Biogeochemical Cycles

**Guiding Question:** How do nutrients cycle through the environment?

**Knowledge and Skills**

- Explain how the law of conservation of matter applies to the behavior of nutrients in the environment.
- Describe the carbon cycle.
- Describe the events of the phosphorus cycle.
- Explain the importance of bacteria to the nitrogen cycle.

**Reading Strategy and Vocabulary**

- **Reading Strategy** Before you read, preview Figure 21. Make a list of questions you have about the carbon cycle. As you read, try to answer those questions.
- **Vocabulary** law of conservation of matter, nutrient, biogeochemical cycle, primary producer, photosynthesis, consumer, decomposer, cellular respiration, eutrophication, nitrogen fixation

**CONSIDER THIS:** A carbon atom in your fingernail today might have helped make up the muscle of a cow a year ago, may have belonged to a blade of grass a month before that, and may have been part of a dinosaur’s tooth 100 million years ago. Matter is never used up, and it never goes away. It just keeps cycling around and around.

**Nutrient Cycling**

Nutrients cycle through the environment endlessly.

Why does matter, such as water, cycle through the environment, never getting used up? Here’s the answer: Matter may be transformed from one type to another, but it cannot be created or destroyed. This principle is called the law of conservation of matter. It explains why the amount of matter in the environment stays the same as it flows through matter cycles, such as the water cycle.

Nutrients are matter that organisms require for their life processes. Organisms need several dozen nutrients. The nutrients required in relatively large amounts are called macronutrients and include nitrogen, carbon, and phosphorus. The nutrients needed in small amounts are called micronutrients. Nutrients circulate endlessly throughout the environment in complex cycles called biogeochemical cycles, or nutrient cycles. Carbon, oxygen, phosphorus, and nitrogen are nutrients that cycle through all of Earth’s spheres and organisms. The water cycle plays parts in all the biogeochemical cycles.

**The Carbon Cycle**

Producers play vital roles in the cycling of carbon through the environment.

From fossil fuels to DNA, from plastics to medicines, carbon (C) atoms are everywhere. The carbon cycle describes the routes that carbon atoms take through the environment.
Producers  **Primary producers** are organisms, including plants and algae, that produce their own food. Producers use the sun's energy or chemical energy along with carbon dioxide to produce carbohydrates. The carbohydrates are used as food by the producers.

Most producers make their own food by using the sun's energy in photosynthesis. In **photosynthesis**, producers pull carbon dioxide out of their environment and combine it with water in the presence of sunlight. The chemical bonds in carbon dioxide \((\text{CO}_2)\) and water \((\text{H}_2\text{O})\) are then broken, producing oxygen \((\text{O}_2)\) and carbohydrates (such as glucose, \(\text{C}_6\text{H}_{12}\text{O}_6\)). (The numbers in front of the chemical formulas below are numbers of molecules.)

\[
6\text{CO}_2 + 6\text{H}_2\text{O} + \text{the sun's energy} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 \text{ (sugar)} + 6\text{O}_2
\]

**Consumers and Decomposers** The carbon in a producer may be passed on to another organism, either a consumer that eats it or a decomposer that breaks down its wastes or remains. **Consumers** are organisms, mainly animals, that must eat other organisms to obtain nutrients. ** Decomposers are organisms such as bacteria and fungi that break down wastes and dead organisms.
**Cellular Respiration** Cellular respiration does not refer to breathing. Cellular respiration is the process by which organisms use oxygen to release the chemical energy of sugars and release CO$_2$ and water. In general terms, it is the chemical reverse of photosynthesis.

\[ C_6H_{12}O_6 \text{ (sugar)} + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy} \]

Most organisms undergo cellular respiration constantly, releasing carbon back into the atmosphere and oceans. Organisms do not release all the carbon they take in, however. They use some of it for their life processes. In fact, the abundance of plants and the fact that they use so much carbon for photosynthesis and other processes makes them a major carbon sink. (A sink is a reservoir of a substance that accepts more of that substance than it releases.)

**Carbon in Sediments** When organisms die in water, their remains may settle in sediments. As new layers of sediment accumulate, pressure on earlier layers increases. These conditions can convert soft tissues into fossil fuels, and shells and skeletons into sedimentary rock such as limestone. Limestone and other sedimentary rock make up the largest reservoir of carbon. Sedimentary rock releases some of its carbon through erosion and volcanic eruptions. Fossil fuel deposits contain a great deal of carbon, which is released when we extract the fossil fuels.

**Carbon in Oceans** The world’s oceans are the second-largest carbon reservoir (Figure 22). They absorb carbon compounds from the atmosphere, from runoff, from undersea volcanoes, and from the wastes and remains of organisms. The rates at which seawater absorbs and releases carbon depend on many factors, including the water temperature and the numbers of marine organisms living in it.

**Human Impacts** Humans shift carbon to the atmosphere in many ways. By extracting fossil fuels, we remove carbon from storage in the lithosphere. By then burning those fossil fuels, we move carbon dioxide into the atmosphere. The cutting of forests and burning of forests to plant farm fields also increase carbon in the atmosphere, both by releasing it from storage in plants and by reducing the plants available to use it. Producers cannot absorb enough carbon to keep up with human activities.

**The Missing Carbon Sink** Our understanding of the carbon cycle is not complete. Scientists have long been baffled by a missing carbon sink. Of the carbon dioxide humans release, scientists have measured how much is returned to the atmosphere and oceans, and more than 1–2 billion metric tons (1.1–2.2 billion tons) are unaccounted for. Many researchers think it must be taken up by the northern forests. But they’d like to know for sure.
The Phosphorus Cycle

The phosphorus cycle (Figure 23) involves mainly the lithosphere and the oceans. Phosphorus is a key component of cell membranes and of several molecules essential to life, including DNA and RNA. Although phosphorus is essential to life, the amount of phosphorus in organisms is dwarfed by the vast amounts in rocks, soil, sediments, and the oceans. Phosphorus is released naturally only when rocks are worn down by water or wind. Because most phosphorus is bound up in rock, the phosphorus available to organisms at any time tends to be very low. This scarcity, along with the need that organisms have for phosphorus, explains why plant and algae growth often jumps dramatically when phosphorus is added to their environments.

Organisms in the Phosphorus Cycle  Plants can take up phosphorus through their roots only when it is dissolved in water. Consumers acquire phosphorus from the water they drink and the organisms they eat. The waste of consumers contains phosphorus that decomposers return to the soil.

Human Impacts  People influence the phosphorus cycle in several ways. We mine phosphorus to use as fertilizer. People also release phosphorus-rich wastewater from their houses and businesses. (Phosphorus compounds are added to many detergents to improve their cleaning power.) Wastewater containing fertilizers and detergents that runs off or leaches into waterways adds phosphorus to them. The addition of phosphorus to bodies of water can lead to an overgrowth of producers (usually algae) in a process called eutrophication. In extreme cases, eutrophication can lead to hypoxia, or extremely low levels of oxygen in a body of water, as decomposers break down all the dead producers. Widespread hypoxia can cause a dead zone like the one in the Gulf of Mexico.

FIGURE 23 Phosphorus Cycle  The phosphorus cycle describes the routes that phosphorus atoms take through the environment. In this diagram, labels in boxes refer to reservoirs of phosphorus, and italic labels refer to processes of the phosphorus cycle.
The Nitrogen Cycle

The nitrogen cycle relies on bacteria that make nitrogen useful to organisms and bacteria that can return it to the atmosphere.

Nitrogen makes up 78 percent of our atmosphere by mass, and is the sixth most abundant element. It is an essential ingredient in the proteins, DNA, and RNA that build our bodies. Like phosphorus, nitrogen is an essential nutrient for plant growth. Thus the nitrogen cycle (Figure 24) is of vital importance to us and to all other organisms. Despite its abundance, nitrogen gas cannot cycle out of the atmosphere and into organisms. For this reason, nitrogen is relatively scarce in the lithosphere, hydrosphere, and in organisms. However, once nitrogen undergoes the right kind of chemical change—assisted by lightning, specialized bacteria, or human technology—it becomes usable to the organisms that need it. Those nitrogen compounds can act as potent fertilizers in the biosphere.

Why is nitrogen scarce in the biosphere?
Nitrogen Fixation To become usable to organisms, nitrogen gas (N\(_2\)) must be “fixed.” Nitrogen fixation is the conversion of nitrogen gas into ammonia. This can be accomplished in two naturally occurring ways: by the intense energy of a lightning strike, or when air in the top layer of soil comes in contact with particular types of nitrogen-fixing bacteria. These bacteria live freely in soil or in association with many types of plants, including soybeans, clover, and other legumes, providing them nutrients by fixing nitrogen for them. Farmers have long nourished their soils by planting crops, such as legumes, whose roots host nitrogen-fixing bacteria.

Nitrification and Denitrification Other types of bacteria living in soil use ammonium ions from nitrogen fixation or from the waste of decomposers to perform nitrification. In this process, the ammonium ions are first converted into nitrite ions (NO\(_2^-\)), then into nitrate ions (NO\(_3^-\)). Plants can take up nitrate ions. The nitrogen cycle is complete when denitrifying bacteria convert nitrates in soil or water back to nitrogen gas.

Human Impacts The slow rate of natural nitrogen fixation limits the flow of nitrogen out of the atmosphere and into the biosphere. But humans can also fix nitrogen. The process was developed shortly before World War I, when German scientist Fritz Haber found a way to synthesize ammonia, a nitrogen compound. Carl Bosch, another German scientist, later built on Haber’s work to produce ammonia on a large scale. The Haber-Bosch process enabled people to overcome the limits on plant productivity imposed by the natural scarcity of nitrogen. Today, humans fix at least as much nitrogen artificially as is fixed naturally.
By fixing atmospheric nitrogen, we increase its flow out of the atmosphere and into other reservoirs. We also affect other parts of the nitrogen cycle. When we burn forests and fields, we force nitrogen out of soils and vegetation and into the atmosphere. When we burn fossil fuels, we increase the rate at which nitric oxide (NO) enters the atmosphere and reacts to form nitrogen dioxide (NO₂). This compound can lead to acid precipitation. These and other human activities unbalance the nitrogen cycle.

**Conflicting Interests** Nitrogen’s natural scarcity and its importance to organisms mean that when it is introduced by people, problems similar to those of introduced phosphorus, such as eutrophication, can occur. The impacts of excess nitrogen from agriculture and other human activities along the Mississippi River are painfully evident to shrimpers and scientists with an interest in the Gulf of Mexico (Figure 25). Yet, farmers upstream also need to continue making a living, so there is a conflict.

The federal government has tried to help resolve that conflict. In 1998, the U.S. Congress passed the Harmful Algal Bloom and Hypoxia Research and Control Act. This law called for an “integrated assessment” of hypoxia in the northern Gulf to address the extent, nature, and causes of the dead zone, as well as its ecological and economic impacts. The assessment report published two years later outlined potential solutions and their estimated social and economic costs. The report proposed that the federal government work with Gulf Coast and Midwestern communities to carry out several proposals, which you can see in Figure 26. In 2004, Congress reauthorized the Act. Several expansions of the plan were under consideration in 2010.

**Proposals for Reducing Gulf of Mexico Dead Zone**

- Reduce nitrogen fertilizer use on Midwestern farms.
- Change the timing of fertilizer use to minimize runoff during the rainy season.
- Plant alternative crops.
- Manage nitrogen-rich livestock manure more effectively.
- Restore nitrogen-absorbing wetlands in the Mississippi River basin.
- Construct artificial wetlands to filter farm runoff.
- Improve sewage treatment.
- Restore frequently flooded lands to reduce runoff.
- Restore wetlands near the Mississippi River’s mouth to improve nitrogen-absorbing ability.

**Connect to the Central Case**

**FIGURE 26** Potential Solutions to the Dead Zone A 2000 assessment of hypoxia in the Gulf of Mexico led to these proposals. Congress continues to work on refining laws concerning the addition of nutrients to the Mississippi River basin in efforts to reduce the dead zone. **Infer** According to these proposals, what group will bear much of the responsibility for reducing the dead zone?

**ANSWERS**

**Figure 26 Farmers**

**Lesson 4 Assessment** For answers to the Lesson 4 Assessment, see page A-4 at the back of the book.

1. **Review** Describe the law of conservation of matter.
2. **Infer** Why is it said that photosynthesis and cellular respiration are reverse chemical processes?
3. **Sequence** Describe the roles of organisms in the phosphorus cycle.
4. **Classify** A classmate describes a bacterium to you as living on the roots of clover and providing nutrients to the plant. Would you classify this bacterium as nitrogen-fixing, nitrifying, or denitrifying? Explain.
5. **THINK IT THROUGH** You’ve been noticing that a local pond has developed a green scum that is getting thicker and thicker. When you look into the water, you see fewer fish and other animals than you used to, and you see fewer birds around the pond. Based on what you learned in this chapter, what is this process called? What are two possible causes?