UNIT 2

Ecology

Chapters

3 The Biosphere

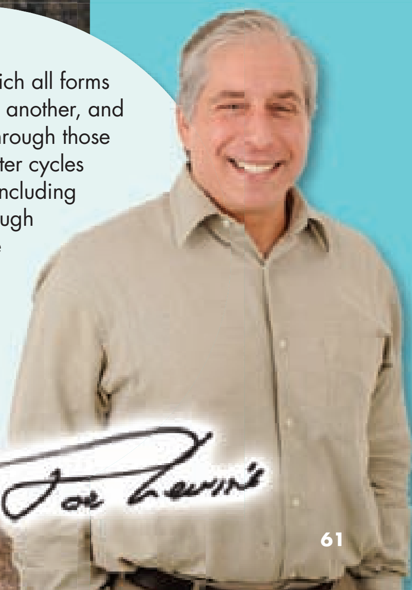
4 Ecosystems and Communities

5 Populations

6 Humans in the Biosphere

INTRODUCE the Big ideas

- **Matter and Energy**
- **Interdependence in Nature**



“Earth is a living planet on which all forms of life are linked to one another, and to land, water, and air. Through those links, energy flows and matter cycles in patterns that support life, including human society. We know enough about these patterns to realize that they are changing, due to human activity, in ways that we don’t understand. Our challenge is to study our impact on the biosphere and plan for a healthy future.”

3 The Biosphere

Big ideas

Matter and Energy, Interdependence in Nature

Q: How do Earth's living and nonliving parts interact and affect the survival of organisms?

Great White Egret among some plants in the Florida Everglades

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INSIDE:

- 3.1 What Is Ecology?
- 3.2 Energy, Producers, and Consumers
- 3.3 Energy Flow in Ecosystems
- 3.4 Cycles of Matter

- Untamed Science Video
- Chapter Mystery

CHAPTER
MYSTERY

CHANGES IN THE BAY

Marine life in Rhode Island's Narragansett Bay is changing. One clue to those changes comes from fishing boat captains who boast about catching bluefish in November—a month after those fish used to head south for winter. Catches of winter flounder, however, are not as plentiful as they once were. These changes in fish populations coincide with the disappearance of the annual spring increase in plant and animal growth. Researchers working in the bay, meanwhile, report puzzling changes in the activities of bacteria living in mud on the bay floor. What's going on? Farms, towns, and cities surround the bay, but direct human influence on the bay has not changed much lately. So why are there so many changes to the bay's plant and animal populations? Could these changes be related to mud-dwelling bacteria? As you read the chapter, look for clues to help you understand the interactions of plants, animals, and bacteria in Narragansett Bay. Then, solve the mystery.

Never Stop Exploring Your World.
Finding out about Narragansett Bay is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where this mystery leads.

UntamedScience™

3.1 What Is Ecology?

Key Questions

What is ecology?

What are biotic and abiotic factors?

What methods are used in ecological studies?

Vocabulary

biosphere • species • population • community • ecology • ecosystem • biome • biotic factor • abiotic factor

Taking Notes

Venn Diagram Make a Venn diagram that shows how the environment consists of biotic factors, abiotic factors, and some components that are truly a mixture of both. Use examples from the lesson.

THINK ABOUT IT Lewis Thomas, a twentieth-century science writer, was sufficiently inspired by astronauts' photographs of Earth to write: "Viewed from the distance of the moon, the astonishing thing about the earth … is that it is alive." Sounds good. But what does it mean? Was Thomas reacting to how green Earth is? Was he talking about how you can see moving clouds from space? How is Earth, in a scientific sense, a "living planet"? And how do we study it?

Studying Our Living Planet

What is ecology?

When biologists want to talk about life on a global scale, they use the term *biosphere*. The **biosphere** consists of all life on Earth and all parts of the Earth in which life exists, including land, water, and the atmosphere. The biosphere contains every organism, from bacteria living underground to giant trees in rain forests, whales in polar seas, mold spores drifting through the air—and, of course, humans. The biosphere extends from about 8 kilometers above Earth's surface to as far as 11 kilometers below the surface of the ocean.

Individual Organism
A **species** is a group of similar organisms that can breed and produce fertile offspring.

A **population** is a group of individuals that belong to the same species and live in the same area.

An assemblage of different populations that live together in a defined area is called a **community.**

The Science of Ecology Organisms in the biosphere interact with each other and with their surroundings, or environment. The study of these interactions is called **ecology.** **Ecology is the scientific study of interactions among organisms and between organisms and their physical environment.** The root of the word *ecology* is the Greek word *oikos*, which means "house." So, ecology is the study of nature's "houses" and the organisms that live in those houses.

Interactions within the biosphere produce a web of interdependence between organisms and the environments in which they live. Organisms respond to their environments and can also change their environments, producing an ever-changing, or dynamic, biosphere.

Ecology and Economics The Greek word *oikos* is also the root of the word *economics*. Economics is concerned with human "houses" and human interactions based on money or trade. Interactions among nature's "houses" are based on energy and nutrients. As their common root implies, human economics and ecology are linked. Humans live within the biosphere and depend on ecological processes to provide such essentials as food and drinkable water that can be bought and sold or traded.

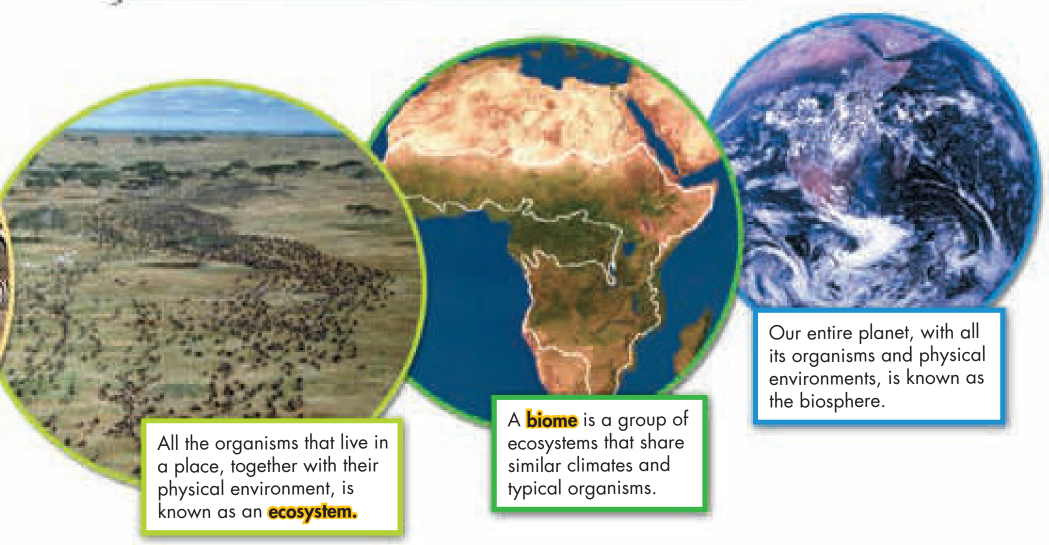
Levels of Organization Ecologists ask many questions about organisms and their environments. Some ecologists focus on the ecology of individual organisms. Others try to understand how interactions among organisms (including humans) influence our global environment. Ecological studies may focus on levels of organization that include those shown in **Figure 3–1.**

In Your Notebook *Draw a circle and label it "Me." Then, draw five concentric circles and label each of them with the appropriate level of organization. Describe your population, community, etc.*

BUILD Vocabulary

PREFIXES The prefix *inter-* means "between or among." *Interdependence* is a noun that means "dependence between or among individuals or things." The physical environment and organisms are considered interdependent because changes in one cause changes in the other.

FIGURE 3–1 Levels of Organization The kinds of questions that ecologists may ask about the living environment can vary, depending on the level at which the ecologist works. **Interpret Visuals** ***What is the difference between a population and a community?***



Biotic and Abiotic Factors

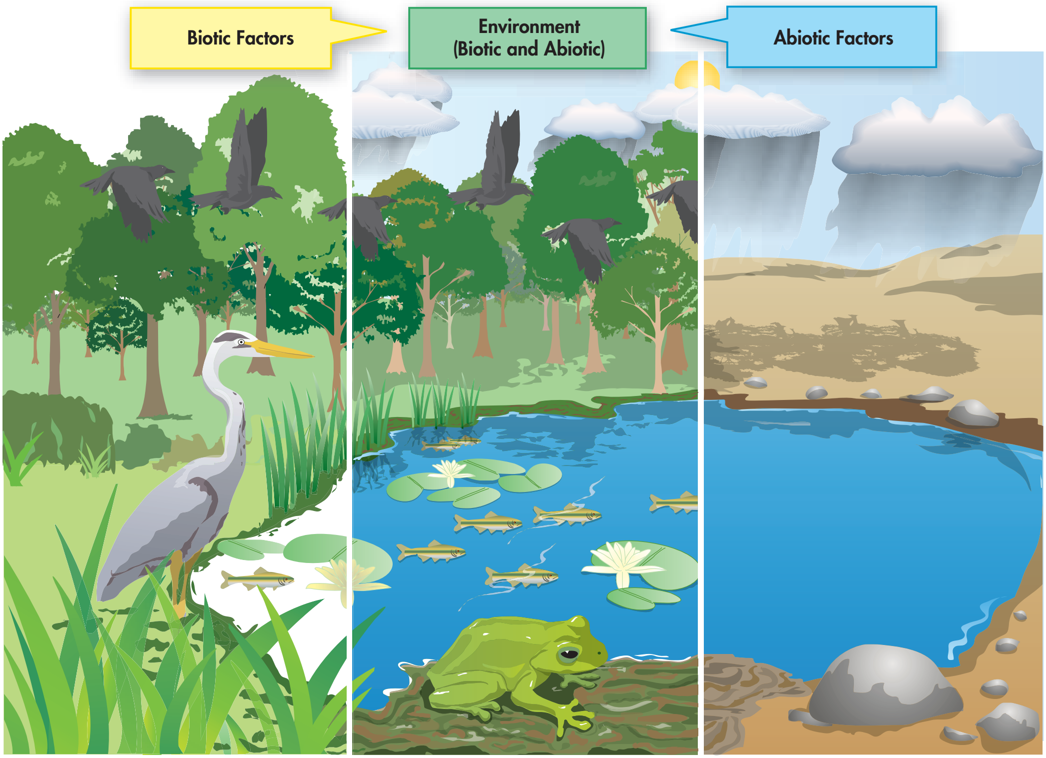
What are biotic and abiotic factors?

Ecologists use the word *environment* to refer to all conditions, or factors, surrounding an organism. Environmental conditions include biotic factors and abiotic factors, as shown in **Figure 3–2.**

Biotic Factors **The biological influences on organisms are called biotic factors.** A **biotic factor** is any living part of the environment with which an organism might interact, including animals, plants, mushrooms, and bacteria. Biotic factors relating to a bullfrog, for example, might include algae it eats as a tadpole, insects it eats as an adult, herons that eat bullfrogs, and other species that compete with bullfrogs for food or space.

Abiotic Factors **Physical components of an ecosystem are called abiotic factors.** An **abiotic factor** is any nonliving part of the environment, such as sunlight, heat, precipitation, humidity, wind or water currents, soil type, and so on. For example, a bullfrog could be affected by abiotic factors such as water availability, temperature, and humidity.

FIGURE 3–2 Biotic and Abiotic Factors Like all ecosystems, this pond is affected by a combination of biotic and abiotic factors. Some environmental factors, such as the "muck" around the edges of the pond, are a mix of biotic and abiotic components. Biotic and abiotic factors are dynamic, meaning that they constantly affect each other. **Classify** ***What biotic factors are visible in this ecosystem?***

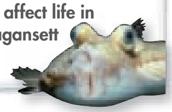


Biotic and Abiotic Factors Together The difference between biotic and abiotic factors may seem to be clear and simple. But if you think carefully, you will realize that many physical factors can be strongly influenced by the activities of organisms. Bullfrogs hang out, for example, in soft "muck" along the shores of ponds. You might think that this muck is strictly part of the physical environment, because it contains nonliving particles of sand and mud. But typical pond muck also contains leaf mold and other decomposing plant material produced by trees and other plants around the pond. That material is decomposing because it serves as "food" for bacteria and fungi that live in the muck.

Taking a slightly wider view, the "abiotic" conditions around that mucky shoreline are strongly influenced by living organisms. A leafy canopy of trees and shrubs often shade the pond's shoreline from direct sun and protect it from strong winds. In this way, organisms living around the pond strongly affect the amount of sunlight the shoreline receives and the range of temperatures it experiences. A forest around a pond also affects the humidity of air close to the ground. The roots of trees and other plants determine how much soil is held in place and how much washes into the pond. Even certain chemical conditions in the soil around the pond are affected by living organisms. If most trees nearby are pines, their decomposing needles make the soil acidic. If the trees nearby are oaks, the soil will be more alkaline. This kind of dynamic mix of biotic and abiotic factors shapes every environment.

MYSTERY CLUE

What are three examples of abiotic factors that might affect life in Narragansett Bay?



In Your Notebook *In your own words, explain the difference between biotic and abiotic factors. Give three examples of each.*

Quick Lab
GUIDED INQUIRY

How Do Abiotic Factors Affect Different Plant Species?

1. Gather four paper cups. Use a pencil to punch three holes in the bottom of each cup. Fill two cups with equal amounts of sand and two cups with the same amount of potting soil. **CAUTION:** *Wash your hands well with soap and warm water after handling soil or plants.*

2. Plant five rice seeds in one sand-filled cup and five rice seeds in one soil-filled cup. Plant five rye seeds in each of the other two cups. Label each cup with the type of seeds and soil it contains.

3. Place all the cups in a warm, sunny location. Each day for two weeks, water the cups equally and record your observations of any plant growth.

Analyze and Conclude

1. **Analyze Data** In which medium did the rice grow better—sand or soil? Which was the better medium for the growth of rye?

2. **Infer** Soil retains more water than sand does, providing a moister environment. What can you infer from your observations about the kind of environment that favors the growth of rice? What kind of environment favors the growth of rye?

3. **Draw Conclusions** Which would compete more successfully in a dry environment—rice or rye? Which would be more successful in a moist environment?

FIGURE 3–3 Ecology Field Work The three fundamental approaches to ecological research involve observing, experimenting, and modeling. This ecologist is measuring a giant *Rafflesia* flower in Borneo.

Ecological Methods

What methods are used in ecological studies?

Some ecologists, like the one in **Figure 3–3,** use measuring tools to assess changes in plant and wildlife communities. Others use DNA studies to identify bacteria in marsh mud. Still others use data gathered by satellites to track ocean surface temperatures. **Regardless of their tools, modern ecologists use three methods in their work: observation, experimentation, and modeling. Each of these approaches relies on scientific methodology to guide inquiry.**

Observation Observation is often the first step in asking ecological questions. Some observations are simple: Which species live here? How many individuals of each species are there? Other observations are more complex: How does an animal protect its young from predators? These types of questions may form the first step in designing experiments and models.

Experimentation Experiments can be used to test hypotheses. An ecologist may, for example, set up an artificial environment in a laboratory or greenhouse to see how growing plants react to different conditions of temperature, lighting, or carbon dioxide concentration. Other experiments carefully alter conditions in selected parts of natural ecosystems.

Modeling Many ecological events, such as effects of global warming on ecosystems, occur over such long periods of time or over such large distances that they are difficult to study directly. Ecologists make models to help them understand these phenomena. Many ecological models consist of mathematical formulas based on data collected through observation and experimentation. Further observations by ecologists can be used to test predictions based on those models.

3.1 Assessment

Review Key Concepts

1. a. Review What are the six different major levels of organization, from smallest to largest, that ecologists commonly study?

b. Apply Concepts Give an example of two objects or activities in your life that are interdependent. Explain your choice.

2. a. Review Is weather a biotic or abiotic factor?

b. Compare and Contrast How are biotic and abiotic factors related? What is the difference between them?

3. a. Review Describe the three basic methods of ecological research.

b. Apply Concepts Give an example of an ecological phenomenon that could be studied by modeling. Explain why modeling would be useful.

PRACTICE PROBLEM

4. Suppose you want to know if the water in a certain stream is safe to drink. Which ecological method(s) would you use in your investigation? Explain your reasoning and outline your procedure.

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3.2 Energy, Producers, and Consumers

THINK ABOUT IT At the core of every organism's interaction with the environment is its need for energy to power life's processes. Ants use energy to carry objects many times their size. Birds use energy to migrate thousands of miles. You need energy to get out of bed in the morning! Where does energy in living systems come from? How is it transferred from one organism to another?

Primary Producers

What are primary producers?

Living systems operate by expending energy. Organisms need energy for growth, reproduction, and their own metabolic processes. In short, if there is no energy, there are no life functions! Yet, no organism can create energy—organisms can only use energy from other sources. You probably know that you get your energy from the plants and animals you eat. But where does the energy in your food come from? For most life on Earth, sunlight is the ultimate energy source. Over the last few decades, however, researchers have discovered that there are other energy sources for life. For some organisms, chemical energy stored in inorganic chemical compounds serves as the ultimate energy source for life processes.

Only algae, certain bacteria, and plants like the one in **Figure 3–4** can capture energy from sunlight or chemicals and convert it into forms that living cells can use. These organisms are called **autotrophs.** Autotrophs use solar or chemical energy to produce "food" by assembling inorganic compounds into complex organic molecules. But autotrophs do more than feed themselves. Autotrophs store energy in forms that make it available to other organisms that eat them. That's why autotrophs are also called **primary producers.** **Primary producers are the first producers of energy-rich compounds that are later used by other organisms.** Primary producers are, therefore, essential to the flow of energy through the biosphere.

FIGURE 3–4 Primary Producers Plants obtain energy from sunlight and turn it into nutrients that can, in turn, be eaten and used for energy by animals such as this caterpillar.

Key Questions

What are primary producers?

How do consumers obtain energy and nutrients?

Vocabulary

autotroph • primary producer • photosynthesis • chemosynthesis • heterotroph • consumer • carnivore • herbivore • scavenger • omnivore • decomposer • detritivore

Taking Notes

Concept Map As you read, use the highlighted vocabulary words to create a concept map that organizes the information in this lesson.

BUILD Vocabulary

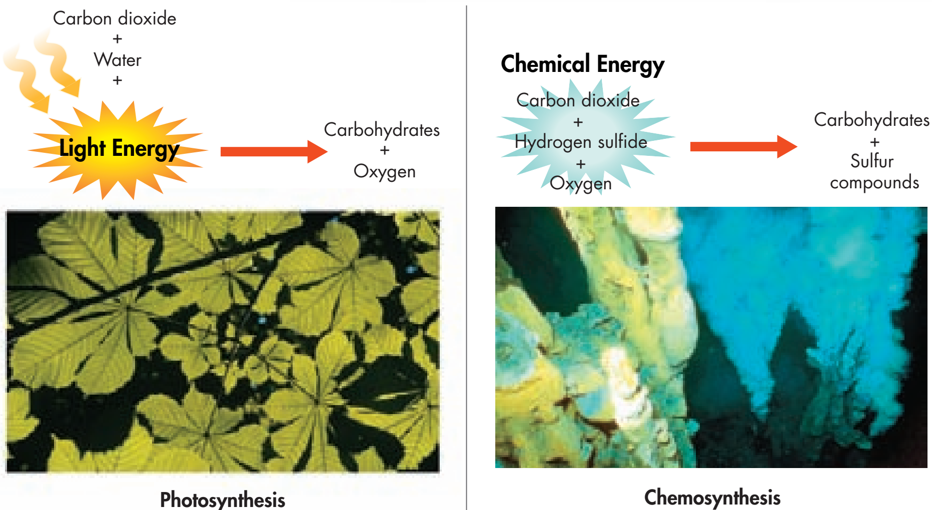
PREFIXES The prefix *auto-* means "by itself." The Greek word *trophikos* means "to feed." An **autotroph** can, therefore, be described as a "self feeder," meaning that it does not need to eat other organisms for food.

Energy From the Sun The best-known and most common primary producers harness solar energy through the process of photosynthesis. **Photosynthesis** captures light energy and uses it to power chemical reactions that convert carbon dioxide and water into oxygen and energy-rich carbohydrates such as sugars and starches. This process, shown in **Figure 3–5** (below left), adds oxygen to the atmosphere and removes carbon dioxide. Without photosynthetic producers, the air would not contain enough oxygen for you to breathe! Plants are the main photosynthetic producers on land. Algae fill that role in freshwater ecosystems and in the sunlit upper layers of the ocean. Photosynthetic bacteria, most commonly cyanobacteria, are important primary producers in ecosystems such as tidal flats and salt marshes.

Life Without Light About 30 years ago, biologists discovered thriving ecosystems around volcanic vents in total darkness on the deep ocean floor. There was no light for photosynthesis, so who or what were the primary producers? Research revealed that these deep-sea ecosystems depended on primary producers that harness chemical energy from inorganic molecules such as hydrogen sulfide. These organisms carry out a process called **chemosynthesis** (kee moh SIN thuh sis) in which chemical energy is used to produce carbohydrates as shown in **Figure 3–5** (below right). Chemosynthetic organisms are not only found in the deepest, darkest ocean, however. Several types of chemosynthetic producers have since been discovered in more parts of the biosphere than anyone expected. Some chemosynthetic bacteria live in harsh environments, such as deep-sea volcanic vents or hot springs. Others live in tidal marshes along the coast.

In Your Notebook *In your own words, explain the differences and similarities between photosynthetic and chemosynthetic producers.*

FIGURE 3–5 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. **Compare and Contrast** *How are photosynthesis and chemosynthesis similar?*



Consumers

How do consumers obtain energy and nutrients?

Animals, fungi, and many bacteria cannot directly harness energy from the environment as primary producers do. These organisms, known as **heterotrophs** (HET uh roh trohfs) must acquire energy from other organisms—by ingesting them in one way or another. Heterotrophs are also called **consumers.** **Organisms that rely on other organisms for energy and nutrients are called consumers.**

Types of Consumers Consumers are classified by the ways in which they acquire energy and nutrients, as shown in **Figure 3–6.** As you will see, the definition of *food* can vary quite a lot among consumers.

FIGURE 3–6 Consumers Consumers rely on other organisms for energy and nutrients. The Amazon rain forest shelters examples of each type of consumer as shown here.

Quick Lab
GUIDED INQUIRY

How Do Different Types of Consumers Interact?

1. Place a potted bean seedling in each of two jars.
2. Add 20 aphids to one jar and cover the jar with screening to prevent the aphids from escaping. Use a rubber band to attach the screening to the jar.
3. Add 20 aphids and 4 ladybird beetles to the second jar. Cover the second jar as you did the first one.
4. Place both jars in a sunny location. Observe the jars each day for one week and record your observations each day. Water the seedlings as needed.

Analyze and Conclude

1. Observe What happened to the aphids and the seedling in the jar without the ladybird beetles? What happened in the jar with the ladybird beetles? How can you explain this difference?

2. Classify Identify each organism in the jars as a producer or a consumer. If the organism is a consumer, what kind of consumer is it?

MYSTERY CLUE

Bacteria are important members of the living community in Narragansett Bay. How do you think the bacterial communities on the floor of the bay might be linked to its producers and consumers?

Beyond Consumer Categories Categorizing consumers is important, but these simple categories often don't express the real complexity of nature. Take herbivores, for instance. Seeds and fruits are usually rich in energy and nutrients, and they are often easy to digest. Leaves are generally poor in nutrients and are usually very difficult to digest. For that reason, herbivores that eat different plant parts often differ greatly in the ways they obtain and digest their food. In fact, only a handful of birds eat leaves, because the kind of digestive system needed to handle leaves efficiently is heavy and difficult to fly around with!

Moreover, organisms in nature often do not stay inside the tidy categories ecologists place them in. For example, some animals often 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 detritus particles—including the feces of other animals! So, these categories make a nice place to start talking about ecosystems, but it is important to expand on this topic by discussing the way that energy and nutrients move through ecosystems.

3.2 Assessment

Review Key Concepts

1. a. Review What are the two primary sources of energy that power living systems?

b. Pose Questions Propose a question that a scientist might ask about the variety of organisms found around deep-sea vents.

2. a. Review Explain how consumers obtain energy.

b. Compare and Contrast How are detritivores different from decomposers? Provide an example of each.

BUILD VOCABULARY

3. The word *autotroph* comes from the Greek words *autos*, meaning "self," and *trophe*, meaning "food or nourishment." Knowing this, what do you think the Greek word *heteros*, as in *heterotroph*, means?

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3.3 Energy Flow in Ecosystems

THINK ABOUT IT What happens to energy stored in body tissues when one organism eats another? That energy moves from the "eaten" to the "eater." You've learned that the flow of energy through an ecosystem always begins with either photosynthetic or chemosynthetic primary producers. Where it goes from there depends literally on who eats whom!

Key Questions

How does energy flow through ecosystems?

What do the three types of ecological pyramids illustrate?

Vocabulary

food chain • phytoplankton • food web • zooplankton • trophic level • ecological pyramid • biomass

Taking Notes

Preview Visuals Before you read, look at **Figure 3–7** and **Figure 3–9.** Note how they are similar and how they are different. Based on the figures, write definitions for *food chain* and *food web*.

Food Chains and Food Webs

How does energy flow through ecosystems?

In every ecosystem, primary producers and consumers are linked through feeding relationships. Despite the great variety of feeding relationships in different ecosystems, energy always flows in similar ways. **Energy flows through an ecosystem in a one-way stream, from primary producers to various consumers.**

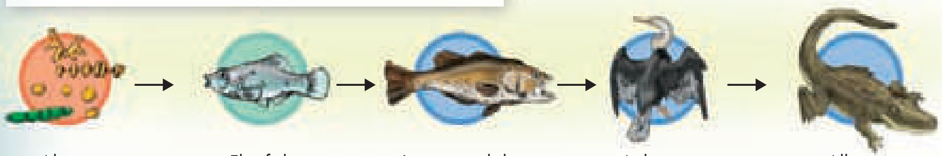
Food Chains

You can think of energy as passing through an ecosystem along a food chain. A **food chain** is a series of steps in which organisms transfer energy by eating and being eaten. Food chains can vary in length. For example, in a prairie ecosystem, a primary producer, such as grass, is eaten by an herbivore, such as a grazing antelope. A carnivore, such as a coyote, in turn feeds upon the antelope. In this two-step chain, the carnivore is just two steps removed from the primary producer.

In some aquatic food chains, primary producers are a mixture of floating algae called **phytoplankton** and attached algae. As shown in **Figure 3–7,** these primary producers may be eaten by small fishes, such as flagfish. Larger fishes, like the largemouth bass, eat the small fishes. The bass are preyed upon by large wading birds, such as the anhinga, which may ultimately be eaten by an alligator. There are four steps in this food chain. The top carnivore is therefore four steps removed from the primary producer.

FIGURE 3–7 Food Chains Food chains show the one-way flow of energy in an ecosystem. **Apply Concepts** ***What is the ultimate source of energy for this food chain?***

Primary producer · Herbivore · Carnivore



Food Webs In most ecosystems, feeding relationships are much more complicated than the relationships described in a single, simple chain. One reason for this is that many animals eat more than one kind of food. For example, on Africa's Serengeti Plain, herbivores, such as zebras, gazelles, and buffaloes, often graze upon several different species of grasses. Several predators such as lions, hyenas, and leopards, in turn, often prey upon those herbivores! Ecologists call this network of feeding interactions a **food web.**

▶ ***Food Chains Within Food Webs*** The Everglades are a complex marshland ecosystem in southern Florida. Here, aquatic and terrestrial organisms interact in many overlapping feeding relationships that have been simplified and represented in **Figure 3–9.** Starting with a primary producer (algae or plants), see how many different routes you can take to reach the alligator, vulture, or anhinga. One path, from the algae to the alligator, is the same food chain you saw in **Figure 3–7.** In fact, each path you trace through the food web is a food chain. You can think of a food web, therefore, as linking together all of the food chains in an ecosystem. Realize, however, that this is a highly simplified representation of this food web, in which many species have been left out. Now, you can begin to appreciate how complicated food webs are!

▶ ***Decomposers and Detritivores in Food Webs*** Decomposers and detritivores are as important in most food webs as other consumers are. Look again at the Everglades web. Although white-tailed deer, moorhens, raccoons, grass shrimp, crayfish, 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 crayfish, grass shrimp, and worms. At the same time, the decomposition process releases nutrients that can be used by primary producers. Thus, decomposers recycle nutrients in food webs as seen in **Figure 3–8.** Without decomposers, nutrients would remain locked within dead organisms.

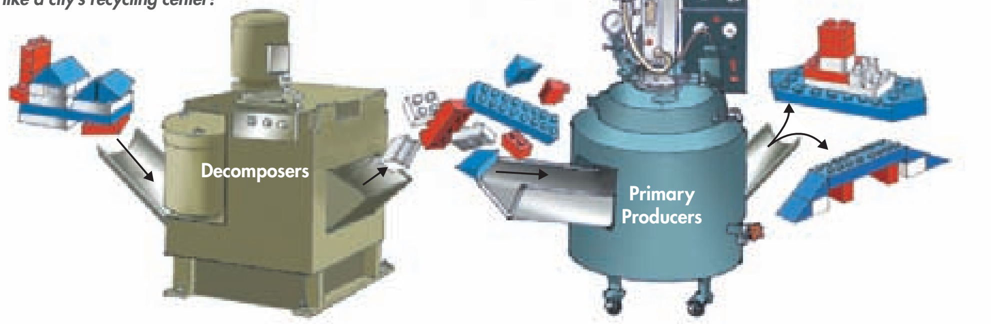
In Your Notebook *Explain how food chains and food webs are related.*

BUILD Vocabulary

ACADEMIC WORDS The verb **convert** means "to change from one form to another." Decomposers convert, or change, dead plant matter into a form called detritus that is eaten by detritivores.

VISUAL ANALOGY

FIGURE 3–8 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?*



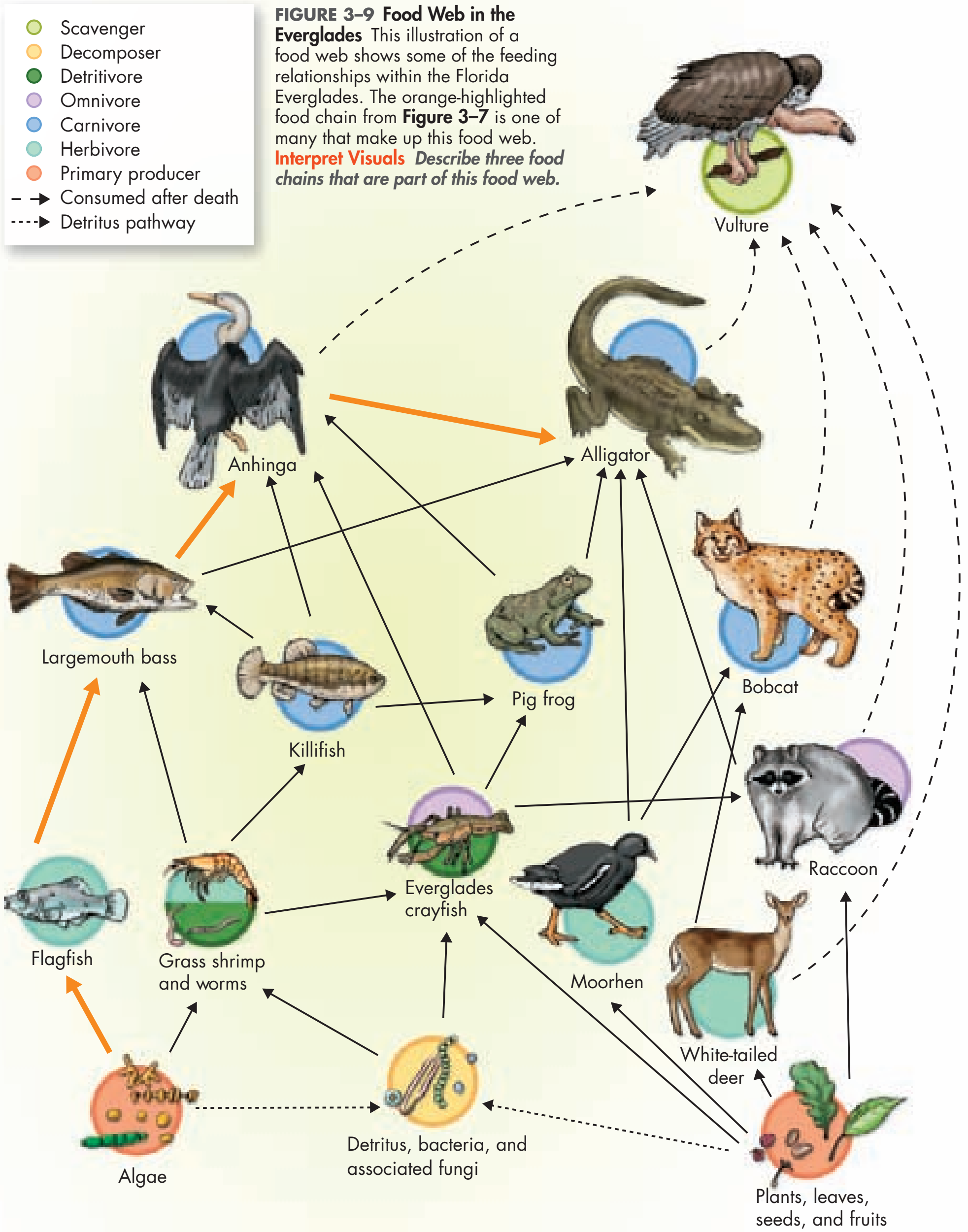


FIGURE 3–9 Food Web in the Everglades This illustration of a food web shows some of the feeding relationships within the Florida Everglades. The orange-highlighted food chain from **Figure 3–7** is one of many that make up this food web. **Interpret Visuals** ***Describe three food chains that are part of this food web.***

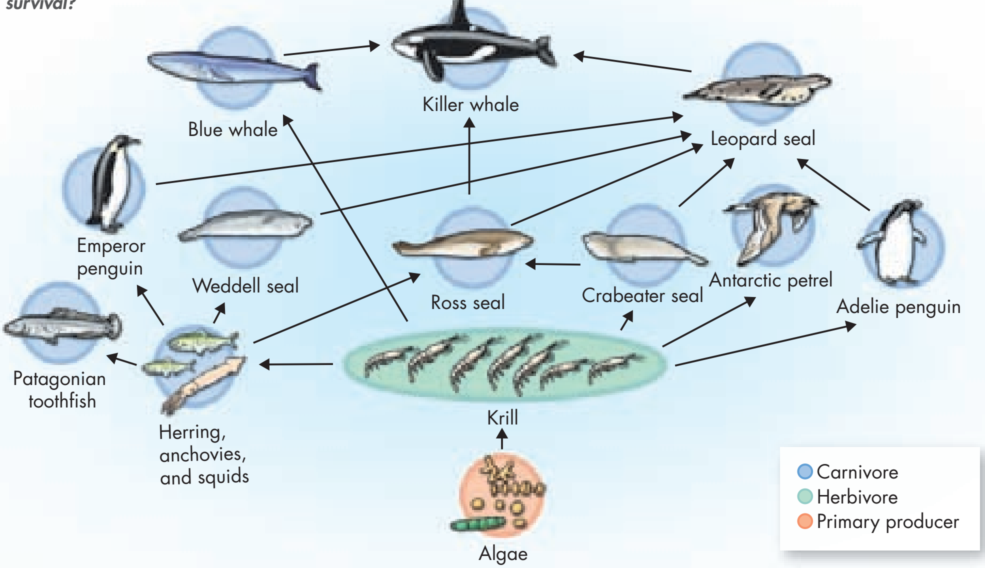
MYSTERY CLUE

Researchers discovered that zooplankton in Narragansett Bay now graze on floating algae more actively through the winter than they ever did before. What effect do you think this might have on the annual late-winter "bloom" of algae that occurs in the water?

Food Webs and Disturbance Food webs are complex, so it is often difficult to predict exactly how they will respond to environmental change. Look again at **Figure 3–9,** and think about the questions an ecologist might ask about the feeding relationships in it following a disturbance. What if an oil spill, for example, 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 crayfish? How about the effects on the grass shrimp and the worms? Do you think those populations would decline? If they did decline, how might pig frogs change their feeding behavior? How might the change in frog behavior then affect the other species on which the frog feeds?

Relationships in food webs are not simple, and, as you know, the food web in **Figure 3–9** has been simplified! So, you might expect that answers to these questions would not be simple either, and you'd be right. However, disturbances *do* happen, and their effects can be dramatic. Consider, for example, one of the most important food webs in the southern oceans. All of the animals in this food web, shown in **Figure 3–10,** depend directly or indirectly on shrimplike animals called krill, which feed on marine algae. Krill are one example of a diverse group of small, swimming animals, called **zooplankton** (zoh oh PLANK tun), that feed on marine algae. Adult krill browse on algae offshore, while their larvae feed on algae that live beneath floating sea ice. In recent years, krill populations have dropped substantially. Over that same period, a large amount of sea ice around Antarctica has melted. With less sea ice remaining, there are fewer of the algae that grow beneath the ice. Given the structure of this food web, a drop in the krill population can cause drops in the populations of all other members of the food web shown.

FIGURE 3–10 Antarctic Food Web All of the animals in this food web depend on one organism: krill. Disturbances to the krill's food source, marine algae, have the potential to cause changes in all of the populations connected to the algae through this food web. **Interpret Visuals** *What do ecologists mean when they say that killer whales* indirectly *depend on krill for survival?*



Trophic Levels and Ecological Pyramids

What do the three types of ecological pyramids illustrate?

Each step in a food chain or food web is called a **trophic level.** Primary producers always make up the first trophic level. Various consumers occupy every other level. One way to illustrate the trophic levels in an ecosystem is with an ecological pyramid. **Ecological pyramids** show the relative amount of energy or matter contained within each trophic level in a given food chain or food web. There are three different types of ecological pyramids: pyramids of energy, pyramids of biomass, and pyramids of numbers.

In Your Notebook *Make a two-column chart to compare the three types of ecological pyramids.*

Pyramids of Energy Theoretically, there is no limit to the number of trophic levels in a food web or the number of organisms that live on each level. But there is one catch. Only a small portion of the energy that passes through any given trophic level is ultimately stored in the bodies of organisms at the next level. This is because organisms expend 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 efficiency of energy transfer from one trophic level to another varies. On average, about 10 percent of the energy available within one trophic level is transferred to the next trophic level, as shown in **Figure 3–11.** 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. Thus, the more levels that exist between a producer and a given consumer, the smaller the percentage of the original energy from producers that is available to that consumer.

Analyzing Data

The 10 Percent Rule

As shown in **Figure 3–11,** an energy pyramid is a diagram that illustrates the transfer of energy through a food chain or food web. In general, only 10 percent of the energy available in one level is stored in the level above. Look at **Figure 3–11** and answer the questions below.

1. Calculate If there are 1000 units of energy available at the producer level of the energy pyramid, approximately how many units of energy are available to the third-level consumer? MATH

2. Interpret Diagrams What is the original source of the energy that flows through most ecosystems? Why must there be a continuous supply of energy into the ecosystem?

3. Infer Why are there usually fewer organisms in the top levels of an energy pyramid?

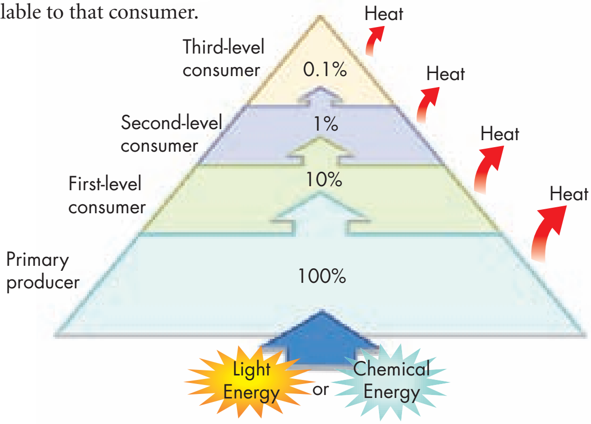


FIGURE 3–11 Pyramid of Energy Pyramids of energy show the relative amount of energy available at each trophic level. An ecosystem requires a constant supply of energy from photosynthetic or chemosynthetic producers. **Apply Concepts** *Explain how the amount of energy available at each trophic level often limits the number of organisms that each level can support.*

FIGURE 3–12 Pyramids of Biomass and Numbers In most cases, pyramids of biomass and numbers follow the same general pattern. In the field modeled here, there are more individual primary producers than first-level consumers. Likewise, the primary producers collectively have more mass. The same patterns hold for the second and third-level consumers. With each step to a higher trophic level, biomass and numbers decrease.

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. **A pyramid of biomass illustrates the relative amount of living organic matter available at each trophic level in an ecosystem.**

Ecologists interested in the number of organisms at each trophic level uses a pyramid of numbers. **A pyramid of numbers shows the relative number of individual organisms at each trophic level in an ecosystem.** In most ecosystems, the shape of the pyramid of numbers is similar to the shape of the pyramid of biomass for the same ecosystem. In this shape, 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 several square meters in a field, and then weighed and counted every organism in that area. The result might look something like the pyramid in **Figure 3–12.**

In some cases, however, consumers are much less massive than organisms they feed upon. Thousands of insects may graze on a single tree, for example, and countless mosquitos can feed off a few deer. Both the tree and deer have a lot of biomass, but they each represent only one organism. In such cases, the pyramid of numbers may be turned upside down, but the pyramid of biomass usually has the normal orientation.

3.3 Assessment

Review Key Concepts

1. a. **Review** Energy is said to flow in a "one-way stream" through an ecosystem. In your own words, describe what that means.
   b. **Form a Hypothesis** Explain what you think might happen to the Everglades ecosystem shown in **Figure 3–9** if there were a sudden decrease in the number of crayfish.
2. a. **Review** On average, what proportion of the energy in an ecosystem is transferred from one trophic level to the next? Where does the rest of the energy go?
   b. **Calculate** Draw an energy pyramid for a five-step food chain. If 100 percent of the energy is available at the first trophic level, what percentage of that energy is available at the highest trophic level? MATH

Apply the Big idea

Interdependence In Nature

3. Refer to **Figure 3–9,** which shows a food web in the Everglades. Choose one of the food chains within the web. Then, write a paragraph describing the feeding relationships among the organisms in the food chain.

BIOLOGY.com Search Lesson 3.3 GO • Lesson Assessment • Self-Test

3.4 Cycles of Matter

THINK ABOUT IT Living organisms are composed mostly of four elements: oxygen, carbon, hydrogen, and nitrogen. These four elements (and a few others, such as sulfur and phosphorus) are the basis of life's most important compounds: water, carbohydrates, lipids, nucleic acids, and proteins. In short, a handful of elements combine to form the building blocks of all known organisms. And yet, organisms cannot manufacture these elements and do not "use them up." So, where do essential elements come from? How does their availability affect ecosystems?

Recycling in the Biosphere

How does matter move through the biosphere?

Matter moves through the biosphere differently than the way in which energy moves. Solar and chemical energy are captured by primary producers and then pass in a one-way fashion from one trophic level to the next—dissipating in the environment as heat along the way. But while energy in the form of sunlight is constantly entering the biosphere, Earth doesn't receive a significant, steady supply of new matter from space. **Unlike the one-way flow of energy, matter is recycled within and between ecosystems.** Elements pass from one organism to another and among parts of the biosphere through closed loops called **biogeochemical cycles,** which are powered by the flow of energy as shown in **Figure 3–13.** As that word suggests, cycles of matter involve *bio*logical processes, *geo*logical processes, and *chem*ical processes. Human activity can also play an important role. As matter moves through these cycles, it is transformed. It is never created or destroyed—just changed.

Key Questions

How does matter move through the biosphere?

How does water cycle through the biosphere?

What is the importance of the main nutrient cycles?

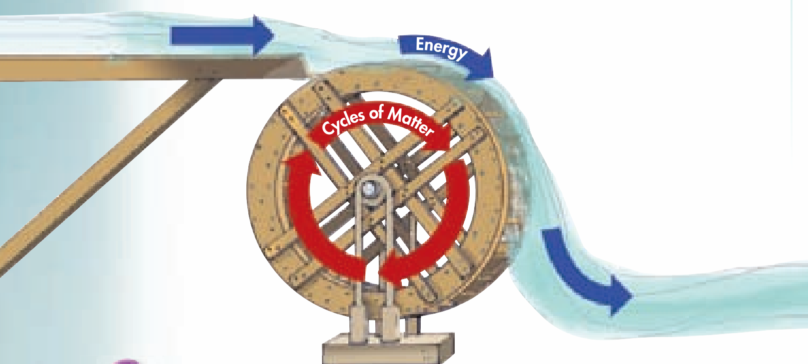
How does nutrient availability relate to the primary productivity of an ecosystem?

Vocabulary

biogeochemical cycle • nutrient • nitrogen fixation • denitrification • limiting nutrient

Taking Notes

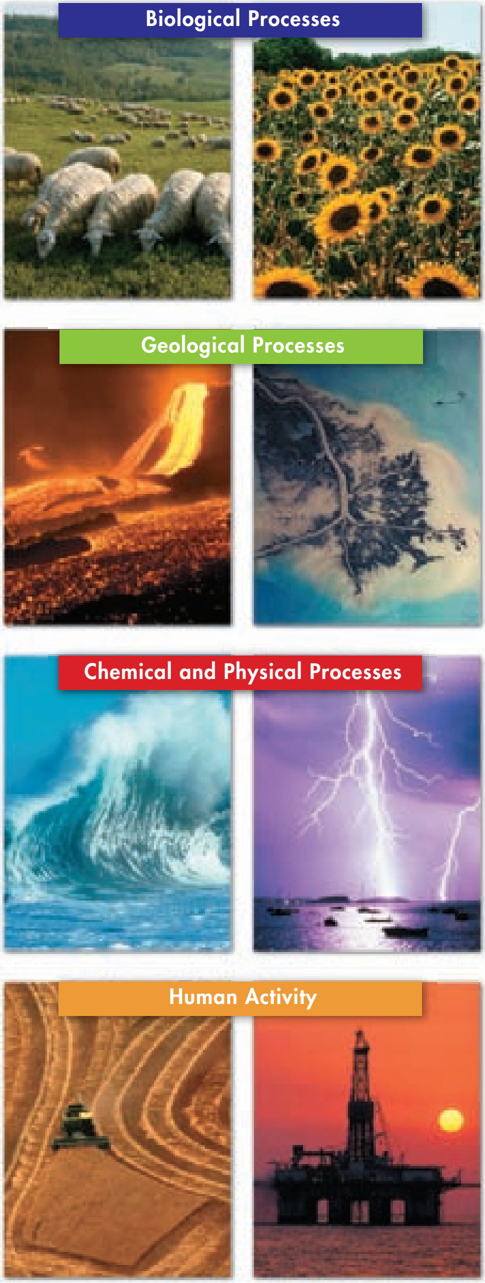
Outline Make an outline using the green and blue headings in this lesson. Fill in details as you read to help you organize the information.



VISUAL ANALOGY

THE MATTER MILL

FIGURE 3–13 Nutrients are recycled through biogeochemical cycles. These cycles are powered by the one-way flow of energy through the biosphere. **Use Analogies** *How is the water flowing over the water wheel similar to the flow of energy in the biosphere?*



There are many ways in which the processes involved in biogeochemical cycles can be classified. Here, we will use the following guidelines:

- ***Biological Processes*** Biological processes consist of any and all activities performed by living organisms. These processes include eating, breathing, "burning" food, and eliminating waste products.
- ***Geological Processes*** Geological processes include volcanic eruptions, the formation and breakdown of rock, and major movements of matter within and below the surface of the earth.
- ***Chemical and Physical Processes*** Chemical and physical processes include the formation of clouds and precipitation, the flow of running water, and the action of lightning.
- ***Human Activity*** Human activities that affect cycles of matter on a global scale include the mining and burning of fossil fuels, the clearing of land for building and farming, the burning of forests, and the manufacture and use of fertilizers.

These processes, shown in **Figure 3–14,** pass the same atoms and molecules around again and again. Imagine, for a moment, that you are a carbon atom in a molecule of carbon dioxide that has just been shot out of a volcano. The leaf of a blueberry bush in a nearby mountain range absorbs you during photosynthesis. You become part of a carbohydrate molecule in a blueberry. A caribou eats the fruit, and within a few hours, you pass out of the animal's body. You are soon swallowed by a dung beetle, which gets eaten by a hungry shrew. You are combined into the body tissues of the shrew, which is then eaten by an owl. You are released back into the atmosphere when the owl exhales carbon dioxide, dissolve in a drop of rainwater, and flow through a river into the ocean.

This could just be part of the never-ending cycle of a carbon atom through the biosphere. Carbon atoms in your body may once have been part of a rock on the ocean floor, the tail of a dinosaur, or even part of a historical figure such as Julius Caesar!

FIGURE 3–14 Biogeochemical Processes Cycles of matter involve biological, geological, chemical, and human factors.

The Water Cycle

How does water cycle through the biosphere?

Every time you see rain or snow, or watch a river flow, you are witnessing part of the water cycle. **Water continuously moves between the oceans, the atmosphere, and land—sometimes outside living organisms and sometimes inside them.** As **Figure 3–15** shows, water molecules typically enter the atmosphere as water vapor, a gas, when they evaporate from the ocean or other bodies of water. Water can also enter the atmosphere by evaporating from the leaves of plants in the process of transpiration (tran spuh RAY shun).

Water vapor may be transported by winds over great distances. If the air carrying it cools, water vapor condenses into tiny droplets that form clouds. When the droplets become large enough, they fall to Earth's surface as precipitation in the form of 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. Precipitation 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 re-enters the atmosphere through transpiration or evaporation begins the cycle anew.

In Your Notebook *Define each of the following terms and describe how they relate to the water cycle:* evaporation, transpiration, precipitation, *and* runoff.

FIGURE 3–15 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. **Interpret Visuals** ***What are the two primary ways in which water that falls to Earth as precipitation passes through the water cycle?***

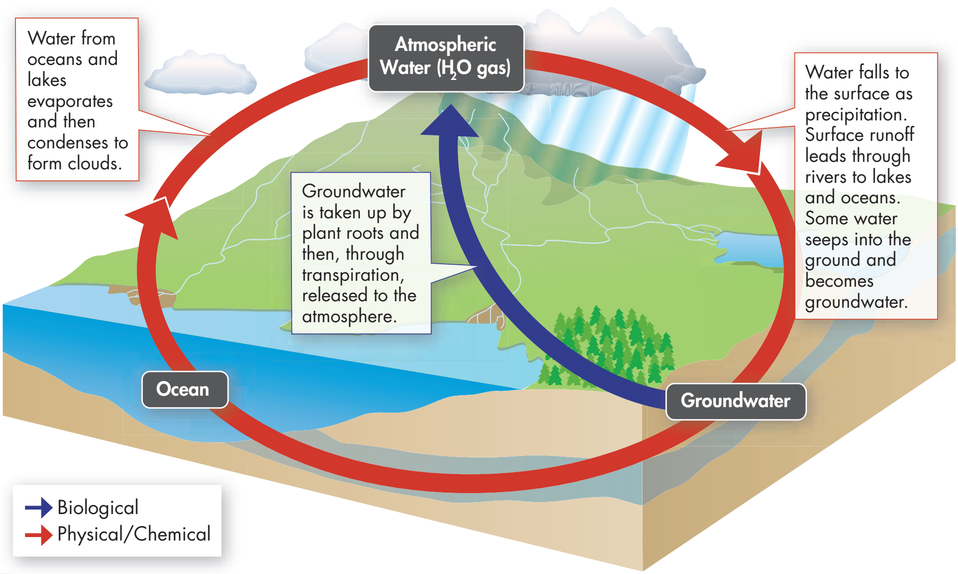


FIGURE 3–16 Oxygen in the Biosphere The oxygen contained in the carbon dioxide exhaled by this bighorn sheep may be taken up by producers and re-released as oxygen gas. Together, respiration and photosynthesis contribute to oxygen's cycling through the biosphere.

Nutrient Cycles

What is the importance of the main nutrient cycles?

The chemical substances that an organism needs to sustain life are called **nutrients.** **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 three pathways, or cycles that move carbon, nitrogen, and phosphorus through the biosphere are especially critical for life.**

Another element, 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 used in respiration by all multicellular forms of life, and many single-celled organisms as well.

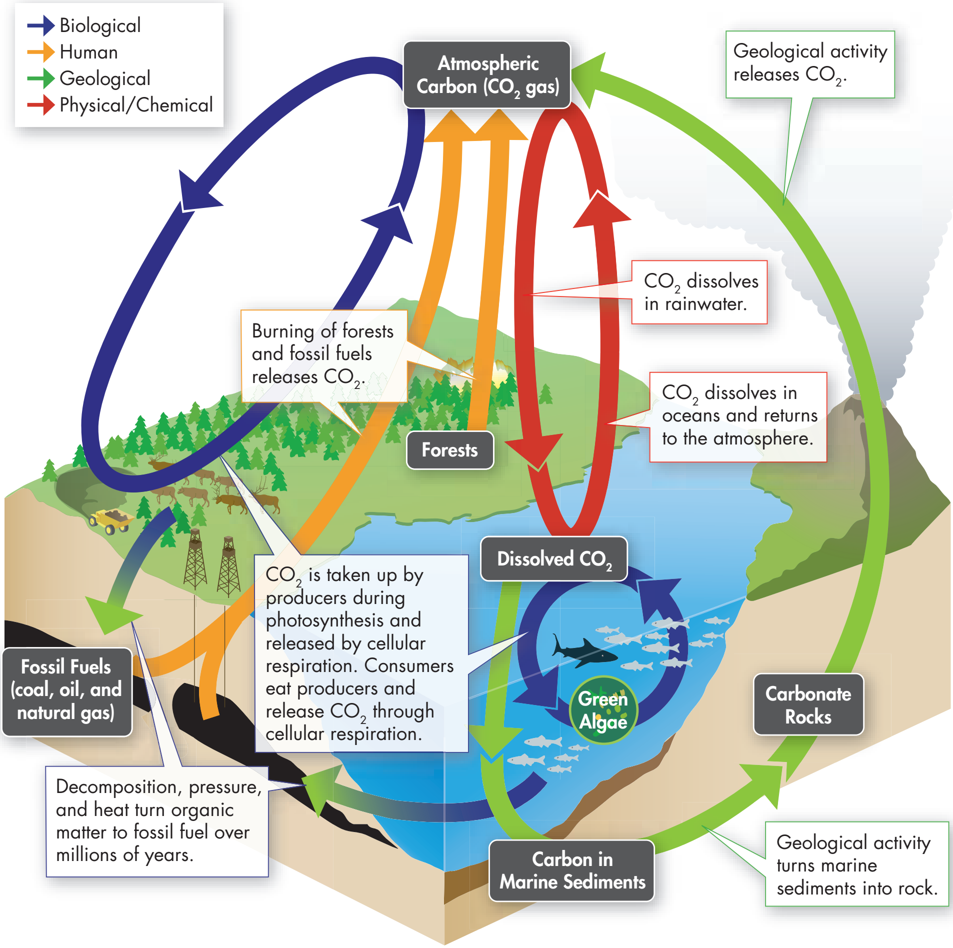
The Carbon Cycle Carbon is a major component of all organic compounds, including carbohydrates, lipids, proteins, and nucleic acids. In fact, carbon is such a key ingredient of living tissue and ecosystems that life on Earth is often described as "carbon-based life." Carbon in the form of calcium carbonate ($CaCO_3$) is an important component of many different kinds of animal skeletons and is also found in several kinds of rocks. Carbon and oxygen form carbon dioxide gas (CO_2), which is an important component of the atmosphere and is dissolved in oceans.

Some carbon-containing compounds that were once part of ancient forests have been buried and transformed by geological processes into coal. The bodies of marine organisms containing carbon have been transformed into oil or natural gas. Coal, oil, and natural gas are often referred to as fossil fuels because they are essentially "fossilized" carbon. Major reservoirs of carbon in the biosphere include the atmosphere, oceans, rocks, fossil fuels, and forests.

Figure 3–17 shows how carbon moves through the biosphere. Carbon dioxide is continuously exchanged between the atmosphere and oceans through chemical and physical processes. Plants take in carbon dioxide during photosynthesis and use the carbon to build carbohydrates. Carbohydrates then pass through food webs to consumers. Many animals—both on land and in the sea—combine carbon with calcium and oxygen as the animals build skeletons of calcium carbonate. Organisms release carbon in the form of carbon dioxide gas by respiration. Also, when organisms die, decomposers break down the bodies, releasing carbon to the environment. Geologic forces can turn accumulated carbon into carbon-containing rocks or fossil fuels. Carbon dioxide is released into the atmosphere by volcanic activity or by human activities, such as the burning of fossil fuels and the clearing and burning of forests.

BUILD Vocabulary

ACADEMIC WORDS The verb **accumulate** means "to collect or gather." Carbon accumulates, or collects, in soil and in the oceans where it cycles among organisms or is turned into fossil fuels.



Scientists know a great deal about the biological, geological, chemical, and human processes that are involved in the carbon cycle, but important questions remain. How much carbon moves through each pathway? How do ecosystems respond to changes in atmospheric carbon dioxide concentration? How much carbon dioxide can the ocean absorb? Later in this unit, you will learn why answers to these questions are so important.

In Your Notebook *Describe one biological, one geological, one chemical, and one human activity that is involved in the carbon cycle.*

FIGURE 3–17 The Carbon Cycle Carbon is found in several large reservoirs in the biosphere. In the atmosphere, it is found as carbon dioxide gas (CO_2); in the oceans, as dissolved carbon dioxide; on land, in organisms, rocks, and soil; and underground, as coal, petroleum, and calcium carbonate. **Interpret Visuals** ***What is one of the processes that takes carbon dioxide out of the atmosphere?***

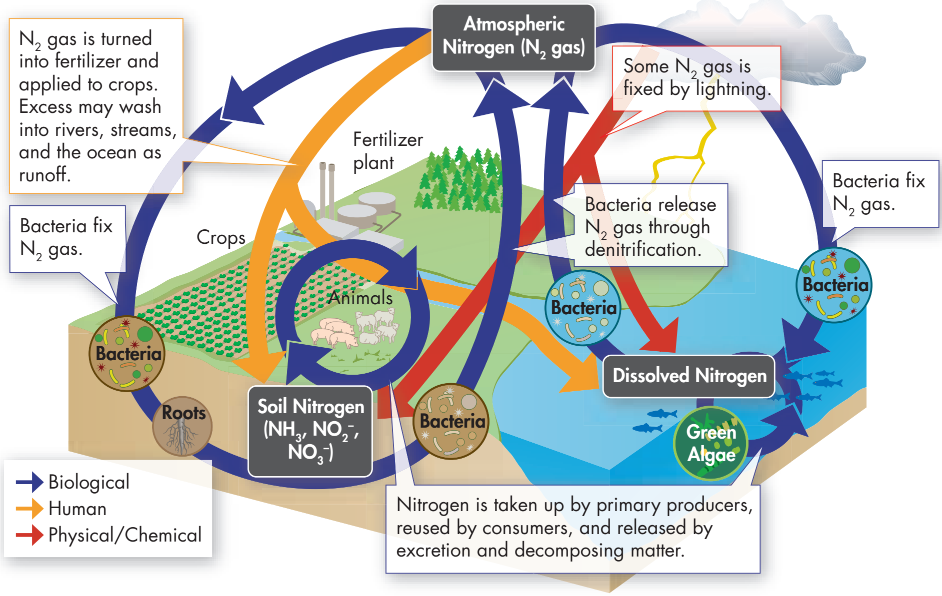


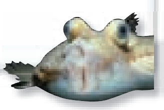
FIGURE 3–18 The Nitrogen Cycle The atmosphere is the largest reservoir of nitrogen in the biosphere. Nitrogen also cycles through the soil and through the tissues of living organisms. **Interpret Visuals** ***Through which two processes does nitrogen gas get converted into usable forms for organisms?***

The Nitrogen Cycle All organisms require nitrogen to make amino acids, which are used to build nucleic acids, which combine to form DNA, RNA, and proteins. Many different forms of nitrogen occur naturally in the biosphere. Nitrogen gas (N_2) makes up 78 percent of Earth's atmosphere. Nitrogen-containing substances such as ammonia (NH_3), nitrate ions (NO_3^-), and nitrite ions (NO_2^-) are found in soil, in the wastes produced by many organisms, and in dead and decaying organic matter. Dissolved nitrogen also exists in several forms in the ocean and other large water bodies. **Figure 3–18** shows how different forms of nitrogen cycle through the biosphere.

Although nitrogen gas is the most abundant form of nitrogen on Earth, only certain types of bacteria can use this form directly. These bacteria live in the soil and on the roots of certain plants, such as peanuts and peas, called legumes. The bacteria convert nitrogen gas into ammonia, in a process known as **nitrogen fixation.** Other soil bacteria convert that fixed nitrogen into nitrates and nitrites. Once these forms of nitrogen are available, primary producers can use them to make proteins and nucleic acids. Consumers eat the producers and reuse nitrogen to make their own nitrogen-containing compounds. Decomposers release nitrogen from waste and dead organisms as ammonia, nitrates, and nitrites that producers may take up again. Other soil bacteria obtain energy by converting nitrates into nitrogen gas, which is released into the atmosphere in a process called **denitrification.** A relatively small amount of nitrogen gas is converted to usable forms by lightning in a process called atmospheric nitrogen fixation. Humans add nitrogen to the biosphere through the manufacture and use of fertilizers. Excess fertilizer is often carried into surface water or groundwater by precipitation.

MYSTERY CLUE

Recently, researchers discovered that levels of dissolved nitrogen in the bay have increased. Given that human activity hasn't changed much, which organisms in the bay do you think might be responsible?



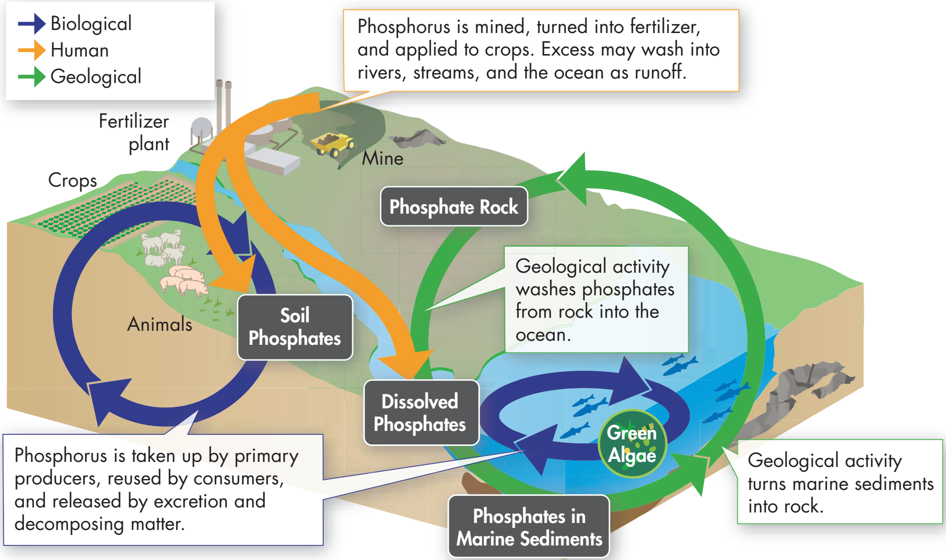


FIGURE 3–19 The Phosphorus Cycle Phosphorus in the biosphere cycles among the land, ocean sediments, and living organisms. Unlike other nutrients, phosphorus is not found in significant quantities in the atmosphere.

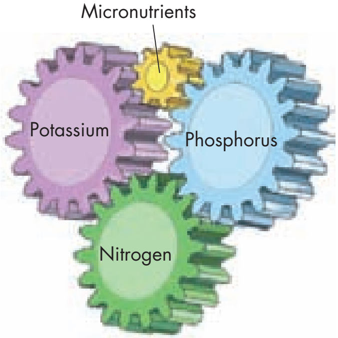
The Phosphorus Cycle Phosphorus is essential to living organisms because it forms a part of vital molecules such as DNA and RNA. Although phosphorus is of great biological importance, it is not abundant in the biosphere. Unlike carbon, oxygen, and nitrogen, phosphorus does not enter the atmosphere in significant amounts. Instead, phosphorus in the form of inorganic phosphate remains mostly on land, in the form of phosphate rock and soil minerals, and in the ocean, as dissolved phosphate and phosphate sediments, as seen in **Figure 3–19.**

As rocks and sediments gradually wear down, phosphate is released. Some phosphate stays on land and cycles between organisms and soil. Plants bind phosphate into organic compounds when they absorb it from soil or water. Organic phosphate moves through the food web, from producers to consumers, and to the rest of the ecosystem. Other phosphate washes into rivers and streams, where it dissolves. This phosphate may eventually makes its way to the ocean, where marine organisms process and incorporate it into biological compounds.

Nutrient Limitation

How does nutrient availability relate to the primary productivity of an ecosystem?

Ecologists are often interested in an ecosystem's primary productivity—the rate at which primary producers create 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. The nutrient whose supply limits productivity is called the **limiting nutrient.**



VISUAL ANALOGY

INTERLOCKING NUTRIENTS

FIGURE 3–20 The movement of each nutrient through ecosystems depends on the movements of all the others, because all are needed for living systems to function. **Use Analogies** *If these gears were modeling nutrient cycling in the ocean, which gear would typically determine how quickly—or slowly—all the other gears turn?*

Nutrient Limitation in Soil In all but the richest soil, the growth of crop plants is typically limited by one or more nutrients that must be taken up by plants through their roots. That's why farmers use fertilizers! Most fertilizers contain large amounts of nitrogen, phosphorus, and potassium, which help plants grow better in poor soil. Micronutrients such as calcium, magnesium, sulfur, iron, and manganese are necessary in relatively small amounts, and these elements are sometimes included in specialty fertilizers. (Carbon is not included in chemical fertilizers because plants acquire carbon dioxide from the atmosphere during photosynthesis.) All nutrient cycles work together like the gears in **Figure 3–20.** If any nutrient is in short supply—if any wheel "sticks"—the whole system slows down or stops altogether.

Nutrient Limitation in Aquatic Ecosystems The open oceans of the world are nutrient-poor compared to many land areas. Seawater typically contains only 0.00005 percent nitrogen, or 1/10,000 of the amount often found in soil. In the ocean and other saltwater environments, nitrogen is often the limiting nutrient. In streams, lakes, and freshwater environments, phosphorus is typically the limiting nutrient.

Sometimes, such as after heavy rains, an aquatic ecosystem receives a large input of a limiting nutrient—for example, runoff from heavily fertilized fields. When this happens, the result can be an algal bloom—a dramatic increase in the amount of algae and other primary producers. Why can runoff from fertilized fields produce algal blooms? More nutrients are available, so producers can grow and reproduce more quickly. If there are not enough consumers to eat the algae, an algal bloom can occur, in which case algae can cover the water's surface and disrupt the functioning of an ecosystem.

3.4 Assessment

Review Key Concepts

1. a. Review How does the way that matter flows through an ecosystem differ from the way that energy flows?

b. Apply Concepts What are the four types of processes that cycle matter through the biosphere? Give an example of each.

2. a. Review By what two processes is water cycled from land to the atmosphere?

b. Sequence 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.

3. a. Review Why do living organisms need nutrients?

b. Predict Based on your knowledge of the carbon cycle, what do you think might happen if humans were to continue to clear and burn vast areas of forests for building?

4. a. Review Explain how a nutrient can be a limiting factor in an ecosystem.

b. Apply Concepts Look back at the nitrogen and phosphorus cycles (**Figures 3–18** and **3–19**). How is fertilizer runoff related to algal blooms?

WRITE ABOUT SCIENCE

Explanation

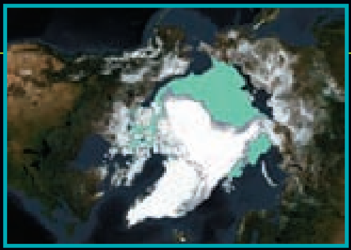
5. Describe how oxygen, although it does not have an independent cycle, moves through the biosphere as part of the carbon cycle. Include a description of the various forms that oxygen takes.

Technology & BIOLOGY

Global Ecology From Space

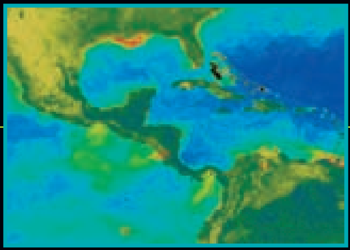
Can ecologists track plant growth around the world? Can they follow temperature change in oceans from day to day, or the amount of polar ice from year to year? Yes! Satellites can provide these data, essential for understanding global ecology. Satellite sensors can be programmed to scan particular bands of the electromagnetic spectrum to reveal global patterns of temperature, rainfall, or the presence of plants on land or algae in the oceans. The resulting false-color images are both beautiful and filled with vital information.

Changes in Polar Ice Cover Sea ice around the North Pole has been melting more each summer since satellites began gathering data in 1979. The image below shows in white the amount of ice remaining at the end of the summer in 2007. The amount of ice at the same time of year for an average year between 1979 and 2007 is shown in green.



2007 White areas show the average minimum amount of arctic ice cover at the end of the summer, 2007.
1979–2007 Green areas show the average minimum amount of ice cover between 1979 and 2007.

Plant and Algal Growth These data were gathered by NASA's Sea-viewing Wide Field-of-view Sensor (SeaWiFS), which is programmed to monitor the color of reflected light. In the image below, you can see how actively plants on land and algae in the oceans were harnessing solar energy for photosynthesis when these data were taken. A measurement of photosynthesis gives a measure of growth rates and the input of energy and nutrients into the ecosystem.



On Land Dark green indicates active plant growth; yellow areas indicate barren deserts or mountains.
In the Sea Dark blue indicates very low active growth of algae. Red indicates the highest active growth.

WRITING Visit the Web site for the Goddard Space Flight Center Scientific Visualization service and select a set of satellite data to examine. Write a brief paragraph explaining what you learned from looking at those data.

Real-World Lab

GUIDED INQUIRY

Pre-Lab: The Effect of Fertilizer on Algae

Problem How do excess nutrients affect the growth of algae?

Materials test tubes, test-tube rack, glass-marking pencil, dropper pipettes, algae culture, 25-mL graduated cylinder, spring water, plant food, cotton balls, grow light

Lab Manual Chapter 3 Lab

Skills Predict, Compare and Contrast, Infer

Connect to the Big Idea In a healthy ecosystem, nutrients cycle among primary producers, consumers, and decomposers. The growth of primary producers is limited by the availability of nutrients. Humans can intentionally increase the amount of nutrients in an ecosystem. For example, farmers may add fertilizer to the soil in which they grow crops. But the addition of nutrients to an ecosystem is not always planned. For example, runoff from soil that contains fertilizer may flow into coastal waters or freshwater ponds. In this lab, you will observe what happens when algae that live in those waters are provided with excess nutrients.

Background Questions

a. **Review** What is a limiting nutrient?

b. **Explain** Why do farmers use fertilizers?

c. **Classify** What role do algae play in freshwater ecosystems?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Design an Experiment** What is the independent variable in this experiment?
2. **Predict** After four days, how will you be able to tell which test tube has more algae?
3. **Control Variables** Why will you grow *Chlorella* in spring water instead of pond water?

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Visit Chapter 3 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Video Help the Untamed Science crew explore food relationships as they turn the ecological pyramid upside down.

Art in Motion View a short animation showing the different levels of organization.

Art Review Review your understanding of which organisms are producers and which are consumers with this drag-and-drop activity.

InterActive Art Build your understanding of the water cycle with this animation.

Data Analysis Collect and analyze some data so you can see how the data is used to monitor a site.

Tutor Tube Get some clarification on producers and consumers and learn how the flow of matter and energy is not what you may think!

Visual Analogies Compare a recycling center to decomposers in this activity. Compare nutrient limitation to a series of cogs in this activity.

3 Study Guide

Big idea Matter and Energy, Interdependence in Nature

The biosphere is composed of an ever-changing mix of living and nonliving components. These components are constantly interacting to form the environments in which organisms struggle to survive and reproduce.

3.1 What Is Ecology?

Ecology is the scientific study of interactions among organisms and between organisms and their physical environment.

The biological influences on organisms are called biotic factors.

Physical components of an ecosystem are called abiotic factors.

Modern ecologists use three methods in their work: observation, experimentation, and modeling. Each of these approaches relies on scientific methodology to guide inquiry.

biosphere (64)
species (64)
population (64)
community (64)
ecology (65)
ecosystem (65)
biome (65)
biotic factor (66)
abiotic factor (66)

3.2 Energy, Producers, and Consumers

Primary producers are the first producers of energy-rich compounds that are later used by other organisms.

Organisms that rely on other organisms for energy and nutrients are called consumers.

autotroph (69)
primary producer (69)
photosynthesis (70)
chemosynthesis (70)
heterotroph (71)
consumer (71)
carnivore (71)
herbivore (71)
scavenger (71)
omnivore (71)
decomposer (71)
detritivore (71)

3.3 Energy Flow in Ecosystems

Energy flows through an ecosystem in a one-way stream, from primary producers to various consumers.

Pyramids of energy show the relative amount of energy available at each trophic level of a food chain or food web. A pyramid of biomass illustrates the relative amount of living organic matter available at each trophic level of an ecosystem. A pyramid of numbers shows the relative number of individual organisms at each trophic level in an ecosystem.

food chain (73)
phytoplankton (73)
food web (74)
zooplankton (76)
trophic level (77)
ecological pyramid (77)
biomass (78)

3.4 Cycles of Matter

Unlike the one-way flow of energy, matter is recycled within and between ecosystems.

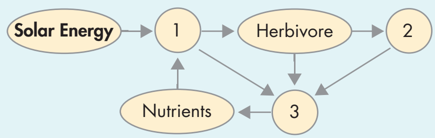
Water continuously moves between the oceans, the atmosphere, and land—sometimes outside living organisms and sometimes inside them.

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 carbon, nitrogen, and phosphorus cycles are especially critical for life.

If ample sunlight and water are available, the primary productivity of an ecosystem may be limited by the availability of nutrients.

biogeochemical cycle (79)
nutrient (82)
nitrogen fixation (84)
denitrification (84)
limiting nutrient (85)

Think Visually Using information from this chapter, complete the following flowchart:



3 Assessment

3.1 What Is Ecology?

Understand Key Concepts

1. All of life on Earth exists in
   a. an ecosystem. **c.** the biosphere.
   b. a biome. **d.** ecology.

2. Which term describes a group of different species that live together in a defined area?
   a. a population **c.** an ecosystem
   b. a community **d.** a biosphere

3. Name the different levels of organization within the biosphere, from smallest to largest.

4. How do ecologists use modeling?

5. Give an example of how a biotic factor might influence the organisms in an ecosystem.

Think Critically

6. **Design an Experiment** Ecologists have discovered that the seeds of many plants that grow in forests cannot germinate unless they have been exposed to fire. Design an experiment to test whether a particular plant has seeds with this requirement. Include your hypothesis statement, a description of control and experimental groups, and an outline of your procedure.

7. **Pose 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?

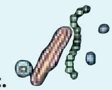
3.2 Energy, Producers, and Consumers

Understand Key Concepts

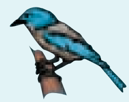
8. Primary producers are organisms that
   a. rely on other organisms for their energy and food supply.
   b. consume plant and animal remains and other dead matter.
   c. use energy they take in from the environment to convert inorganic molecules into complex organic molecules.
   d. obtain energy by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

9. Which of the following organisms is a decomposer?

a.


c.


b.


d.


10. Which of the following describes how ALL consumers get their energy?
    a. directly from the sun
    b. from eating primary producers
    c. from inorganic chemicals like hydrogen sulfide
    d. from eating organisms that are living or were once living

11. What is chemosynthesis?

Think Critically

12. **Classify** Classify each of the following as an herbivore, a carnivore, an omnivore, or a detritivore: earthworm, bear, cow, snail, owl, human.

13. **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 hypothesis can you make to explain the ultimate source of energy for these organisms?

3.3 Energy Flow in Ecosystems

Understand Key Concepts

14. The series of steps in which a large fish eats a small fish that has eaten algae is a
    a. food web. **c.** pyramid of numbers.
    b. food chain. **d.** pyramid of biomass.

15. The total amount of living tissue at each trophic level in an ecosystem can be shown in a(n)
    a. energy pyramid. **c.** biomass pyramid.
    b. pyramid of numbers. **d.** biogeochemical cycle.

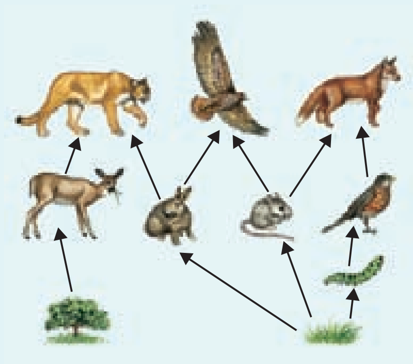
Think Critically

16. Which group of organisms is always found at the base of a food chain or food web?

17. **Apply Concepts** Why is the transfer of energy in a food chain usually only about 10 percent efficient?

18. **Use Models** Describe a food chain of which you are a member. You may draw or use words to describe the chain.

19. **Use Models** Create flowcharts that show four different food chains in the food web shown below.



3.4 Cycles of Matter

Understand Key Concepts

20. Nutrients move through an ecosystem in
- **a.** biogeochemical cycles.
- **b.** water cycles.
- **c.** energy pyramids.
- **d.** ecological pyramids.

21. Which biogeochemical cycle does NOT include a major path in which the substance cycles through the atmosphere?
- **a.** water cycle
- **b.** carbon cycle
- **c.** nitrogen cycle
- **d.** phosphorus cycle

22. List two ways in which water enters the atmosphere in the water cycle.

23. Explain the process of nitrogen fixation.

24. What is meant by "nutrient limitation"?

solve the CHAPTER MYSTERY

CHANGES IN THE BAY

According to one hypothesis, rising water temperatures have caused most of the changes reported in Narragansett Bay. The bay's temperature has risen more than 1.5°C (3°F) since 1960. This warmth encourages bluefish to stay in the bay later in the fall. It also allows predatory warm-water shrimp to remain in the bay all winter, feeding on baby flounder. Warmer water also enables zooplankton to graze heavily on marine algae. This eliminates the late-winter algal bloom whose primary production used to provide organic carbon to the entire food web.

Those food web changes, in turn, seem to be driving unexpected shifts in the activities of bacteria that transform nitrogen. When the spring bloom provided organic carbon, bacteria denitrified the water, releasing nitrogen into the atmosphere. Now, the bacterial community has changed and actually fixes nitrogen, bringing more of it into the water. It is still not clear what this change means for the long-term health of the bay and adjacent coastal waters.

1. **Compare and Contrast** Compare the original situation in the bay with the current situation, taking note of changes in both the food web and the nitrogen cycle.

2. **Infer** Narragansett Bay harbors sea jellies that prefer warm water and have previously been present only in summer and early fall. These sea jellies eat fish eggs, fish larvae, and zooplankton. If the bay continues to warm, what do you think might happen to the population of sea jellies in the bay? What might that mean for the organisms the jellies feed on?

3. **Connect to the Big idea** Explain how the Narragansett Bay example demonstrates interconnections among members of a food web and abiotic environmental factors. Can you find similar studies in other aquatic habitats, such as Chesapeake Bay, the Everglades, or the Mississippi River delta? Explain.

Think Critically

25. Form a Hypothesis Ecologists discovered that trout were dying in a stream that ran through some farmland where nitrogen fertilizer was used on the crops. How might you explain what happened?

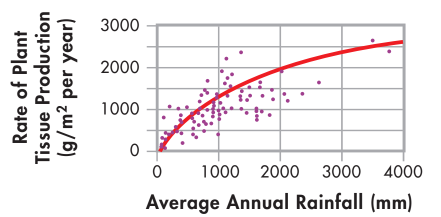
26. Apply Concepts Using a flowchart, trace the flow of energy in a simple marine food chain. Then, show where nitrogen is cycled through the chain when the top-level carnivore dies and is decomposed.

Connecting Concepts

Use Science Graphics

The graph below shows the effect of annual rainfall on the rate of primary productivity in an ecosystem. Use the graph to answer questions 27–29.

The Effect of Rainfall on Plant Productivity



27. Interpret Graphs What happens to productivity as rainfall increases?

28. Predict 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.

29. Apply Concepts What factors other than water might affect primary productivity?

Write About Science

30. Explanation Write a paragraph that (1) names and defines the levels of organization that an ecologist studies; (2) identifies the level that you would choose to study if you were an ecologist; (3) describes the method or methods you would use to study this level; and (4) gives a reason for your choice of method or methods.

31. Description Describe how biogeochemical cycles provide organisms with the raw materials necessary to synthesize complex organic compounds. Refer back to Chapter 2 for help in answering this question.

32. Assess the Big idea Explain how an element like carbon can be included in both the biotic and abiotic factors of an ecosystem.

Analyzing Data

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 table.

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

33. Interpret Tables Which of the following is the best description of what happens to the amount of available oxygen as you get deeper in the ocean?

a. Available oxygen decreases at a constant rate.
b. Available oxygen increases at a constant rate.
c. Available oxygen remains steady until about 100 m, then drops rapidly.
d. Oxygen is available at all ocean depths.

34. Draw Conclusions 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.

Standardized Test Prep

Multiple Choice

1. A group of individuals that belong to a single species and that live together in a defined area is termed a(n)
   A population. **C** community.
   B ecosystem. **D** biome.

2. Which of the following is NOT true about matter in the biosphere?
   A Matter is recycled in the biosphere.
   B Biogeochemical cycles transform and reuse molecules.
   C The total amount of matter decreases over time.
   D Water and nutrients pass between organisms and the environment.

3. Which is a source of energy for Earth's living things?
   A wind energy only
   B sunlight only
   C wind energy and sunlight
   D sunlight and chemical energy

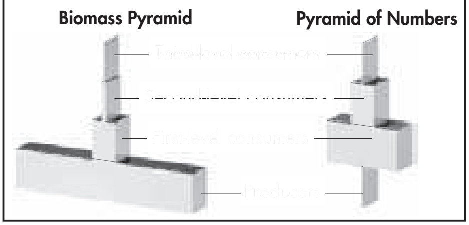
4. Which of the following is a primary producer?
   A a producer, like algae
   B a carnivore, like a lion
   C an omnivore, like a human
   D a detritivore, like an earthworm

5. Human activities, such as the burning of fossil fuels, move carbon through the carbon cycle. Which other processes also participate in the carbon cycle?
   A biological processes only
   B geochemical processes only
   C chemical processes only
   D a combination of biological, geological, and chemical processes

6. What are the physical, or nonliving components of an ecosystem called?
   A abiotic factors
   B temperate conditions
   C biotic factors
   D antibiotic factors

Questions 7–8

The diagrams below represent the amount of biomass and the numbers of organisms in an ecosystem.



7. What can you conclude about the ecosystem from the pyramid of numbers shown?
   A There are more first-level consumers than producers.
   B There are more third-level consumers than second-level consumers.
   C There are more producers than first-level consumers.
   D There are more second-level consumers than first-level consumers.

8. What can you conclude about the producers in the ecosystem based on the two pyramids shown?
   A The producers in the ecosystem are probably very small organisms.
   B There are no producers in the ecosystem.
   C The producers in the ecosystem are probably large organisms.
   D Decomposers in the ecosystem outnumber the producers in the ecosystem.

Open-Ended Response

9. What ultimately happens to the bulk of matter in any trophic level of a biomass pyramid—that is, the matter that does not get passed to the trophic level above?

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9
See Lesson	3.1	3.4	3.2	3.2	3.4	3.1	3.3	3.3	3.3