2.2 Nutrient Cycles in Ecosystems

Earth's biosphere is like a sealed terrarium in which all nutrients that support life and all wastes that are produced are constantly recycled within its boundaries. The carbon cycle, nitrogen cycle, and phosphorus cycle move nutrients into and out of terrestrial and aquatic ecosystems. Human activities such as land clearing, agriculture, industry, and motorized transportation can affect nutrient cycles.

Words to Know

cellular respiration
denitrification
nitrification
nutrients
photosynthesis
sedimentation
weathering

Did You Know?

Biosphere II still exists in the dry grasslands of Arizona. Parts of the giant sealed structure will be used to model the effects of climate change on ecosystems.

Figure 2.14 Biosphere II a few months before the beginning of the experiment

It was the ultimate test of survival for the eight scientists who sealed themselves within Biosphere II in Arizona on September 26, 1991 (Figure 2.14). Their mission was to sustain themselves within the largest closed ecological system in the world for two years. Biosphere II was designed to investigate the complex interactions that take place on Biosphere I—Earth—and to function as a model system for space colonization. Like Earth's biosphere, Biosphere II was intended to be entirely self-sustaining, like a giant, sealed terrarium. Nothing could leave or enter Biosphere II. All chemicals and atoms had to be recycled. If any harmful substances were created, they were trapped within Biosphere II's huge sealed structure.

Biosphere II contained a variety of model ecosystems, such as rainforest, wetland, savanna, desert, and ocean (complete with coral reef), and agricultural fields for food production. The scientists, who were called bionauts, also shared their miniature Earth with 3800 species of plants and animals. Within three months, the oxygen levels in Biosphere II dropped from 21 percent to 14 percent, and the bionauts requested that additional oxygen be pumped into the structure. Carbon dioxide gas and nitrous oxide gas rose to dangerously high levels. Morning glory, which was introduced to absorb excess carbon dioxide, crowded out other plant life. Populations of cockroaches and ants exploded in number, and the bionauts were unable to grow enough food to stay healthy.

When the bionauts left Biosphere II two years later, 19 of the 25 vertebrate species had become extinct, and all the plant pollinators had disappeared.

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).

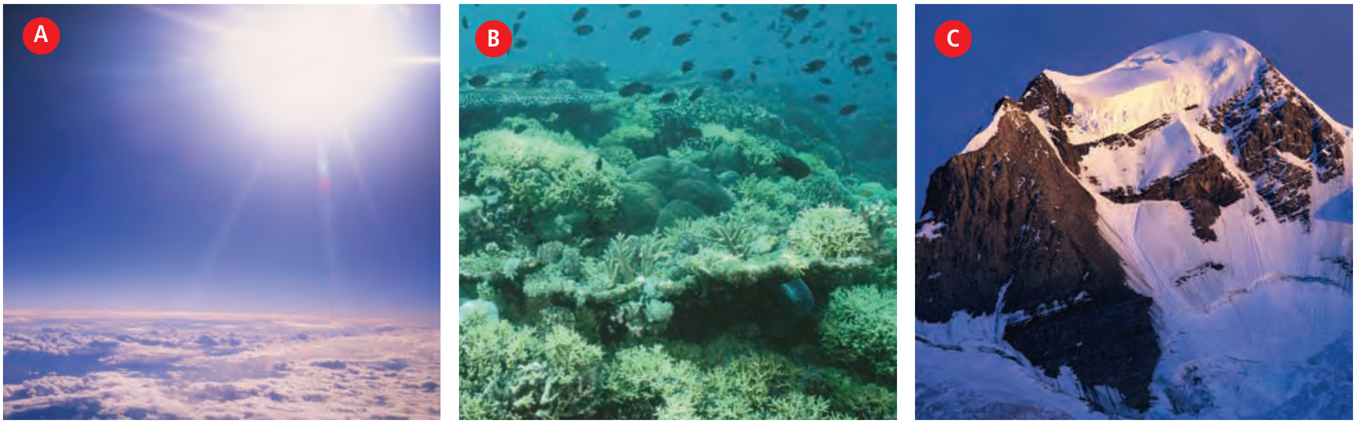


Figure 2.15 The atmosphere (A), oceans (B), and land masses (C) are stores for nutrients that are essential for life.

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.

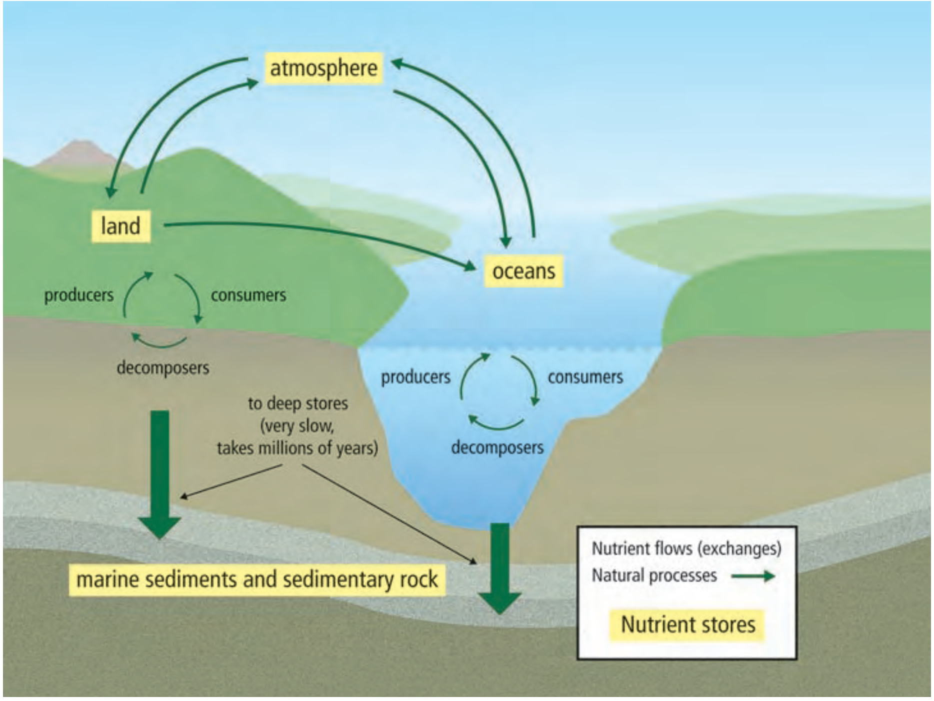


Figure 2.16 A general model of a nutrient cycle

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.

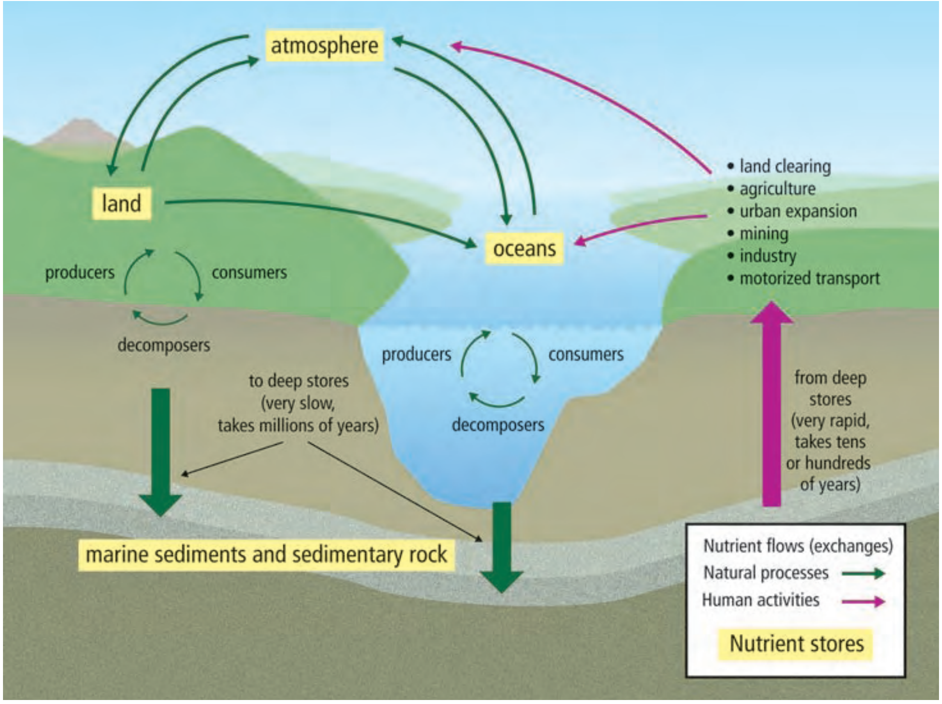


Figure 2.17 A nutrient cycle including human activities

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:

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

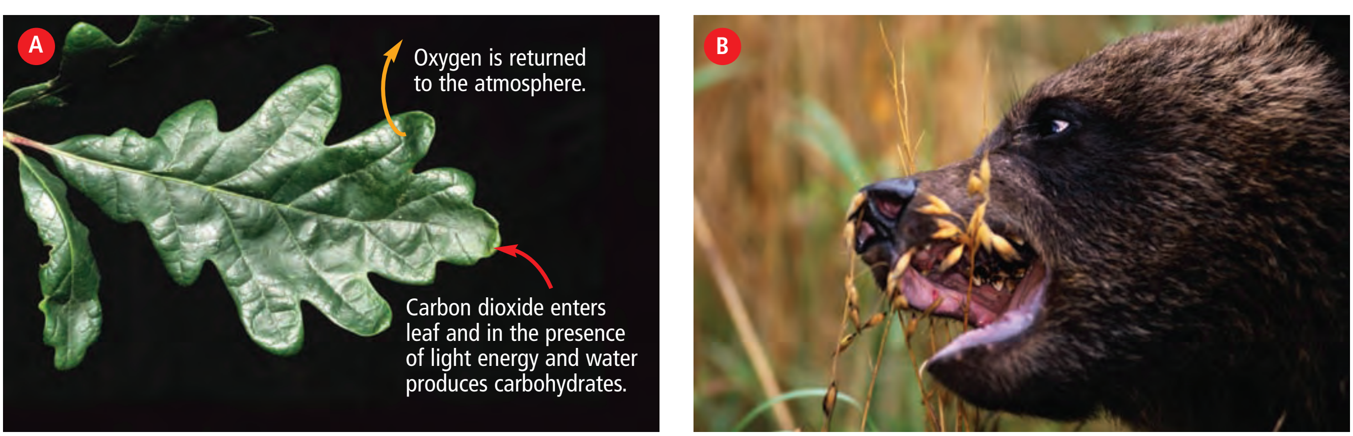


Figure 2.22 Producers remove carbon dioxide from the atmosphere during photosynthesis and produce oxygen, which is returned to the atmosphere (A). Consumers eat producers and obtain energy from them in the form of carbohydrates (B).

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.

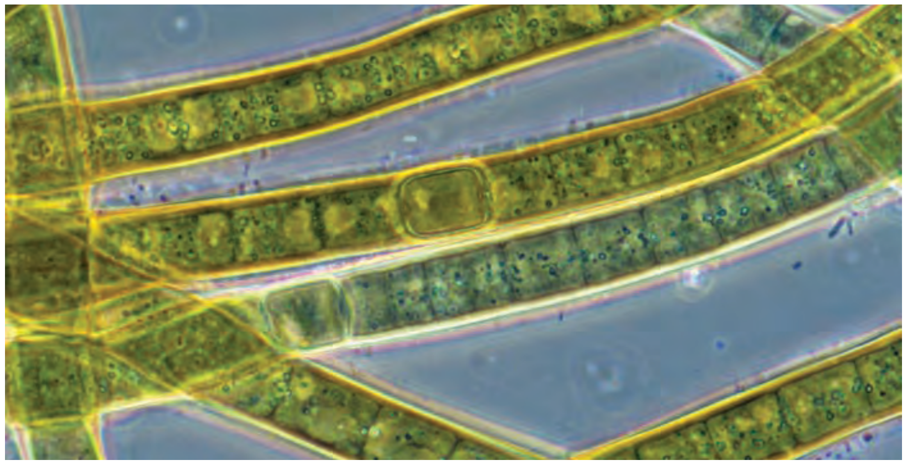


Figure 2.23 Microscopic cyanobacteria

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:

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

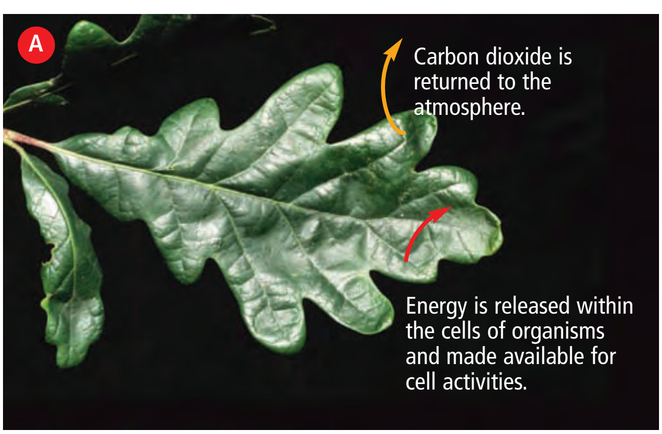


Figure 2.24 Producers release carbon dioxide back into the atmosphere (in the absence of sunlight) during cellular respiration (A). Consumers also release carbon dioxide when they exhale (B).

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.

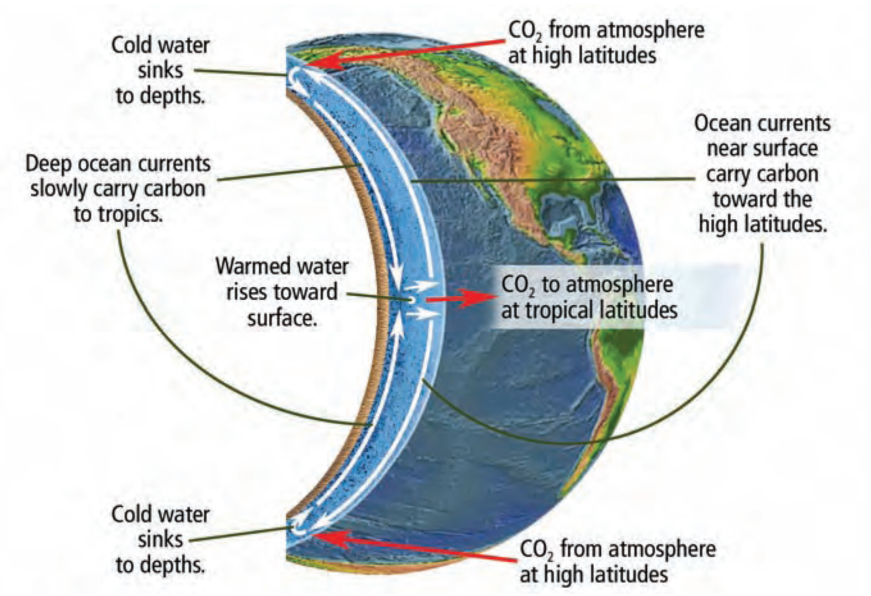


Figure 2.25 Ocean mixing

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.

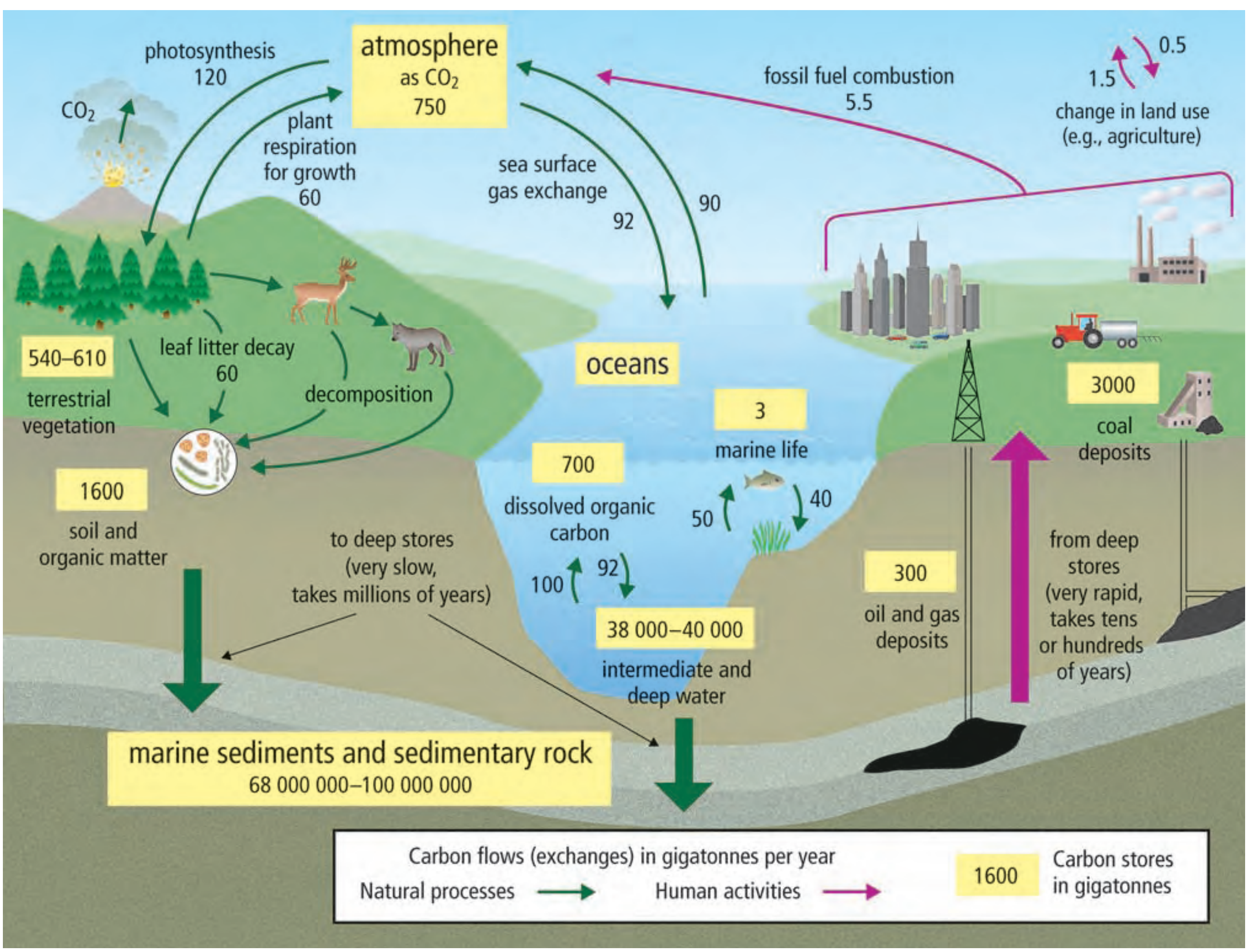


Figure 2.27 The carbon cycle

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.

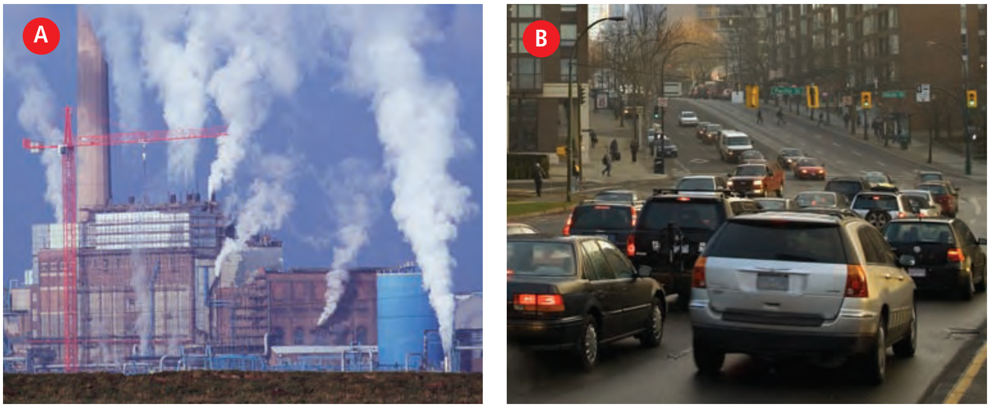


Figure 2.28 The burning of fossil fuels for industry (A) and for driving cars and trucks (B) contributes huge amounts of carbon dioxide to the atmosphere.

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.

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.

Figure 2.31 Lightning fixes nitrogen in the atmosphere.

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.

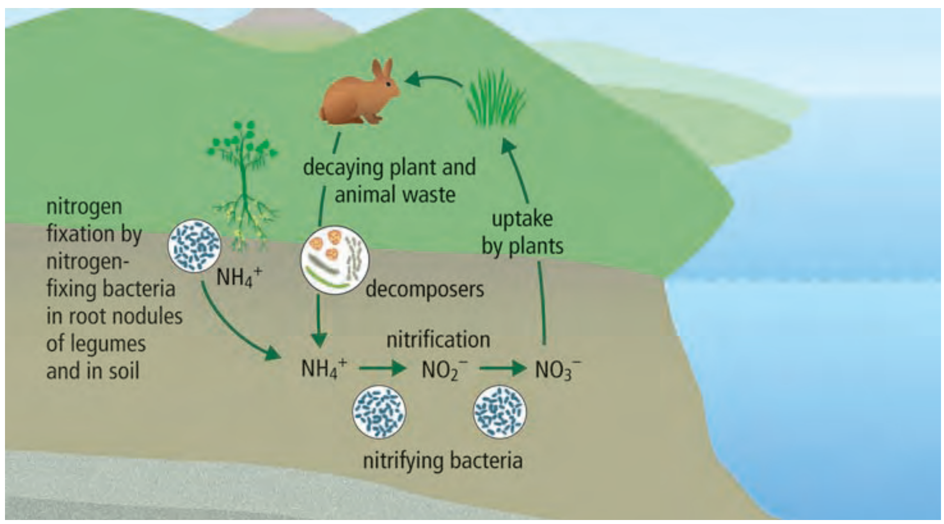


Figure 2.35 The process of nitrification

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.

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

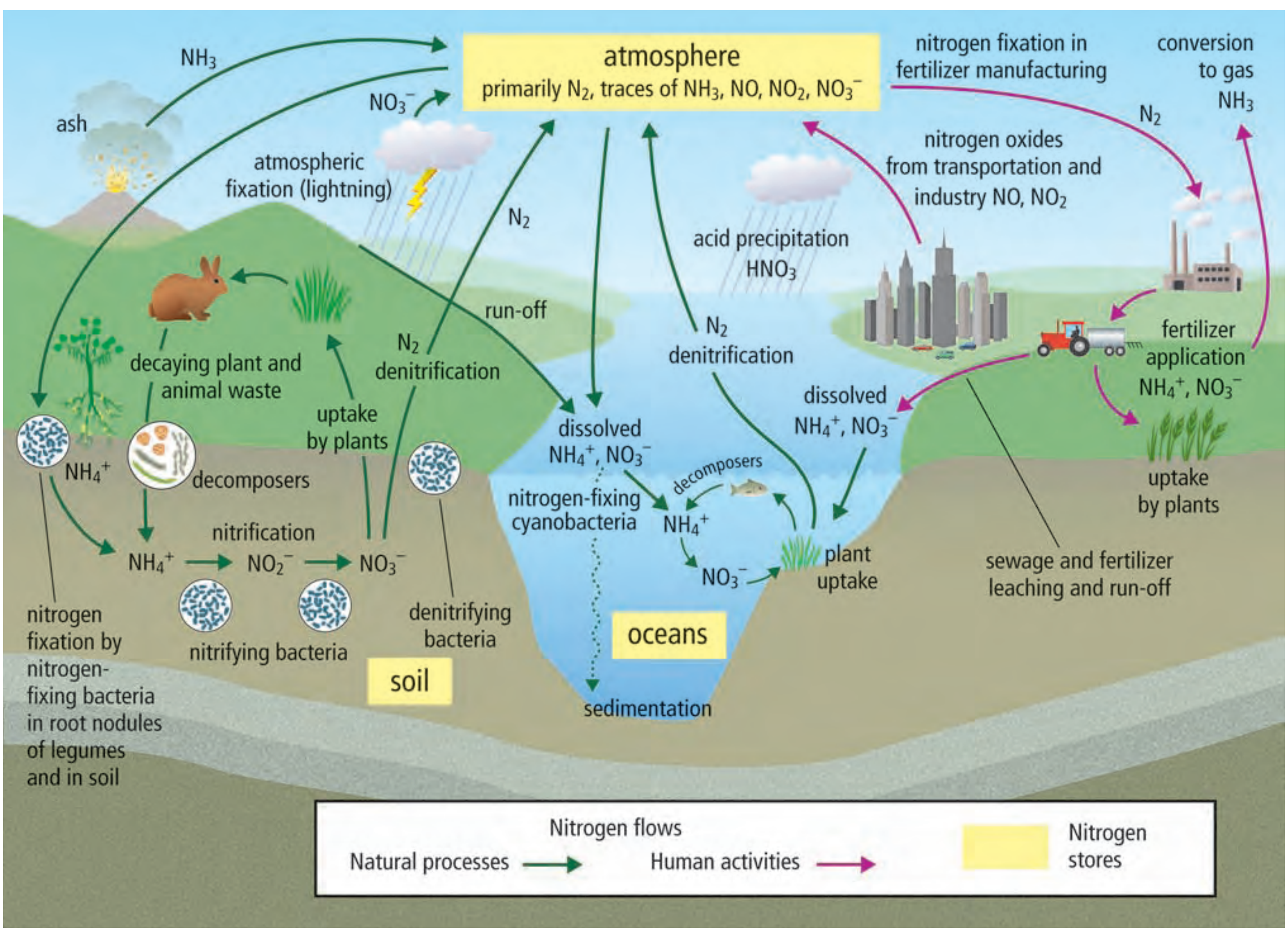


Figure 2.37 The nitrogen cycle

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.

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

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).

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

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.

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).

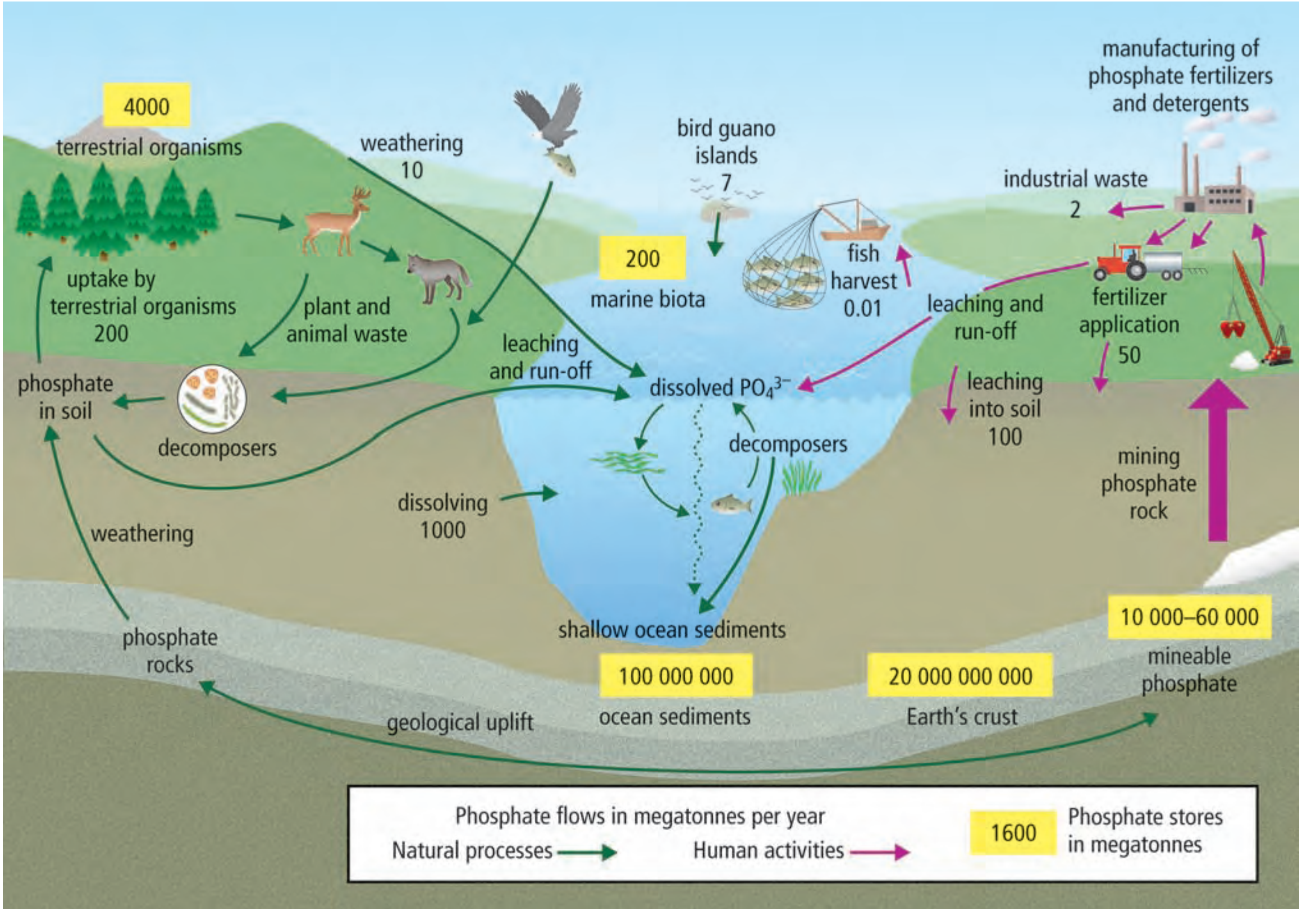


Figure 2.46 The phosphorus cycle

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.

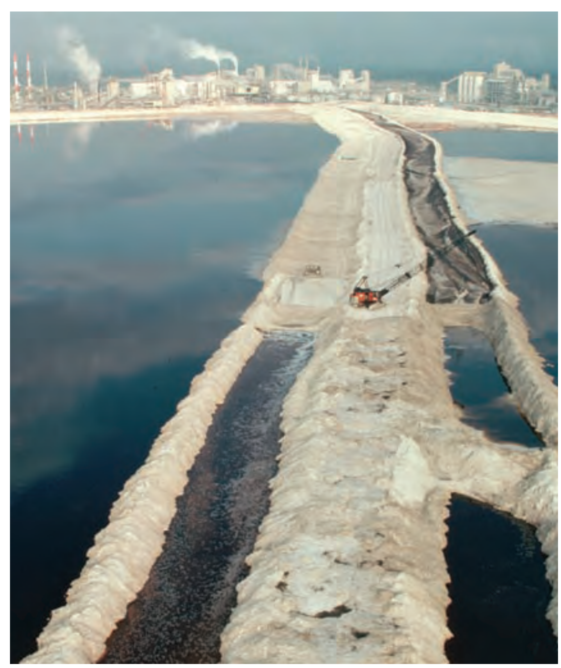


Figure 2.47 Phosphate mining operation east of Tampa, Florida. Florida provides a large percentage of the world's phosphate supply.

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.

Figure 2.49 Sockeye run in the Fraser River

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.

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**.

Anchor Activity

2-2B The Amazing Nutrient Cycle Race

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.

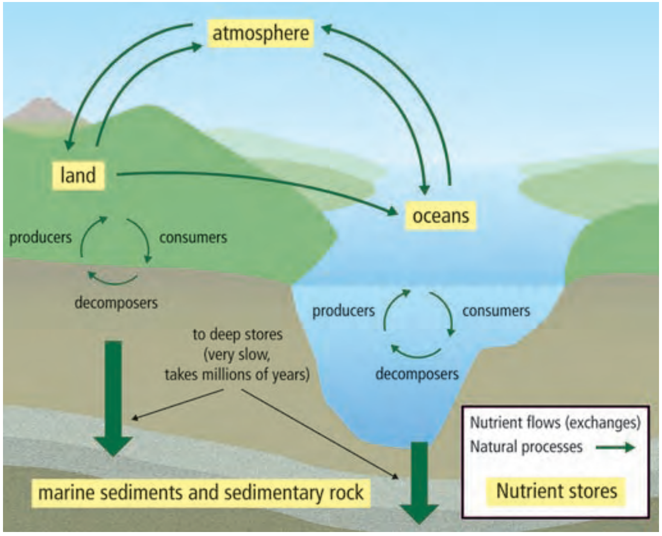
Questions

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?