Chapter 15 Principles of Ecology

Chapter Outline

15.1 The Science of Ecology
15.2 Flow of Energy
15.3 Recycling Matter
15.4 References

15.1 The Science of Ecology

Lesson Objectives

- State what ecologists study, and identify levels of organization in ecology.
- Define ecosystem, niche, and habitat, and explain how the concepts are related.
- Describe methods of ecology, such as field studies, sampling, statistical analysis, and modeling.

Ecology is the scientific study of the interactions of living things with each other and their relationships with the environment. Ecology is usually considered to be a major branch of biology. However, ecology has a more broad scope, because it includes both organisms and their environments. Examining the interactions between organisms and the environment can provide a basic understanding of the richness of life on earth and can help us understand how to protect that richness, which is increasingly threatened by human activity. Regardless of the challenges associated with conducting research in natural environments, ecologists often carry out field experiments to test their hypotheses.

Organisms and the Environment

Ecology is guided by a number of basic principles. One principle is that each living organism has a continual relationship with every other element in its environment. In this context, the environment includes both living and nonliving components.

Organisms

An **organism** is a life form consisting of one or more cells. All organisms have properties of life, including the ability to grow and reproduce. These properties of life require energy and materials from the environment. Therefore, an organism is not a closed system. Individual organisms depend on and are influenced by the environment.

The Environment

To the ecologist, the **environment** of an organism includes both physical aspects and other organisms. These two components of the environment are called abiotic and biotic components, respectively.

- **Abiotic components**, or abiotic factors, are the non-living physical aspects of the environment. Examples include sunlight, soil, temperature, wind, water, and air.
- **Biotic components**, or biotic factors, are the living organisms in the environment. They include organisms of the same and different species.

Biotic components can be very important environmental influences on organisms. For example, the first photosynthetic life forms on Earth produced oxygen, which led to the development of an oxygen-rich atmosphere. This change in Earth's atmosphere, in turn, caused the extinction of many life forms for which oxygen was toxic and the evolution of many other life forms for which oxygen was necessary.

Levels of Organization

Ecologists study organisms and their environments at different levels. The most inclusive level is the biosphere. The **biosphere** consists of all the organisms on planet Earth and the areas where they live. It occurs in a very thin layer of the planet, extending from about 11,000 meters below sea level to 15,000 meters above sea level. An image of the biosphere is shown in **Figure** 15.1. Different colors on the map indicate the numbers of food-producing organisms in different parts of the biosphere. Ecological issues that might be investigated at the biosphere level include ocean pollution, air pollution, and global climate change.

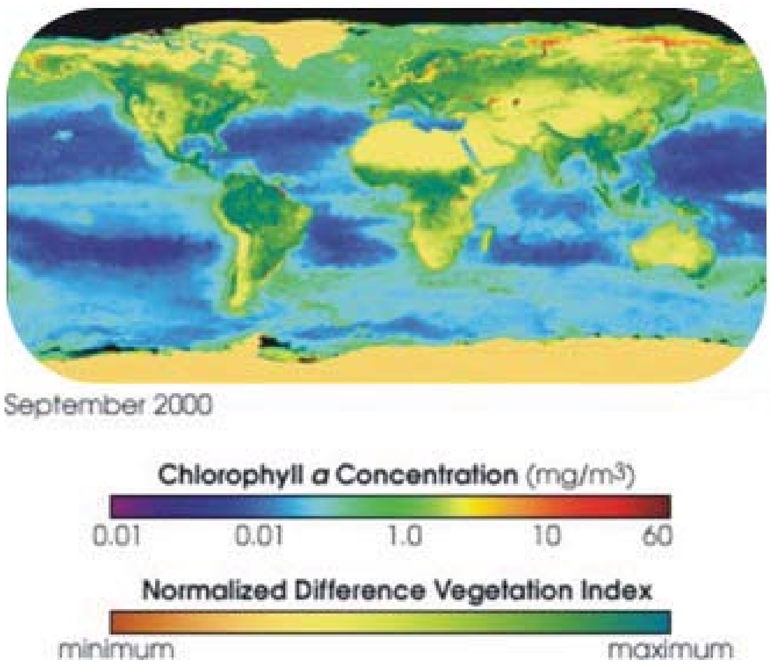

FIGURE 15.1

This image of Earth's surface shows the density of the chief life forms that produce food for other organisms in the biosphere. Plants are the chief food producers on land, and phytoplankton are the chief food producers in the ocean. The map shows the density of plants with a measure called the normalized difference vegetation index and the density of phytoplankton with the chlorophyll concentration.

Ecologists also study organisms and their environments at the population level. A **population** consists of organisms of the same species that live in the same area and interact with one another. You will read more about populations in the *Populations* chapter. Important ecological issues at the population level include:

- rapid growth of the human population, which has led to overpopulation and environmental damage;
- rapid decline in populations of many nonhuman species, which has led to the extinction of numerous species.

Another level at which ecologists study organisms and their environments is the community level. A **community** consists of populations of different species that live in the same area and interact with one another. For example, populations of coyotes and rabbits might interact in a grassland community. Coyotes hunt down and eat rabbits for food, so the two species have a predator-prey relationship. Ecological issues at the community level include how changes in the size of one population affect other populations. The *Populations* chapter discusses population interactions in communities in detail.

Ecosystem

A community can also be defined as the biotic component of an ecosystem. An **ecosystem** is a natural unit consisting of all the living organisms in an area functioning together with all the nonliving physical factors of the environment. The concept of an ecosystem can apply to units of different sizes. For example, a large body of fresh water could be considered an ecosystem, and so could a small piece of dead wood. Both contain a community of species that interact with one another and with the abiotic components of their environment. Another example of an ecosystem is a desert, like the one shown in **Figure** 15.2.

FIGURE 15.2
This desert ecosystem in southern California has fewer species than most other types of ecosystems, but it is still home to a community of interacting species (such as the cacti and grasses shown here) and potent environmental factors such as extreme heat and dryness.

Like most natural systems, ecosystems are not closed, at least not in terms of energy. Ecosystems depend on continuous inputs of energy from outside the system. Most ecosystems obtain energy from sunlight. Some obtain energy from chemical compounds. In Lesson 2, you will read how energy is transferred in ecosystems. In contrast to energy, matter is recycled in ecosystems. Elements such as carbon and nitrogen, which are needed by living organisms, are used over and over again. You will read how elements and water are recycled through ecosystems in Lesson 3.

Niche

One of the most important ideas associated with ecosystems is the niche concept. A **niche** refers to the role of a species in its ecosystem. It includes all the ways species' members interact with the abiotic and biotic components of the ecosystem.

Two important aspects of a species' niche include the food it eats and how it obtains the food. **Figure** 15.3 shows pictures of birds that occupy different niches. The various species eat different types of food and obtain the food in different ways. Notice how each species has evolved a beak that suits it for these aspects of its niche.

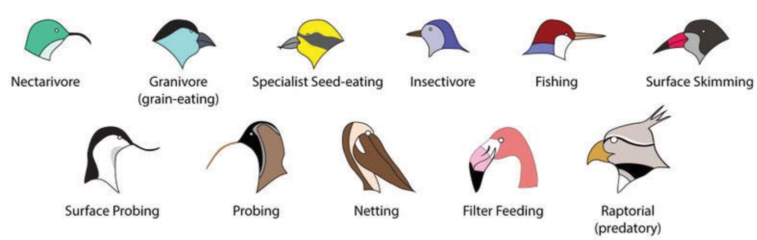

FIGURE 15.3
Each of these 11 species of birds has a distinctive beak that suits it for its particular niche. For example, the long slender beak of the Nectarivore allows it to sip nectar from flowers, and the short sturdy beak of the Granivore allows it to crush hard, tough grains.

Habitat

Another aspect of a species' niche is its habitat. A species' **habitat** is the physical environment to which it has become adapted and in which it can survive. A habitat is generally described in terms of abiotic factors, such as the average amount of sunlight received each day, the range of annual temperatures, and average yearly rainfall. These and other factors in a habitat determine many of the traits of the organisms that can survive there.

Consider a habitat with very low temperatures. Mammals that live in the habitat must have insulation to help them stay warm. Otherwise, their body temperature will drop to a level that is too low for survival. Species that live in these habitats have evolved fur, blubber, and other traits that provide insulation in order for them to survive in the cold.

Human destruction of habitats is the major factor causing other species to decrease and become endangered or go extinct. Small habitats can support only small populations of organisms. Small populations are more susceptible to being wiped out by catastrophic events from which a large population could bounce back. Habitat destruction caused the extinction of the dusky seaside sparrow shown in **Figure** 15.4. Many other bird species are currently declining worldwide. More than 1,200 species face extinction during the next century due mostly to habitat loss and climate change.

FIGURE 15.4
The dusky seaside sparrow, which used to live in marshy areas of southern Florida, was declared extinct in 1990.

Competitive Exclusion Principle

A given habitat may contain many different species, each occupying a different niche. However, two different species cannot occupy the same niche in the same geographic area for very long. This is known as the **competitive exclusion principle**. It is another basic principle of ecology. If two species were to occupy the same niche, they would compete with one another for the same food and other resources in the environment. Eventually, one species would outcompete and replace the other.

Humans often introduce new species into areas where their niches are already occupied by native species. This may occur intentionally or by accident. Consider the example of kudzu. Kudzu is a Japanese vine that was introduced intentionally to the southeastern United States in the 1870s to help control soil erosion. The southeastern United States turned out to be a perfect habitat for kudzu, because it has no natural enemies there. As a result, kudzu was able to outcompete native species of vines and take over their niches. The extent to which kudzu has invaded some habitats in the southeastern United States is shown in **Figure** 15.5.

FIGURE 15.5
Kudzu covers the trees in this habitat near Atlanta, Georgia, in the southeastern United States. Native species of vines cannot compete with kudzu's thriving growth and lack of natural enemies.

Methods of Ecology

Ecology is more holistic, or all-encompassing, than some other fields of biology. Ecologists study both biotic and abiotic factors and how they interact. Therefore, ecologists often use methods and data from other areas of science, such as geology, geography, climatology, chemistry, and physics. In addition, researchers in ecology are more likely than researchers in some other sciences to use field studies to collect data.

Field Studies

Ecological research often includes field studies because ecologists generally are interested in the natural world. **Field studies** involve the collection of data in real-world settings, rather than in controlled laboratory settings. The general aim of field studies is to collect observations in wild populations without impacting the environment or its organisms in any way.

Ecologists commonly undertake field studies to determine the numbers of organisms of particular species in a given geographic area. Such studies are useful for a variety of purposes. For example, the data might help an ecologist decide whether a given species is in danger of extinction.

Sampling

In field studies, it usually is not possible to investigate all the organisms in an area. Therefore, some type of sampling scheme is generally necessary. For example, assume an ecologist wants to find the number of insects of a particular species in a given area. There may be thousands of members of the species in the area. So, for practical reasons, the ecologist might count only a sample of the insects. In order to select the sample, the ecologist could divide the entire area into a grid of one-meter-square test plots. Then the ecologist might systematically select every tenth (or other numbered) test plot and count all the insects in the plot.

Statistical Analysis

Like other scientists, ecologists may use two different types of statistical analysis to interpret the data they collect: descriptive statistics and inferential statistics. **Descriptive statistics** are used to describe data. For example, the ecologist studying insects might calculate the mean number of insects per test plot and find that it is 24. This descriptive statistic summarizes the counts from all the test plots in a single number. Other descriptive statistics, such as the range, describe variation in data. The **range** is the difference between the highest and lowest values in a sample. In the same example, if the numbers of insects per test plot ranged from 2 to 102, the range would be 100.

Scientists often want to make inferences about a population based on data from a sample. For example, the ecologist counting insects might want to estimate the number of insects in the entire area based on data for the test plots sampled. Drawing inferences about a population from a sample requires the use of inferential statistics. **Inferential statistics** can be used to determine the chances that a sample truly represents the population from which it was drawn. It tells the investigator how much confidence can be placed in inferences about the population that are based on the sample.

Modeling

Ecologists, like other scientists, often use models to help understand complex phenomena. Ecological systems are often modeled using computer simulations. Computer simulations can incorporate many different variables and their interactions. This is one reason they are useful for modeling ecological systems. Computer simulations are also working models, so they can show what may happen in a system over time. Simulations can be used to refine models, test hypotheses, and make predictions. For example, simulations of global warming have been used to make predictions about future climates.

Lesson Summary

- Ecology is the scientific study of living things and their relationships with the environment. Levels of organization in ecology include the biosphere, population, community, and ecosystem.
- An ecosystem is a natural unit consisting of all the living organisms in an area functioning together with all the non-living physical factors of the environment. Each species has a unique role in an ecosystem, called its niche. The physical environment where a species lives is its habitat.
- Ecologists use field studies and sampling schemes to gather data in natural environments. Like other scientists, ecologists use statistics to describe and make inferences from data. They also use computer simulations to model complex phenomena.

Review Questions

1. Define abiotic and biotic components of the environment.
2. What does the biosphere consist of?
3. How do ecologists define an ecosystem?
4. What does the competitive exclusion principle state?
5. Assume an ecologist is studying interactions among different species in an ecosystem. What level of organization should the ecologist study? Why?
6. Why are field studies and computer simulations important methods of investigation in ecology?
7. Compare and contrast the ecosystem concepts of niche and habitat.

Further Reading / Supplemental Links

- Desonie, Dana, Biosphere: *Ecosystems and Biodiversity Loss.* Chelsea House Publications, 2007.
- Novacek, Michael, Terra: *Our 100-Million-Year-Old Ecosystem and the Threats That Now Put It at Risk.* Farrar, Straus, and Giroux, 2007.
- http://estrellamountain.edu/faculty/farabee/biobk/BioBookcommecosys.html
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- http://www.science.doe.gov/ober/CCRD/model.html
- http://www.dmoz.org/Science/Biology/Ecology/
- http://www.enviroliteracy.org/category.php/3.html
- http://www.sciencedaily.com/news/earth_climate/ecosystems/
- http://www.topix.net/science/ecology
- http://en.wikipedia.org

Vocabulary

abiotic components
The non-living physical aspects of the environment; includes sunlight, soil, temperature, wind, water, and air; also known as abiotic factors.

biosphere
The areas of Earth where all organisms live; extends from about 11,000 meters below sea level to 15,000 meters above sea level.

biotic components
The living organisms in the environment; also known as biotic factors.

community
Populations of different species that live in the same area and interact with one another.

competitive exclusion principle
States that two different species cannot occupy the same niche in the same geographic area for very long.

descriptive statistics
Statistical analysis used to describe data.

ecology
The scientific study of the interactions of living things with each other and their relationships with the environment.

ecosystem
A natural unit consisting of all the living organisms in an area functioning together with all the nonliving physical factors of the environment.

field studies
Studies that involve the collection of data in real-world settings, rather than in controlled laboratory settings; allows observations of wild populations without impacting the environment or its organisms in any way.

habitat
The physical environment to which an organism has become adapted and in which it can survive.

inferential statistics
Statistical analysis that draws inferences about a population from a sample; used to determine the chances that a sample truly represents the population from which it was drawn.

niche
The role of a species in its ecosystem; includes all the ways species' members interact with the abiotic and biotic components of the ecosystem.

organism
A life form consisting of one or more cells.

population
Organisms of the same species that live in the same area and interact with one another.

range
Statistic used to describe the difference between the highest and lowest values in a sample.

Points to Consider

An ecosystem needs continuous inputs of energy in order for its organisms to survive. In most ecosystems, this energy comes from sunlight.

- Which organisms in an ecosystem capture the energy from sunlight? How do they transform the energy so that other organisms in the ecosystem can use it? Why is the energy that enters an ecosystem eventually used up?

15.2 Flow of Energy

Lesson Objectives

- Describe how autotrophs use energy to produce organic molecules.
- Identify different types of consumers, and give examples of each type.
- Explain how decomposers resupply elements to producers.
- Describe food chains and food webs, and explain how energy is transferred between their trophic levels.

Introduction

Energy enters most ecosystems from sunlight. However, some ecosystems, such as hydrothermal vent ecosystems at the bottom of the ocean, receive no sunlight and obtain energy instead from chemical compounds. Energy is used by some organisms in the ecosystem to make food. These organisms are called primary producers, or autotrophs, which include small plants, algae, photosynthetic prokaryotes and chemosynthetic prokaryotes. From primary producers, energy eventually is transferred to all the other organisms in the ecosystem through consumers or decomposers known as heterotrophs.

Producers

Producers are organisms that produce organic compounds from energy and simple inorganic molecules. Producers are also called **autotrophs**, which literally means "self nutrition." This is because producers synthesize food for themselves. They take energy and materials from the abiotic environment and use them to make organic molecules. Autotrophs are a vital part of all ecosystems. The stability of the producers is vital to the survival of every ecosystem; without this stability an ecosystem may not thrive; in fact, the ecosystem may collapse. The organic molecules the producers make are needed by all the organisms in the ecosystem. There are two basic types of autotrophs: photoautotrophs and chemoautotrophs. They differ in the type of energy they use to synthesize food.

Photoautotrophs

Photoautotrophs are organisms that use energy from sunlight to make food by photosynthesis. As you may recall from the *Photosynthesis* Chapter, **photosynthesis** is the process by which carbon dioxide and water are converted to glucose and oxygen, using sunlight for energy. Glucose, a carbohydrate, is an organic compound that can be used by autotrophs and other organisms for energy. As shown in **Figure** 15.6, photoautotrophs include plants, algae, and certain bacteria.

Plants are the most important photoautotrophs in land-based, or terrestrial, ecosystems. There is great variation in the plant kingdom. Plants include organisms as different as trees, grasses, mosses, and ferns. Nonetheless, all plants are eukaryotes that contain chloroplasts, the cellular "machinery" needed for photosynthesis.

Algae are photoautotrophs found in most ecosystems, but they generally are more important in water-based, or

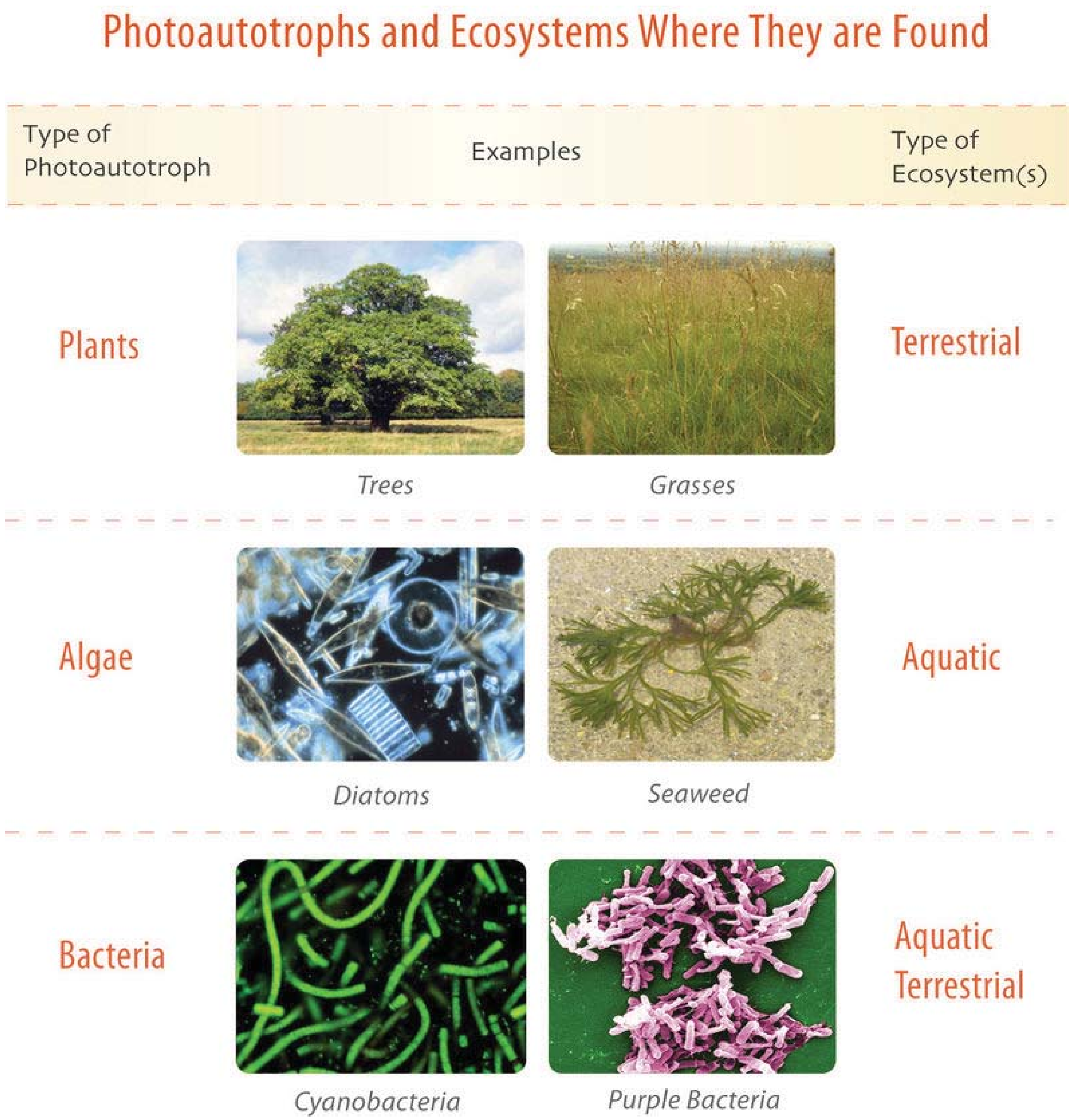

FIGURE 15.6

Different types of photoautotrophs are important in different types of ecosystems. Each type of photoautotroph pictured here is an important producer in some ecosystem.

aquatic, ecosystems. Like plants, algae are eukaryotes that contain chloroplasts for photosynthesis. Algae include single-celled eukaryotes, such as diatoms, as well as multicellular eukaryotes, such as seaweed.

Photoautotrophic bacteria, called **cyanobacteria**, are also important producers in aquatic ecosystems. Cyanobacteria were formerly called *blue-green algae*, but they are now classified as bacteria. Other photosynthetic bacteria, including purple photosynthetic bacteria, are producers in terrestrial as well as aquatic ecosystems.

Both cyanobacteria and algae make up **phytoplankton**. Phytoplankton refers to all the tiny photoautotrophs found on or near the surface of a body of water. Phytoplankton usually is the primary producer in aquatic ecosystems.

Chemoautotrophs

In some places where life is found on Earth, there is not enough light to provide energy for photosynthesis. In these places, producers called **chemoautotrophs** use the energy stored in chemical compounds to make organic molecules by chemosynthesis. **Chemosynthesis** is the process by which carbon dioxide and water are converted to carbohydrates. Instead of using energy from sunlight, chemoautotrophs use energy from the oxidation of inorganic compounds, such as hydrogen sulfide (H_2S). Oxidation is an energy-releasing chemical reaction in which a molecule, atom, or ion loses electrons.

Chemoautotrophs include bacteria called nitrifying bacteria, which you will read more about in Lesson 3. Nitrifying bacteria live underground in soil. They oxidize nitrogen-containing compounds and change them to a form that plants can use.

Chemoautotrophs also include archaea. **Archaea** are a domain of microorganisms that resemble bacteria. Most archaea live in extreme environments, such as around hydrothermal vents in the deep ocean. Hot water containing hydrogen sulfide and other toxic substances escapes from the ocean floor at these vents, creating a hostile environment for most organisms. Near the vents, archaea cover the sea floor or live in or on the bodies of other organisms, such as tube worms. In these ecosystems, archaea use the toxic chemicals released from the vents to produce organic compounds. The organic compounds can then be used by other organisms, including tube worms. Archaea are able to sustain thriving communities, like the one shown in **Figure** 15.7, even in these hostile environments.

FIGURE 15.7

Red tube worms, each containing millions of archaea microorganisms, grow in a cluster around a hydrothermal vent in the deep ocean floor. Archaea produce food for themselves (and for the tube worms) by chemosynthesis.

Consumers

Consumers are organisms that depend on producers or other types of organisms for food. They are also called **heterotrophs**, which literally means "other nutrition." Heterotrophs are unable to make organic compounds from inorganic molecules and energy. Instead, they take in organic molecules by consuming other organisms. All animals and fungi and many bacteria are heterotrophs. A few insect-eating plants are also heterotrophic. Heterotrophs can be classified on the basis of the types of organisms they consume. They include herbivores, omnivores, and carnivores.

Herbivores

Herbivores are organisms that consume only producers such as plants or algae. In most ecosystems, herbivores form a necessary link between producers and other consumers. Herbivores transform the energy stored in producers to compounds that can be used by other organisms.

In terrestrial ecosystems, many animals and fungi and some bacteria are herbivores. Herbivorous animals include deer, rabbits, and mice. Herbivores may specialize in particular types of plants, such as grasses, or specific plant parts, such as leaves, nectar, or roots. Examples of herbivores are shown in **Figure** 15.8.

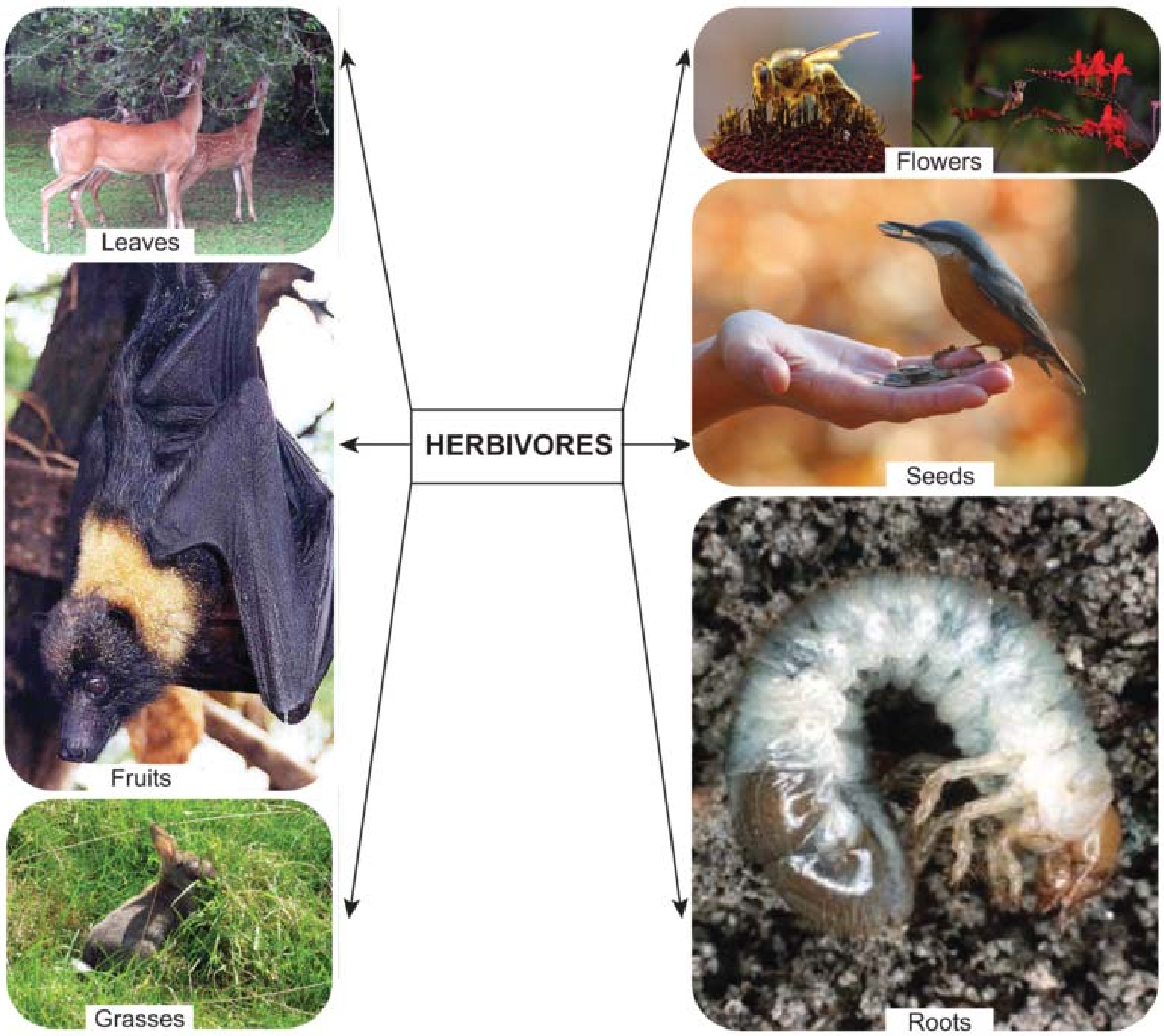

FIGURE 15.8

Deer browse on leaves. A hummingbird sips nectar from a flower. A bee gathers pollen from a flower. Many bats, including this one, primarily eat fruit. Some birds mainly eat seeds. A rabbit eats grasses. Beetle larvae like this one eat plant roots.

In aquatic ecosystems, the main herbivores are the heterotrophic organisms that make up zooplankton. **Zooplankton** refers to all the small organisms that feed on phytoplankton. These organisms include both single-celled organisms such as protozoa and multicellular organisms such as jellyfish. Phytoplankton and zooplankton together make up large communities of producers and herbivores called **plankton**.

Carnivores

Carnivores are organisms that eat a diet consisting mainly of herbivores or other carnivores. Carnivores include lions, wolves, polar bears, hawks, frogs, fish, and spiders. Animals that eat only meat are called obligate carnivores. They generally have a relatively short digestive system that cannot break down the tough cellulose found in plants. Other carnivores, including dogs, can digest plant foods but do not commonly eat them. Certain carnivores, called **scavengers**, mainly eat the carcasses of dead animals. Scavengers include vultures, raccoons, and blowflies.

A tiny minority of plants—including Venus flytraps and pitcher plants—are also carnivorous. These plants trap and digest insects. Some fungi are carnivorous as well. Carnivorous fungi capture and digest microscopic protozoan organisms such as amoebas.

Omnivores

Omnivores are organisms that eat both plants and animals as primary food sources. Humans are an example of an omnivorous species. Although some humans eat foods derived only from plants or only from animals, the majority of humans eat foods from both sources. Other examples of omnivorous animals are pigs, brown bears, gulls, and crows. Aquatic omnivores include some species of fish, such as piranhas.

Decomposers

When a plant or animal dies, it leaves behind energy and matter in the form of the organic compounds that make up its remains. **Decomposers** are organisms that consume dead organisms and other organic waste. They recycle materials from the dead organisms and waste back into the ecosystem. These recycled materials are used by the producers to remake organic compounds. Therefore, decomposers, like producers, are an essential part of every ecosystem, and their stability is essential to the survival of each ecosystem. In essence, this process completes and restarts the "circle of life." As stated above, scavengers consume the carcasses of dead animals. The remains of dead plants are consumed by organisms called detritivores.

Decomposers, producers and consumers (**6e**) are reviewed at http://www.youtube.com/watch?v=_Z2SIdzT5jU (4:17).

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Detritivores

When plants drop leaves or die, they contribute to detritus. **Detritus** consists of dead leaves and other plant remains that accumulate on the ground or at the bottom of a body of water. Detritus may also include animal feces and other organic debris. Heterotrophic organisms called **detritivores** feed on detritus. Earthworms, millipedes, and woodlice are detritivores that consume rotting leaves and other dead plant material in or on soil. Dung beetles, like the one shown in **Figure 4**, consume feces. In aquatic ecosystems, detritivores include "bottom feeders," such as sea cucumbers and catfish.

FIGURE 15.9
Dung beetle rolling a ball of feces to its nest to feed its offspring.

Saprotrophs

After scavengers and detritivores feed on dead organic matter, some unused energy and organic compounds still remain. For example, scavengers cannot consume bones, feathers, and fur of dead animals, and detritivores cannot consume wood and other indigestible plant material. Organisms called **saprotrophs** complete the breakdown of any remaining organic matter. The main saprotrophs that decompose dead animal matter are bacteria. The main saprotrophs that decompose dead plant matter are fungi. Fungi are also the only organisms that can decompose dead wood. Single-celled protozoa are common saprotrophs in aquatic ecosystems as well as in soil.

Saprotrophs convert dead organic material into carbon dioxide and compounds containing nitrogen or other elements needed by living organisms. The elements are then available to be used again by producers for the synthesis of organic compounds.

Food Chains and Food Webs

Food chains and food webs represent the feeding relationships in ecosystems. They show who eats whom. Therefore, they model the flow of energy and materials through ecosystems.

Food Chains

A **food chain** represents a simple linear pathway through which energy and materials are transferred from one species to another in an ecosystem. In general, food chains show how energy and materials flow from producers to

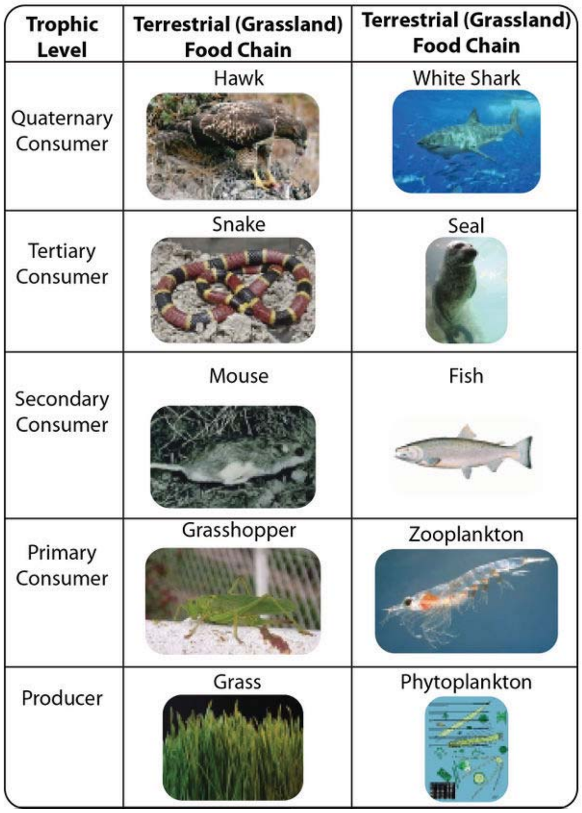

FIGURE 15.10
In the aquatic food chain on the right, phytoplankton is the producer. Phytoplankton is eaten by zooplankton, which is the primary consumer. Zooplankton, in turn, is eaten by fish (secondary consumers). Fish are eaten by seals (tertiary consumers), and seals are eaten by white sharks (quaternary consumers).

consumers. Energy and materials also flow from producers and consumers to decomposers, but this step usually is not included in food chains. Two examples of food chains are shown in **Figure** 15.10.

A musical summary of food chains (**6f**) can be heard at http://www.youtube.com/watch?v=TE6wqG4nb3M (2:46).

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Food Webs

Food chains tend to be overly simplistic representations of what really happens in nature. Most organisms consume multiple species and are, in turn, consumed by multiple other species. A food web represents these more complex interactions. A **food web** is a diagram of feeding relationships that includes multiple intersecting food chains. An example of a food web is shown in **Figure** below.

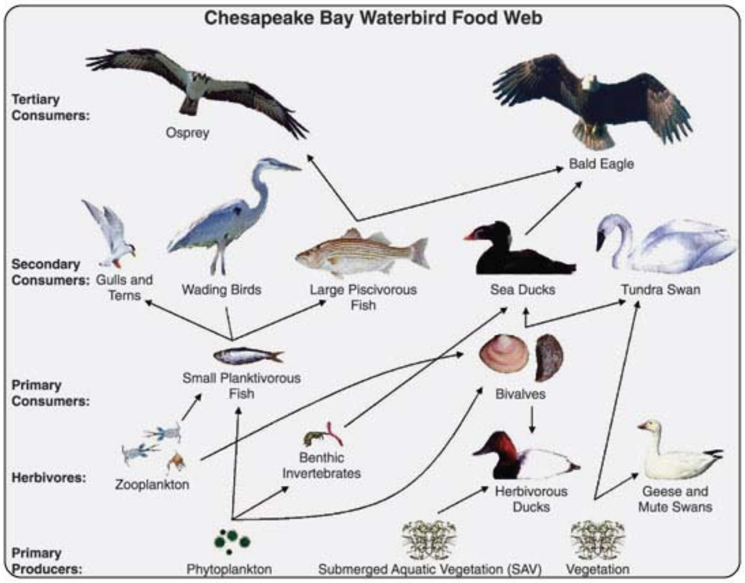

FIGURE 15.11

Food Web. This food web consists of several different food chains. Which organisms are producers in all of the food chains included in the food web?

Trophic Levels and Energy Transfer

The different feeding positions in a food chain or web are called **trophic levels**. The first trophic level consists of producers, the second of primary consumers, the third of secondary consumers, and so on. There usually are no more than four or five trophic levels in a food chain or web. Humans may fall into second, third, and fourth trophic levels of food chains or webs. They eat producers such as grain, primary consumers such as cows, and tertiary consumers such as salmon.

Energy is passed up the food chain from one trophic level to the next. However, only about 10 percent of the total energy stored in organisms at one trophic level is actually transferred to organisms at the next trophic level. The rest of the energy is used for metabolic processes or lost to the environment as heat. As a result, less energy is available to organisms at each successive trophic level. This explains why there are rarely more than four or five trophic levels. The amount of energy at different trophic levels can be represented by an energy pyramid like the one in **Figure** 15.12.

Pyramid of Energy

Because there is less energy at higher trophic levels, there are usually fewer organisms as well. Organisms tend to be larger in size at higher trophic levels, but their smaller numbers still result in less biomass. **Biomass** is the total mass of organisms in a trophic level (or other grouping of organisms). The biomass pyramid in **Figure** 15.13 shows how biomass of organisms changes from first to higher trophic levels in a food chain.

Energy pyramids (**6f**) are discussed at http://www.youtube.com/watch?v=8T2nEMzk6_E&feature=related (1:44).

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Pyramid of Biomass

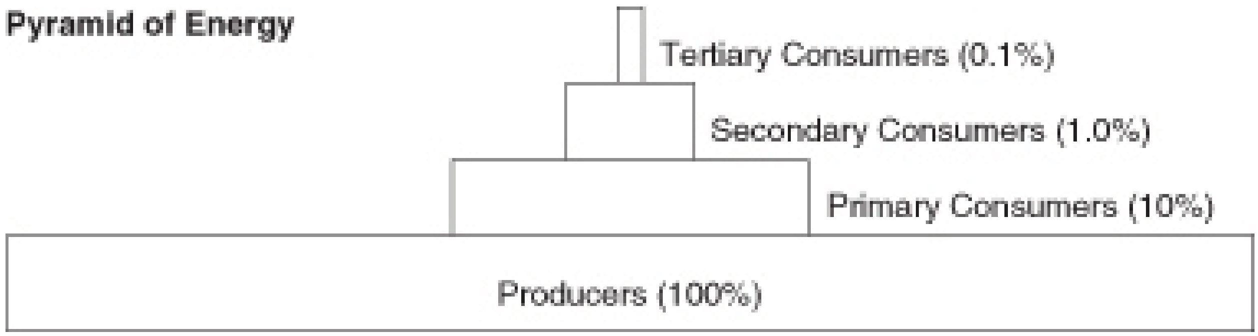

FIGURE 15.12
This pyramid shows the total energy stored in organisms at each trophic level in an ecosystem. Starting with primary consumers, each trophic level in the food chain has only 10 percent of the energy of the level below it. The pyramid makes it clear why there can be only a limited number of trophic levels in a food chain or web.

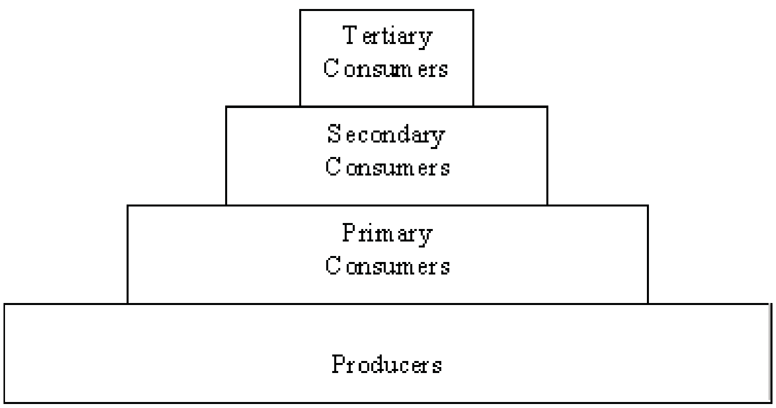

FIGURE 15.13
This pyramid shows the total biomass, or mass of organisms, at each trophic level in an ecosystem. How does this pyramid relate to the energy pyramid in **Figure** ?

The materials in dead organisms and wastes at all trophic levels are broken down by decomposers. Organisms such as detritivores and saprotrophs return needed elements to the ecosystem and use up most remaining energy. Because of the reduction in energy at each trophic level, virtually no energy remains. Therefore, energy must be continuously added to ecosystems by producers.

Lesson Summary

- Producers in ecosystems are autotrophs. They use energy from sunlight or chemical compounds to synthesize organic molecules from carbon dioxide and other simple inorganic molecules.
- Consumers in ecosystems are heterotrophs, or organisms that consume other organisms for food. Consumers include herbivores such as deer, carnivores such as lions, and omnivores such as humans.
- Decomposers break down dead organisms and other organic wastes in ecosystems. They resupply producers with the elements they need to synthesize organic compounds.
- Food chains and food webs model feeding relationships in ecosystems. They show how energy and materials

are transferred between trophic level when consumers eat producers or other organisms.

Review Questions

1. How do autotrophs use energy to produce organic molecules?
2. Define three different types of consumers, and name an example of each.
3. How do decomposers resupply elements to producers?
4. How is energy transferred between trophic levels in a food chain?
5. In the food web figure, identify two independent food chains.
6. If one million kilocalories of energy are stored in producers in an ecosystem, how many kilocalories can be transferred to tertiary consumers in the ecosystem? Show the calculations that support your answer.
7. Draw a terrestrial food chain that includes four trophic levels.
8. All organisms consist of carbon compounds. Infer how the amount of carbon stored in organisms changes from one trophic level to the next. Explain your answer.

Further Reading / Supplemental Links

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Vocabulary

Archaea
A prokaryotic domain of microorganisms that resemble bacteria; most archaea live in extreme environments, such as around hydrothermal vents in the deep ocean and are chemoautotrophs.

autotrophs
Organisms that produce organic compounds from energy and simple inorganic molecules; also known as producers.

carnivores
Organisms that eat a diet consisting mainly of herbivores or other carnivores.

chemoautotrophs
Organisms that use the energy stored in chemical compounds to make organic molecules by chemosynthesis.

chemosynthesis
The process by which carbon dioxide and water are converted to carbohydrates; uses energy from the oxidation of inorganic compounds.

consumers
Organisms that depend on producers or other types of organisms for food.

decomposers
Organisms that consume dead organisms and other organic waste.

detritivores
Organisms that consume the remains of dead plants (detritus).

detritus
Dead leaves and other plant remains that accumulate on the ground or at the bottom of a body of water.

food chain
A simple linear pathway through which energy and materials are transferred from one species to another in an ecosystem.

food web
A diagram of feeding relationships that includes multiple intersecting food chains.

herbivores
Organisms that consume only producers such as plants or algae; form a necessary link between producers and other consumers.

heterotrophs
Organisms that depend on producers or other types of organisms for food; also called consumers.

omnivores
Organisms that eat both plants and animals as primary food sources.

oxidation
An energy-releasing chemical reaction in which a molecule, atom, or ion loses electrons.

photoautotrophs
Organisms that use energy from sunlight to make food by photosynthesis; includes plants, algae, and certain bacteria.

photosynthesis
The process by which carbon dioxide and water are converted to glucose and oxygen, using sunlight for energy.

phytoplankton
All the tiny photoautotrophs found on or near the surface of a body of water; usually is the primary producer in aquatic ecosystems; includes both cyanobacteria and algae.

plankton
Large communities of producers and herbivores; made up of phytoplankton and zooplankton.

producers
Organisms that produce organic compounds from energy and simple inorganic molecules.

saprotrophs
Organisms that complete the breakdown of any remaining organic matter, such as bones, feathers, and fur of dead animals, and wood and other indigestible plant material.

scavengers
Carnivores that mainly eat the carcasses of dead animals.

trophic levels
The different feeding positions in a food chain or web.

zooplankton
All the small organisms that feed on phytoplankton; includes both single-celled organisms such as protozoa and multicellular organisms such as jellyfish.

Points to Consider

Matter recycles through the biotic components of ecosystems as producers synthesize organic compounds and other organisms consume the compounds.

- Do you think abiotic components of ecosystems also play roles in recycling matter?
- What abiotic components do you think might be involved? For example, what abiotic components do you think might be involved in the cycling of water?

15.3 Recycling Matter

Lesson Objectives

- Define and give examples of biogeochemical cycles that recycle matter.
- Describe the water cycle and the processes by which water changes state.
- Summarize the organic and geological pathways of the carbon cycle.
- Outline the nitrogen cycle and state the roles of bacteria in the cycle.

Introduction

Unlike energy, elements are not lost and replaced as they pass through ecosystems. Instead, they are recycled repeatedly. All chemical elements that are needed by living things are recycled in ecosystems, including carbon, nitrogen, hydrogen, oxygen, phosphorus, and sulfur. Water is also recycled.

Biogeochemical Cycles

A biogeochemical cycle is a closed loop through which a chemical element or water moves through ecosystems. In the term *biogeochemical, bio-* refers to biotic components and *geo-* to geological and other abiotic components. Chemicals cycle through both biotic and abiotic components of ecosystems. For example, an element might move from the atmosphere to ocean water, from ocean water to ocean organisms, and then back to the atmosphere to repeat the cycle.

Elements or water may be held for various lengths of time by different components of a biogeochemical cycle. Components that hold elements or water for a relatively short period of time are called exchange pools. For example, the atmosphere is an exchange pool for water. It holds water for several days at the longest. This is a very short time compared with the thousands of years the deep ocean can hold water. The ocean is an example of a reservoir for water. Reservoirs are components of a geochemical cycle that hold elements or water for a relatively long period of time.

Water Cycle

Earth's water is constantly in motion. Although the water on Earth is billions of years old, individual water molecules are always moving through the water cycle. The **water cycle** describes the continuous movement of water molecules on, above, and below Earth's surface. It is shown in **Figure** 15.14. Like other biogeochemical cycles, there is no beginning or end to the water cycle. It just keeps repeating. During the cycle, water occurs in its three different states: gas (water vapor), liquid (water), and solid (ice). Processes involved in changes of state in the water cycle include evaporation, sublimation, and transpiration.

The water cycle (**6d**) is demonstrated at http://www.youtube.com/watch?v=iohKd5FWZOE&feature=related (4:00).

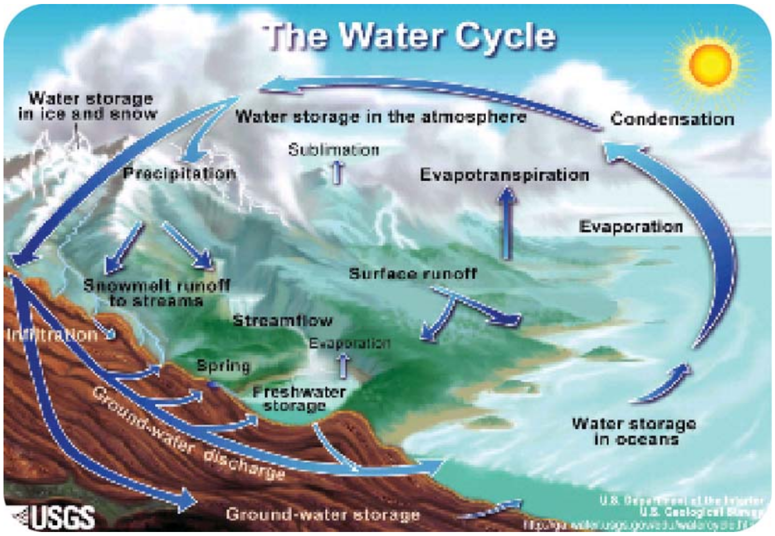

FIGURE 15.14
This diagram of the water cycle shows where water is stored and the processes by which water moves through the cycle, including evaporation, condensation, and precipitation.

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The *Water Cycle Jump* (**6d**) can be viewed at http://www.youtube.com/watch?v=BayExatv8lE (1:31).

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Evaporation, Sublimation, and Transpiration

The sun is the driving force behind the water cycle. It heats oceans, lakes, and other bodies of water, causing water to evaporate from the surface and enter the atmosphere as water vapor. Water in soil also evaporates easily. In addition, the sun heats ice and snow, causing it to turn directly into water vapor in the process of **sublimation**. Water also evaporates from the above-ground parts of plants. Transpiration is another process by which plants lose water. **Transpiration** occurs when stomata in leaves open to take in carbon dioxide for photosynthesis and lose water to the atmosphere in the process.

The water cycle plays an important role in climate. For molecules of liquid water to change to water vapor, kinetic energy is required, or the energy of movement. As faster-moving molecules evaporate, the remaining molecules have lower average kinetic energy, and the temperature of ocean water thus decreases. The primary way that oceans slow global warming is by heat uptake which warms ocean water and removes some energy from the atmosphere.

Condensation and Precipitation

Rising air currents carry water vapor from all these sources into the atmosphere. As the water vapor rises higher into the atmosphere or is carried toward the poles by winds, the air becomes cooler. Cooler air cannot hold as much water vapor, so the water vapor condenses into tiny water droplets around particles in the air. The tiny water droplets form clouds.

Air currents cause the tiny water droplets in clouds to collide and merge into larger droplets. When water droplets in clouds become large enough to fall, they become **precipitation**. Most precipitation falls back into the ocean. Precipitation that falls at high altitudes or near the poles can accumulate as ice caps and glaciers. These masses of ice can store frozen water for hundreds of years or longer.

Infiltration and Runoff

Rain that falls on land may either soak into the ground, which is called **infiltration**, or flow over the land as **runoff**. Snow that falls on land eventually melts, with the exception of snow that accumulates at high altitudes or near the poles. Like rain water, snowmelt can either infiltrate the ground or run off.

Water that infiltrates the ground is called **groundwater**. Groundwater close to the surface can be taken up by plants. Alternatively, it may flow out of the ground as a spring or slowly seep from the ground into bodies of water such as ponds, lakes, or the ocean. Groundwater can also flow deeper underground. It may eventually reach an aquifer. An **aquifer** is an underground layer of water-bearing, permeable rock. Groundwater may be stored in an aquifer for thousands of years. Wells drilled into an aquifer can tap this underground water and pump it to the surface for human use.

Runoff water from rain or snowmelt eventually flows into streams and rivers. The water is then carried to ponds, lakes, or the ocean. From these bodies of water, water molecules can evaporate to form water vapor and continue the cycle.

Carbon Cycle

Runoff, streams, and rivers can gradually dissolve carbon in rocks and carry it to the ocean. The ocean is a major reservoir for stored carbon. It is just one of four major reservoirs. The other three are the atmosphere, the biosphere, and organic sediments such as fossil fuels. Fossil fuels, including petroleum and coal, form from the remains of dead organisms. All of these reservoirs of carbon are interconnected by pathways of exchange in the carbon cycle, which is shown in **Figure** 15.15.

Carbon occurs in a various forms in different parts of the carbon cycle. Some of the different forms in which carbon appears are described in **Table** 15.1. Refer to the table as you read how carbon moves between reservoirs of the cycle.

TABLE 15.1: Forms of Carbon in the Carbon Cycle: Carbon Dioxide, Gas, Calcium Carbonate, Solids

Form of Carbon	Chemical Formula	State	Main Reservoir
Carbon Dioxide	CO_2	Gas	Atmosphere
Carbonic Acid	H_2CO_3	Liquid	Ocean
Bicarbonate Ion	HCO_3^-	Liquid(dissolvedion)	Ocean
Organic Compounds	*Examples:* Glucose, $C_6H_{12}O_6$ Methane, CH_4	Solid Gas	Biosphere Organic Sediments (Fossil Fuels)

TABLE 15.1: (continued)

Form of Carbon	Chemical Formula	State	Main Reservoir
Other Carbon Compounds	*Examples:* Calcium Carbonate, $CaCO_3$ Calcium Magnesium Carbonate, $CaMg(CO_3)_2$	Solid Solid	Sedimentary Rock, Shells Sedimentary Rock

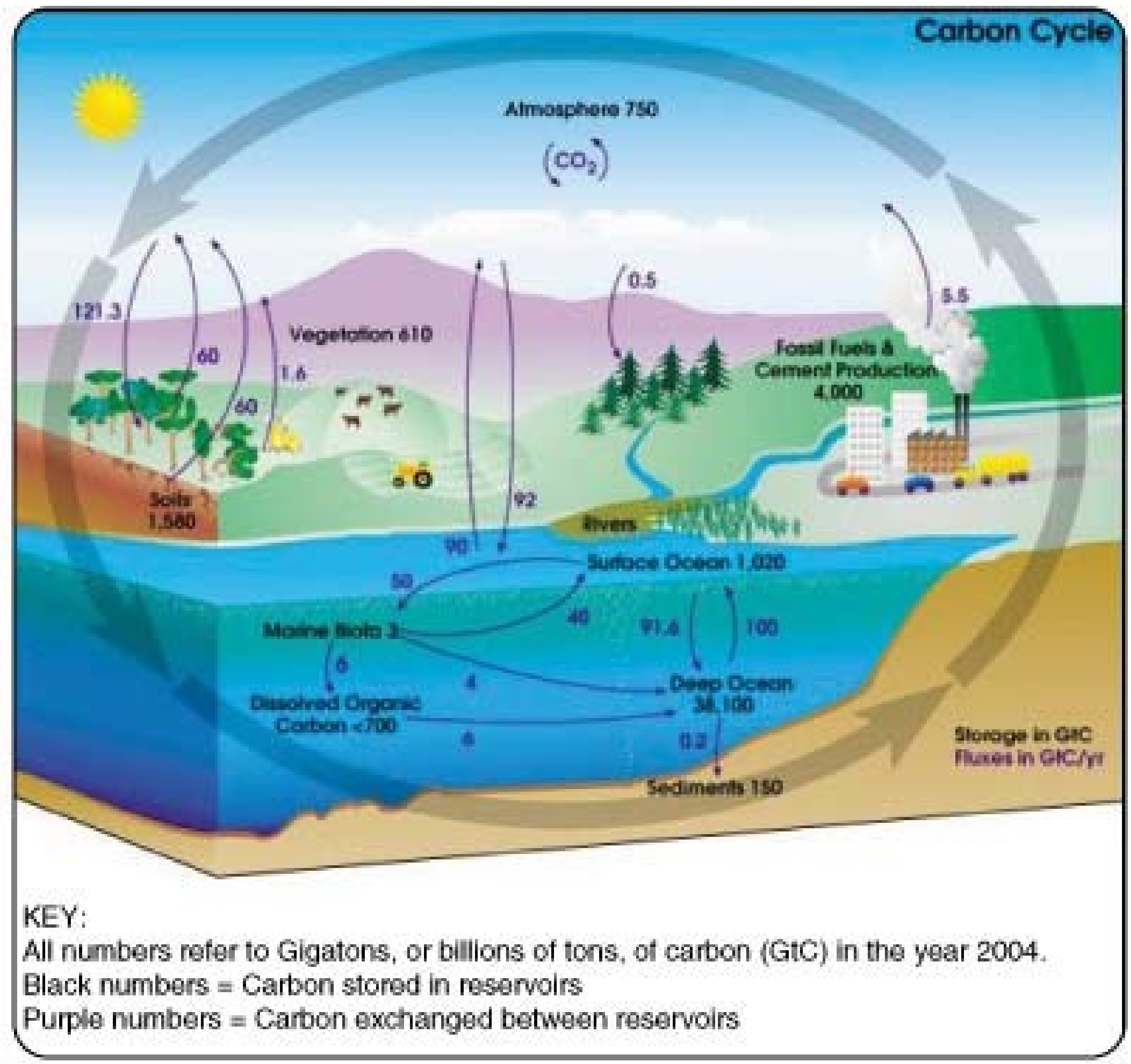


FIGURE 15.15

This drawing of the carbon cycle shows the amounts of carbon stored in and exchanged between carbon reservoirs on land and in water. Another 70 million GtC of carbon may be stored in sedimentary rock. If this is true, it would make sedimentary rock the greatest reservoir of carbon on Earth.

KEY: C = Carbon, O = Oxygen, H = Hydrogen

Carbon in the Atmosphere

In the atmosphere, carbon exists primarily as carbon dioxide (CO_2). Carbon dioxide enters the atmosphere from several different sources, including those listed below.

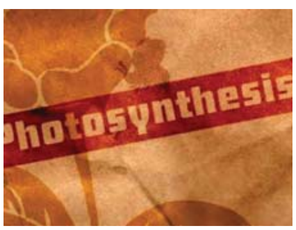
- Living organisms release carbon dioxide as a byproduct of cellular respiration.
- Carbon dioxide is given off when dead organisms and other organic materials decompose.
- Burning organic material, such as fossil fuels, releases carbon dioxide.
- When volcanoes erupt, they give off carbon dioxide that is stored in the mantle.
- Carbon dioxide is released when limestone is heated during the production of cement.
- Ocean water releases dissolved carbon dioxide into the atmosphere when water temperature rises.

A much smaller amount of carbon in the atmosphere is present as methane gas (CH_4). Methane is released into the atmosphere when dead organisms and other organic matter decay in the absence of oxygen. It is produced by landfills, the mining of fossil fuels, and some types of agriculture.

There are also several different ways that carbon leaves the atmosphere. Carbon dioxide is removed from the atmosphere when plants and other autotrophs take in carbon dioxide to make organic compounds during photosynthesis or chemosynthesis. Carbon dioxide is also removed when ocean water cools and dissolves more carbon dioxide from the air. These processes are also represented in **Figure** 15.15.

Because of human activities, there is more carbon dioxide in the atmosphere today than in the past hundreds of thousands of years. Burning fossil fuels and producing concrete has released great quantities of carbon dioxide into the atmosphere. Cutting forests and clearing land has also increased carbon dioxide into the atmosphere because these activities reduce the number of autotrophic organisms that use up carbon dioxide in photosynthesis. In addition, clearing often involves burning, which releases carbon dioxide that was previously stored in autotrophs.

The carbon cycle (**6d**) is discussed in the following video: http://www.youtube.com/watch?v=0Vwa6qtEih8 (1:56).



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Carbon in Ocean Water

Most carbon enters the ocean when carbon dioxide in the atmosphere dissolves in ocean water. When carbon dioxide dissolves in water (H_2O), it forms an acid called carbonic acid (H_2CO_3). The reaction is given by the equation:

$CO_2 + H_2O \leftrightarrow H_2CO_3$.

The double-headed arrow indicates that the reaction can occur in either direction, depending on the conditions and the amount of carbon dioxide present. For example, the reaction occurs more readily in the left-to-right direction in cold water. As a result, near the poles, where ocean water is cooler, more carbon dioxide is dissolved and there is more carbonic acid in the water. Although carbonic acid is a weak acid, it is an important regulator of the acid-base (pH) balance of ocean water.

Carbonic acid, in turn, readily separates into hydrogen ions (H^+) and bicarbonate ions ($HCO_3{}^-$). This occurs in the following reaction:

$H_2CO_3 \leftrightarrow H^+ + HCO_3{}^-$.

Due to these two reactions, most dissolved carbon dioxide in the ocean is in the form of bicarbonate ions. Another source of bicarbonate ions in ocean water is runoff. Flowing water erodes rocks containing carbon compounds such as calcium carbonate. This forms bicarbonate ions, which the runoff carries to streams, rivers, and eventually the ocean. Many of the bicarbonate ions in ocean water are moved by ocean currents into the deep ocean. Carbon can be held in this deep ocean reservoir as bicarbonate ions for thousands of years or more.

Carbon in the Biosphere

Bicarbonate ions near the surface of the ocean may be taken up by photosynthetic algae and bacteria that live near the surface. These and other autotrophic organisms use bicarbonate ions or other forms of carbon to synthesize organic compounds. Carbon is essential for life because it is the main ingredient of every type of organic compound. Organic compounds make up the cells and tissues of all organisms and keep organisms alive and functioning. Carbon enters all ecosystems, both terrestrial and aquatic, through autotrophs such as plants or algae. Autotrophs use carbon dioxide from the air, or bicarbonate ions from the water, to make organic compounds such as glucose. Heterotrophs consume the organic molecules and pass the carbon through food chains and webs.

How does carbon cycle back to the atmosphere or ocean? All organisms release carbon dioxide as a byproduct of cellular respiration. Recall from the *Cellular Respiration* chapter that **cellular respiration** is the process by which cells oxidize glucose and produce carbon dioxide, water, and energy. Decomposers also release carbon dioxide when they break down dead organisms and other organic waste.

In a balanced ecosystem, the amount of carbon used in photosynthesis and passed through the ecosystem is about the same as the amount given off in respiration and decomposition. This cycling of carbon between the atmosphere and organisms forms an organic pathway in the carbon cycle. Carbon can cycle quickly through this organic pathway, especially in aquatic ecosystems. In fact, during a given period of time, much more carbon is recycled through the organic pathway than through the geological pathway you will read about next.

Carbon in Rocks and Sediments

The geological pathway of the carbon cycle takes much longer than the organic pathway described above. In fact, it usually takes millions of years for carbon to cycle through the geological pathway. It involves processes such as rock formation, subduction, and volcanism.

As stated previously, most carbon in ocean water is in the form of bicarbonate ions. Bicarbonate ions may bind with other ions, such as calcium ions (Ca^+) or magnesium ions (Mg^+), and form insoluble compounds. Because the compounds are insoluble, they precipitate out of water and gradually form sedimentary rock, such as limestone (calcium carbonate, $CaCO_3$) or dolomite [calcium magnesium carbonate $CaMg(CO_3)_2$.

Dead organisms also settle to the bottom of the ocean. Many of them have shells containing calcium carbonate. Over millions of years, the pressure of additional layers of sediments gradually changes their calcium carbonate and other remaining organic compounds to carbon-containing sedimentary rock.

During some periods in Earth's history, very rich organic sediments were deposited. These deposits formed pockets of hydrocarbons. Hydrocarbons are organic compounds that contain only carbon and hydrogen. The hydrocarbons found in sediments are fossil fuels such as natural gas. The hydrocarbon methane is the chief component of natural gas.

Carbon-containing rocks and sediments on the ocean floor gradually move toward the edges of the ocean due to a process called seafloor spreading. The rocks eventually reach cracks in the crust, where they are pulled down into the mantle. This process, called **subduction**, occurs at subduction zones. In the mantle, the rocks melt and their carbon is stored. When volcanoes erupt, they return some of the stored carbon in the mantle to the atmosphere in the form of carbon dioxide, a process known as **volcanism**. This brings the geological pathway of the carbon cycle full circle.

Nitrogen Cycle

The atmosphere is the largest reservoir of nitrogen on Earth. It consists of 78 percent nitrogen gas (N_2). The **nitrogen cycle** moves nitrogen through abiotic and biotic components of ecosystems. **Figure** 15.16 shows how nitrogen cycles through a terrestrial ecosystem. Nitrogen passes from the atmosphere into soil. Then it moves through several different organisms before returning to the atmosphere to complete the cycle. In aquatic ecosystems, nitrogen passes through a similar cycle.

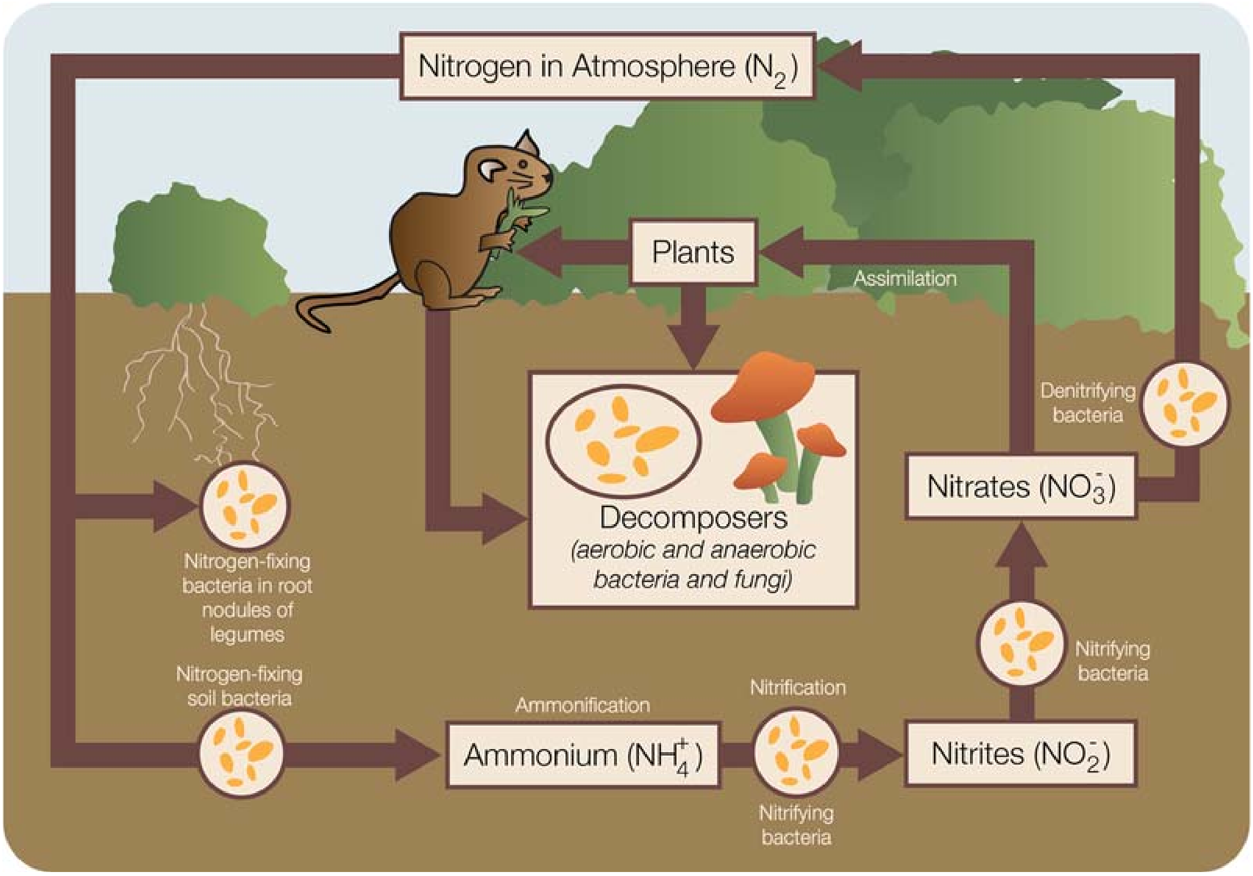
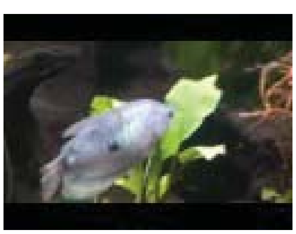


FIGURE 15.16
In a terrestrial ecosystem, the nitrogen cycle may include plants and consumers as well as several types of bacteria.

The nitrogen cycle (**6d**) is discussed at http://www.youtube.com/watch?v=pdY4I-EaqJA&feature=fvw (5:08).



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Absorption of Nitrogen

Plants and other producers use nitrogen to synthesize nitrogen-containing organic compounds. These include chlorophyll, proteins, and nucleic acids. Other organisms that consume producers make use of the nitrogen in these organic compounds. Plants absorb substances such as nitrogen from the soil through their root hairs. However, they cannot absorb nitrogen gas directly. They can absorb nitrogen only in the form of nitrogen-containing ions, such as nitrate ions (NO_3^-).

Nitrogen Fixation

The process of converting nitrogen gas to nitrate ions that plants can absorb is called **nitrogen fixation**. It is carried out mainly by nitrogen-fixing bacteria, which secrete enzymes needed for the process. Some nitrogen-fixing bacteria live in soil. Others live in the root nodules of legumes such as peas and beans. In aquatic ecosystems, some cyanobacteria are nitrogen fixing. They convert nitrogen gas to nitrate ions that algae and other aquatic producers can use.

Nitrogen gas in the atmosphere can be converted to nitrates by several other means. One way is by the energy in lightning. Nitrogen is also converted to nitrates as a result of certain human activities. These include the production of fertilizers and explosives and the burning of fossil fuels. These human activities also create the gas nitrous oxide (N_2O). The concentration of this gas in the atmosphere has tripled over the past hundred years as a result. Nitrous oxide is a greenhouse gas that contributes to global warming and other environmental problems.

Ammonification and Nitrification

After being used by plants and animals, nitrogen is released back into the environment. When decomposers break down organic remains and wastes, they release nitrogen in the form of ammonium ions (NH_4^-). This is called **ammonification**. It occurs in both terrestrial and aquatic ecosystems. In terrestrial ecosystems, some nitrogen-fixing bacteria in soil and root nodules also convert nitrogen gas directly into ammonium ions.

Although some plants can absorb nitrogen in the form of ammonium ions, others cannot. In fact, ammonium ions may be toxic to some plants and other organisms. Certain soil bacteria, called nitrifying bacteria, convert ammonium ions to nitrites (NO_2^-). Other nitrifying bacteria convert the nitrites to nitrates, which plants can absorb. The process of converting ammonium ions to nitrites or nitrates is called **nitrification**.

Denitrification and the Anammox Reaction

Still other bacteria, called denitrifying bacteria, convert some of the nitrates in soil back into nitrogen gas in a process called **denitrification**. The process is the opposite of nitrogen fixation. Denitrification returns nitrogen gas back to the atmosphere, where it can continue the nitrogen cycle.

In the ocean, another reaction occurs to cycle nitrogen back to nitrogen gas in the atmosphere. The reaction, called the **anammox reaction**, is enabled by certain bacteria in the water. In the reaction, ammonium and nitrite ions combine to form water and nitrogen gas. This is shown by the equation:

$NH_4^+ + NO_2^- \rightarrow N_2 + 2H_2O$.

The anammox reaction may contribute up to half of the nitrogen gas released into the atmosphere by the ocean. The reaction may also significantly limit production in ocean ecosystems by removing nitrogen compounds that are needed by aquatic producers and other organisms.

Lesson Summary

- Biogeochemical cycles are closed loops through which chemical elements or water move through ecosystems. Examples of biogeochemical cycles include the water cycle, carbon cycle, and nitrogen cycle.
- The water cycle recycles water through ecosystems. Processes by which water changes state in the water cycle include evaporation, sublimation, transpiration, and condensation.

- The organic pathway of the carbon cycle moves carbon from the atmosphere, through producers and other organisms in ecosystems, and back to the atmosphere. The geological pathway moves carbon from the atmosphere, through the ocean to rocks and the mantle, and back to the atmosphere.
- The nitrogen cycle moves nitrogen gas from the atmosphere into soil or water, where nitrogen-fixing bacteria convert it to a form that producers can use. Nitrifying bacteria help nitrogen cycle through ecosystems. Denitrifying bacteria return nitrogen gas back to the atmosphere. The anammox reaction returns nitrogen back to the atmosphere from ocean water.

Review Questions

1. What is a biogeochemical cycle? Name one example.
2. Identify and define two processes by which water changes state in the water cycle.
3. State three ways that carbon dioxide enters Earth's atmosphere.
4. How do bacteria convert nitrogen gas to a form that producers can use?
5. Describe all the ways that a single tree might be involved in the carbon cycle.
6. Explain why growing a crop of legumes can improve the ability of the soil to support the growth of other plants.
7. Compare and contrast organic and geological pathways in the carbon cycle.
8. Identify an exchange pool and a reservoir in the water cycle. Explain your choices.

Further Reading / Supplemental Links

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- http://en.wikipedia.org

Vocabulary

ammonification
The release of nitrogen in the form of ammonium ions ($NH_4{}^-$) due to the break down of organic remains and wastes by decomposers.

anammox reaction
Reaction in which ammonium and nitrite ions combine to form water and nitrogen gas; enabled by certain bacteria in the water.

aquifer
An underground layer of water-bearing, permeable rock.

biogeochemical cycle
A closed loop through which a chemical element or water moves through ecosystems.

carbon cycle
Pathways of exchange that interconnect the four major reservoirs of carbon: the ocean, the atmosphere, the biosphere and organic sediments, such as fossil fuels.

cellular respiration
The process by which cells oxidize glucose and produce carbon dioxide, water, and energy.

denitrification
The conversion of some of the nitrates in soil back into nitrogen gas; done by denitrifying bacteria; returns nitrogen gas back to the atmosphere, where it can continue the nitrogen cycle.

groundwater
Water that infiltrates the ground.

infiltration
Rain that falls on land and soaks into the ground.

nitrification
The process of converting ammonium ions to nitrites or nitrates.

nitrogen cycle
The cycle that moves nitrogen through abiotic and biotic components of ecosystems.

nitrogen fixation
The process of converting nitrogen gas to nitrate ions that plants can absorb; carried out mainly by nitrogen-fixing bacteria.

precipitation
Forms when water droplets in clouds become large enough to fall.

runoff
Rain that falls on land and flows over the land.

subduction
A process where carbon containing rocks and sediments on the ocean floor are pulled down into the mantle; due to seafloor spreading.

sublimation
The transformation of snow and ice directly into water vapor; occurs as the snow and ice are heated by the sun.

transpiration
A process by which plants lose water; occurs when stomata in leaves open to take in carbon dioxide for photosynthesis and lose water to the atmosphere in the process.

volcanism
The process of returning some of the stored carbon in the mantle to the atmosphere in the form of carbon dioxide; occurs when volcanoes erupt.

water cycle
Describes the continuous movement of water molecules on, above, and below Earth's surface.

Points to Consider

Matter is recycled through abiotic and biotic components of all ecosystems. However, ecosystems vary in the amount of matter they recycle. For example, forests recycle more matter than deserts.

- What factors do you think might cause ecosystems to differ in this way?
- What abiotic components of the environment do you think might be important?
- What about the amount of sunlight or precipitation that ecosystems receive?
- What roles do you think these abiotic components play in cycles of matter?

15.4 References

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6. Tree: Haabet; Grass: Polishname; Diatoms: Gordon T. Taylor/Stony Brook University/National Oceanic and Atmospheric Administration; Seaweed: Flyingdream; Cyanobacteria: Barry H. Rosen/US Geological Survey; Purple bacteria: Janice Carr/Centers for Disease Control and Prevention; Composite created by CK-12 Foundation. Tree: http://en.wikipedia.org/wiki/Image:Raunkiaer.jpg; Grass: http://en.wikipedia.org/wiki/Image:TallWildGrass.jpg; Diatoms: http://en.wikipedia.org/wiki/Image:Diatoms_through_the_microscope.jpg; Seaweed: http://en.wikipedia.org/wiki/Image:Codiumfragile.jpg; Cyanobacteria: http://microbiology.usgs.gov/image_gallery_cyanobacteria_phormidium.html; Purple bacteria: http://phil.cdc.gov/phil/details.asp (ID 9999) . All images are under the public domain
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