CHAPTER 4

Ecosystems

4.1 Energy, Producers, and Consumers

4.2 Energy Flow in Ecosystems

4.3 Cycles of Matter

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A Common Kingfisher captures its meal

HS-LS2-2, HS-LS2-3, HS-LS2-4, HS-LS2-5, HS-LS4-5, HS-LS4-6, HS-ESS2-6, HS-ETS1-3

CASE STUDY

What's to blame for the bloom?

Green slime. Toxic muck. Tourist-repelling, fish-killing scum. Guacamole-thick sludge. These are just a few of the more polite words used to describe an ugly green "living carpet" that spread across bodies of water in and around Florida during the summer of 2016. That "carpet" was an algal bloom— an out-of-control growth of algae. Often, either algae themselves, or bacteria that grow on dead algae, release poisonous and often foul-smelling compounds that can kill aquatic animals and affect human health.

Natural blooms of aquatic algae can appear in freshwater and salt-water ecosystems at certain times of year. Usually natural blooms provide some extra input into the food chain, and color the water green for a while. But not-so-natural blooms produced by the effects of human activity, can cause serious problems. The giant 2016 bloom in Florida, for example, started in Lake Okeechobee. From there, thick, floating mats of algae spread along rivers and into coastal areas along both the Atlantic and Gulf Coasts. These poisonous mats, so large that they could be seen from space, fouled beaches and marinas and killed fish.

Unfortunately, this is not an isolated event. Toxic algal blooms are happening more frequently and in more places, growing larger, and lasting longer. In 2015, the biggest algal bloom ever recorded on the United States West Coast stretched all the way from California's Channel Islands to the Alaskan Peninsula. That bloom forced closures of fish and shellfish industries in California, Oregon, and Washington for months, causing losses of millions of dollars. Freshwater algal blooms also occur in small lakes and streams, and can cover many square kilometers in both Lake Erie and Lake Michigan.

What's going on? Some algal blooms—usually mild ones—occur naturally in freshwater and salt-water ecosystems when available nutrients combine with favorable temperatures and other environmental factors. In lakes, natural blooms often occur in springtime. In coastal oceans, they often occur in summer. But around the world, in fresh and salt water alike, bigger and more frequent blooms seem to result from several factors involved in global change.

Researchers hypothesize that the Florida bloom—which involved both freshwater and salt-water ecosystems—was triggered by unusually heavy rains. The West Coast bloom seems to have been caused by unusually warm water in the Pacific.

Why would heavy rains trigger a bloom in Florida? And why would higher temperatures cause one off the coast of California? Despite their different causes, did those blooms have anything in common? Do we know enough to act in ways that could head off future blooms?

Throughout this chapter, look for connections to the CASE STUDY to help you answer these questions.

LESSON 4.1

Energy, Producers, and Consumers

KEY QUESTIONS

- *What are primary producers?*
- *How do consumers obtain energy and nutrients?*

HS-LS2-3: Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.

VOCABULARY
autotroph
primary producer
photosynthesis
chemosynthesis
heterotroph
consumer
detritus

READING TOOL

As you read, make a concept map to show the relationships between different types of organisms. Complete the concept map in your **Biology Foundations Workbook.**

All living things need energy. You think about energy and its relationship to your life all the time, whether you realize it or not, and not just when you grab an "energy bar" on your way to exercise. To control your weight, you need to balance energy you take in, energy your body uses at rest, energy you "spend" during exercise, and energy your body stores. When we burn "fossil fuels" we release energy captured and stored by ancient organisms! But where does all that energy come from?

Primary Producers

No living thing can *create* energy, but organisms called **autotrophs** can capture energy from nonliving sources and convert it into forms living cells can use. Autotrophs also store energy in ways that make it available to other organisms, which is why they are also called **primary producers**. ***Primary producers are the first producers of energy-rich compounds that can be used later by other organisms.*** All life depends on primary producers.

Energy From the Sun The energy that powers most life on Earth comes from sunlight. Algae and plants harness solar energy to build living tissues through **photosynthesis**, using that energy to convert carbon dioxide and water into oxygen and energy-rich carbohydrates such as sugars and starches. Photosynthetic primary producers also add oxygen to the atmosphere and remove carbon dioxide. Plants are the main primary producers on land. Algae and plants share that role in freshwater ecosystems, and algae do most of the heavy lifting in sunlit parts of the ocean. Certain bacteria also harness sunlight, but use a different kind of photosynthesis. These bacteria are important primary producers in places such as tidal flats, salt marshes, and mangrove forests.

Life Without Light In 1979, biologists discovered thriving ecosystems inhabited by strange animals around volcanic vents spewing superheated water in the pitch-black depths of the Pacific Ocean. Where did the energy that powers life in these ecosystems come from? It turns out that the water gushing from those vents is rich in energy-rich inorganic compounds. Some bacteria can not only tolerate high temperatures near the vent, but can also harness chemical energy from inorganic molecules such as hydrogen sulfide. These bacteria use a process called **chemosynthesis** (kee moh SIN thuh sis) in which chemical energy is used to produce carbohydrates as shown on the right in **Figure 4-1**. Around the vents, many chemosynthetic bacteria live inside the tissues of certain types of worms and large clams. The bacteria pass some of the carbohydrates they produce to their animal partners.

This astonishing discovery opened researchers' eyes to the ecological importance of chemosynthesis. Thanks to studies that were inspired by this work, we now know that chemosynthetic primary producers are a lot more common, and live in many more environments, than anyone expected. Recent studies have shown that chemosynthetic bacteria thrive deep within Earth's crust, in total darkness and exposed to extremely high temperatures. They are also found closer to the surface in underground streams and caves previously thought to be lifeless. Still other chemosynthetic bacteria live buried in the mud of tidal flats all over the world. We have a great deal more to learn about these lightless ecosystems—all of it fascinating.

READING CHECK **Compare and Contrast** How are photosynthesis and chemosynthesis similar? How are they different?

BUILD VOCABULARY

Prefixes The prefix *chemo-* means "chemical," or "chemistry." The process of chemosynthesis uses chemical energy to produce organic compounds in an organism.

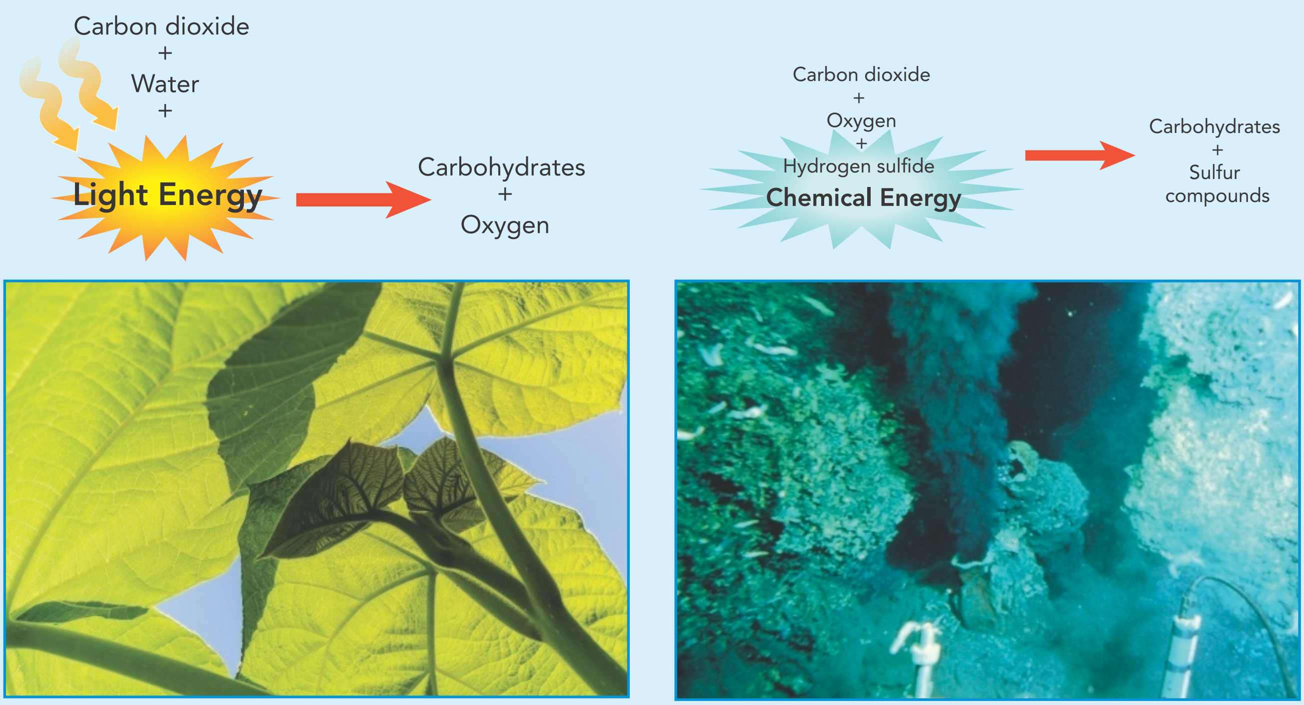
VIDEO

Watch an interactive video that compares the flow of energy and the roles of producers and consumers in two ecosystems: a kelp forest and a hydrothermal vent.

Figure 4-1

Photosynthesis and Chemosynthesis

Plants use the energy from sunlight to carry out the process of photosynthesis. Other autotrophs, such as sulfur bacteria, use the energy stored in chemical bonds in a process called chemosynthesis. In both cases, energy-rich carbohydrates are produced.



Photosynthesis **Chemosynthesis**

INTERACTIVITY

Explore producers and consumer types such as herbivores, omnivores, carnivores, scavengers, decomposers, and detritivores.

Consumers

Animals, fungi, and many bacteria cannot harness energy directly from the environment as primary producers do. These organisms, known as **heterotrophs**, must acquire energy from other organisms, usually by eating them. Heterotrophs are also called **consumers**. ***Consumers are organisms that rely on other organisms for energy and nutrients.***

Types of Consumers Consumers are classified by the way they acquire energy and nutrients from other organisms. Some examples of the different types of consumers are shown in **Figure 4-2**.

Beyond Consumer Categories Many organisms do not fit neatly inside the tidy categories ecologists try to place them in. For example, some animals usually described as carnivores, such as hyenas, will scavenge if they get a chance. Many aquatic animals eat a mixture of algae, bits of animal carcasses, and tiny bits of organic matter—including the feces of other animals! Toucans use their razor-sharp bills to cut up fruit, but they also can swallow frogs, small mammals, and even baby monkeys! Consumers often lumped together may also differ from one another in more subtle ways. Herbivores may select different parts of the plants they eat. That's important because different plant parts often contain very different amounts of available energy.

INTERACTIVITY

Figure 4-2

Consumers

Consumers rely on other organisms for energy and nutrients. The Amazon rain forest shelters examples of each type of consumer, as shown here.

Carnivores kill and eat other animals. Carnivores include snakes, dogs, cats, and this giant river otter.

Herbivores like this military macaw obtain energy and nutrients by eating plant leaves, roots, seeds, or fruits. Common herbivores include cows, caterpillars, and deer.

Scavengers are animals that consume the carcasses of other animals that have been killed by predators or have died of other causes. This king vulture is a scavenger.

Omnivores are animals that eat both plants and other animals. Humans, bears, pigs, and this white-nosed coati are omnivores.

Decomposers "feed" by chemically breaking down organic matter. This process produces **detritus**, or small pieces of dead and decaying plant and animal remains. Bacteria and fungi, like these mushrooms, are decomposers.

Detritivores such as this giant earthworm chew or grind detritus particles into smaller pieces. Many types of mites, snails, shrimp, and crabs are detritivores. They commonly digest decomposers that live on, and in, detritus particles.

Fruits, such as berries are easy to digest, and are usually rich in energy and nutrients. So it isn't surprising that many birds and mammals feed on these types of foods. The world's human population also gets much of its energy from the seeds of grasses: rice, corn, wheat, oats, and barley.

Leaves are plentiful in many ecosystems, but are low in energy and tough to digest. Why? Leaves are composed largely of cellulose. No multicellular organism can manufacture an enzyme to break down cellulose molecules. Only fungi and certain single-celled organisms manufacture those enzymes. So how can many animals eat leaves? Animals that eat leaves have microorganisms inside their guts that digest cellulose for them!

Cattle and many other grazing animals spend a long time chewing their food into a pulp. When they swallow this pulp, it enters a complex digestive tract, part of which supports microorganisms that can break down cellulose. Many grazers periodically regurgitate the mixture of food and bacteria, which is called cud. Then they chew the cud and reswallow it. Even with all this extra work, grazers can extract relatively little energy from each mouthful of leaves. They therefore spend a lot of their time eating. What's more, the kind of digestive system needed to extract energy and nutrients from leaves is very heavy. That's why only a handful of birds eat leaves.

Analyzing Data

Ocean Water and Oxygen Concentration

Samples of ocean water are taken at different depths, and the amount of oxygen in the water at each depth is measured. The results are shown in the data table.

1. **Analyze Data** Describe what happens to the amount of available oxygen as you get deeper in the ocean.
2. **Infer** Light can penetrate to only a depth of between 50 and 100 m in most ocean water. What effect does this have on the water's oxygen concentration? Explain.

Concentration of Oxygen

Depth of Sample (m)	Oxygen Concentration (ppm)
0	7.5
50	7.4
100	7.4
150	4.5
200	3.2
250	3.1
300	2.9

HS-LS2-3

LESSON 4.1 Review

KEY QUESTIONS

1. What are the two primary sources of energy that power living systems?
2. How do consumers obtain energy?

CRITICAL THINKING

3. **Develop Models** Draw a model to illustrate the flow of energy from a nonliving source to an herbivore.
4. **Construct an Explanation** Termites are insects that feed on wood, which contains cellulose. Scientists have observed that some termite species prefer wood that has been attacked by fungi. Construct an explanation for this observation.

LESSON 4.2 Energy Flow in Ecosystems

KEY QUESTIONS

- *How does energy flow through ecosystems?*
- *How do ecological pyramids help analyze energy flow through trophic levels?*

HS-LS2-4: Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.

VOCABULARY

food chain
phytoplankton
food web
trophic level
ecological pyramid
biomass

READING TOOL

As you read, identify the main idea and supporting details under each heading. Take notes in your **Biology Foundations Workbook.**

When one organism eats another, energy moves from the "eaten" to the "eater." That sounds simple, but you would be surprised at how complicated ecological studies of "Who eats whom?" can be!

Food Chains and Food Webs

In every ecosystem, primary producers and consumers are linked through feeding relationships. Details of those relationships vary a lot among ecosystems, but energy always flows in similar ways. ***Energy flows through an ecosystem in a one-way stream, from primary producers through various consumers.***

Food Chains The simplest way to think of energy moving through an ecosystem is to imagine it flowing along a food chain. A **food chain** is a series of organisms in which energy is transferred from one organism to another. Some food chains are very short. In Gorongosa National Park in Mozambique, an antelope feeds on grass, a primary producer. A lion feeds upon the antelope, making the lion two steps removed from the primary producer.

In the open ocean, food chains can be much longer. There, primary producers are usually tiny floating algae called **phytoplankton**, which are mostly eaten by small animal plankton. There are typically two or three more steps in this food chain to larger fish like tuna, which are four or five steps from primary producers.

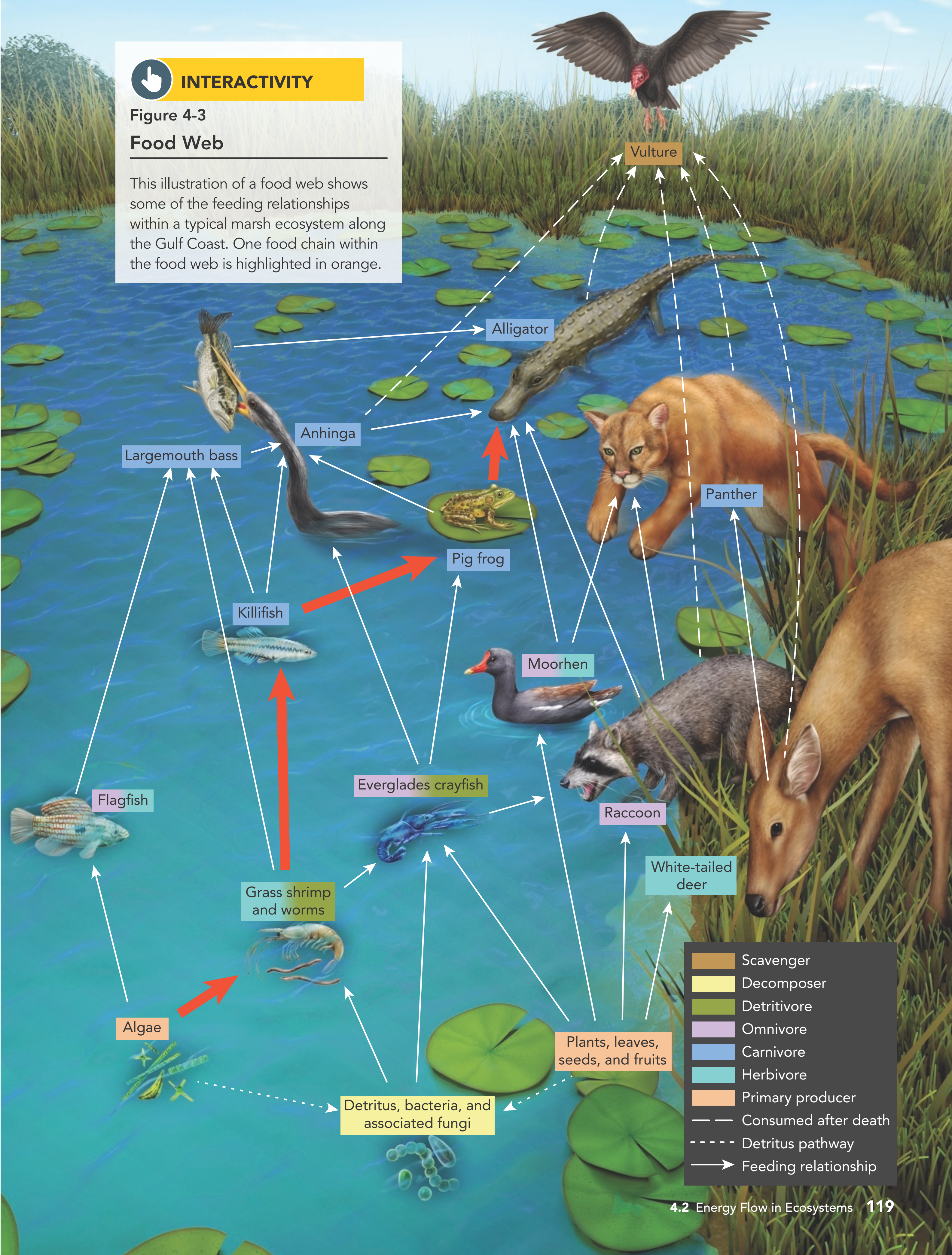
Food Webs In most ecosystems, energy and matter move through feeding relationships that are much more complicated than a simple chain. Why? Many animals eat more than one kind of food. For example, in many salt marshes along the coast of Florida and other Gulf states, raccoons and moorhens eat several species of plants, as shown in **Figure 4-3**. Several predators, such as alligators and panthers, in turn, often prey upon these animals. Ecologists call this network of feeding interactions, through which both energy and matter move, a **food web**.

INTERACTIVITY

Figure 4-3

Food Web

This illustration of a food web shows some of the feeding relationships within a typical marsh ecosystem along the Gulf Coast. One food chain within the food web is highlighted in orange.



INTERACTIVITY

Use the interactive food web activity to explore the effects of invasive species on food webs.

BUILD VOCABULARY

Academic Words The word convert means "to change from one form to another." Decomposers convert, or change, uneaten dead plant matter into detritus.

Food Chains Within Food Webs Look back at **Figure 4-3**. Starting with a primary producer, see how many different routes, or food chains, you can take to reach the vulture, panther, or alligator. One path, from the algae to the alligator, is highlighted in orange. A food web, therefore, is a network that includes all the food chains in an ecosystem. Note that this is a highly simplified representation of this food web, in which many species have been left out. Now, you can appreciate how complicated food webs are!

Decomposers and Detritivores in Food Webs Decomposers and detritivores have vital roles in the movement of energy and matter through food webs. Look again at the food web. Although white-tailed deer, raccoons, shrimp, and flagfish feed at least partly on primary producers, most producers die without being eaten. In the detritus pathway, decomposers convert that dead material to detritus, which is eaten by detritivores, such as shrimp and crayfish. Decomposition also releases matter in the form of nutrients that can be used by primary producers as shown in **Figure 4-4**. Without decomposers, nutrients would remain locked within dead organisms.

Food Webs and Disturbance

Food webs are complex, so it is difficult to predict exactly how they will respond to an environmental change. Look again at **Figure 4-3**. Think about questions an ecologist might ask about changes following a disturbance. What if an oil spill caused a serious decline in the number of the bacteria and fungi that break down detritus? What effect do you think that might have on populations of shrimp and crayfish? Do you think those populations would decline? If they did, how might pig frogs change their feeding behavior? How might changes in frog behavior affect other species?

Because food webs contain so many different interactions among so many different organisms, you might expect that answers to these questions would not be simple or easy to predict—and you'd be right! Sometimes the effects of disturbances are minor. Other times a disturbance can have dramatic effects throughout the web.

READING CHECK **Explain** How are food chains and food webs related?

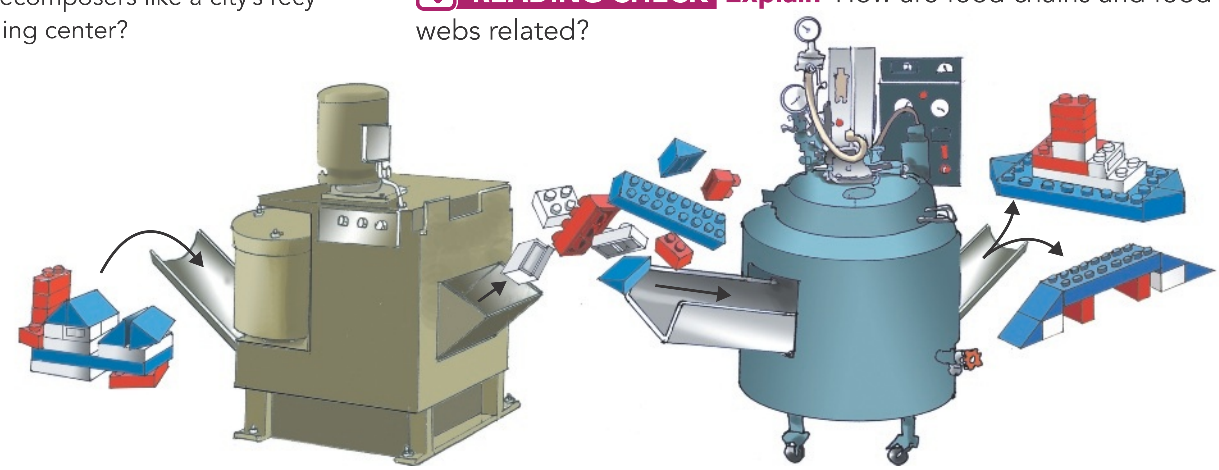
Visual Analogy

Figure 4-4

Earth's Recycling Center

Decomposers break down dead and decaying matter and release nutrients that can be reused by primary producers.

Use Analogies How are decomposers like a city's recycling center?



Decomposers **Primary Producers**

Ecological Pyramids

Each step in a food chain or food web is called a **trophic level**. Primary producers make up the first trophic level. Various consumers occupy other levels. One way to illustrate trophic levels in an ecosystem is with a model called an ecological pyramid. **Ecological pyramids** are models that show the relative amount of energy or matter contained within each trophic level in a food chain or food web.

READING TOOL

Refer to the Pyramid of Energy visual. Draw a concept map that shows how the terms are related.

Pyramids of Energy

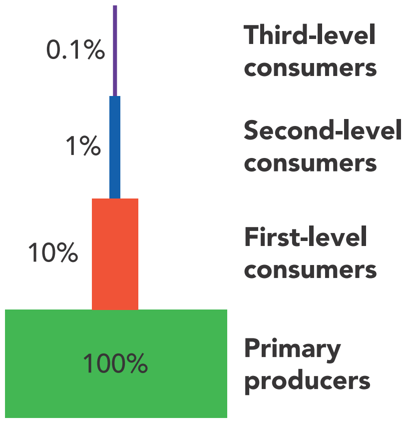
Theoretically, there is no limit to the number of trophic levels in a food web, or the number of organisms on each level. But there's a catch. Only a small portion of the energy stored in any trophic level is available to organisms at the next level. This is because organisms use up much of the energy they acquire on life processes, such as respiration, movement, growth, and reproduction. Most of the remaining energy is released into the environment as heat—a byproduct of these activities. ***Pyramids of energy show the relative amount of energy available at each trophic level of a food chain or food web.***

The shape of a pyramid of energy depends on the efficiency of energy transfer from one trophic level to the next. On average, about 10 percent of the energy available within one trophic level is transferred to the next trophic level, as shown in **Figure 4-5**. For instance, one tenth of the solar energy captured and stored in the leaves of grasses ends up stored in the tissues of cows and other grazers. One tenth of that energy—10 percent of 10 percent, or 1 percent of the original amount—gets stored in the tissues of humans who eat cows.

Figure 4-5

Pyramid of Energy

Pyramids of energy show the amount of energy available at each trophic level. An ecosystem requires a constant supply of energy from photosynthetic or chemosynthetic producers.



HS-LS2-4

Quick Lab — Open-Ended Inquiry

How Can You Model Energy Flow in Ecosystems?

1. Using materials of your choice, develop a mathematical model of energy flow through four trophic levels in an ecosystem. To start, decide what will represent one energy unit. Then, decide what will represent the trophic levels.

2. Model the amount of available energy in the first trophic level. Set up a data table to record the number of energy units available in your model.
3. Next, model how this energy transfers to the second, third, and fourth trophic levels. Record your data in your data table.

ANALYZE AND CONCLUDE

1. **Use Models** About how much energy is transferred from one trophic level to the next? How does your model show this flow of energy?
2. **Evaluate Claims** A classmate claims that energy is conserved as it flows through an ecosystem. Use your model and scientific reasoning to support or refute this claim.
3. **Support Claims** Support the claim that matter is conserved when one organism eats another.

Figure 4-6

Pyramids of Biomass and Numbers

With each step to a higher trophic level, biomass and numbers decrease. The pyramid shape shows this relationship.

INTERACTIVITY

Learn more about how energy flows through ecosystems by interacting with ecological pyramids.

Pyramids of Biomass and Numbers The total amount of living tissue within a given trophic level is called its **biomass**. Biomass is usually measured in grams of organic matter per unit area. The amount of biomass a given trophic level can support is determined, in part, by the amount of energy available to the organisms in that trophic level. ***A pyramid of biomass is a model that illustrates the relative amount of living organic matter in each trophic level of an ecosystem.***

Ecologists interested in the number of organisms at each trophic level often use a pyramid of numbers. ***A pyramid of numbers is a model that shows the relative number of individual organisms at each trophic level in an ecosystem.*** In most ecosystems, the pyramid of numbers is similar in shape to the pyramid of biomass. The numbers of individuals on each level decrease from the level below it. To understand this point more clearly, imagine that an ecologist marked off a large field, and then weighed and counted every organism in that area. The result might look something like the pyramid in **Figure 4-6**.

In some cases, however, consumers are much smaller in size and mass than the organisms they feed upon. Thousands of insects may graze on a single tree, for example. In such cases, the normal pyramid of numbers may be turned upside down, but the pyramid of biomass usually has the normal orientation. Even a single tree has a lot more biomass than the insects that feed on it!

HS-LS2-4

LESSON 4.2 Review

KEY QUESTIONS

1. Energy is said to flow in a "one-way" stream through an ecosystem. In your own words, describe what that means.
2. What are the three types of ecological pyramids? Explain how each type of pyramid models energy and matter in ecosystems.

CRITICAL THINKING

3. **Construct an Explanation** Suppose there was a sudden decrease in the number of crayfish in the food web shown in **Figure 4-3**. Construct an explanation to explain how this change may affect the food web.
4. **Calculate** Imagine you have a five-step food chain. If 100 percent of the energy is available at the first trophic level, what percentage of energy is available at the highest trophic level?
5. **Use Models** Choose one of the food chains shown within the food web in **Figure 4-3**. Write a paragraph describing the feeding relationships among the organisms in the food chain. **Hint:** Use the terms *producers*, *consumers*, and *decomposers* in your description.
6. **Construct an Explanation** Why are decomposers and detritivores essential parts of all food webs?

Cycles of Matter

LESSON 4.3

KEY QUESTIONS

- *How does matter flow between trophic levels and among ecosystems?*
- *How does water cycle globally?*
- *What is the importance of the main nutrient cycles?*
- *How does nutrient availability affect primary productivity?*

HS-LS2-3: Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.
HS-LS2-4: Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.
HS-LS2-5: Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.
HS-ESS2-6: Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

All organisms are composed of compounds that act as the building blocks of living tissue: water, carbohydrates, lipids, nucleic acids, and proteins. Those compounds are mainly made up of elements often called *essential nutrients*. Six of these elements—oxygen, hydrogen, carbon, nitrogen, phosphorus, and potassium—are required in relatively large amounts. But organisms can't manufacture these elements and they never get "used up." So, where do essential nutrients come from? How does their availability affect ecosystems?

Recycling in Nature

You might think that matter would flow through ecosystems as energy does. But there's a big difference. As nutrients move through ecosystems, the compounds they form are often transformed. But matter is never created or destroyed. ***Matter flows from one trophic level to another, and elements are recycled within and among ecosystems.*** These cycles, called **biogeochemical cycles**, are powered by the flow of energy as shown in **Figure 4-7**.

VOCABULARY
biogeochemical cycle
nutrient
nitrogen fixation
denitrification
limiting nutrient

READING TOOL

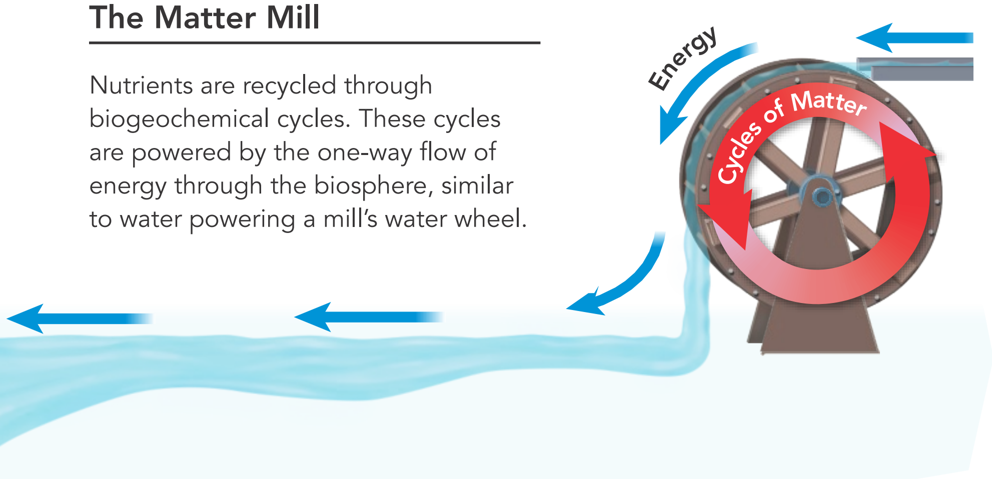
Before you read, preview and compare each of the cycle diagrams. Take notes in your **Biology Foundations Workbook.**

Visual Analogy

Figure 4-7

The Matter Mill

Nutrients are recycled through biogeochemical cycles. These cycles are powered by the one-way flow of energy through the biosphere, similar to water powering a mill's water wheel.



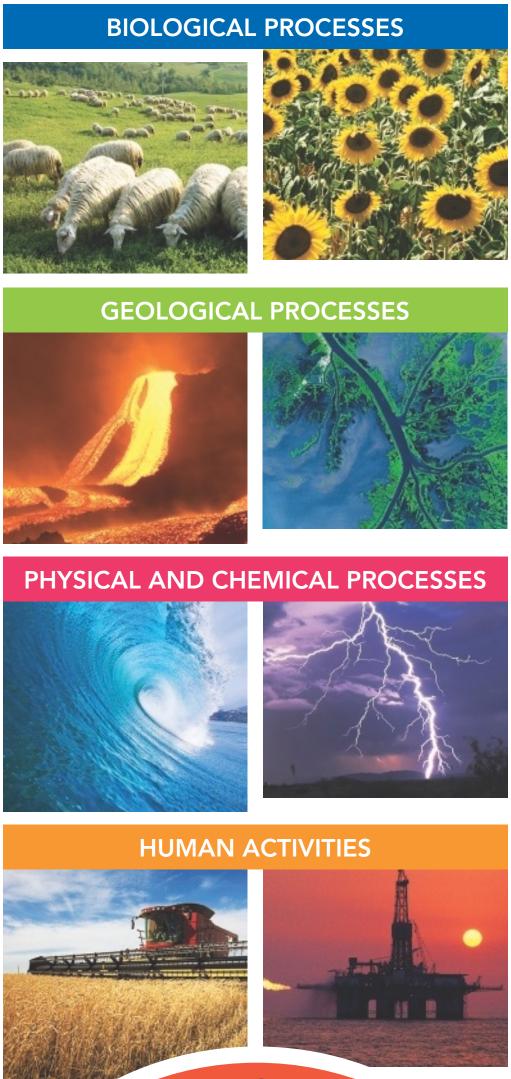
The processes that drive these cycles can be classified as biological processes, geological processes, physical and chemical processes, and processes driven by human activity, as shown in **Figure 4-8**. This cycling continues indefinitely, because matter is never created or destroyed.

Biological Processes Biological processes consist of any activities performed by living organisms. These include photosynthesis, eating, "burning" food (respiration), and eliminating waste products. These processes occur mainly in the biosphere, but affect the other three spheres as well.

Geological Processes Geological processes include volcanic eruptions, formation and breakdown of rock, and major movements of matter within and below Earth's surface. These processes occur mainly in the geosphere, but also affect the other three spheres.

Physical and Chemical Processes Physical and chemical processes include cloud formation and precipitation, the flow of running water, and the action of lightning. These processes occur primarily in the hydrosphere, atmosphere, and geosphere, but also affect the biosphere.

Human Activities Human activities that affect these cycles on a global scale include mining and burning of fossil fuels, clearing land for building and farming, cutting or burning and replanting of forests, and manufacture and use of fertilizers. Human causes of global change are found in the outermost ring of our global change model. Humans can change system processes in the four spheres leading to measurable changes in the system.



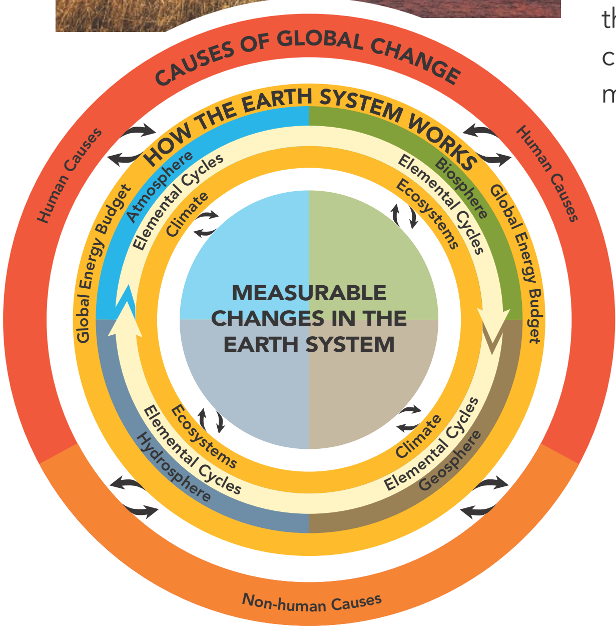


Figure 4-8

Global Processes and Global Systems

Biological, geological, physical, and chemical processes, as well as human activities, cycle atoms like carbon and nitrogen, through the biosphere, atmosphere, hydrosphere, and geosphere. These processes and the Elemental Cycles are represented in the Understanding Global Change model. Human activities are located in the model's outer ring, labeled "Causes of Global Change." Human activities can affect the global system processes located within the model's middle ring, and result in "Measurable Changes in The Earth System."

The Water Cycle

Every time you see rain or snow, or watch a river flow, you are witnessing part of the water cycle. ***Water cycles among the hydrosphere, the atmosphere, and the geosphere—sometimes outside the biosphere and sometimes within it.*** As **Figure 4-9** shows, water molecules typically enter the atmosphere as water vapor, a gas, when they evaporate from the ocean or other parts of the hydrosphere. Water can also enter the atmosphere from the biosphere by evaporating from leaves of plants in the process of transpiration. This cycle is represented in the Understanding Global Change diagram within the hydrosphere.

Water vapor may be transported through the atmosphere over great distances by winds. If the air carrying the water vapor cools, the water condenses into tiny droplets that form clouds. When the droplets become large enough, they fall as rain, snow, sleet, or hail. On land, some precipitation flows along the surface in what scientists call runoff, until it enters a river or stream that carries it to an ocean or lake.

Water can also be absorbed into the soil and is then called groundwater. Groundwater can enter plants through their roots, or flow into rivers, streams, lakes, or oceans. Some groundwater penetrates deeply enough into the ground to become part of underground reservoirs. Water that reenters the atmosphere through transpiration or evaporation begins the cycle anew. So the water cycle, like other cycles of matter, can be shown as passing through the atmosphere, hydrosphere, geosphere, and biosphere.

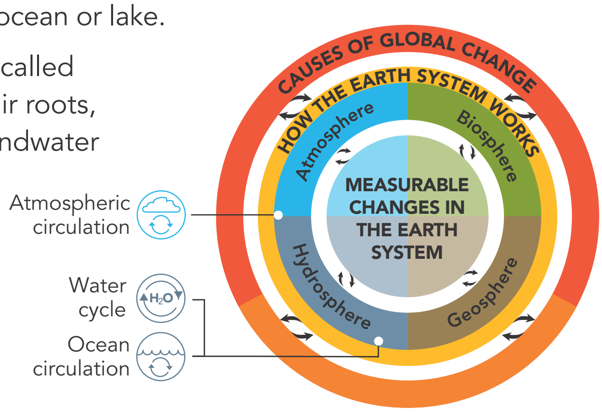
ANIMATION

hhmi | BioInteractive

Figure 4-9

The Water Cycle

This diagram shows the main processes involved in the water cycle. Scientists estimate that it can take a single water molecule as long as 4000 years to complete one cycle.



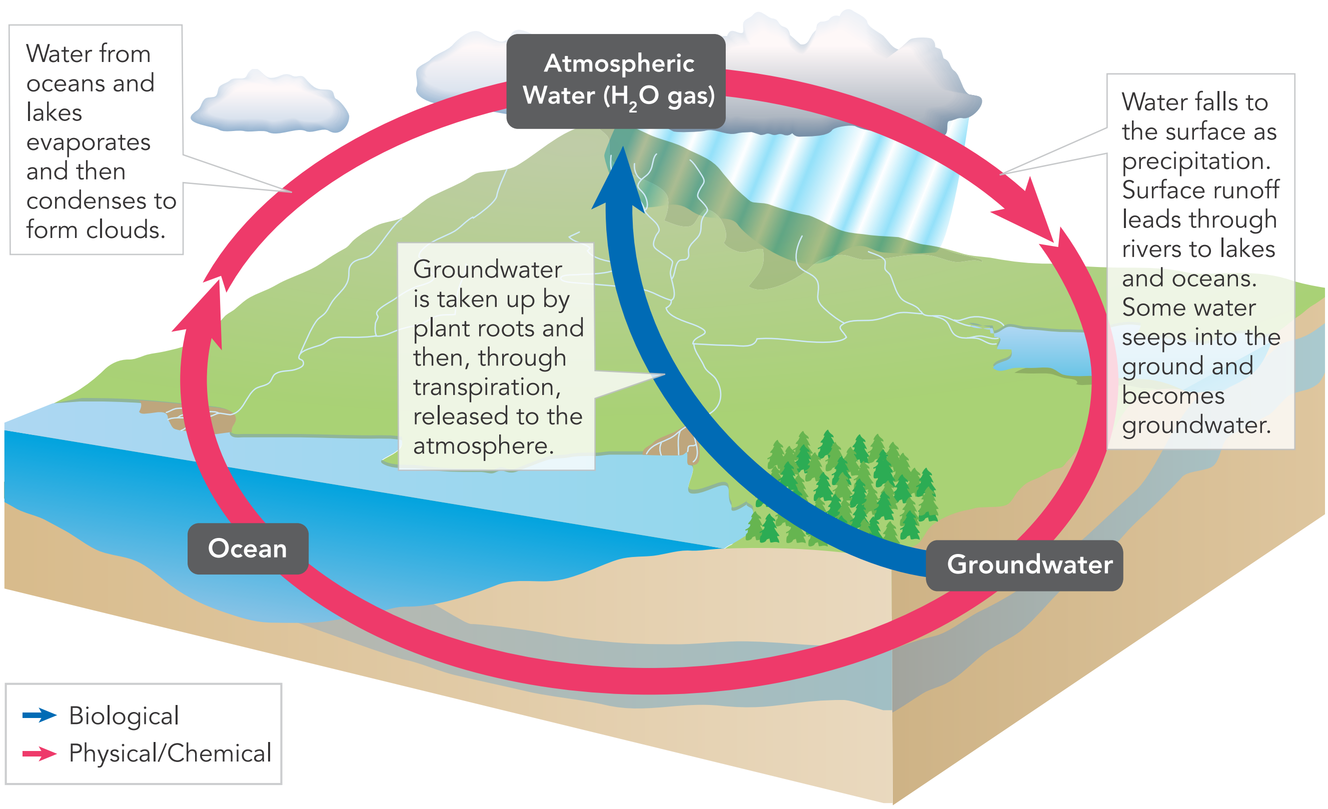


Figure 4-10

Rainforests Have Many Benefits

Rainforest trees return water to the atmosphere through transpiration. The trees also absorb excess carbon dioxide from the atmosphere.

INTERACTIVITY

Apply your engineering skills to design a wetland ecosystem.

READING TOOL

As you read about a process, locate it in the corresponding cycle diagrams to help you understand the text.

In the past, many people viewed the water cycle as a physical phenomenon that affects life but is itself little affected by life. But we now know that water cycles locally through the biosphere, and that rainfall patterns can be strongly affected by living organisms. For example, rainforest trees (**Figure 4-10**) return a great deal of water to the atmosphere through transpiration from their leaves. That moisture feeds heavy local rainstorms. Cutting down large tracts of rainforests can interrupt this cycle, and can cause long-lasting local climate change. As you will see in subsequent chapters, other human-caused changes in the biosphere may also affect the global water cycle.

READING CHECK **Interpret Visuals** What are the two primary ways that precipitation passes through the water cycle?

Nutrient Cycles

Nutrients are elements that an organism needs to sustain life. ***Every organism needs nutrients to build tissues and carry out life functions. Like water, nutrients pass through organisms and the environment through biogeochemical cycles. The cycles that carry carbon, nitrogen, and phosphorus through the biosphere are especially vital for life.***

Note that oxygen participates in parts of the carbon, nitrogen, and phosphorus cycles by combining with these elements and cycling with them through parts of their journeys. Oxygen gas in the atmosphere is released by one of the most important of all biological activities: photosynthesis. Oxygen is also used in cellular respiration by all multicellular forms of life, and many single-celled organisms.

The Carbon Cycle Carbon is a major component of organic compounds, including carbohydrates, lipids, proteins, and nucleic acids. In fact, carbon is such a key ingredient of living tissue that life on Earth is often described as "carbon-based life." Carbon in the form of calcium carbonate ($CaCO_3$) is an essential part of many different kinds of animal skeletons and is also found in several kinds of rocks. Other forms of carbon make up fossil fuels. Carbon and oxygen form carbon dioxide gas (CO_2), an important component of the atmosphere. Major reservoirs of carbon are located in all four global systems. The carbon cycle is shown in **Figure 4-11**.

Biological Processes Across the biosphere, plants and algae remove carbon dioxide from the atmosphere through photosynthesis, and return some carbon dioxide to the atmosphere through respiration. Primary producers use the carbon dioxide taken in during photosynthesis to build carbohydrates. Those carbohydrates pass from primary producers to heterotrophs, where they are used as energy sources or as part of the raw materials to build proteins, lipids, and nucleic acids.

When organisms die, decomposers usually break down their bodies, releasing carbon (and other nutrients). But sometimes, primary producers are buried before they decompose. Million of years ago, remains of many land plants were buried, and transformed, over time, into coal deposits. Similarly, buried remains of marine algae were transformed into oil or natural gas. Over geologic time, this process removed carbon from the atmosphere and stored it in the geosphere. That's why coal, oil, and natural gas are called fossil fuels. They are, in fact, "fossilized" organic carbon!

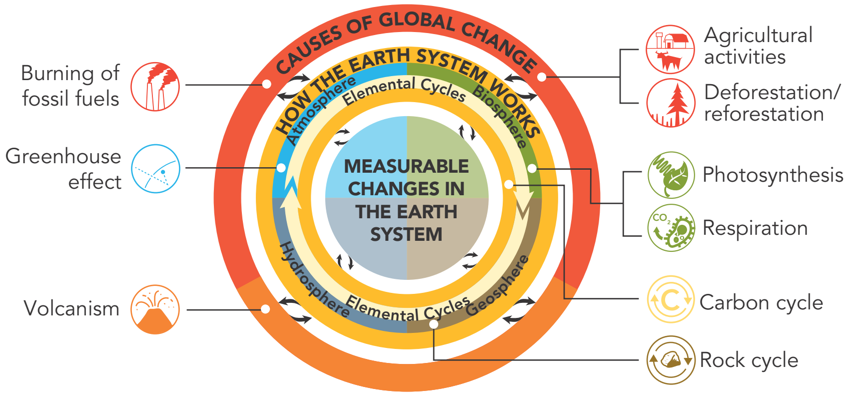
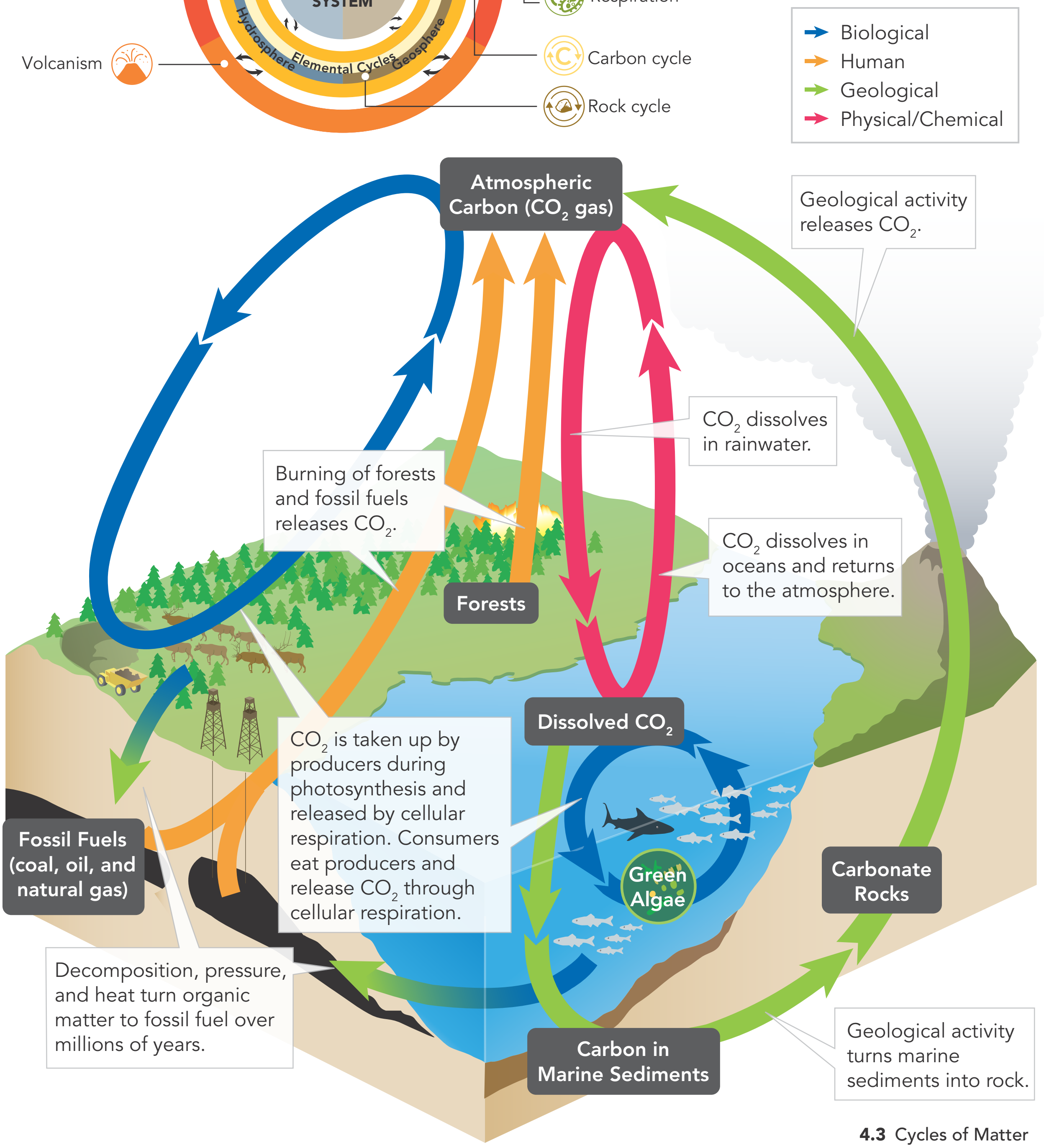


Figure 4-11

The Carbon Cycle

Carbon is found in several large reservoirs. In the atmosphere, it can be found as carbon dioxide gas (CO_2); in the hydrosphere, as dissolved carbon dioxide; in the geosphere, in rocks and soil, and underground, as coal and petroleum, and calcium carbonate; and in the biosphere as organic matter.



Amazingly, we can measure the effects of photosynthesis, respiration, and decomposition on the atmosphere! During our northern temperate zone summer, primary producers photosynthesize actively, removing carbon dioxide from the air. In winter, photosynthesis slows down, but respiration and decomposition continue, returning carbon dioxide to the air. These biological processes cause enough of a change in atmospheric carbon dioxide concentration to show up in measurements taken at a research station in Hawaii, as shown in **Figure 4-12**.

INTERACTIVITY

Examine the effects of human activities on the water, carbon, and nitrogen cycles.

Geological Processes Dissolved carbon dioxide in the oceans may combine with calcium and magnesium to form insoluble compounds called carbonates. These carbonates can accumulate on the ocean bottom and combine with skeletons of marine organisms to form vast deposits that harden into sedimentary rocks such as limestone and dolomite. In certain places, geological activity forces those rocks beneath the surface, so deeply that intense heat drives the carbon dioxide out in gaseous form. When volcanoes erupt, this underground carbon dioxide is released into the atmosphere.

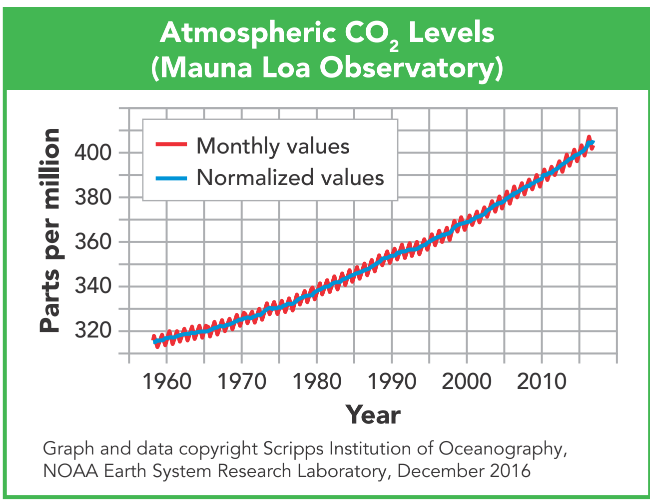
Chemical and Physical Processes Carbon dioxide is constantly exchanged between the atmosphere and oceans through chemical and physical processes. Carbon dioxide in the atmosphere can also dissolve in rainwater, forming a weak acid.

Human Activity When we extract coal, oil, and natural gas from the carbon reservoir in the geosphere and burn them, we return carbon that was removed and stored over millions of years to the atmosphere in a very short time. We also release carbon from the carbon reserve in the biosphere by clearing and burning forests. The change in atmospheric carbon dioxide levels is shown in **Figure 4-12**. The carbon released by human activity has a significant impact on the global carbon cycle. Our addition of carbon dioxide to the atmosphere is significantly adding to the greenhouse effect, raising average global temperature and driving climate change.

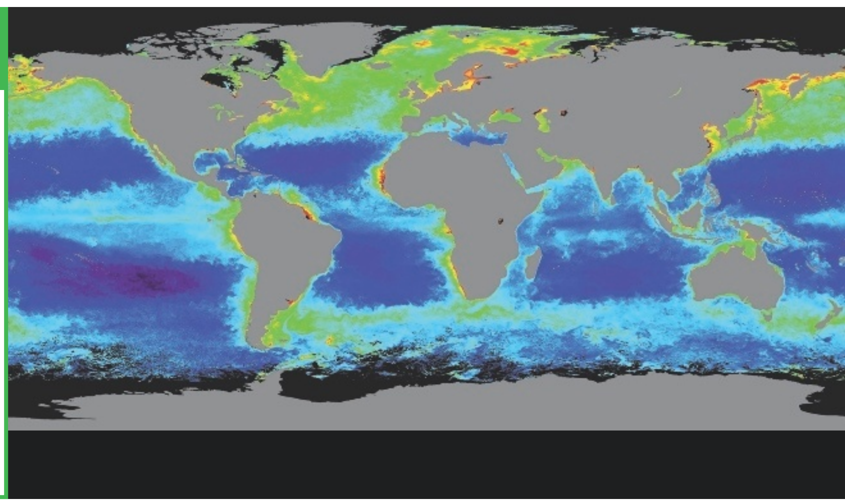
Figure 4-12

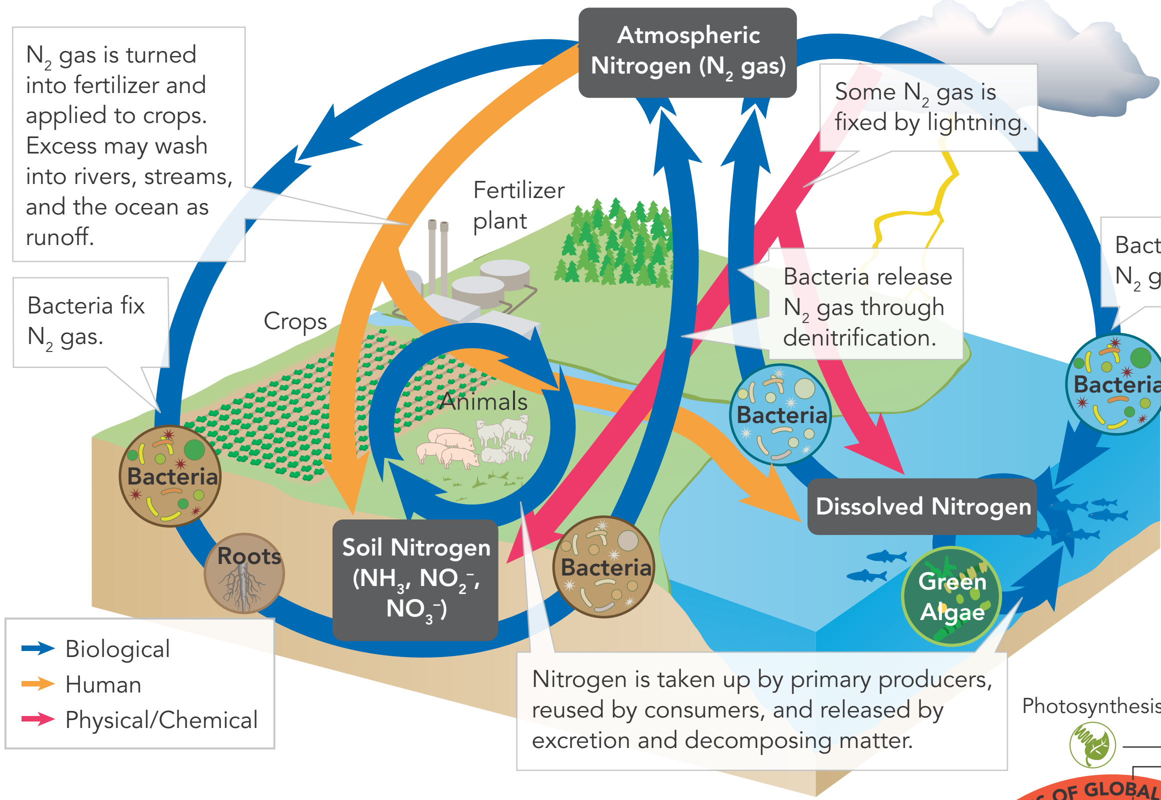
Atmospheric Carbon Dioxide Concentrations

The graph shows a steady increase in atmospheric CO_2 concentrations over the last several decades. Seasonal variations—the regular ups and downs in the graph—are due to variations in photosynthesis between summer and winter. The green regions of the satellite map (right) show areas of active photosynthesis in summer.



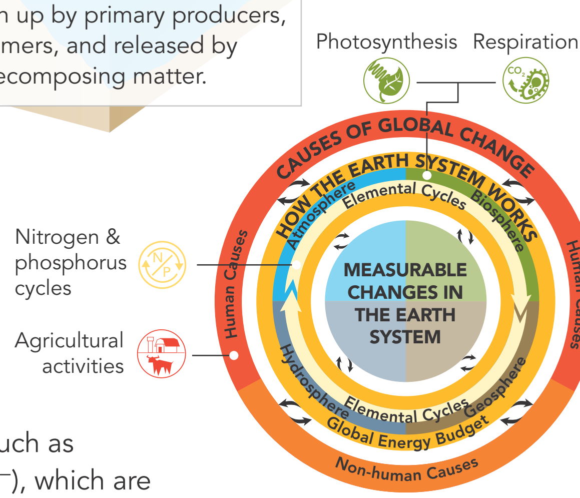
Graph and data copyright Scripps Institution of Oceanography, NOAA Earth System Research Laboratory, December 2016





The Nitrogen Cycle

The Nitrogen Cycle All organisms require nitrogen to make amino acids, which combine to form proteins, and nucleic acids such as DNA and RNA. Many different forms of nitrogen occur naturally. The largest reservoir of nitrogen is in the atmosphere, where nitrogen gas (N_2) makes up 78 percent of the air we breathe. Nitrogen reservoirs in the biosphere and geosphere include nitrogen-containing substances such as ammonia (NH_3), nitrate ions (NO_3^-), and nitrite ions (NO_2^-), which are found in soil, in wastes produced by many organisms, and in dead and decaying organic matter. There is also a large reservoir of dissolved nitrogen in the hydrosphere. **Figure 4-13** shows how different forms of nitrogen cycle through the biosphere.



CASE STUDY

Figure 4-13

The Nitrogen Cycle

The atmosphere is the largest reservoir of nitrogen. Nitrogen also cycles through the biosphere, geosphere, and hydrosphere.

Natural Processes Nitrogen gas is abundant, but most organisms can't use it. Among living organisms, only certain types of bacteria can convert nitrogen gas into ammonia, a process known as **nitrogen fixation**. Some nitrogen-fixing bacteria live in soil and on the roots of plants such as peanuts and peas. Lightning can fix small amounts of nitrogen in a process called atmospheric nitrogen fixation.

Other bacteria convert ammonia into nitrite and nitrate, which can be used by primary producers. When consumers eat producers, those nitrogen compounds are reused. The bacteria and fungi that act as decomposers are also vital parts of the nitrogen cycle. Decomposers release nitrogen compounds from animal wastes and dead organisms that producers may take up again. Some bacteria obtain energy by converting nitrates into nitrogen gas, which is released into the atmosphere in a process called **denitrification**.

CASE STUDY

Exploration Lab

Guided Inquiry

The Effect of Fertilizer on Algae

Problem How do excess nutrients affect the growth of algae?

In this lab, you will plan and carry out an investigation that tests the effects of fertilizer concentration on algae growth. You will select nutrient amounts and compare the growth of algae when nutrients are limited and when nutrients are abundant.

You can find this lab in your digital course.

Human Activities Humans have used various forms of organic matter as fertilizer for a long time. But our involvement in the nitrogen cycle skyrocketed in the early twentieth century after two Nobel Prize-winning German chemists developed an industrial process that could remove nitrogen gas from the atmosphere and transform it into forms that could be used in fertilizer. Today, the use of this process around the world enables humans to fix more nitrogen than all natural processes combined.

The Phosphorus Cycle Phosphorus is essential to life because it is part of molecules such as DNA and RNA. Unlike carbon, oxygen, and nitrogen, phosphorus does not cycle through the atmosphere. One reservoir of inorganic phosphorus is found in the geosphere in the form of phosphate rock and soil minerals. Another reservoir is located in the hydrosphere, in the form of dissolved phosphate and phosphate sediments in both freshwater and marine environments. The phosphorus cycle is shown in **Figure 4-14**.

Nutrient Limitation

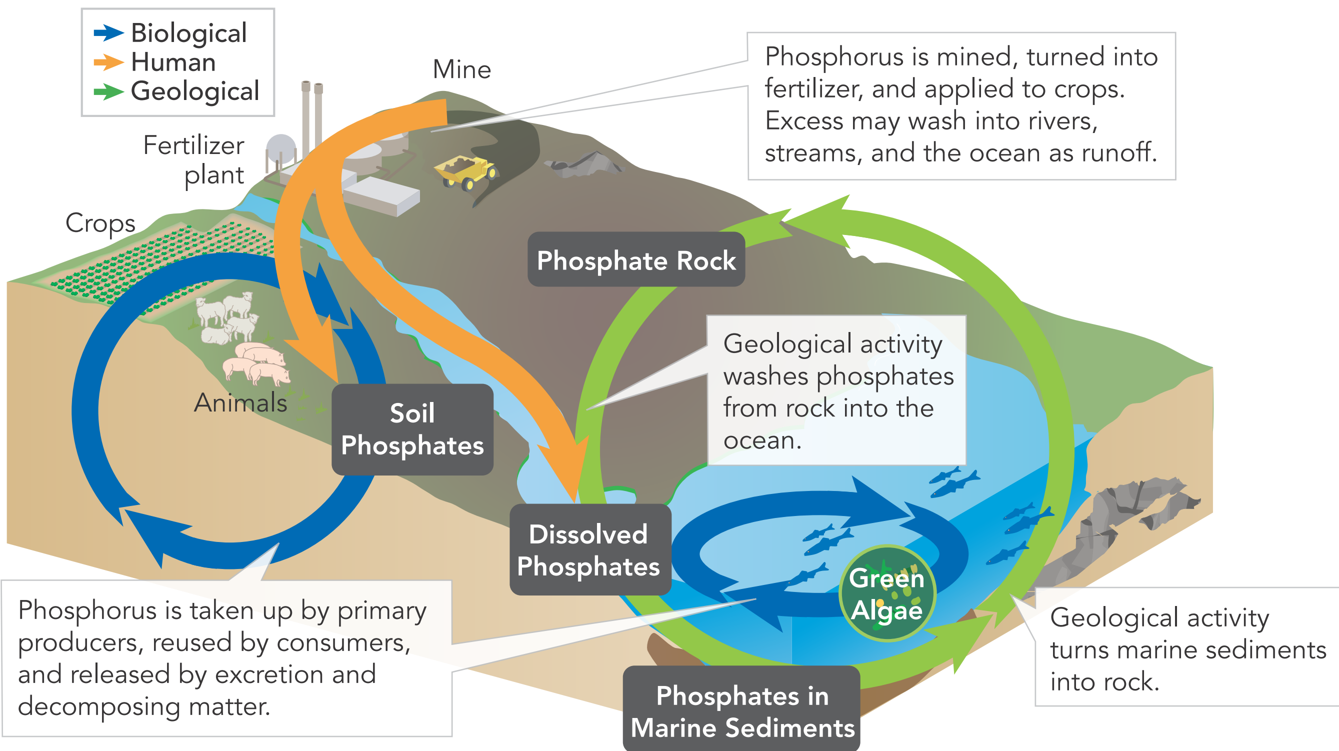
Ecologists are often interested in an ecosystem's primary productivity—the rate at which primary producers create new organic material. ***If ample sunlight and water are available, the primary productivity of an ecosystem may be limited by the availability of nutrients.*** If even a single essential nutrient is in short supply, primary productivity will be limited. All nutrient cycles work together like the gears in **Figure 4-15**. If any nutrient is in short supply—if any wheel "sticks"—the productivity of the entire food web can be limited. Any nutrient whose supply limits productivity is called a **limiting nutrient**.

CASE STUDY

Figure 4-14

The Phosphorus Cycle

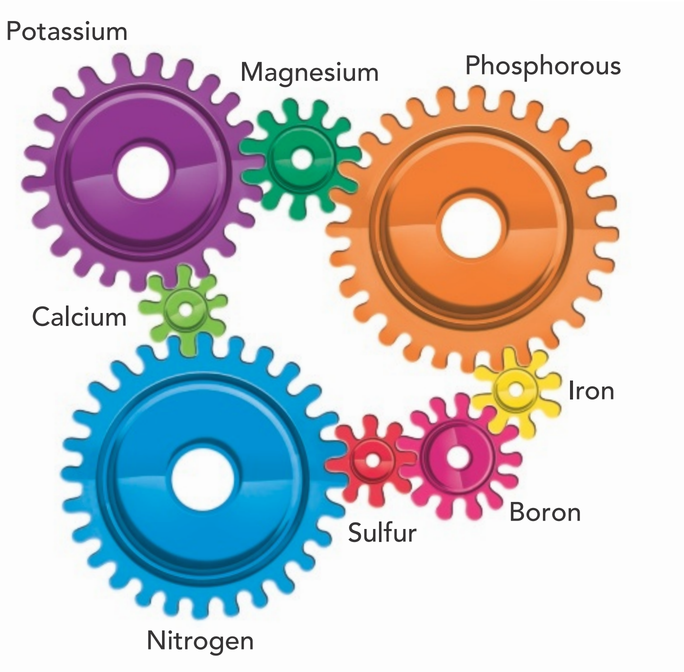
Phosphorus in the biosphere cycles among the land, ocean sediments, and living organisms.



Nutrient Limitation in Soil In all but the richest soil, plant growth can be limited by a short supply of one or more nutrients. Nutrient limitation is the reason farmers use fertilizers to maximize crop growth. Most fertilizers contain nitrogen, phosphorus, and potassium, all of which help plants grow better in poor soil. Micronutrients such as calcium, magnesium, sulfur, iron, and manganese are sometimes included in small amounts. Carbon is not included in fertilizers because plants absorb carbon dioxide from the atmosphere. Applying too much fertilizer to soil near streams and rivers, however, can disrupt natural nutrient cycles, with serious consequences.

Nutrient Limitation in Aquatic Ecosystems In the ocean, nitrogen is often the limiting nutrient. Seawater typically contains only 0.00005 percent nitrogen, or 1/10,000 of the amount often found in soil. In streams, lakes, and freshwater environments, on the other hand, phosphorus is often the limiting nutrient.

Sometimes, runoff from heavy rains carries large amounts of a limiting nutrient from heavily fertilized fields into aquatic ecosystems. This fertilizer runoff delivers abnormally high concentrations of limiting nutrients such as nitrogen and phosphorus into bodies of water. These nutrients stimulate primary producers such as algae to grow and reproduce far beyond their normal rates, causing what is called an algal bloom. Severe algal blooms can cover the water's surface and disrupt the functioning of an entire ecosystem. In the ocean, excess nitrogen is often the cause of an algal bloom. In freshwater environments, excess phosphorus is usually the cause.



Visual Analogy

Figure 4-15

Interlocking Nutrients

The movement of each nutrient through ecosystems depends on the movements of all the others, because all are needed for living systems to function.

HS-LS2-3, HS-LS2-4, HS-LS2-5, HS-ESS2-6

LESSON 4.3 Review

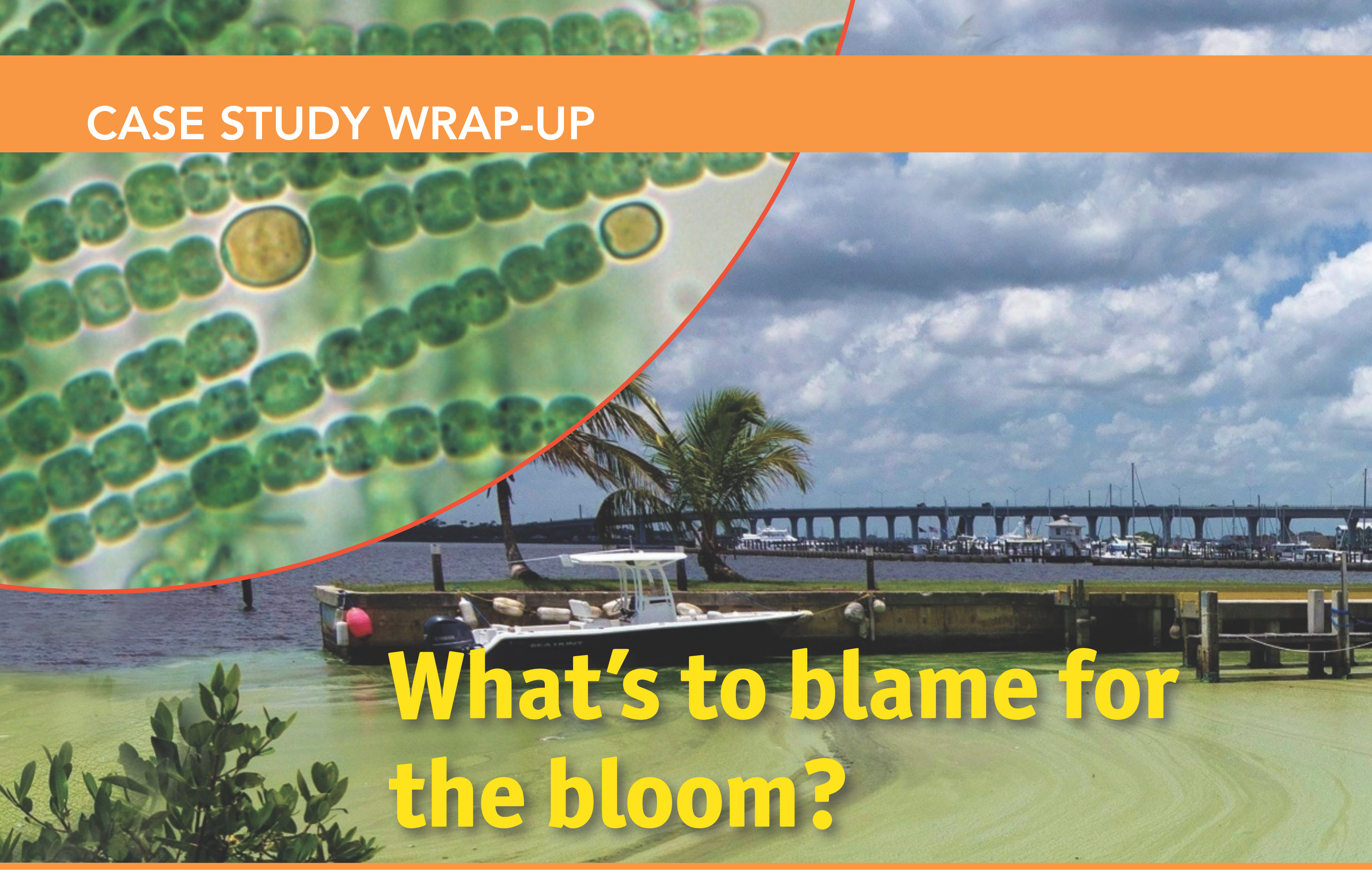
KEY QUESTIONS

1. How does the way that matter cycles through an ecosystem differ from the way that energy flows?
2. What two processes cycle water from the land to the atmosphere?
3. Why do living organisms need nutrients?
4. Explain how a nutrient can be a limiting factor in an ecosystem.

CRITICAL THINKING

5. **Analyze Data** Based on your knowledge of the carbon cycle and the graph in **Figure 4-12**, predict what will happen if humans continue to clear and burn vast areas of forests for farming.
6. **Construct an Explanation** Describe one way in which water from the ocean may make one complete cycle through the atmosphere and back to the ocean. Include the names of each process involved in your cycle.
7. **Develop Models** Although oxygen does not have an independent cycle, it moves through the biosphere as part of the carbon cycle. Develop a model to illustrate how oxygen fits into the carbon cycle. Include the various forms that oxygen takes in your model.
8. CASE STUDY Review the nitrogen and phosphorus cycles. How is fertilizer runoff related to algal blooms?

CASE STUDY WRAP-UP



What's to blame for the bloom?

Global change is causing rapidly-spreading, severe algal blooms.

HS-LS2-2, HS-LS4-5, HS-LS4-6

Make Your Case

You've learned that algal blooms can form when limiting nutrients are present, and that other environmental factors help drive rapid algal growth. Often, global climate change plays a major role. In 2016, winter rains in Florida were unusually heavy. And water in the eastern Pacific Ocean was unusually warm. But heavy rains and warmer water alone couldn't have caused blooms. What other factors were involved? In Florida, rains washed fertilizer containing both nitrogen and phosphorus into Lake Okeechobee. The lake reached flood stage, so that nutrient-rich water had to be diverted into rivers that flowed to both coasts, driving blooms in both freshwater and salt water. Might similar factors have fuelled the West Coast bloom?

Communicating Information

1. **Ask Questions** How could human activities have contributed to both blooms in different ways? Examine limiting factors for algal growth as you gather evidence to support your argument.
2. **Construct a Solution** What actions could be taken in Florida to help prevent the same situation from occurring again? Conduct research and cite evidence to support your solution. (**Hint:** Through what ecosystem did overflow from Lake Okeechobee pass before people changed the drainage pattern?)

Technology on the Case

Turning Waste Into a Solution

Thick, brown sludge. Clogged pipes. If you think that's a problem, you would be correct. But it turns out it can also be a solution.

Wastewater from homes, businesses, and even farms often ends up in wastewater treatment plants. These plants process wastewater so that the water can be returned safely to the environment. Wastewater contains much more than just water, including food, feces, dirt, soaps, and industrial chemicals.

One of the challenges of treating wastewater is removing the limiting nutrients, such as phosphorus and nitrogen. If the nutrients are not removed, they may end up in our lakes and streams. One way that scientists and engineers are working to make wastewater treatment plants more efficient at removing phosphorus is by harnessing a chemical called struvite. Struvite itself is a problem for wastewater treatment plants because it accumulates on the walls of pipes, eventually leading to clogged pipes. However, water treatment plants are now being designed to intentionally make struvite. Why? Because struvite can be used as a fertilizer.

Struvite crystals contain phosphorus, nitrogen, and magnesium. Producing and collecting struvite results in less phosphorus entering our waterways. In addition, selling struvite as a fertilizer allows the facilities to offset the costs of wastewater treatment. Another benefit of struvite is that the struvite crystals slowly release nitrogen and phosphate. This slow release decreases the runoff of limiting nutrients.

Careers on the Case

Work Toward a Solution

People in many careers help keep aquatic ecosystems healthy and the water safe for human use.

Water Quality Technician

Bodies of water can be fouled by living things, such as bacteria and algae. The water can also contain toxic elements or other harmful chemicals. The job of the water quality technician is to test water supplies to make sure they meet environmental standards.

VIDEO

Watch this video to learn about other careers in biology.

hhmi | BioInteractive

STUDY GUIDE

Lesson Review

Go to your Biology Foundations Workbook for longer versions of these lesson summaries.

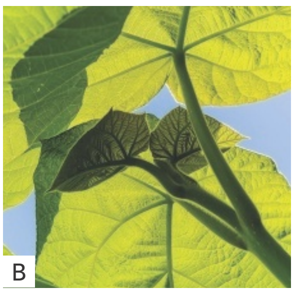
4.1 Energy, Producers, and Consumers

With few exceptions, energy for life ultimately comes from the sun. Primary producers are the first producers of energy-rich compounds that are later used by other organisms. Primary producers are also called autotrophs.

Organisms that rely on other organisms for energy and nutrients are called heterotrophs, or consumers. Consumers can be further classified according to the type of food they eat. Herbivores eat plants. Carnivores kill and eat other animals. Omnivores eat both plant and animal matter. Scavengers eat the carcasses of dead animals. Decomposers chemically break down organic matter, producing detritus. Detritivores eat detritus.

- autotroph
- primary producer
- photosynthesis
- chemosynthesis
- heterotroph
- consumer
- detritus


A


B


C


D

Identify Is each organism shown a producer, an herbivore, a carnivore, or a decomposer?

4.2 Energy Flow in Ecosystems

Energy flows through an ecosystem in a one-way stream, from primary producers to various consumers. A food chain is a series of steps in which organisms transfer energy by eating and being eaten. A food web is a network of complex feeding relationships in an ecosystem.

Ecological pyramids show the relative amount of energy or matter contained within each trophic level in a given food chain or food web. Pyramids of energy show the amount of energy available at each trophic level. Pyramids of biomass and numbers show the relative amounts of living organic matter and relative numbers of individual organisms, respectively, at each trophic level.

- food chain
- phytoplankton
- food web
- trophic level
- ecological pyramid
- biomass

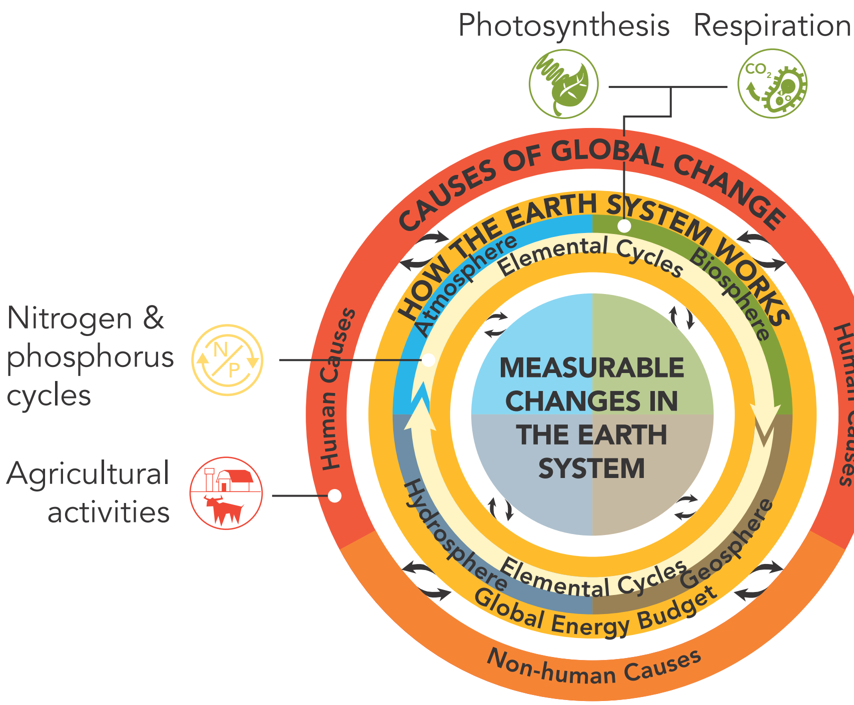
4.3 Cycles of Matter

Matter is recycled within and among ecosystems, unlike the one-way flow of energy. Matter cycles through organisms and the environment through biogeochemical cycles. The flow of matter can involve biological processes, geological processes, chemical and physical processes, and human activity. These global processes cycle matter through global systems.

Water cycles among the oceans, atmosphere, and land. The water cycle affects life and is affected by living organisms.

Every organism needs nutrients to survive. The carbon, nitrogen, and phosphorus cycles are especially important for life. The availability of nutrients can influence the long-term survival of organisms. If ample sunlight and water are available, the primary productivity of an ecosystem may still be limited by the availability of nutrients.

- biogeochemical cycle
- nutrient
- nitrogen fixation
- denitrification
- limiting nutrient



Evaluate Models Through which spheres does nitrogen cycle? Describe how photosynthesis, respiration, and agricultural activities influence the nitrogen cycle.

Organize Information

Cite evidence for each statement from the text, investigations, and other activities you have completed. Then, draw a model to support each statement.

Statement	Evidence	Model
Consumers are dependent on producers.	1.	2.
The amount of available energy is reduced at each successive trophic level.	3.	4.
Water cycles through ecosystems.	5.	6.

PERFORMANCE-BASED ASSESSMENT

Can Algal Blooms Be Useful?

Evaluate a Solution

HS-LS2-5, HS-ETS1-3, CCSS.ELA-LITERACY.RST.9-10.1

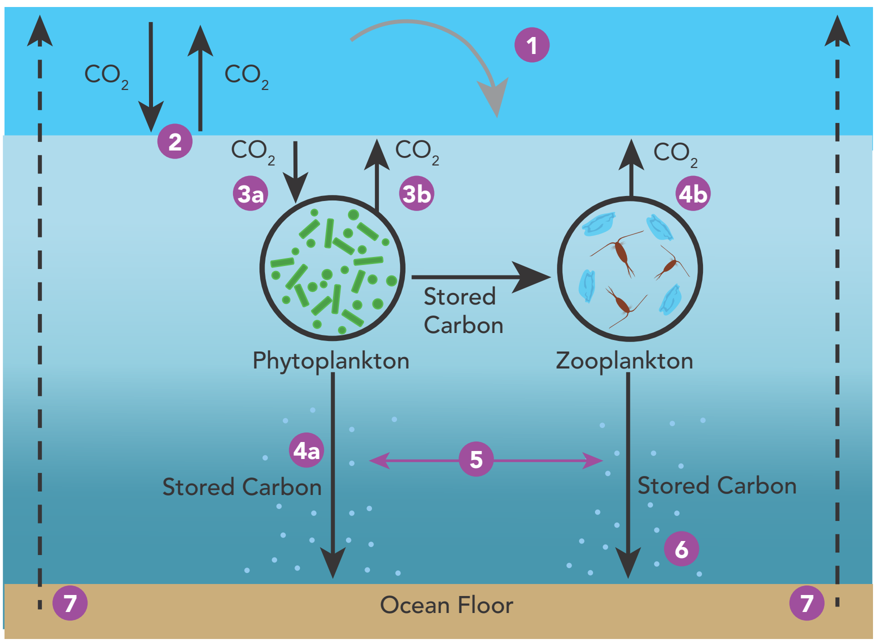
STEM A significant amount of primary production occurs in the sea, as marine algae take in carbon dioxide to build living tissue. Studies had shown that surface water in parts of the ocean contains high enough concentrations of nitrogen and phosphorus to support higher rates of primary production than naturally occur there. What's missing? A vital micronutrient: iron.

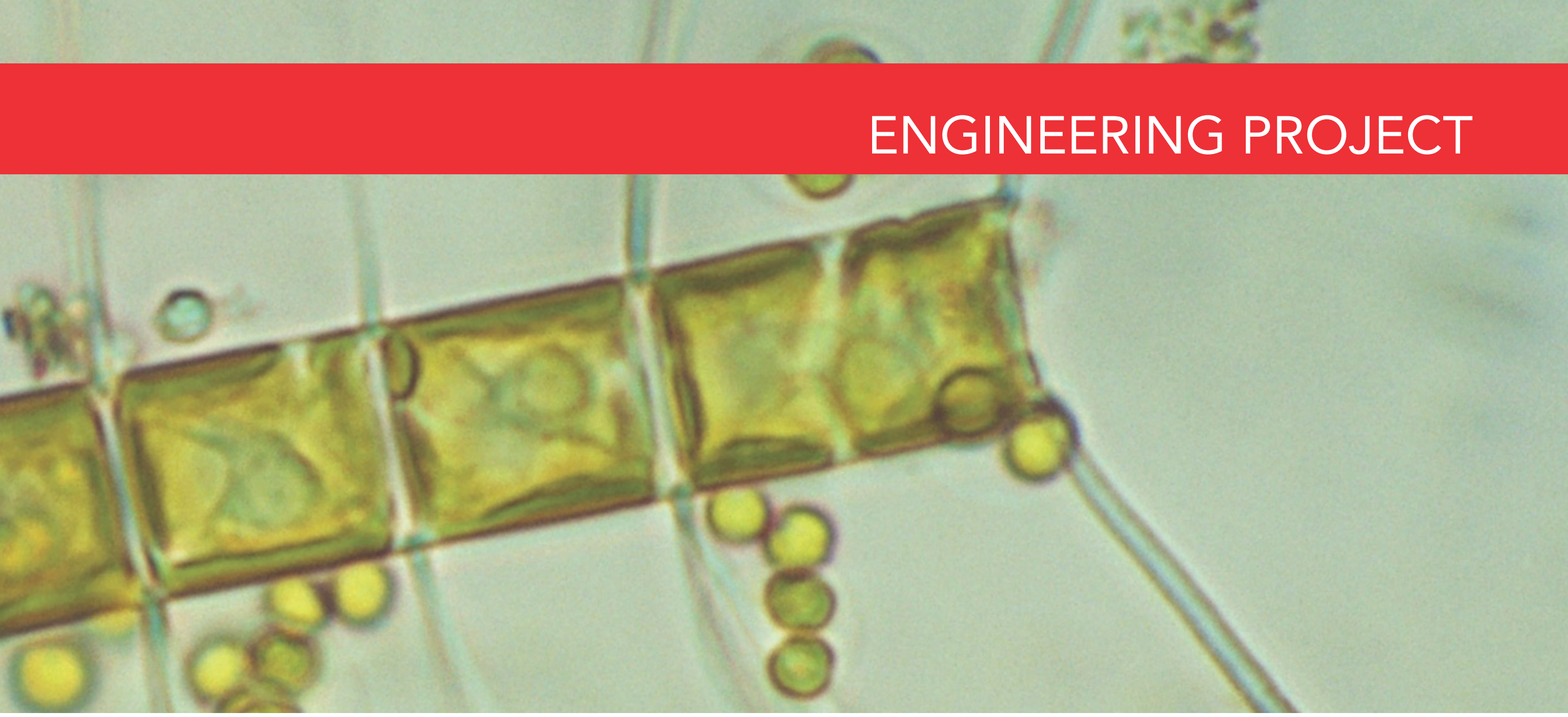
So it seemed reasonable, back in the 1990's, when scientists trying to avoid human-caused climate change proposed to stimulate algal growth by adding iron to the ocean. They hoped that this increased marine primary productivity would remove carbon dioxide from the atmosphere and store it at the bottom of the sea. Here is the system that researchers hypothesized (and hoped!) they could tweak, using iron fertilization, to accomplish that goal.

1 Iron, a micronutrient essential to algal growth, is added to parts of the ocean where the lack of iron limits phytoplankton growth.

2 Atmospheric CO_2 can dissolve in the ocean, or can be released from the ocean into the atmosphere, depending on its relative concentrations in air and water. When atmospheric carbon dioxide concentrations rise, or when dissolved CO_2 concentrations drop, more dissolves in the ocean.

3 Algae take up dissolved carbon dioxide during photosynthesis (3a). Some of this carbon is released when the algae respire (3b), and some is stored in cell structures.





Floating algae are important primary producers in the sea. Could they be useful in removing large amounts of excess carbon dioxide from the atmosphere? Or is the ocean's role in the carbon cycle more complicated than it appears?

4 Some algae are eaten by zooplankton and other consumers. These organisms store some of that carbon, and release some when they respire.

5 If algae die without being eaten, they may sink to the bottom of the ocean, taking captured carbon with them. Other organisms that also die and sink to the bottom, along with their solid wastes, also carry stored carbon with them.

6 If the remains of those organisms, along with solid wastes of consumers, are buried rapidly, this captured carbon can be stored on the ocean floor.

7 Dead organisms on and near the ocean floor could decompose, returning carbon to the sea, and, ultimately to the atmosphere.

1. **Develop Models** Using **Figure 4-11**, the Understanding Global Change model, and your own research, develop a model that focuses on carbon cycle pathways in the ocean. Be certain to include any step whose rate could affect where carbon ends up!

2. **Construct an Argument** Closely examine each step in your model to see which pathways store carbon, and which end up releasing it back into the atmosphere. What assumptions about the rate of processes in each step are necessary in order to hypothesize that iron fertilization would reduce atmospheric carbon dioxide concentrations?

3. **Conduct Research** In the years since ocean iron fertilization was proposed, researchers gathered data to test those assumptions and hypotheses. Search for information about those experiments. What is the current scientific consensus on whether or not ocean iron fertilization could help to limit climate change? Do current data support or reject the hypothesis that this solution would work? Why or why not?

4. **Communicate** Write an evaluation of the ocean iron fertilization solution to climate change. Support your argument with evidence from your research and the model you developed.

ASSESSMENT

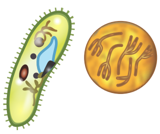
KEY QUESTIONS AND TERMS

4.1 Energy, Producers, and Consumers

HS-LS2-3

1. Primary producers are organisms that
   a. rely on other organisms for their energy and food supply.
   b. consume plant and animal remains and other dead matter.
   c. use energy they take in from the environment to convert inorganic molecules into complex organic molecules.
   d. obtain energy by eating only plants.
2. Which of the following organisms is a carnivore?

a. 

b. 

c. 

d. 

3. How are detritivores different from decomposers? Provide an example of each.
4. Classify each of the following as an herbivore, a carnivore, an omnivore, or a detritivore.
   a. an earthworm that eats the decaying remains of plants and animals
   b. a bear that feeds on plants and animals
   c. a cow that feeds only on plants
   d. a snail that feeds on plants, algae, and fungi
   e. an owl that feeds only on animals
   f. a human that feeds on plants and animals
5. What are the two basic processes in which energy from nonliving sources is captured and stored in molecules that can be used by living things? How are they similar? How are they different?

4.2 Energy Flow in Ecosystems

HS-LS2-4

6. The series of steps in which a large fish eats a small fish that has eaten algae is a
   a. food web.
   b. food chain.
   c. pyramid of numbers.
   d. pyramid of biomass.
7. The total amount of living tissue at each trophic level in an ecosystem can be shown in a(n)
   a. pyramid of energy.
   b. pyramid of numbers.
   c. pyramid of biomass.
   d. biogeochemical cycle.
8. Which group of organisms is always found at the base of a food chain or food web?
9. What ultimately happens to the bulk of matter in any trophic level of a pyramid of biomass—that is, the matter that does not get passed to the trophic level above?
10. Why is the transfer of energy in a food chain usually only about 10 percent efficient?
11. Describe the flow of energy in an ecosystem.

4.3 Cycles of Matter

HS-LS2-3, HS-LS2-4, HS-LS2-5, HS-ESS2-6

12. Which of the following is NOT true about matter in the biosphere?
    a. Matter is transferred in one direction through the biosphere.
    b. Biogeochemical cycles transform and reuse molecules.
    c. The total amount of matter decreases over time.
    d. Human activity does not affect the movement of matter.
13. Nutrients move through an ecosystem in
    a. biogeochemical cycles.
    b. water cycles.
    c. pyramids of energy.
    d. ecological pyramids.
14. Which biogeochemical cycle does NOT include a major path in which the substance cycles through the atmosphere?
15. List two ways in which water enters the atmosphere in the water cycle.
16. Describe three ways in which carbon is stored in the biosphere.
17. Explain the process of nitrogen fixation.
18. What is meant by "nutrient limitation"?
19. How do changes in nutrient levels affect the structure of aquatic food webs?
20. Construct a table with a row for each of the following cycles of matter (water, carbon, and nitrogen) and a column for each process (physical/chemical, biological, geological, and human). Fill in the table with examples of each process, using the text and figures in Lesson 4.3.

CRITICAL THINKING

HS-LS2-3, HS-LS2-4, HS-LS2-5

21. **Develop Models** Give an example of an ecological phenomenon that could be studied by modeling. Explain why modeling would be useful.

22. **Ask Questions** You live near a pond that you have observed for years. One year you notice the water is choked with a massive overgrowth of green algae. What are some of the questions you might have about this unusual growth?

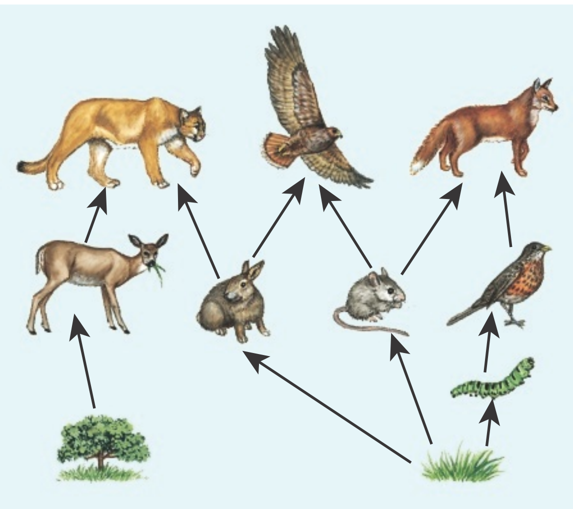
23. **Use Models** Study the food web shown.

a. Use the food web to identify and distinguish the producers and consumers.

b. Identify examples of decomposers that could be added to the food web. How are decomposers distinguished from producers and consumers?

c. Identify and draw two different food chains from the food web: one food chain that ends with a second-level consumer and one that ends with a third-level consumer.

d. Using the two food chains, compare the energy available to the second-level consumer with the energy available to the third-level consumer. Assume that the amount of energy supplied by producers is the same in all food chains.



24. **Form a Hypothesis** People who explore caves where there is running water but no sunlight often find them populated with unique types of fishes and insects. What testable hypothesis can you develop to explain the ultimate source of energy for these organisms?

25. **Analyze Text Structure** Using the text from Lessons 4.2 and 4.3, analyze the relationships among the key terms *food chain, food web, nutrient,* and *biogeochemical cycle.*

26. **Construct an Explanation** Why are normally unseen members of the food web, such as soil microorganisms, essential to the nitrogen cycle? Use a model to support your answer.

27. **Cite Evidence** Ecologists discovered that larger-than-normal numbers of trout were dying in a stream that ran through some farmland. A local scientist claimed nitrogen fertilizer that was used on the crops caused the deaths. Explain the types of evidence that would support the scientist's claim.

28. **Use Models** Using a flowchart, trace the flow of energy in a simple marine food chain. Then, show where nitrogen is cycled through the chain when the top-level carnivore dies and is decomposed.

29. **Construct an Explanation** Explain the role of photosynthesis in the carbon cycle.

30. **Evaluate a Solution** Phosphate detergents are effective for cleaning laundry and dirty dishes. However, these phosphorus-laden products have been banned in Australia, the European Union, Canada, and some states in the United States. Why do you think the detergents were banned? How might you evaluate the effectiveness of this solution?

31. **Construct an Explanation** Explain why available energy is reduced as energy transfers through the trophic levels of an ecosystem.

CHAPTER 4

ASSESSMENT

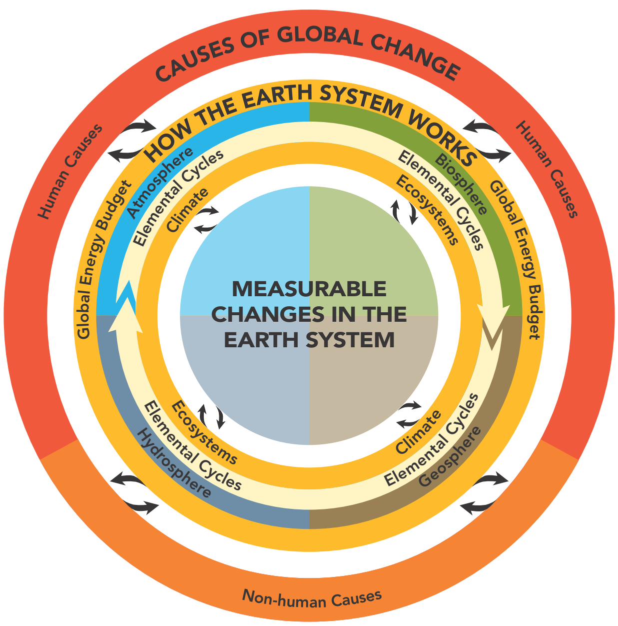
CROSSCUTTING CONCEPTS

32. **Energy and Matter** The cycling of matter is dependent on the flow of energy. Using the carbon cycle, explain how this flow of energy drives the cycling of carbon through the environment.

33. **Systems and System Models** Think about the connections and interactions among processes and phenomena in the Understanding Global Change model.

    a. Select at least one topic from each of the three categories in the Understanding Global Change model (Causes of Global Change, How the Earth System Works, and Measurable Changes in the Earth System) and explain if and how these processes or phenomena are related.

    b. For each of your chosen topics, use words and arrows to describe how these phenomena or processes are related to three additional concepts discussed in Chapter 4.



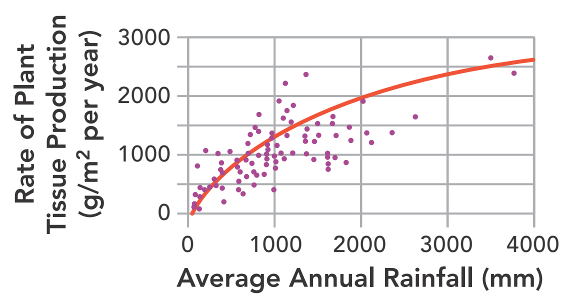
MATH CONNECTIONS

Analyze and Interpret Data

CCSS.MATH.CONTENT.HSN.Q.A.1

The graph below shows the effect of annual rainfall on the rate of primary productivity in an ecosystem. Use this graph to answer questions 34–36.

The Effect of Rainfall on Plant Productivity



34. **Analyze Data** What happens to productivity as rainfall increases?

35. **Construct Graphs** What do you think the graph would look like if the x-axis were extended out to 6000 mm? Represent your prediction in a graph and explain your answer.

36. **Draw Conclusions** What factors other than water might affect primary productivity?

LANGUAGE ARTS CONNECTIONS

Write About Science

CCSS-ELA-LITERACY.WHST.9-10.2

37. **Conduct Research Projects** Sustainable agriculture is a method of growing and raising food by taking advantage of natural biogeochemical cycles without disrupting them. Write down a question you have about sustainable agriculture and conduct a research project to answer your question. Use multiple sources to gather your information.

Read About Science

CCSS-ELA-LITERACY.RST.9-10.1

38. **Cite Textual Evidence** Describe how biogeochemical cycles provide organisms with the raw materials necessary to synthesize complex organic compounds. Cite textual evidence from Chapter 2 to support your response.

CHAPTER 4

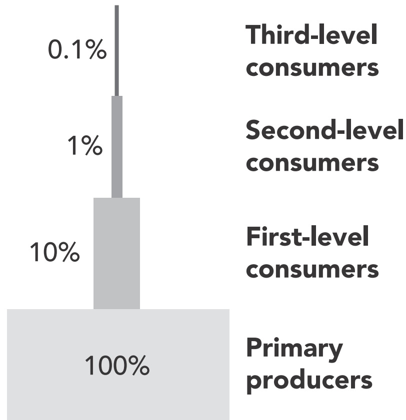
END-OF-COURSE TEST PRACTICE

1. A carnivore obtains energy by eating other animals. Which of the following shows the process by which energy flows to a carnivorous animal?
   A. light energy → plant → carnivore
   B. plant → light energy → carnivore
   C. light energy → herbivore → carnivore
   D. light energy → plant → herbivore → carnivore
   E. light energy → plant → decomposer → herbivore → carnivore

2. The diagram is a pyramid of biomass for a meadow ecosystem. The triangular shape of the diagram is useful for explaining which relationship among the trophic levels in this ecosystem?

   A. The amount of living organic matter is equal at all trophic levels in this ecosystem.
   B. Third-level consumers in this ecosystem have the greatest amount of living organic matter.
   C. With each step to a higher trophic level in this ecosystem, the amount of living organic matter increases.
   D. Third-level consumers in this ecosystem provide living organic matter to producers and other consumers.
   E. The amount of living organic matter decreases at each trophic level in this ecosystem.

3. The ecological pyramid models energy flow in a particular ecosystem.



   If the primary producers produce 5000 energy units, about how much of this energy is available to the secondary consumers?
   A. 5 energy units
   B. 50 energy units
   C. 1000 energy units
   D. 5000 energy units
   E. 5,000,000 energy units

4. Which of the following explains the role of plants in the carbon cycle?
   A. Plants transfer carbon in the atmosphere to carbohydrates in the biosphere.
   B. Plants transport carbon dioxide in the atmosphere to groundwater.
   C. Plants transfer oxygen and carbon in the biosphere to carbon dioxide in the atmosphere.
   D. Plants transfer oxygen in the atmosphere to fossil fuels.
   E. Plants transfer carbon in the groundwater to carbohydrates in the biosphere.

ASSESSMENT

For additional assessment practice, go online to access your digital course.

If You Have Trouble With...				
Question	1	2	3	4
See Lesson	4.1	4.2	4.2	4.3
Performance Expectation	HS-LS2-3	HS-LS2-4	HS-LS2-4	HS-LS2-5