 Insecticide spraying is a common method by which POPs are introduced into ecosystems.

Table 2.2 Bioaccumulation of DDT in a Food Chain

Consumer	Bioaccumulation (ppm)
Plankton	0.04
Minnow	0.94
Adult fish	2.07
Heron	3.57
Osprey	13.80
Cormorant	26.40

One well-known POP is the insecticide **DDT** (dichloro-diphenyl trichloroethane). DDT was introduced in 1941 to control disease-carrying mosquitoes. Although now banned in many countries because it biomagnifies, it has a long half-life and persists in the environment. DDT binds strongly to soil particles and persists for as long as 15 years. Bound in soil, DDT begins to bioaccumulate in plants and then in the fatty tissue of the fish, birds, and animals that eat the plants. Washed into streams and lakes, it affects aquatic food chains by first accumulating in plankton. In Table 2.2, you can see how low levels of DDT become magnified through the food chain.

Chemical accumulation is measured in **parts per million (ppm)**. One ppm means one particle of a given substance mixed with 999 999 other particles, which is equivalent to one drop of dye mixed with 150 L of water (about what a home hot-water tank holds). DDT is considered toxic or harmful at levels of 5 ppm. In animals, DDT is changed into a chemical form that bioaccumulates in fat tissue and can cause nervous system, immune system, and reproductive disorders.

internet connect

Some chemicals, called endocrine disruptors, affect the endocrine (hormone) system by mimicking the female hormone estrogen. One effect is eggshell thinning in birds of prey such as eagles. To find out more about endocrine disruptors, go to **www.bcscience10.ca**.

Reading Check

1. What is bioaccumulation?
2. What is biomagnification?
3. How does a chemical bioaccumulate in an organism?
4. What are persistent organic pollutants?
5. What does ppm mean?

Heavy Metals

Heavy metals are metallic elements with a high density that are toxic to organisms at low concentrations. Within the biosphere, they do not degrade and cannot be destroyed. Some heavy metals such as copper, selenium, and zinc are essential to human health in very small quantities. Heavy metals can be found in water and air and are taken in through the food chain. They can bioaccumulate within organisms and biomagnify, moving up the food chain like POPs. The three most polluting heavy metals are lead (Pb), cadmium (Cd), and mercury (Hg).

Lead

Lead is naturally present in all soils, generally in the range of 15 ppm to 40 ppm. However, these levels have increased due to human activities. In the past, lead was used in insecticides, in paints, and as an anti-knock ingredient in gasoline. Today, most products and manufacturing processes have been changed to reduce the amount of lead entering the environment, and nearly all lead-acid batteries are recycled. Other uses of lead, such as in electronics where it is contained in radiation shielding and soldered joints, still contribute to lead levels in the environment. However, much smaller percentages of electronics are recycled. Consumer electronics waste makes up 40 percent of the lead found in landfills (Figure 2.57).

Lead is extremely toxic. It has an accepted toxic level of 0.0012 ppm, although it is not considered safe at any level. Lead particles can be ingested (eaten), absorbed through the skin, or inhaled. Harmful effects in humans may include anemia (a blood condition), nervous system damage, sterility in men, low fertility rates in women, impaired mental development, and kidney failure. Similar effects are seen in fish and birds.

Figure 2.57 Electronics waste has introduced a large amount of lead into ecosystems.

Cadmium

Cadmium is found in Earth's crust and is released into the environment through rock weathering, volcanoes, and forest fires. (The cadmium stored in trees is released into the air when trees burn.) Cadmium is also released in the manufacture of plastics and nickel-cadmium rechargeable batteries, and it enters soil and water through zinc production and phosphate ore mining. Cadmium is strongly chemically attracted to organic matter in soil. When present in soil, it can be extremely dangerous, as plants take up the cadmium in their roots and animals eat the plants. Cadmium is highly toxic to earthworms and other soil organisms at very low levels. In fish, it is associated with higher death rates and lower reproduction and growth rates.

Did You Know?

Although synthetic chemicals can be hazardous, many also have enormous benefits. Even DDT reduced the number of deaths from malaria when it was first introduced. When countries banned DDT, malaria-related death rates increased.

Figure 2.58 Smoking is the major source of cadmium poisoning in humans.

For humans, the most serious source of cadmium poisoning is smoking, as tobacco plants easily absorb the metal (Figure 2.58). Cadmium can accumulate in lung tissue, causing lung diseases such as cancer. Non-smokers ingest cadmium mainly through foods such as mushrooms, shellfish, fish, and seaweed. Cadmium moves from the digestive system to the liver and then to the kidneys. The half-life of cadmium in the kidneys and in bone tissue is 30 years. Cadmium exposure can lead to infertility and damage to the central nervous system, immune system, and DNA.

Mercury

Every year, up to 6000 tonnes of mercury are released through natural sources such as volcanoes, geothermal springs, and rock weathering. In the last 150 years, this annual amount has doubled through the burning of fossil fuels, waste incineration, mining, and industrial uses such as the manufacture of batteries (including the kind many of us throw out each week). Coal burning accounts for more than 40 percent of mercury released into the atmosphere (Figure 2.59). Mercury returns to the Earth in rainfall and dust and binds to soil particles to form compounds that are then transported by air and water.

Explore More

Many Canadian First Nations and Inuit people have suffered mercury poisoning by eating contaminated fish. Find out about the Grassy Narrows tragedy of the 1970s and mercury poisoning among the Inuit in northern Quebec, whose diets include large amounts of fish. Start your research at **www.bcscience10.ca**.

Figure 2.59 Coal burning is a major source of mercury.

Organisms also circulate mercury through the food chain. Some bacteria in soils change compounds such as mercury sulfide into methylmercury, a highly toxic compound that bioaccumulates in the brain, heart, and kidneys of vertebrates. In humans, methylmercury is absorbed during digestion, then enters the blood and is stored in the brain. It affects nerve cells, the heart, kidneys, and lungs and suppresses the immune system. In fish, levels of methylmercury depend on what they eat, how long they live, and how high they are in the food chain.

Reading Check

1. What are heavy metals?
2. How was lead introduced into ecosystems in the past?
3. How does cadmium enter the environment?
4. What are some natural sources of mercury?
5. Explain how methylmercury is formed.

Reducing the Effects of Chemical Pollution

The effects of chemical pollution on the environment can be large, but scientists are constantly working to find new ways to solve these problems. One method is to trap the contaminant in the soil. For example, phosphate fertilizer is added to lead-contaminated soil, causing a chemical reaction between the phosphate and the lead that produces lead pyromorphite. This mineral is highly insoluble, so it cannot be easily spread by water and is less likely to enter the food chain. The lead remains in the soil but in a much less harmful form.

Another approach looks to nature and the process of biodegradation for help. **Bioremediation** (the prefix "bio-" means living things, and "remediation" means to remedy) is the use of living organisms—usually micro-organisms or plants—to do the clean-up naturally, only faster through biodegradation. Micro-organisms that naturally feed on chemicals and reduce them to non-toxic compounds can be added to contaminated soil (Figure 2.60). Working at the molecular level, scientists have extracted enzymes from chemical-eating bacteria or pesticide-resistant insects and used these to create new environmental clean-up technologies.

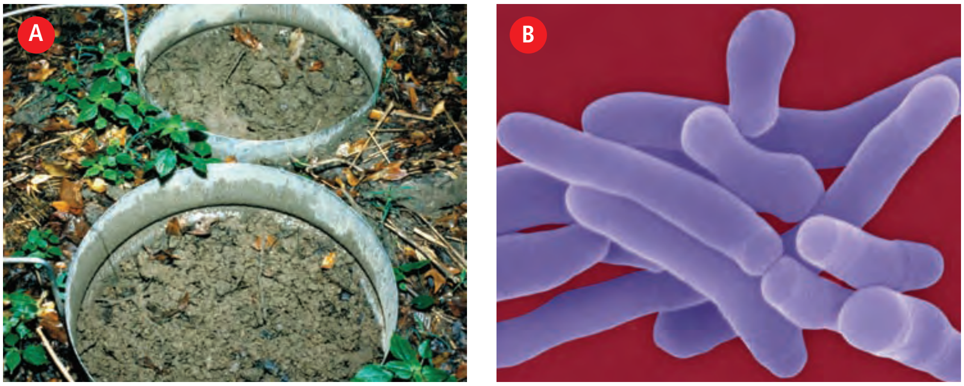


Figure 2.60 Soil tests of the effectiveness of PCB biodegradation by micro-organisms (A). *Rhodococcus* bacteria can biodegrade PCBs (B).

Plants such as fescue, alfalfa, juniper, and poplar trees also act as natural traps to biodegrade hazardous wastes in soil, taking in and concentrating heavy metals in their tissues. In wetland ecosystems, water hyacinth and bulrushes may be used. Plants can also act as stabilizers, reducing wind and water erosion that could spread the contaminants. Bioremediation is often used in resource industries such as forestry, mining, and energy production. The oil industry, for instance, often uses bacteria to clean up pollution created by spills and underground leaks.

2-3B Testing the Effect of a Chemical Pollutant

SkillCheck

- Measuring
- Controlling variables
- Graphing
- Evaluating information

Safety

- Glassware can break. Handle with care.
- Wash your hands thoroughly after doing this investigation

Materials

- 30 lettuce seeds previously soaked in 10 percent bleach solution
- six 9 cm petri dishes
- labelling marker
- 6 pieces of 7.5 cm filter paper
- graduated cylinder
- 2 mL 0.2 M NaCl
- 2 mL 0.1 M NaCl
- 2 mL 0.075 M NaCl
- 2 mL 0.050 M NaCl
- 2 mL 0.025 M NaCl
- 2 mL tap water
- sealable plastic bag

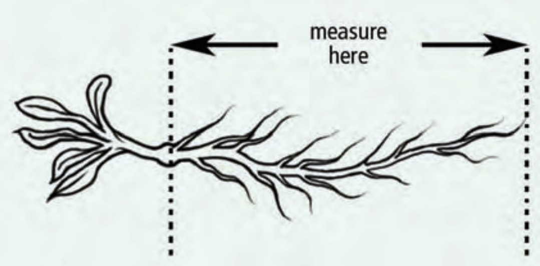
A bioassay is an experiment that tests how toxic a chemical will be to a living organism. The organism is exposed to different concentrations of the chemical to determine at what point the chemical causes harm. Salt is used on roads in the winter to help de-ice highways. The salt eventually ends up in streams. Scientists often use lettuce seeds as test organisms because they are inexpensive yet effective for testing pollutants in water and soil. In this investigation, you will test the effect of different concentrations of salt on lettuce seeds to see how lettuce growth is affected. You will determine the effect on growth by measuring germination rates and root lengths.

Question

How will saltwater affect the growth of lettuce seeds?

Procedure

1. Obtain 30 lettuce seeds from your teacher.
2. Label the lids of the petri dishes with your initials, and number them from 1 to 6.
3. Place a paper filter into each petri dish.
4. To petri dish number 1, add the 0.2 M NaCl solution. Repeat this procedure for petri dishes number 2 to number 5, each time adding a lower concentration of NaCl as specified in the materials list. Add 2 mL of tap water to dish number 6.
5. Add five lettuce seeds to each dish. Space the seeds out over the filter paper. Do not let the seeds touch the sides of the petri dish. Put the lids on the petri dishes.
6. Place the six dishes in the plastic bag and seal the bag. Keep the bag in the dark at a constant temperature (if possible, about 24°C) for 5 d.
7. After the 5 d period, count how many seeds have begun to germinate and measure the root length of each to the nearest millimetre. Make sure you measure only the root, not the shoot, as shown below.



8. Record your results in a table like the one on the next page.
9. Share results as a class, and calculate class averages. Record those results in your table.
10. Clean up and put away the equipment you have used.

Petri Dish Number	NaCl Concentration	Group		Class Average	
		Number of Seeds Germinated	Root Length (mm)	Number of Seeds Germinated	Root Length (mm)
1 0.2 M					
2 0.1 M					
3 0.075 M					
4 0.050 M					
5 0.025 M					
6 0 M					

Analyze

1. Construct a line graph that shows the effect on lettuce seed germination of different NaCl concentrations. Put the concentration of NaCl on the *x*-axis and the number of seeds germinating on the *y*-axis.
2. Construct a line graph that shows the effect on lettuce seed root length of different NaCl concentrations. Put the concentration of NaCl on the *x*-axis and the average root length on the *y*-axis.
3. Do you observe a relationship between seed germination and the concentration of salt in your graph? Explain any pattern you observe.

Science Skills

Go to Science Skill 5 for information on how to construct a graph.

Conclude and Apply

1. From your results, do you think salt is toxic to lettuce seeds? Explain.
2. Would you recommend that a department of highways use salt on roads in winter? Give reasons for your answer.
3. If you were going to repeat this experiment, what changes would you make to improve your results?

Science Watch

Pollution in the North

In recent years, tonnes of hazardous chemicals have been carried northward thousands of kilometres to the Arctic. More than 3.7 million people in eight countries are constantly exposed to these toxins.

Persistent organic pollutants such as DDT, toxaphene, and chlordane are applied in fields or sprayed on crops in temperate and tropical climates, where they evaporate. Fossil fuels, PCBs, and the heavy metals cadmium and mercury are present in air emissions from burning fuel for energy and from waste incineration. These toxic substances in low concentrations are carried in warm ocean and wind currents. They then are carried in water vapour into the atmosphere, deposited back down in rain, carried up again, and returned again as rain. This process continues to move toxins up the continent until they reach the North, where the cold locks them away. Chemical breakdown is very slow in this area of frigid temperatures and little sunlight. The Arctic lacks the soil and plant life that absorb pollution elsewhere, so the toxins remain for decades, even centuries.

Once in these cold ecosystems, the contaminants enter food chains and bioaccumulate in fish, birds, marine mammals, and humans. Inuit hunters are reporting abnormalities in animals such as seals without hair, polar bears without reproductive organs, and seals with burn-like holes on their skin. Researchers have found that these toxins not only harm wildlife but also accumulate in the breast milk of Inuit women at levels nine times higher than in women to the south.

Some scientists are trying to identify the properties that cause chemicals to accumulate. Others are looking for ways to get rid of the heavy metals left from the disposal of electronic products. Scientists continue to find solutions to these problems, but the once pristine North will continue to suffer for centuries from the consequences of pollution that comes from far away.

Checking water pollution levels in the Arctic Ocean

Questions

1. How are toxic substances transported to the Arctic?
2. State two ways in which contamination from toxic chemicals harms this ecosystem.
3. What effects of contamination have been seen in wildlife?

Check Your Understanding

Checking Concepts

1. Provide several reasons to explain why amphibians are disappearing.
2. Describe how synthetic chemicals become biomagnified in organisms.
3. What factors determine whether or not a chemical will bioaccumulate?
4. What are PCBs?
5. List some sources of PCBs.
6. Give an example of a persistent organic pollutant (POP).
7. How does DDT bioaccumulate?
8. Explain what 2 ppm means.
9. Which is more toxic—a chemical with a toxic level of 3 ppm or a chemical with a toxic level of 0.03 ppm? Explain.
10. What effect does DDT have on humans?
11. Explain why the effect of biomagnification is so great in killer whales.
12. List three health effects of methylmercury.
13. (a) What type of heavy metal poisoning is caused by the activity shown below?
    (b) Explain how this heavy metal can harm the human body.

14. What is bioremediation?

Understanding Key Ideas

15. Scientists study the health of amphibians, such as frogs, in order to evaluate the health of an ecosystem. Explain why.
16. Create a chart to summarize the environmental effects of the heavy metals lead, cadmium, and mercury. Use the following headings in your chart: Natural Sources, Human-made Sources, Effects on Plants and Animals, Effects on Humans.
17. Explain why a chemical with a long half-life may create problems in the environment.
18. A persistent organic pollutant is estimated to have a half-life of 30 y. If 3 tonnes of the chemical exists in a polluted area today, how much of the chemical will remain after 120 y?
19. Explain how an organism could be affected by a persistent organic pollutant when the chemical was applied 1000 km from the organism's habitat.
20. How can plants be used for bioremediation?
21. Design an experiment to determine what level of a new synthetic insect killer called Beegone is lethal to geraniums.

Pause and Reflect

You are a journalist writing a story about the effects of bioaccumulation of certain synthetic chemicals. What questions would you ask a group of scientists who have recently announced a new chemical discovery?

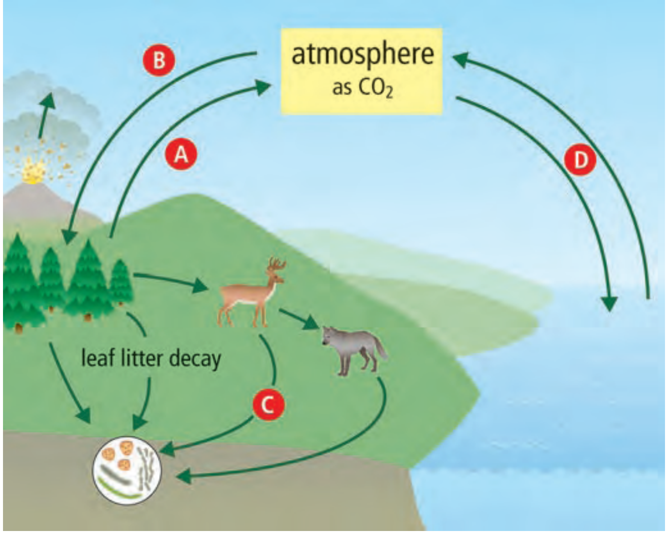
Prepare Your Own Summary

In this chapter, you investigated energy flow, nutrient cycles, and the bioaccumulation of chemicals in ecosystems. Create your own summary of the key ideas from this chapter. You may include graphic organizers or illustrations with your notes. (See Science Skill 11 for help with using graphic organizers.) Use the following headings to organize your notes:

1. Energy Flow in Ecosystems
2. Nutrient Cycles in Ecosystems
3. Human Activities and Ecosystems
4. Effects of Bioaccumulation

Checking Concepts

1. Describe two ways in which decomposers contribute to ecosystems.
2. Describe the flow of energy from the Sun to a wolf.
3. What happens to most of the energy from the Sun that is trapped by plants?
4. What are the two major life processes that involve both carbon and oxygen?
5. Write the equation that summarizes the process of cellular respiration.
6. (a) Identify the nutrient cycle shown in the illustration below.
   (b) Identify the processes indicated by the arrows labelled A to D.



7. What are two major ways in which nitrogen is fixed in ecosystems?
8. Identify the product formed as a result of:
   (a) nitrification
   (b) denitrification
9. Explain how weathering releases phosphate from rock.
10. (a) What is happening in the photograph below?
    (b) How does this activity affect the phosphorus cycle?

11. Give an example in which carbon moves from the abiotic to the biotic part of an ecosystem.
12. How do shelled marine organisms contribute to the carbon cycle?
13. (a) Where and in what form does carbon enter long-term stores?
    (b) Where and in what form does carbon leave long-term stores?
14. Explain how the phosphorus cycle differs from:
    (a) the carbon cycle
    (b) the nitrogen cycle
15. A food web contains green plants, rabbits, squirrels, mice, seed-eating birds, hawks, and owls.
    (a) Which organisms in this food web would contain the greatest biomass? Explain.
    (b) Which organisms in this food web would contain the least biomass? Explain.

16. How do bacteria enable plants to take up nitrogen?
17. (a) Name the two largest stores of carbon.
    (b) Explain how these carbon stores have become so substantial.
18. Why are heavy metals harmful to the environment?
19. How do PCBs harm orcas?
20. List two effects of persistent organic pollutants on organisms.

Understanding Key Ideas

21. How does the flow of energy through an ecosystem differ from the cycle of nutrients in an ecosystem?
22. Scientists are studying an ecosystem that has 452 individuals of species A and 12 individuals of species B. Answer the following questions in terms of energy flow and trophic levels.
    (a) Which species is most likely to consist of herbivores?
    (b) Which species is most likely to consist of carnivores?
23. Explain why you would not gain 450 g if you were to eat a 450 g meal.
24. Explain how an increase in agricultural activity might affect a local fishery.
25. How is volcanic activity involved in the following?
    (a) the carbon cycle
    (b) the nitrogen cycle
26. Explain the role of decomposers in the carbon cycle.
27. Farmers often add nitrogen and phosphorus to their crops but not carbon. Explain why.
28. At which trophic level are organisms most affected by biomagnification? Explain.
29. (a) If the secondary consumers in a food chain use 4200 kcal/m^2 of energy, what amount of energy was used by the producers in that food chain?
    (b) What amount of energy will be available to the tertiary consumers?
30. Explain how zooplankton and phytoplankton in a water ecosystem can contain levels of 0.04 ppm of a chemical but adult fish living in the same ecosystem contain levels of 5 ppm.

Applying Your Understanding

31. Each cigarette contains 1 μg to 2 μg of cadmium, 40 to 60 percent of which is inhaled into the lungs and from there passes throughout the body. Cadmium absorption appears to be higher from smoking than from environmental exposure in the workplace, probably because the cadmium particles in cigarette smoke are so small they pass through the cigarette filter and become deposited in lung tissue. Smoke from a smouldering cigarette is also very high in cadmium. Breathing air with high levels of cadmium can severely damage the lungs or cause death. Breathing in lower levels over years is also risky, as cadmium can build up in the kidneys and result in kidney disease.
    (a) What evidence is there that cadmium bioaccumulates in humans?
    (b) Are individuals exposed to secondhand smoke at risk?
    (c) Suppose a person smoked 15 cigarettes per day, and 50 percent of the cadmium in each cigarette was absorbed. Calculate the daily intake of cadmium.
    (d) Cadmium has a half-life of 30 y. Once a person stops smoking, how long will it be before the body is rid of the cadmium inhaled?

Pause and Reflect

The biosphere is like a sealed terrarium in which all the nutrients that support life and all the wastes that are produced are constantly recycled within its boundaries. Refer to one of the nutrient cycles you studied in this chapter to explain this concept.