APES STUDY GUIDE: SPECIAL TEXT EXCERPT "Living in the Environment" by Miller and Spoolman.

Please read the entire excerpt. Print a hard copy of the study guide and handwrite your responses in the spaces provided. DO NOT SKIP THE CRITICAL THINKING QUESTIONS. THEY ARE OLD FRQs and will give you invaluable practice with this style of questioning. ACADEMIC HONESTY IS REQUIRED.

1. What is the current concentration of carbon dioxide in the atmosphere? Why is atmospheric C important?

2. Identify the biological processes responsible for circulating carbon in the biosphere.

3. According to the text excerpt, what is the residence time for carbon dioxide in the atmosphere?

4. Identify and describe TWO human activities that increase the concentration of carbon in the atmosphere.

5. Identify another carbon containing greenhouse gas, other than carbon dioxide.

6. Identify an environmental problem that results from elevated carbon levels in the atmosphere.

7. What is the current concentration of nitrogen gas in the atmosphere? What is the biological importance of nitrogen?

8. There are two ways to fix nitrogen into nutrients. Describe ONE abiotic and ONE biotic method of nitrogen fixation.

9. Nitrogen transforms chemically throughout the N cycle. Identify and describe TWO chemical transformations that occur in the nitrogen cycle and discuss the importance of each transformation to an ecosystem.

10. Contrast the process of nitrification with that of denitrification. Be specific.

11. Describe TWO ways in which agricultural practices might impact the levels of nitrogen in the atmosphere.

12. Describe ONE way in which agricultural practices might impact nitrogen levels in surface water.

13. Identify TWO major ways in which the phosphorus and carbon cycles differ.

14. State the biological importance of phosphorus.

15. How does deforestation impact the phosphorus cycle? Be specific.

16. Identify TWO sulfur bearing compounds that originate from volcanic eruptions.

17. Describe THREE human activities that release sulfur dioxide to the atmosphere and ONE way in which this impacts ecosystems.


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Figure 3-16 This glacier in Patagonia, Argentina, stores water for long periods of time as part of the hydrologic cycle.

bacteria—as long as these natural processes are not overloaded. Thus, *the hydrologic cycle can be viewed as a cycle of natural renewal of water quality.*

Only about 0.024% of the earth's vast water supply is available to humans and other species as liquid freshwater in accessible groundwater deposits and in lakes, rivers, and streams (see Figure 25, p. S50, in Supplement 6). The rest is too salty for us to use, is stored as ice, or is too deep underground to extract at affordable prices using current technology.

Humans alter the water cycle in three major ways (see the red arrows and boxes in Figure 3-15). *First,* we withdraw large quantities of freshwater from rivers, lakes, and aquifers sometimes faster than nature can replace it. As a result, some aquifers are being depleted and some rivers no longer flow to the ocean. *Second,* we clear vegetation from land for agriculture, mining, road building, and other activities, and cover much of the land with buildings, concrete, and asphalt. This increases runoff and reduces infiltration that would normally recharge groundwater supplies. *Third,* we drain and fill wetlands for farming and urban development. Left undisturbed, wetlands provide the natural service of flood control, acting like sponges to absorb and hold overflows of water from drenching rains or rapidly melting snow.

CONSIDER THIS. . .

CONNECTIONS Clearing a Rain Forest Can Affect Local Weather and Climate

Clearing vegetation can alter weather patterns by reducing transpiration, especially in dense tropical rain forests (**Core Case Study**). Because so many plants in such a forest transpire water into the atmosphere, vegetation is the primary source of local rainfall. Cutting down large areas of forest raises ground temperatures (because it reduces shade) and can reduce local rainfall so much that the forest cannot grow back. If this occurs over a large area for three or more decades, the climate of the affected area can change, and much less diverse tropical grasslands can replace biologically diverse forests.

The Carbon Cycle

Carbon is the basic building block of the carbohydrates, fats, proteins, DNA, and other organic compounds necessary for life. Various compounds of carbon circulate through the biosphere, the atmosphere, and parts of the hydrosphere, in the **carbon cycle** shown in Figure 3-17.

The carbon cycle is based on carbon dioxide (CO_2) gas, which makes up about 0.039% of the volume of the earth's atmosphere and is also dissolved in water. Carbon dioxide (along with water vapor in the water cycle) is a key component of the atmosphere's thermostat. If the carbon cycle removes too much CO_2 from the atmosphere, the atmosphere will cool, and if it generates too much CO_2, the atmosphere will get warmer. Thus, even slight changes in this cycle caused by natural or human factors can affect the earth's climate and ultimately help to determine the types of life that can exist in various places.

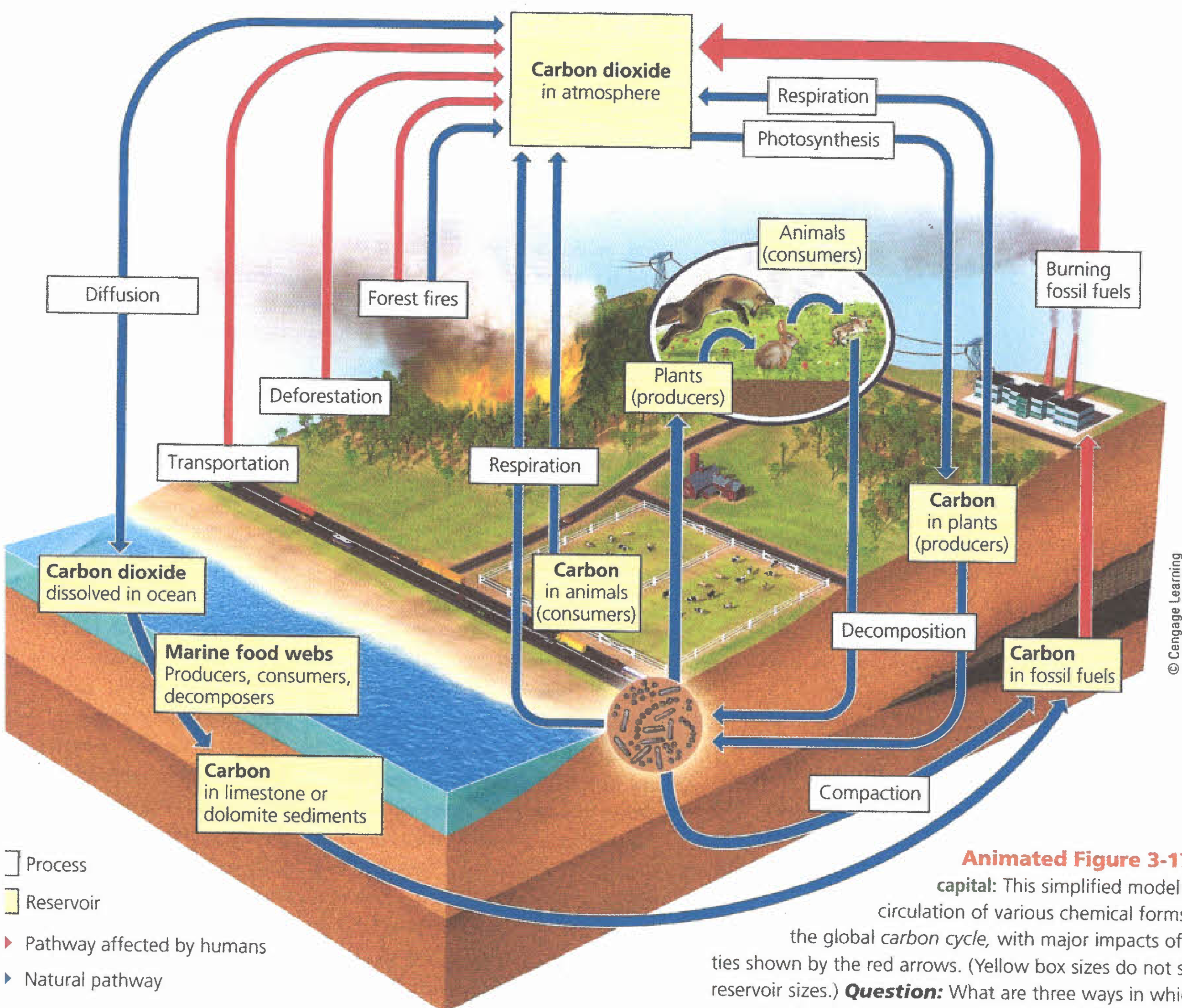
Terrestrial producers remove CO_2 from the atmosphere and aquatic producers remove it from the water. These producers then use the CO_2 and photosynthesis to produce complex carbohydrates such as glucose ($C_6H_{12}O_6$).

The cells in oxygen-consuming producers, consumers, and decomposers then carry out aerobic respiration. This process breaks down glucose and other complex organic compounds to produce CO_2 in the atmosphere and water for reuse by producers. Because of this linkage between *photosynthesis* in producers and *aerobic respiration* in producers, consumers, and decomposers, these processes circulate carbon in the biosphere. Oxygen and hydrogen—the other elements in carbohydrates—cycle almost in step with carbon.

Some carbon atoms take a long time to recycle. Decomposers release the carbon stored in the bodies of dead organisms on land back into the air as CO_2, which can remain in the atmosphere for 100 years or more. And in water, decomposers release carbon that can be stored as insoluble carbonates in bottom sediment for very long periods of time. Indeed, marine sediments are the earth's largest store of carbon. Over millions of years, buried deposits of dead plant matter and bacteria were compressed between layers of sediment, where high pressure and heat converted them to carbon-containing *fossil fuels* such as coal, oil, and natural gas (see Figure 2-13, p. 43, and Figure 3-17).

This long-stored carbon was not released to the atmosphere as CO_2 until fossil fuels were extracted and burned. Small portions of these deposits have also been exposed to air by long-term geological processes that can take place over millions of years. However, in only a few hundred years, we have extracted and burned huge quantities of fossil fuels that took millions of years to form. This is why, on a human time scale, fossil fuels are nonrenewable resources.

We are altering the carbon cycle (see the red arrows in Figure 3-17), mostly by adding large amounts of carbon dioxide to the atmosphere (see Figure 14, p. S70, Supplement 7) when we burn carbon-containing fossil fuels (especially coal to produce electricity). We also alter the cycle by clearing carbon-absorbing vegetation from forests,



Animated Figure 3-17 Natural capital: This simplified model illustrates the circulation of various chemical forms of carbon in the global *carbon cycle,* with major impacts of human activities shown by the red arrows. (Yellow box sizes do not show relative reservoir sizes.) ***Question:*** What are three ways in which you directly or indirectly affect the carbon cycle?

especially tropical forests, faster than it can grow back (**Core Case Study**). Human activities are altering both the rate of energy flow and the cycling of nutrients within the carbon cycle. In other words, humanity has a large and growing *carbon footprint* that makes up a significant part of our overall ecological footprints (see Figure 1-13, p. 14).

Computer models of the earth's climate systems indicate that increased concentrations of atmospheric CO_2 and other greenhouse gases including methane (CH_4) are very likely to warm the atmosphere by enhancing the planet's natural greenhouse effect (which is why they are called greenhouse gases), and thus to change the earth's climate during this century, as we discuss in Chapter 19.

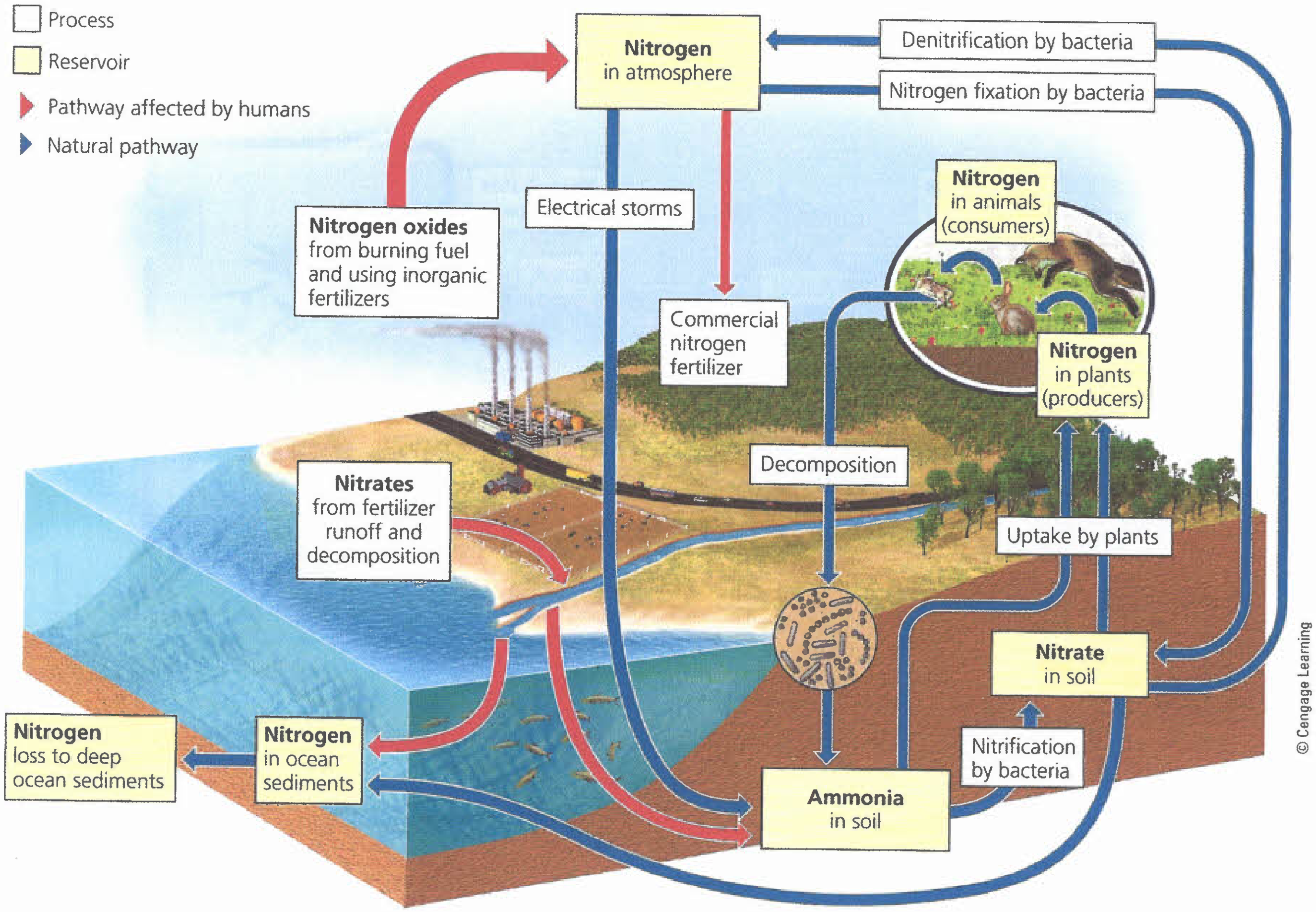
The Nitrogen Cycle: Bacteria in Action

The major reservoir for nitrogen is the atmosphere. Chemically unreactive nitrogen gas (N_2) makes up 78% of the volume of the atmosphere. Nitrogen is a crucial component of proteins, many vitamins, and nucleic acids such as DNA (see Figure 8, p. S17, in Supplement 4). However, N_2 cannot be absorbed and used directly as a nutrient by multicellular plants or animals.

Two natural processes convert, or *fix,* N_2 into compounds that plants and animals can use as nutrients. One such process is electrical discharges, or lightning, taking place in the atmosphere. The other takes place in aquatic systems, in soil, and in the roots of some plants, where specialized bacteria, called *nitrogen-fixing bacteria,* complete this conversion as part of the **nitrogen cycle**, which is depicted in Figure 3-18.

The nitrogen cycle consists of several major steps. In *nitrogen fixation,* specialized bacteria in soil, as well as blue-green algae (cyanobacteria) in aquatic environments, combine gaseous N_2 with hydrogen to make ammonia (NH_3). The bacteria use some of the ammonia they produce as a nutrient and excrete the rest into the soil or water. Some of the ammonia is converted to ammonium ions (NH_4^+) that plants can use as a nutrient.

Ammonia that is not taken up by plants may undergo *nitrification.* In this process, specialized soil bacteria such as



Animated Figure 3-18 Natural capital: This is a simplified model of the circulation of various chemical forms of nitrogen in the global *nitrogen cycle*, with major human impacts shown by the red arrows. (Yellow box sizes do not show relative reservoir sizes.) ***Question:*** What are two ways in which the carbon cycle and the nitrogen cycle are linked?

the Rhizobium bacteria convert most of the NH_3 and NH_4^+ in the soil to *nitrate ions* (NO_3^-), which are easily taken up by the roots of plants. The plants then use these forms of nitrogen to produce various amino acids, proteins, nucleic acids, and vitamins. Animals that eat plants eventually consume these nitrogen-containing compounds, as do detritus feeders and decomposers.

Plants and animals return nitrogen-rich organic compounds to the environment as both wastes and cast-off particles of tissues such as leaves, skin, or hair, and through their bodies when they die and are decomposed or eaten by detritus feeders. Vast armies of specialized decomposer bacteria convert this detritus into simpler nitrogen-containing inorganic compounds such as ammonia (NH_3) and water-soluble salts containing ammonium ions (NH_4^+).

In *denitrification*, specialized bacteria in waterlogged soil and in the bottom sediments of lakes, oceans, swamps, and bogs convert NH_3 and NH_4^+ back into nitrate ions, and then into nitrogen gas (N_2), which is released to the atmosphere to begin the nitrogen cycle again.

We intervene in the nitrogen cycle in several ways (see the red arrows in Figure 3-18) that affect what goes on in the atmosphere and in aquatic systems. We add large amounts of nitrogen oxides to the atmosphere when we burn gasoline and other fuels and when we use commercial nitrate fertilizers. For example, we add nitric oxide (NO) into the atmosphere when N_2 and O_2 combine as we burn any fuel at high temperatures, such as in car, truck, and jet engines. In the atmosphere, this gas can be converted to nitrogen dioxide gas (NO_2) and nitric acid vapor (HNO_3), which can return to the earth's surface as damaging *acid deposition*, commonly called *acid rain*.

We also add nitrous oxide (N_2O) to the atmosphere through the action of anaerobic bacteria on commercial nitrogen-containing fertilizer or organic animal manure applied to the soil. This greenhouse gas can warm the atmosphere and take part in reactions that deplete stratospheric ozone, which keeps most of the sun's harmful ultraviolet radiation from reaching the earth's surface (as we discuss in Chapter 18).

We are also removing large amounts of nitrogen (N_2) from the atmosphere faster than the cycle can replace it. This N_2 is removed primarily for use in industrial processes that convert it to ammonia (NH_3) and ammonium ions (NH_4^+) used in fertilizers.

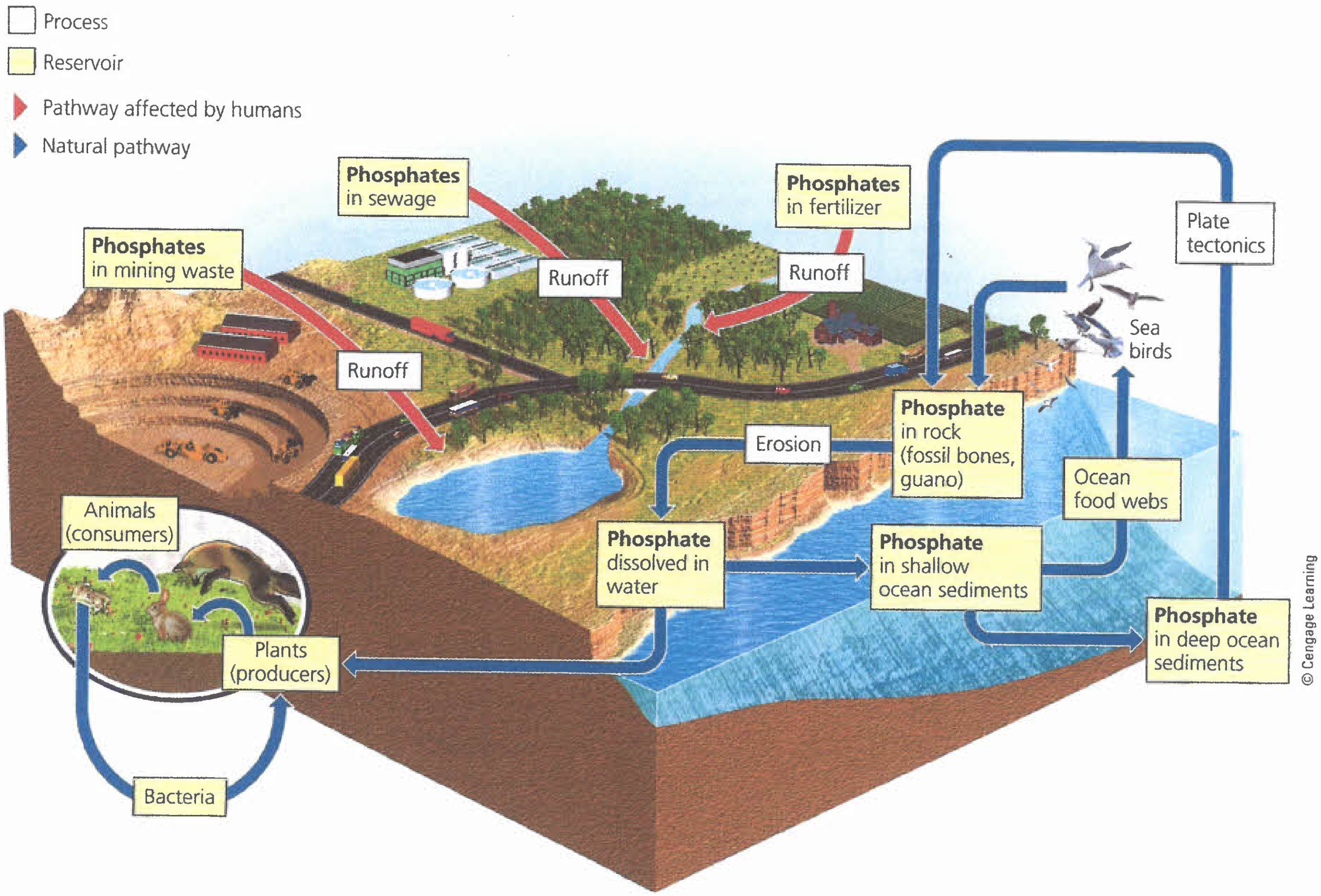


Figure 3-19 **Natural capital:** This is a simplified model of the circulation of various chemical forms of phosphorus (mostly phosphates) in the *phosphorus cycle,* with major human impacts shown by the red arrows. (Yellow box sizes do not show relative reservoir sizes.) ***Questions:*** What are two ways in which the phosphorus cycle and the nitrogen cycle are linked? What are two ways in which the phosphorus cycle and the carbon cycle are linked?

We upset the nitrogen cycle in aquatic ecosystems by adding excess nitrates (NO_3^-) to bodies of water through agricultural runoff of fertilizers and animal manure and through discharges from municipal sewage treatment systems. This can cause excessive growth of algae that can disrupt aquatic systems.

According to the 2005 Millennium Ecosystem Assessment, since 1950, human activities have more than doubled the annual release of nitrogen from the land into the rest of the environment. This is mostly from the greatly increased use of inorganic fertilizers to grow crops. The amount released is projected to double again by 2050 (see Figure 16, p. S70, in Supplement 7).

This excessive input of nitrogen into the air and water contributes to pollution and other problems to be discussed in later chapters. Nitrogen overload is a serious and growing local, regional, and global environmental problem that has attracted little attention. Princeton University physicist Robert Socolow calls for countries around the world to work out some type of nitrogen management agreement to help prevent this problem from reaching crisis levels.

CONSIDER THIS. . .

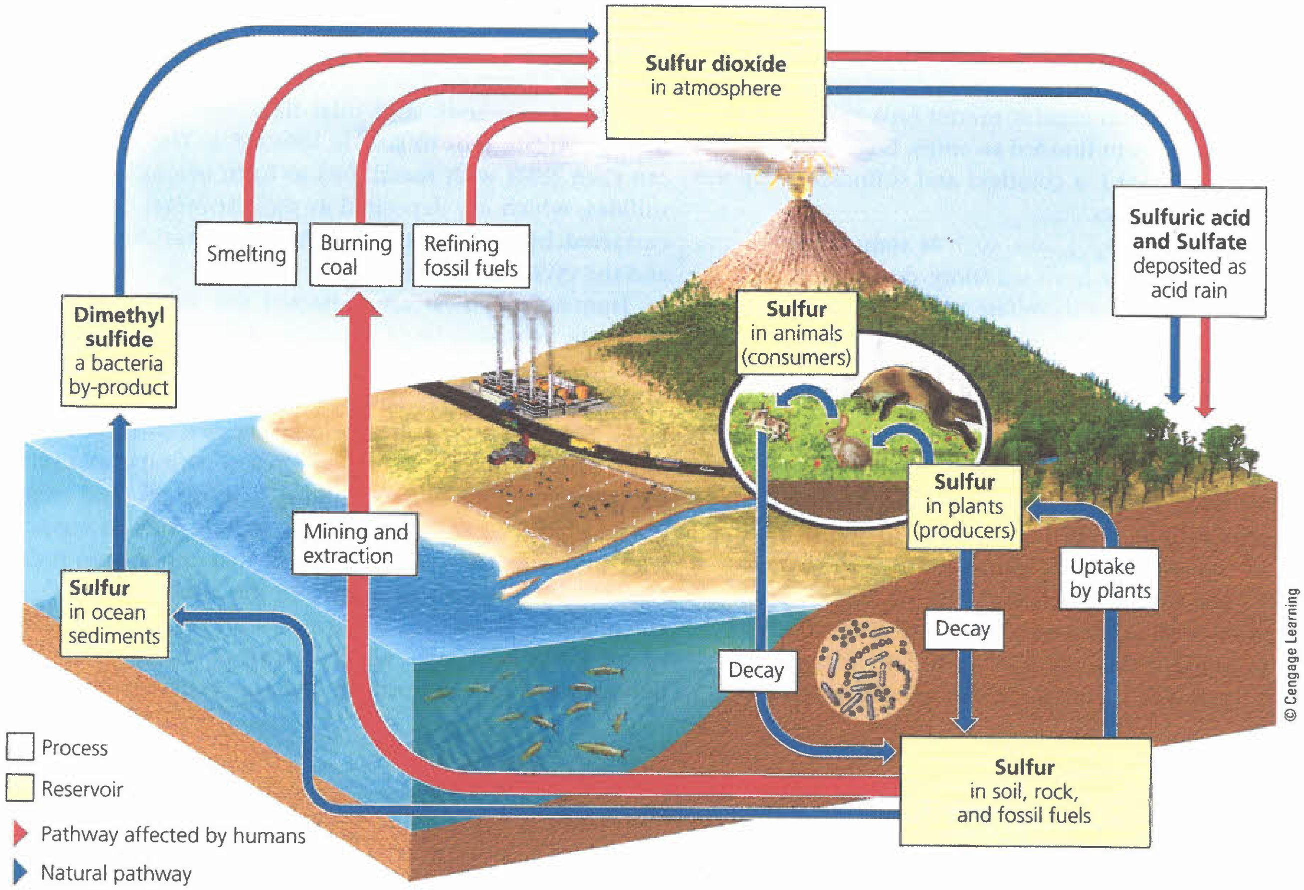
THINKING ABOUT The Nitrogen Cycle and Tropical Deforestation

What effects might the clearing and degrading of tropical rain forests (**Core Case Study**) have on the nitrogen cycle in these forest ecosystems and on any nearby aquatic systems? (See Figure 2-1, p. 30, and Figure 2-5, p. 37.)

The Phosphorus Cycle

Compounds of phosphorus (P) circulate through water, the earth's crust, and living organisms in the **phosphorus cycle**, depicted in Figure 3-19. Most of these compounds contain *phosphate* ions (PO_4^{3-}), which serve as an important nutrient. In contrast to the cycles of water, carbon, and nitrogen, the phosphorus cycle does not include the atmosphere. The major reservoir for phosphorus is phosphate salts containing PO_4^{3-} in terrestrial rock formations and ocean-bottom sediments. The phosphorus cycle is slow compared to the water, carbon, and nitrogen cycles.

As water runs over exposed rocks, it slowly erodes away inorganic compounds that contain phosphate ions.



Animated Figure 3-20 **Natural capital:** This is a simplified model of the circulation of various chemical forms of sulfur in the *sulfur cycle*, with major impacts of human activities shown by the red arrows. (Yellow box sizes do not show relative reservoir sizes.) ***Question:*** What are two ways in which the sulfur cycle is linked to each of the phosphorus, nitrogen, and carbon cycles?

The running water carries these phosphate ions into the soil where they can be absorbed by the roots of plants and by other producers. Phosphate compounds are also transferred by food webs from producers to consumers, eventually including detritus feeders and decomposers. In both producers and consumers, phosphates are a component of biologically important molecules such as nucleic acids (see Figure 7, p. S16, in Supplement 4) and energy transfer molecules such as ADP and ATP (see Figure 11, p. S18, in Supplement 4). Phosphate is also a major component of vertebrate bones and teeth.

Phosphate can be lost from the cycle for long periods of time when it is washed from the land into streams and rivers and is carried to the ocean. There it can be deposited as marine sediment and remain trapped for millions of years. Over time, geological processes can uplift and expose these seafloor deposits, from which phosphate can be eroded to start the cycle again.

Because most soils contain little phosphate, the lack of it often limits plant growth on land unless phosphorus (as phosphate salts mined from the earth) is applied to the soil as a fertilizer. Lack of phosphorus also limits the growth of producer populations in many freshwater streams and lakes because phosphate salts are only slightly soluble in water and thus do not release many phosphate ions that producers need as nutrients.

Human activities are affecting the phosphorus cycle (as shown by the red arrows in Figure 3-19). One such activity is the removal of large amounts of phosphate from the earth to make fertilizer. Also, by clearing tropical forests (**Core Case Study**), we reduce phosphate levels in tropical soils. Topsoil that is eroded from fertilized crop fields, lawns, and golf courses carries large quantities of phosphate ions into streams, lakes, and oceans. There they stimulate the growth of producers such as algae and various aquatic plants. Phosphate-rich runoff from the land often produces huge populations of algae, which then upset chemical cycling and other processes in bodies of water.

The Sulfur Cycle

Sulfur circulates through the biosphere in the **sulfur cycle**, shown in Figure 3-20. Much of the earth's sulfur is stored underground in rocks and minerals and in the form of sulfate (SO_4^{2-}) salts buried deep under ocean sediments.

Sulfur also enters the atmosphere from several natural sources. Hydrogen sulfide (H_2S)—a colorless, highly poisonous gas with a rotten-egg smell—is released from active volcanoes and from organic matter broken down by anaerobic decomposers in flooded swamps, bogs, and tidal flats. Sulfur dioxide (SO_2), a colorless and suffocating gas, also comes from volcanoes.

Particles of sulfate (SO_4^{2-}) salts, such as ammonium sulfate, enter the atmosphere from sea spray, dust storms, and forest fires. Plant roots absorb sulfate ions and incorporate the sulfur as an essential component of many proteins.

Certain marine algae produce large amounts of volatile dimethyl sulfide, or DMS (CH_3SCH_3). Tiny droplets of DMS serve as nuclei for the condensation of water into droplets found in clouds. In this way, changes in DMS emissions can affect cloud cover and climate.

In the atmosphere, DMS is converted to sulfur dioxide, some of which in turn is converted to sulfur trioxide gas (SO_3) and to tiny droplets of sulfuric acid (H_2SO_4). DMS also reacts with other atmospheric chemicals such as ammonia to produce tiny particles of sulfate salts. These droplets and particles fall to the earth as components of *acid deposition,* which along with other air pollutants can harm trees and aquatic life.

In the oxygen-deficient environments of flooded soils, freshwater wetlands, and tidal flats, specialized bacteria convert sulfate ions to sulfide ions (S^{2-}). The sulfide ions can then react with metal ions to form insoluble metallic sulfides, which are deposited as rock or metal ores (often extracted by mining and converted to various metals), and the cycle continues.

Human activities have affected the sulfur cycle primarily by releasing large amounts of sulfur dioxide (SO_2) into the atmosphere (as shown by the red arrows in Figure 3-20). We release sulfur to the atmosphere in three ways. *First,* we burn sulfur-containing coal and oil to produce electric power. *Second,* we refine sulfur-containing oil (petroleum) to make gasoline, heating oil, and other useful products. *Third,* we extract metals such as copper, lead, and zinc from sulfur-containing compounds in rocks that are mined for these metals. In the atmosphere, SO_2 is converted to droplets of sulfuric acid (H_2SO_4) and particles of sulfate (SO_4^{2-}) salts, which return to the earth as acid deposition, which in turn can damage ecosystems.

3-5 How Do Scientists Study Ecosystems?

CONCEPT 3-5

Scientists use both field research and laboratory research, as well as mathematical and other models, to learn about ecosystems.

Some Scientists Study Nature Directly

Scientists use both field and laboratory research and mathematical and other models to learn about ecosystems (**Concept 3-5**). *Field research,* sometimes called "muddy-boots biology," involves going into forests and other natural settings to observe and measure the structure of ecosystems and what happens in them (see Chapter 2 opening photo). Most of what we know about ecosystems has come from such research.

Scientists have been particularly creative in studying tropical forests (**Core Case Study**). In a few cases, ecologists have erected tall construction cranes that provide them access to the canopies of tropical forests. This, along with rope walkways between treetops (Figure 3-21), has helped them to identify and observe the rich diversity of species living or feeding in these treetop habitats.

Sometimes ecologists carry out controlled experiments by isolating and changing a variable in part of an area and comparing the results with nearby unchanged areas. A good example of this is reported in the Core Case Study of Chapter 2 (p. 30).

Scientists also use aircraft and satellites equipped with sophisticated cameras and other *remote sensing* devices to scan and collect data on the earth's surface. Then they use *geographic information system (GIS)* software to capture, store, analyze, and display such information. Such software can store geographic and ecological spatial data electronically as numbers or as images. For example, a GIS can convert digital satellite images into global, regional, and local maps showing variations in vegetation, gross primary productivity, air pollution emissions, and many other variables.

Scientists can also attach tiny radio transmitters to animals and use global positioning systems (GPS) to learn about the animals by tracking where they go and how far they go. This technology is very important for studying endangered species. **Green Careers:** GIS analyst; remote sensing analyst

Some Scientists Study Ecosystems in the Laboratory

Since the 1960s, ecologists have increasingly supplemented field research by using *laboratory research*—setting up, observing, and making measurements of model ecosystems and populations under laboratory conditions (Figure 3-22). They have created such simplified systems in containers such as culture tubes, bottles, aquariums, and greenhouses, and in indoor and outdoor chambers where they can control temperature, light, CO_2, humidity, and other variables.

Such systems make it easier for scientists to carry out controlled experiments. In addition, laboratory experiments often are quicker and less costly than similar exper-