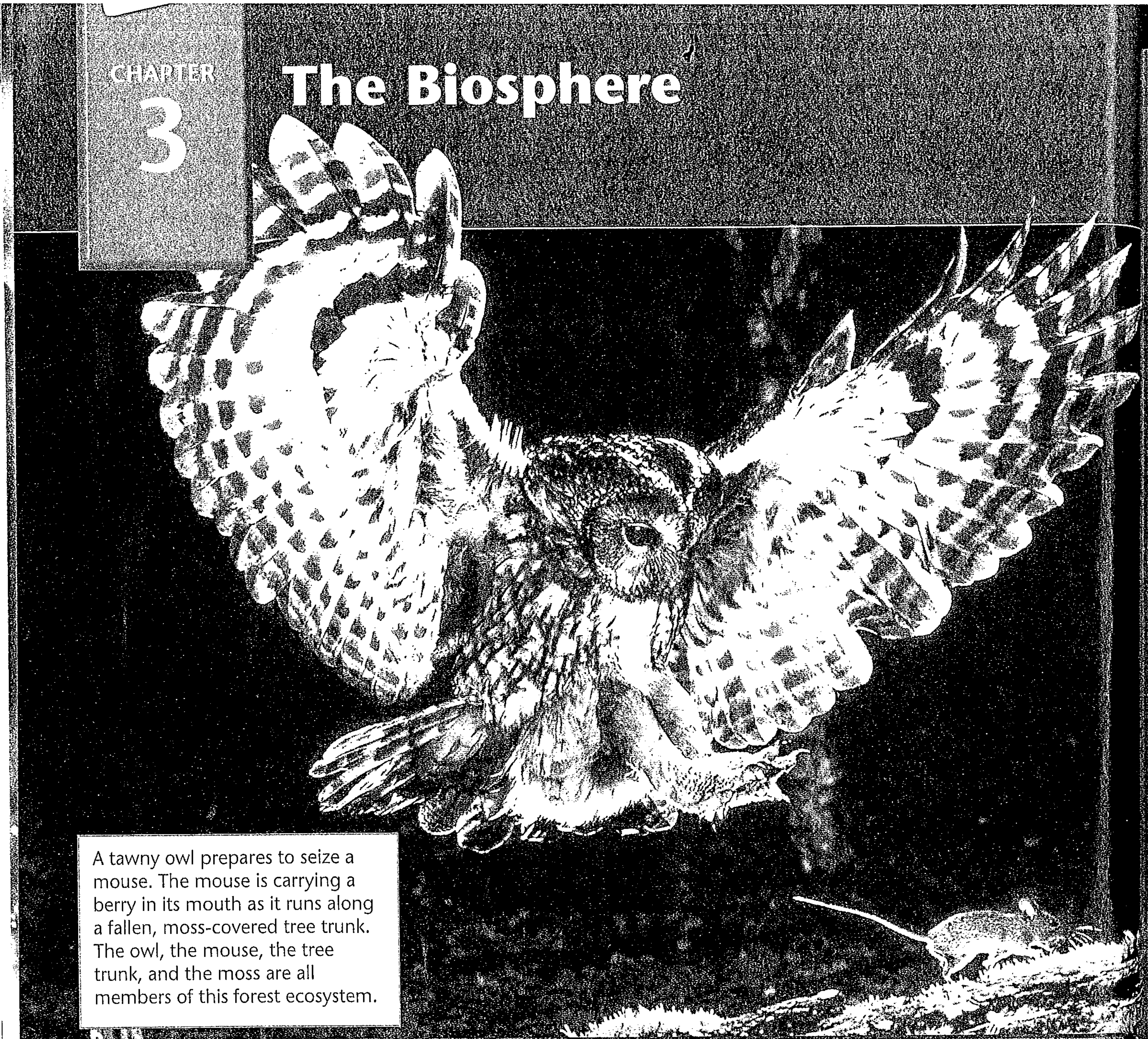
CHAPTER 3

The Biosphere



A tawny owl prepares to seize a mouse. The mouse is carrying a berry in its mouth as it runs along a fallen, moss-covered tree trunk. The owl, the mouse, the tree trunk, and the moss are all members of this forest ecosystem.

Inquiry Activity

How do organisms affect one another's survival?

Procedure

1. Make a list of all the types of organisms, including plants, humans, insects, and so on, that you have seen near your home or school.
2. Make a diagram that shows how the organisms on your list interact with one another.

Think About It

1. **Classifying** Which organisms on your list provide energy or nutrients to the others?
2. **Predicting** What would you expect to happen if all the plants on your diagram died? Explain your answer.
3. **Asking Questions** Why is it difficult to make accurate predictions about changes in communities of organisms?

3–1 What Is Ecology?

"Floods hit Texas!" "Wildfires char three states!" "Drought withers Florida!" Such news often flashes across television screens, newspapers, and the Internet. We are fascinated and frightened by these natural events, but there are other stories, as well. Some tell of projects to restore wetlands in southern Florida and along the Mississippi River for the purpose of controlling floods and droughts. Others report on improvements in air and water quality as a result of changes in the gasoline that we put in our cars. Like all organisms, we interact with our environment. To understand these interactions better and to learn how to control them, we turn to the science called ecology.

Guide for Reading

Key Concepts
- What different levels of organization do ecologists study?
- What methods are used to study ecology?

Vocabulary
ecology
biosphere
species
population
community
ecosystem
biome

Reading Strategy: Asking Questions Before you read, rewrite the headings in this section as *how, what,* or *why* questions about ecology. Then, as you read, write brief answers to your questions.

Interactions and Interdependence

Ecology (ee-KAHL-uh-jee) is the scientific study of interactions among organisms and between organisms and their environment, or surroundings. The word *ecology* was coined in 1866 by the German biologist Ernst Haeckel. Haeckel based this term on the Greek word *oikos,* meaning house, which is also the root of the word *economy.* Haeckel saw the living world as a household with an economy in which each organism plays a role.

Nature's "houses" come in many sizes—from single cells to the entire planet. The largest of these houses is called the biosphere. The **biosphere** contains the combined portions of the planet in which all of life exists, including land, water, and air, or atmosphere. It extends from about 8 kilometers above Earth's surface to as far as 11 kilometers below the surface of the ocean.

Interactions within the biosphere produce a web of interdependence between organisms and the environment in which they live. Whether it occurs on top of a glacier, in a forest like the one in **Figure 3–1,** or deep within an ocean trench, the interdependence of life on Earth contributes to an ever-changing, or dynamic, biosphere.

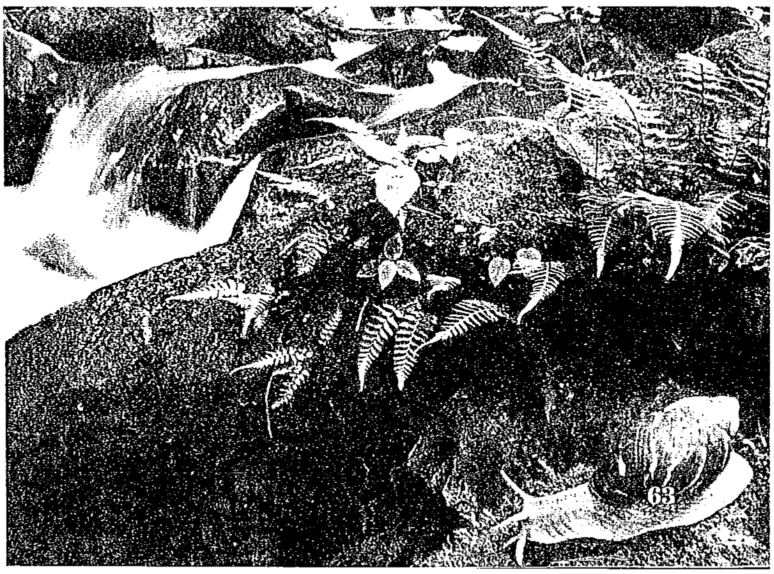
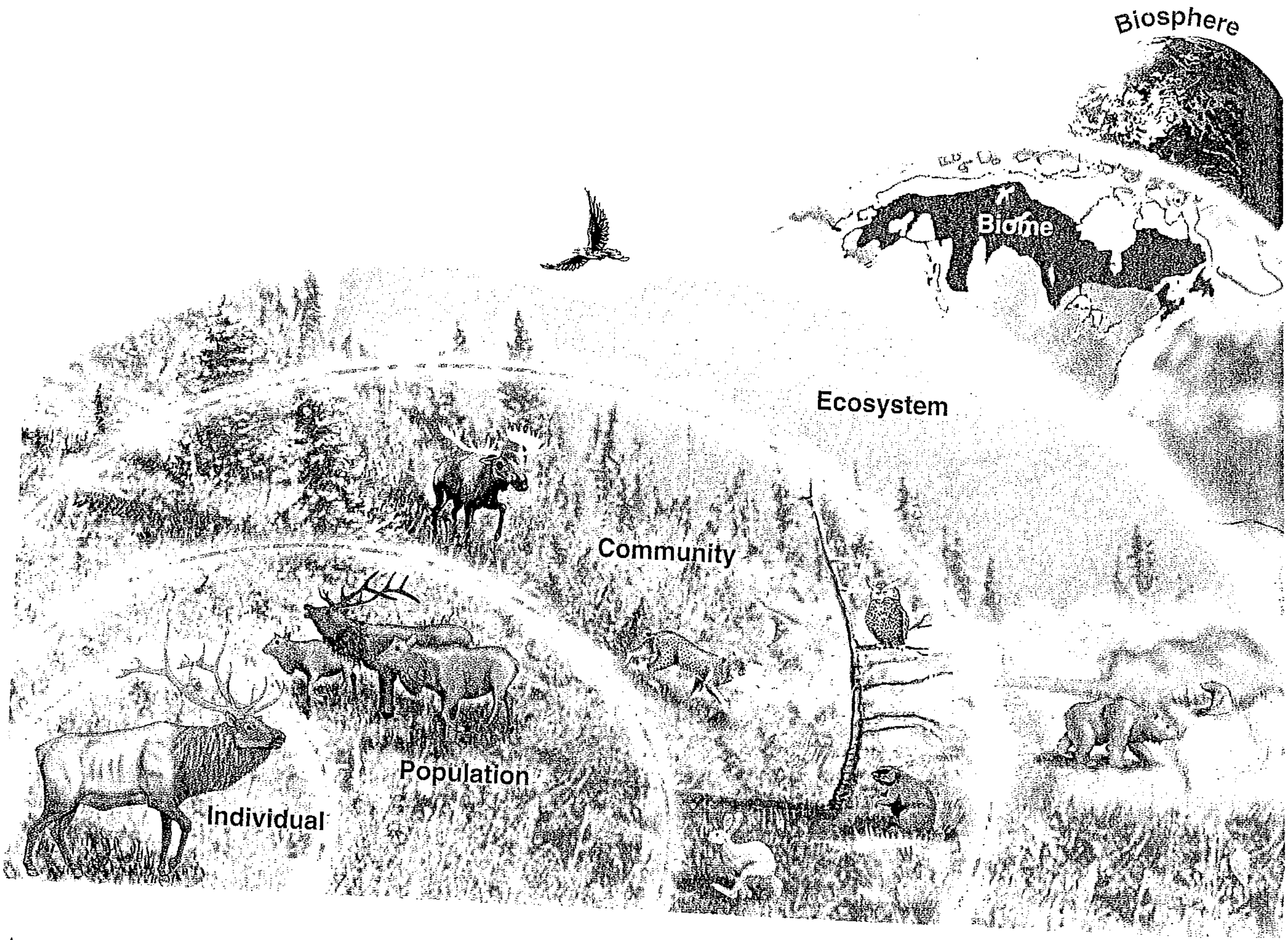


Figure 3–1 Organisms and their environment are interdependent. This giant land snail could not survive without plants and algae to eat, and the plants and algae could not grow unless bacteria and other organisms helped recycle nutrients in the water and soil. **Classifying** *List the organisms that you see in the photograph. Then, list the nonliving parts of the environment with which the organisms interact.*



▲ **Figure 3–2** The study of ecology ranges from the study of an individual organism to populations, communities, ecosystems, biomes—and, finally, to the entire biosphere. The information that ecologists gain at each level contributes to our understanding of natural systems.

Levels of Organization

To understand relationships within the biosphere, ecologists ask questions about events and organisms that range in complexity from a single individual to the entire biosphere. The many levels of organization that ecologists study are shown in **Figure 3–2.**

Some ecologists study interactions between a particular kind of organism and its surroundings. Such studies focus on the species level. A **species** is a group of organisms so similar to one another that they can breed and produce fertile offspring. Other ecologists study **populations,** or groups of individuals that belong to the same species and live in the same area. Still other ecologists study **communities,** or assemblages of different populations that live together in a defined area.

Ecologists may study a particular ecosystem. An **ecosystem** is a collection of all the organisms that live in a particular place, together with their nonliving, or physical, environment. Larger systems called biomes are also studied by teams of ecologists. A **biome** is a group of ecosystems that have the same climate and similar dominant communities. The highest level of organization that ecologists study is the entire biosphere itself.

✓CHECKPOINT *What is an ecosystem?*

Ecological Methods

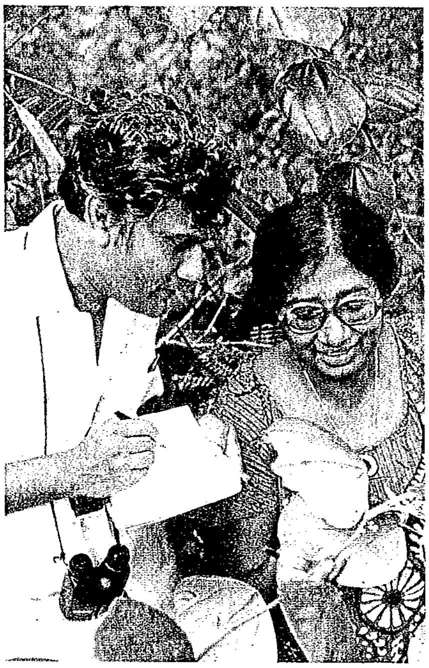
Ecologists use a wide range of tools and techniques to study the living world. Some, like the scientists in **Figure 3–3**, use binoculars and field guides to assess changes in plant and wildlife communities. Others use studies of DNA to identify bacteria in the mud of coastal marshes. Still others use radio tags to track migrating wildlife or use data gathered by satellites.

Regardless of the tools they use, scientists conduct modern ecological research using three basic approaches: observing, experimenting, and modeling. All of these approaches rely on the application of scientific methods to guide ecological inquiry.

Observing Observing is often the first step in asking ecological questions. Some observations are simple: What species live here? How many individuals of each species are there? Other observations are more complex and may form the first step in designing experiments and models.

Experimenting Experiments can be used to test hypotheses. An ecologist may set up an artificial environment in a laboratory to imitate and manipulate conditions that organisms would encounter in the natural world. Other experiments are conducted within natural ecosystems.

Modeling Many ecological phenomena occur over long periods of time or on such large spatial scales that they are difficult to study. Ecologists make models to gain insight into complex phenomena such as the effects of global warming on ecosystems. Many ecological models consist of mathematical formulas based on data collected through observation and experimentation. The predictions made by ecological models are often tested by further observations and experiments.



▲ **Figure 3–3** **The three fundamental approaches to ecological research involve observing, experimenting, and modeling.** These ecologists are studying a rain forest ecosystem in Sri Lanka. They are using field observations to collect data on vines and other plants.

3–1 Section Assessment

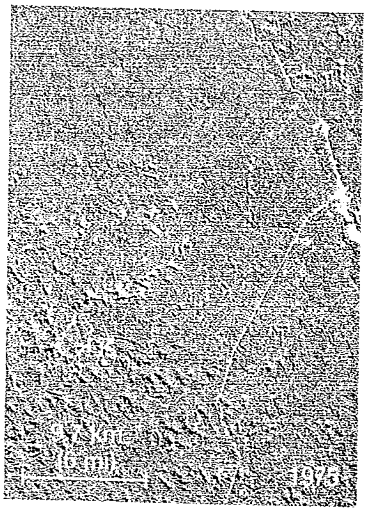
1. **Key Concept** List the six different levels of organization that ecologists study, in order from smallest to largest.
2. **Key Concept** Describe the three basic methods of ecological research.
3. Identify two ways in which you interact every day with each of the three parts of the biosphere—land, water, and air.
4. **Critical Thinking Applying Concepts** Suppose you wanted to know if the water in a certain stream is safe to drink. Which ecological method(s) would you choose, and why?
5. **Critical Thinking Applying Concepts** Give an example of an ecological phenomenon that could be studied by modeling. Explain why modeling would be useful.

Thinking Visually

Creating a Table
Refer to **Figure 3–2**, which shows the various levels of organization that ecologists study. In a table, provide examples of the ecological levels where you live—individuals, populations, communities, and ecosystems—that could be studied by ecologists. *Hint:* You may wish to use library resources or the Internet.

TECHNOLOGY & SOCIETY

Exploring Ecology From Space



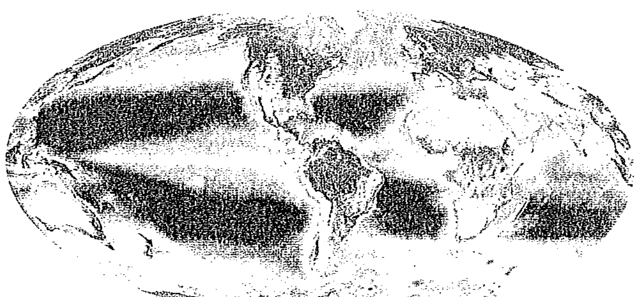
Modern research in global ecology would not be possible if all its tools were earth-bound. Studies on a planetary scale require enormous data-gathering networks. Through a process called remote sensing, satellites extend the range of information that ecologists can collect within the biosphere.

Remote-sensing satellites are fitted with optical sensors that can scan several bands of the electromagnetic spectrum and convert those bands into electrical signals. The signals are run through a computer and converted into digital values, which are used to construct an image.

Remote sensing provides detailed images of essentially every square meter of Earth's surface. How else could scientists view all the world's lakes and oceans to see where concentrations of algae are the highest? Or view areas of destroyed forests in places like the Amazon Basin or northern Russia?

Global Change

The false-color image below was assembled from data gathered by NASA's Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Project. The project's goal is to study factors that affect global change and to assess the oceans' role in the global carbon cycle, as well as other chemical cycles. The different ocean colors indicate varying concentrations of microscopic algae. Blue represents the least amount of algae, and red represents the highest amount. On land, the dark green areas have the most vegetation, and gold land areas have the least.



Rain Forest Destruction

Satellite images that show the presence or absence of vegetation are useful in studying the effects of human activity on natural ecosystems. The two images above, taken 26 years apart, show the same tract of land in a Brazilian rain forest. Red areas show undisturbed forest, and whitish areas show places where trees have been cut and cleared. Note the "fishbone" pattern of vegetation clearing. This pattern occurs because cutting of forests typically begins along existing roads and rivers and then spreads out as new roads and paths are cut.

Data in images such as these, especially when taken over time, help ecologists estimate the rate at which rain forests are being cut down. These data are also valuable in discussing the effects of development with local governments.

Research and Decide

Use library or Internet resources to learn more about the use of satellites in ecological studies. Decide how ecologists and local governments might use the data in their discussion.

Go Online PHSchool.com
For: Links from the authors
Visit: PHSchool.com
Web Code: cbe-2031

3–2 Energy Flow

At the core of every organism's interaction with the environment is its need for energy to power life's processes. Consider, for example, the energy that ants use to carry objects many times their size or the energy that birds use to migrate thousands of miles. Think about the energy that you need to get out of bed in the morning! The flow of energy through an ecosystem is one of the most important factors that determines the system's capacity to sustain life.

Guide for Reading

Key Concepts
- Where does the energy for life processes come from?
- How does energy flow through living systems?
- How efficient is the transfer of energy among organisms in an ecosystem?

Vocabulary
autotroph • producer
photosynthesis
chemosynthesis • heterotroph
consumer • herbivore
carnivore • omnivore
detritivore • decomposer
food chain • food web
trophic level
ecological pyramid • biomass

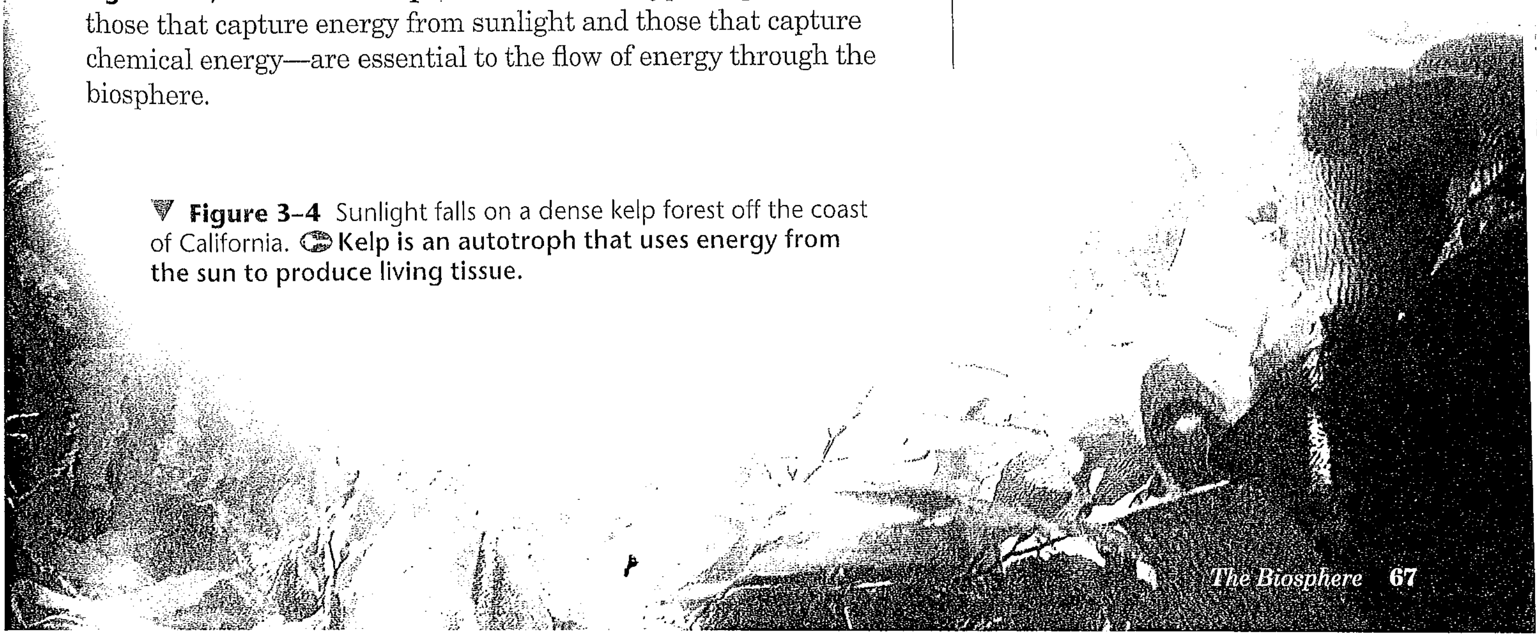
Reading Strategy: Building Vocabulary As you read, make notes about the meaning of each term in the list above and how it relates to energy flow in the biosphere. Then, draw a concept map to show the relationships among these terms.

Producers

Without a constant input of energy, living systems cannot function. **Sunlight is the main energy source for life on Earth.** Of all the sun's energy that reaches Earth's surface, only a small amount—less than 1 percent—is used by living things. This seemingly small amount is enough to produce as much as 3.5 kilograms of living tissue per square meter a year in some tropical forests.

In a few ecosystems, some organisms obtain energy from a source other than sunlight. **Some types of organisms rely on the energy stored in inorganic chemical compounds.** For instance, mineral water that flows underground or boils out of hot springs and undersea vents is loaded with chemical energy.

Only plants, some algae, and certain bacteria can capture energy from sunlight or chemicals and use that energy to produce food. These organisms are called **autotrophs.** Autotrophs use energy from the environment to fuel the assembly of simple inorganic compounds into complex organic molecules. These organic molecules combine and recombine to produce living tissue. Because they make their own food, autotrophs, like the kelp in **Figure 3–4**, are also called **producers.** Both types of producers—those that capture energy from sunlight and those that capture chemical energy—are essential to the flow of energy through the biosphere.



▼ **Figure 3–4** Sunlight falls on a dense kelp forest off the coast of California. **Kelp is an autotroph that uses energy from the sun to produce living tissue.**

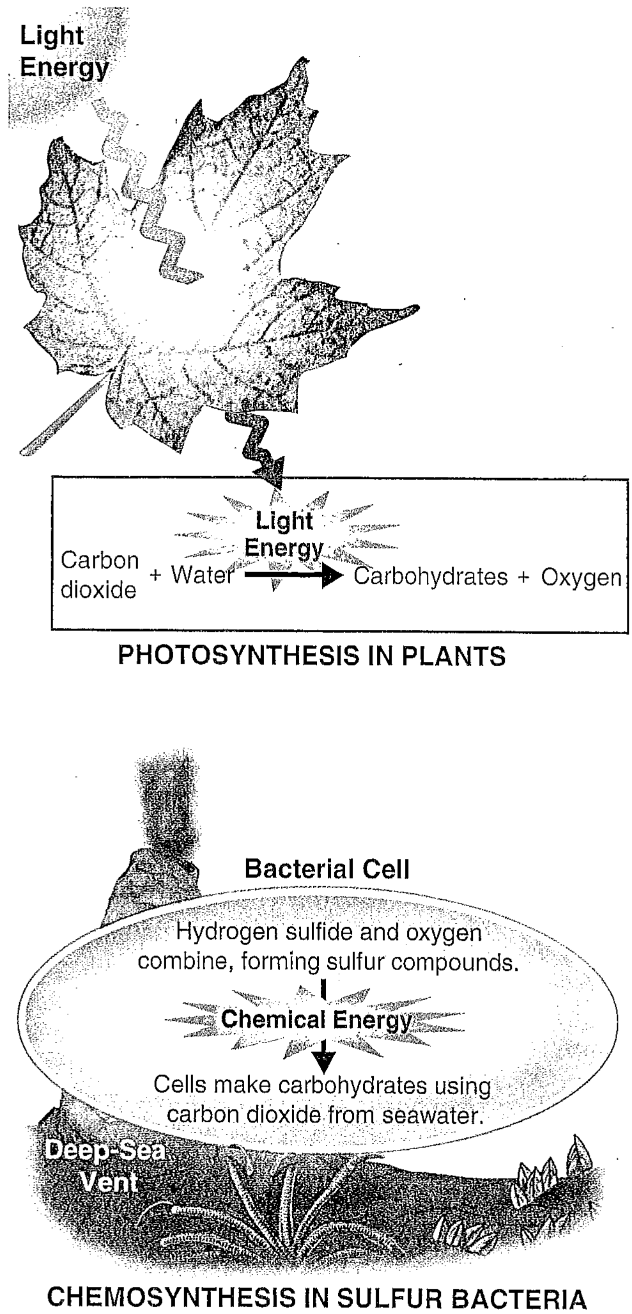


Figure 3–5 **Sunlight is the main energy source for life on Earth. Some types of organisms rely on the energy stored in inorganic chemical compounds.** Plants use the energy from sunlight to carry out the process of photosynthesis. Other autotrophs, such as sulfur bacteria, use the energy stored in chemical bonds for chemosynthesis. In both cases, energy-rich carbohydrates are produced.

Energy From the Sun The best-known autotrophs are those that harness solar energy through a process known as photosynthesis. During **photosynthesis,** these autotrophs use light energy 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** (top), is responsible for adding oxygen to—and removing carbon dioxide from—Earth's atmosphere. In fact, were it not for photosynthetic autotrophs, the air would not contain enough oxygen for you to breathe!

On land, plants are the main autotrophs. In freshwater ecosystems and in the sunlit upper layers of the ocean, algae are the main autotrophs. Photosynthetic bacteria, the most common of which are the cyanobacteria (sy-an-oh-bak-TEER-ee-uh), are important in certain wet ecosystems such as tidal flats and salt marshes.

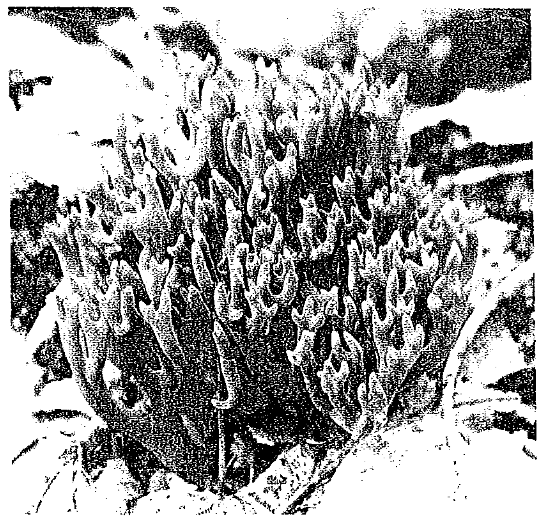
Life Without Light Although plants are the most visible and best-known autotrophs, some autotrophs can produce food in the absence of light. Such autotrophs rely on energy within the chemical bonds of inorganic molecules such as hydrogen sulfide. When organisms use chemical energy to produce carbohydrates, the process is called **chemosynthesis** (kee-moh-SIN-thuh-sis), as shown in **Figure 3–5** (bottom). This process is performed by several types of bacteria. Surprisingly, these bacteria represent a large proportion of living autotrophs. Some chemosynthetic bacteria live in very remote places on Earth, such as volcanic vents on the deep-ocean floor and hot springs in Yellowstone Park. Others live in more common places, such as tidal marshes along the coast.

✓CHECKPOINT *What is the difference between photosynthesis and chemosynthesis?*

Consumers

Many organisms—including animals, fungi, and many bacteria—cannot harness energy directly from the physical environment as autotrophs do. The only way these organisms can acquire energy is from other organisms. Organisms that rely on other organisms for their energy and food supply are called **heterotrophs** (HET-ur-oh-trohfs). Heterotrophs are also called **consumers.**

There are many different types of heterotrophs. **Herbivores** obtain energy by eating only plants. Some herbivores are cows, caterpillars, and deer. **Carnivores,** including snakes, dogs, and owls, eat animals. Humans, bears, crows, and other **omnivores** eat both plants and animals. **Detritivores,** (dee-TRYT-uh-vawrz), such as mites, earthworms, snails, and crabs, feed on plant and animal remains and other dead matter, collectively called detritus. Another important group of heterotrophs, called **decomposers,** breaks down organic matter. Bacteria and fungi, such as the one in **Figure 3–6,** are decomposers.



▲ **Figure 3–6** This fungus, growing on the forest floor, is a decomposer that obtains nutrients by breaking down dead and decaying plants and animals. It is called a coral fungus because of its color and shape. **Classifying** *Is the fungus a producer or a consumer?*

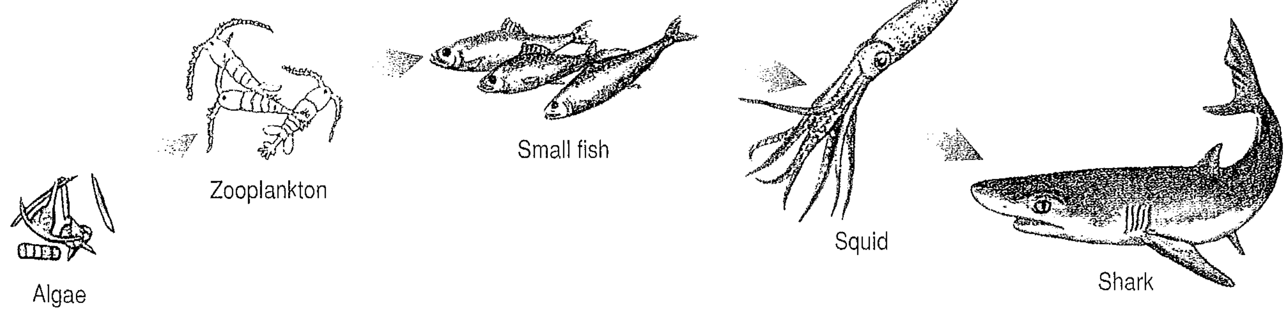
Feeding Relationships

What happens to the energy in an ecosystem when one organism eats another? That energy moves along a one-way path. **Energy flows through an ecosystem in one direction, from the sun or inorganic compounds to autotrophs (producers) and then to various heterotrophs (consumers).** The relationships between producers and consumers connect organisms into feeding networks based on who eats whom.

Food Chains The energy stored by producers can be passed through an ecosystem along a **food chain,** a series of steps in which organisms transfer energy by eating and being eaten. For example, in a prairie ecosystem, a food chain might consist of a producer, such as grass, that is fed upon by a herbivore, such as a grazing antelope. The herbivore is in turn fed upon by a carnivore, such as a coyote. In this situation, the carnivore is only two steps removed from the producer.

In some marine food chains, such as the one in **Figure 3–7,** the producers are microscopic algae that are eaten by very small organisms called zooplankton (zoh-oh-PLANK-tun). The zooplankton, in turn, are eaten by small fish, such as herring. The herring are eaten by squid, which are ultimately eaten by large fish, such as sharks. In this food chain, the top carnivore is four steps removed from the producer.

▼ **Figure 3–7** **Food chains show the one-way flow of energy in an ecosystem.** In this marine food chain, energy is passed from the producers (algae) to four different groups of consumers.



Quick Lab

How is a food chain organized?

Materials 2 wide-mouth jars, 2 pieces of flexible screening, 2 rubber bands, 2 bean seedlings in small pots or paper cups, pea aphids, ladybird beetles

Procedure

1. Place a potted bean seedling in each of the 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. **Formulating Hypotheses** Record your hypothesis about how the presence of the ladybird beetles will affect the survival of the aphids and the bean seedling. Also, record your prediction of what will happen to the organisms in each jar during the next week.
5. 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. **Observing** What happened to the aphids and the seedling in the jar without the ladybird beetles? In the jar with the ladybird beetles? How can you explain this difference?
2. **Classifying** Identify each organism in the jars as a producer or a consumer.

Food Webs In most ecosystems, feeding relationships are more complex than can be shown in a food chain. Consider, for example, the relationships in a salt marsh. Although some producers—including marsh grass and other salt-tolerant plants—are eaten by water birds, grasshoppers, and other herbivores, most producers complete their life cycles, then die and decompose. Decomposers convert the dead plant matter to detritus, which is eaten by detritivores, such as sandhoppers. The detritivores are in turn eaten by smelt and other small fish. Some of those consumers will also eat detritus directly. Add mice, larger fish, and hawks to the scenario, and feeding relationships can get very confusing!

When the feeding relationships among the various organisms in an ecosystem form a network of complex interactions, ecologists describe these relationships as a **food web.** A food web links all the food chains in an ecosystem together. The food web in **Figure 3–8**, for example, shows the feeding relationships in a salt-marsh community.

Trophic Levels Each step in a food chain or food web is called a **trophic** (TRAHF-ik) **level.** Producers make up the first trophic level. Consumers make up the second, third, or higher trophic levels. Each consumer depends on the trophic level below it for energy.

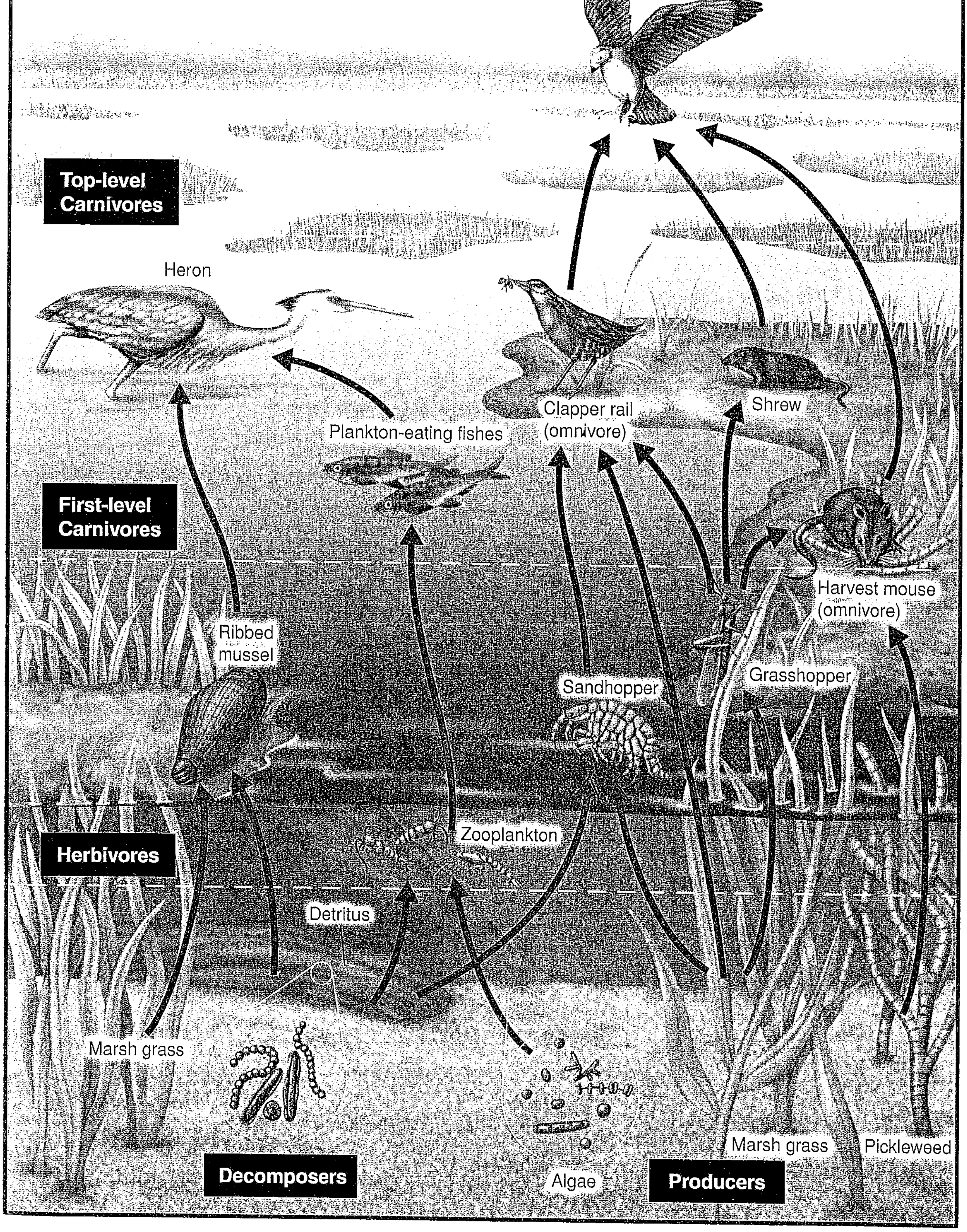
✓CHECKPOINT *What is a food web?*

Word Origins

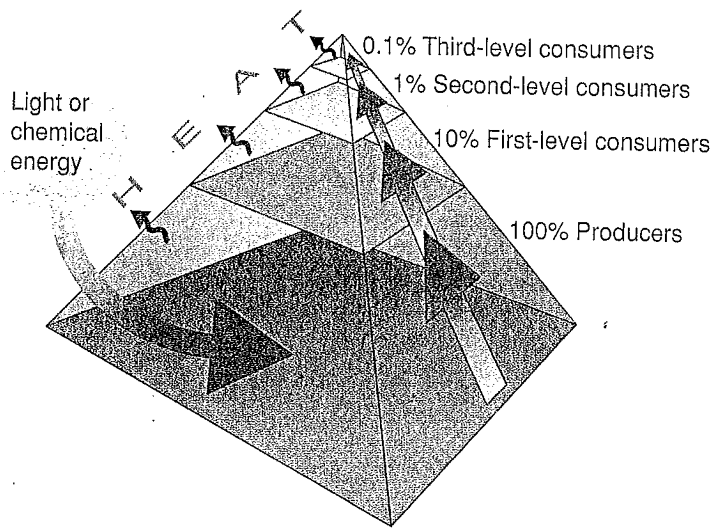
Trophic originates from the Greek word *trophe,* which means "food or nourishment." **What do you think are the original meanings of the words** ***heterotroph*** **and** ***autotroph*****?**

FIGURE 3–8 FOOD WEB IN A SALT MARSH

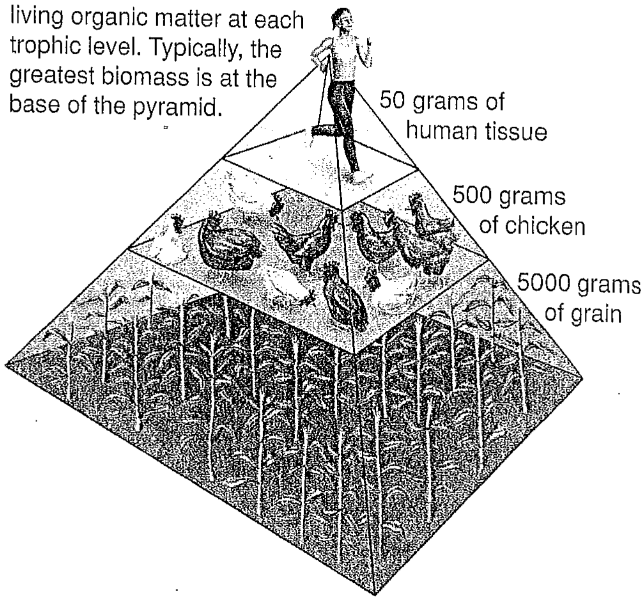
This illustration of a food web shows some of the feeding relationships in a salt marsh. **Interpreting Graphics** *What does the marsh hawk feed on?*



Energy Pyramid
Shows the relative amount of energy available at each trophic level. Organisms use about 10 percent of this energy for life processes. The rest is lost as heat.



Biomass Pyramid
Represents the amount of living organic matter at each trophic level. Typically, the greatest biomass is at the base of the pyramid.



Ecological Pyramids

The amount of energy or matter in an ecosystem can be represented by an ecological pyramid. An **ecological pyramid** is a diagram that shows the relative amounts of energy or matter contained within each trophic level in a food chain or food web. Ecologists recognize three different types of ecological pyramids: energy pyramids, biomass pyramids, and pyramids of numbers. **Figure 3–9** shows an example of each type.

Energy Pyramid Theoretically, there is no limit to the number of trophic levels that a food chain can support. But there is one hitch. Only part of the energy that is stored in one trophic level is passed on to the next level. This is because organisms use much of the energy that they consume for life processes, such as respiration, movement, and reproduction. Some of the remaining energy is released into the environment as heat. **Only about 10 percent of the energy available within one trophic level is transferred to organisms at the next trophic level.** For instance, one tenth of the solar energy captured by grasses ends up stored in the tissues of cows and other grazers. Only one tenth of that energy—10 percent of 10 percent, or 1 percent total—is transferred to the humans that eat the cows. Thus, the more levels that exist between a producer and a top-level consumer in an ecosystem, the less energy that remains from the original amount.

Biomass Pyramid The total amount of living tissue within a given trophic level is called **biomass.** Biomass is usually expressed in terms of grams of organic matter per unit area. A biomass pyramid represents the amount of potential food available for each trophic level in an ecosystem.

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For: Links on energy pyramids
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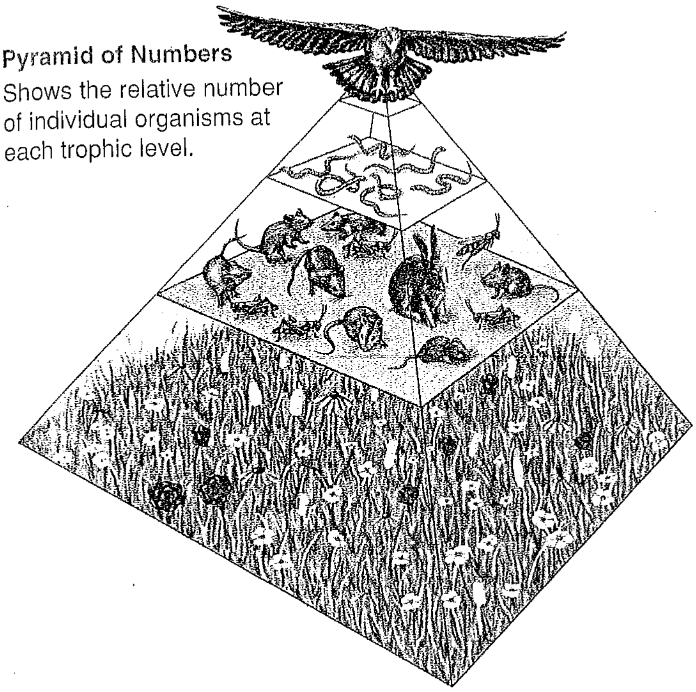


Figure 3–9 Ecological pyramids show the decreasing amounts of energy, living tissue, or number of organisms at successive feeding levels. The pyramid is divided into sections that represent each trophic level. **Because each trophic level harvests only about one tenth of the energy from the level below, it can support only about one tenth the amount of living tissue.**

Pyramid of Numbers Ecological pyramids can also be based on the numbers of individual organisms at each trophic level. For some ecosystems, such as the meadow shown in **Figure 3–9** above, the shape of the pyramid of numbers is the same as that of the energy and biomass pyramids. This, however, is not always the case. In most forests, for example, there are fewer producers than there are consumers. A single tree has a large amount of energy and biomass, but it is only one organism. Many insects live in the tree, but they have less energy and biomass. Thus, a pyramid of numbers for a forest ecosystem would not resemble a typical pyramid at all!

3–2 Section Assessment

1. **Key Concept** What are the two main forms of energy that power living systems?
2. **Key Concept** Briefly describe the flow of energy among organisms in an ecosystem.
3. **Key Concept** What proportion of energy is transferred from one trophic level to the next in an ecosystem?
4. Explain the relationships in this food chain: omnivore, herbivore, and autotroph.
5. **Critical Thinking Calculating** 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 the total energy is available at the highest trophic level?

Focus on the BIG Idea

Interdependence in Nature Refer to **Figure 3–8,** which shows a food web in a salt marsh. Choose one of the food chains within this web. Then, write a paragraph describing the feeding relationships among the organisms in the food chain. *Hint:* Use the terms *producers, consumers,* and *decomposers* in your description.

3–3 Cycles of Matter

Guide for Reading

Key Concepts
- How does matter move among the living and nonliving parts of an ecosystem?
- How are nutrients important in living systems?

Vocabulary
biogeochemical cycle
evaporation
transpiration
nutrient
nitrogen fixation
denitrification
primary productivity
limiting nutrient
algal bloom

Reading Strategy: Using Visuals Before you read, preview the cycles shown in **Figures 3–11, 3–13, 3–14,** and **3–15.** Notice how each diagram is similar to or different from the others. As you read, take notes on how each chemical moves through the biosphere.

Energy is crucial to an ecosystem. But all organisms need more than energy to survive. They also need water, minerals, and other life-sustaining compounds. In most organisms, more than 95 percent of the body is made up of just four elements: oxygen, carbon, hydrogen, and nitrogen. Although these four elements are common on Earth, organisms cannot use them unless the elements are in a chemical form that cells can take up.

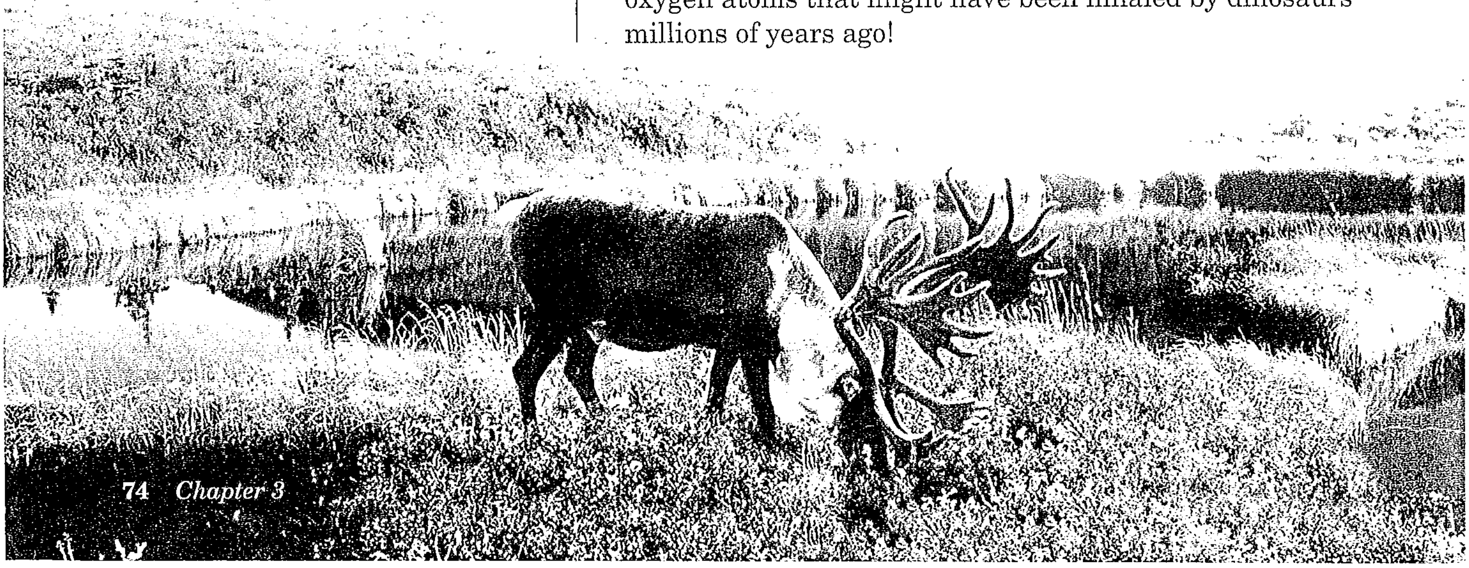
Recycling in the Biosphere

Energy and matter move through the biosphere very differently. **Unlike the one-way flow of energy, matter is recycled within and between ecosystems.** Elements, chemical compounds, and other forms of matter are passed from one organism to another and from one part of the biosphere to another through **biogeochemical cycles.** As the long word suggests, biogeochemical cycles connect *bio*logical, *geo*logical, and *chemi*cal aspects of the biosphere.

Matter can cycle through the biosphere because biological systems do not use up matter, they transform it. The matter is assembled into living tissue or passed out of the body as waste products. Imagine, for a moment, that you are a carbon atom in a molecule of carbon dioxide floating in the air of a wetland like the one in **Figure 3–10.** The leaf of a blueberry bush absorbs you during photosynthesis. You become part of a carbohydrate molecule and are used to make fruit. The fruit is eaten by a caribou, and within a few hours, you are passed out of the animal's body. You are soon swallowed by a dung beetle, then combined into the body tissue of a hungry shrew, which is then eaten by an owl. Finally, you are released into the atmosphere once again when the owl exhales. Then, the cycle starts again.

Simply put, biogeochemical cycles pass the same molecules around again and again within the biosphere. Just think—with every breath you take, you inhale hundreds of thousands of oxygen atoms that might have been inhaled by dinosaurs millions of years ago!

Figure 3–10 **Matter moves through an ecosystem in biogeochemical cycles.** In this Alaskan wetland, matter is recycled through the air, the shrubs, the pond, and the caribou—as it is used, transformed, moved, and reused.



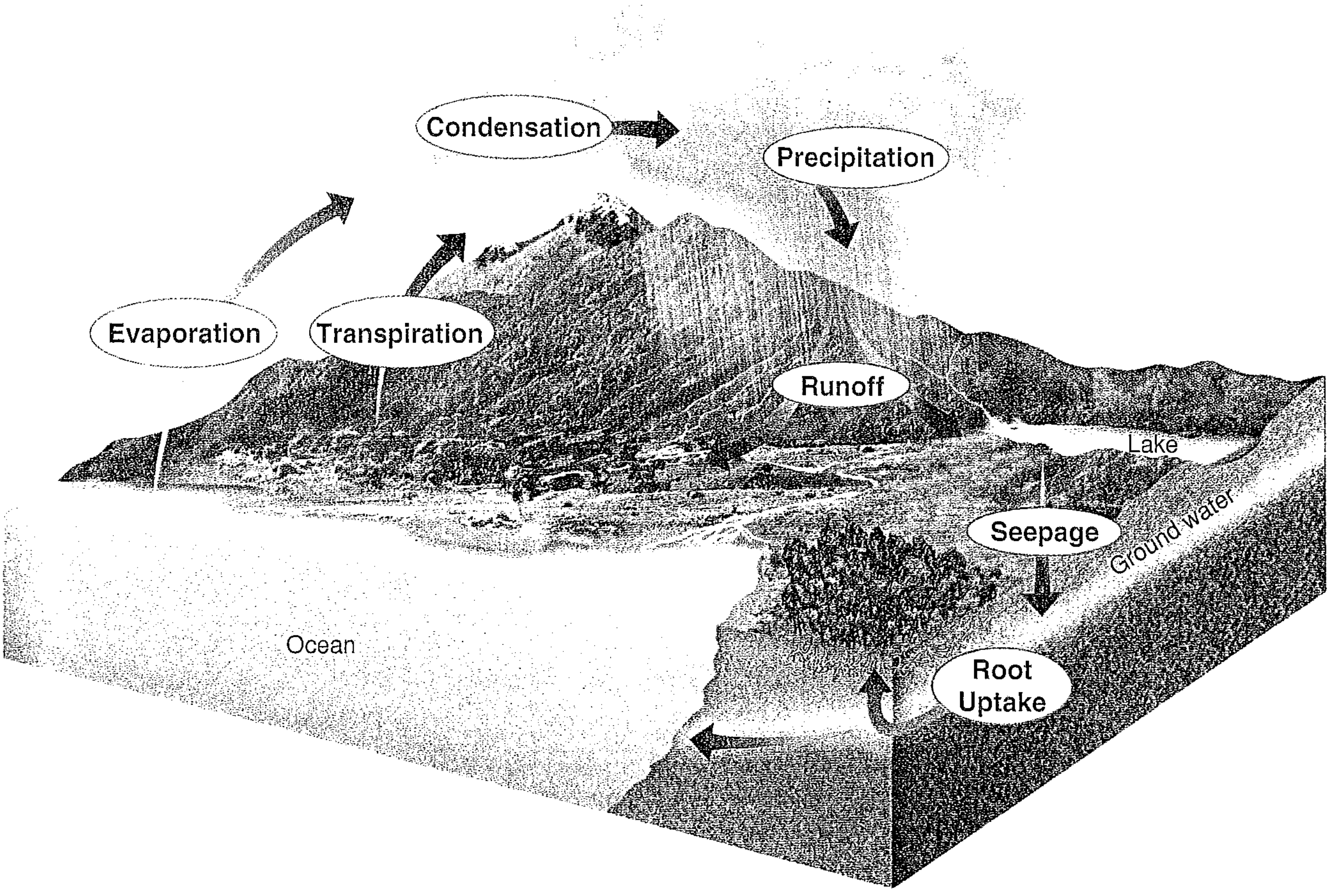


Figure 3–11 This diagram shows the main processes involved in the water cycle. Scientists estimate that it can take a single water molecule as long as 4000 years to complete one cycle. **Interpreting Graphics** *What happens to the water that evaporates from oceans and lakes?*

The Water Cycle

All living things require water to survive. Where does all this water come from? It moves between the ocean, atmosphere, and land. As **Figure 3–11** shows, water molecules enter the atmosphere as water vapor, a gas, when they evaporate from the ocean or other bodies of water. The process by which water changes from liquid form to an atmospheric gas is called **evaporation** (ee-vap-uh-RAY-shun). Water can also enter the atmosphere by evaporating from the leaves of plants in the process of **transpiration** (tran-spuh-RAY-shun).

During the day, the sun heats the atmosphere. As the warm, moist air rises, it cools. Eventually, the water vapor condenses into tiny droplets that form clouds. When the droplets become large enough, the water returns to Earth's surface in the form of precipitation—rain, snow, sleet, or hail.

On land, much of the precipitation runs along the surface of the ground until it enters a river or stream that carries the runoff back to an ocean or lake. Rain also seeps into the soil, some of it deeply enough to become ground water. Water in the soil enters plants through the roots, and the water cycle begins anew.

✓CHECKPOINT *How are evaporation and transpiration related?*

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▲ **Figure 3–12 Like all living organisms, the owl monkey needs nutrients to grow and carry out essential life functions.** This monkey, which is found in Central and South America, obtains most of its nutrients by eating plants.

Nutrient Cycles

The food you eat provides energy and chemicals that keep you alive. All the chemical substances that an organism needs to sustain life are its **nutrients.** Think of them as the body's chemical "building blocks." Primary producers, such as plants, usually obtain nutrients in simple inorganic forms from their environment. Consumers, such as the monkey in **Figure 3–12**, obtain nutrients by eating other organisms. **Every living organism needs nutrients to build tissues and carry out essential life functions. Like water, nutrients are passed between organisms and the environment through biogeochemical cycles.**

The carbon cycle, nitrogen cycle, and phosphorus cycle are especially important. Note also that oxygen participates in all these cycles by combining with these elements and cycling with them during various parts of their journey.

CHECKPOINT *What is a nutrient?*

The Carbon Cycle Carbon plays many roles. Carbon is a key ingredient of living tissue. In the form of calcium carbonate ($CaCO_3$), carbon is an important component of animal skeletons and is found in several kinds of rocks. Carbon and oxygen form carbon dioxide gas (CO_2), an important component of the atmosphere. Carbon dioxide is taken in by plants during photosynthesis and is given off by both plants and animals during respiration. Four main types of processes move carbon through its cycle:

- Biological processes, such as photosynthesis, respiration, and decomposition, take up and release carbon and oxygen.
- Geochemical processes, such as erosion and volcanic activity, release carbon dioxide to the atmosphere and oceans.
- Mixed biogeochemical processes, such as the burial and decomposition of dead organisms and their conversion under pressure into coal and petroleum (fossil fuels), store carbon underground.
- Human activities, such as mining, cutting and burning forests, and burning fossil fuels, release carbon dioxide into the atmosphere.

Scientists identified these processes decades ago, but they are still actively investigating them. For example, how much carbon moves through each part of the cycle? How do other parts of the carbon cycle respond to changes in atmospheric carbon dioxide? How much carbon dioxide can the ocean absorb? Later in this unit, you will learn why answers to these questions are so important.

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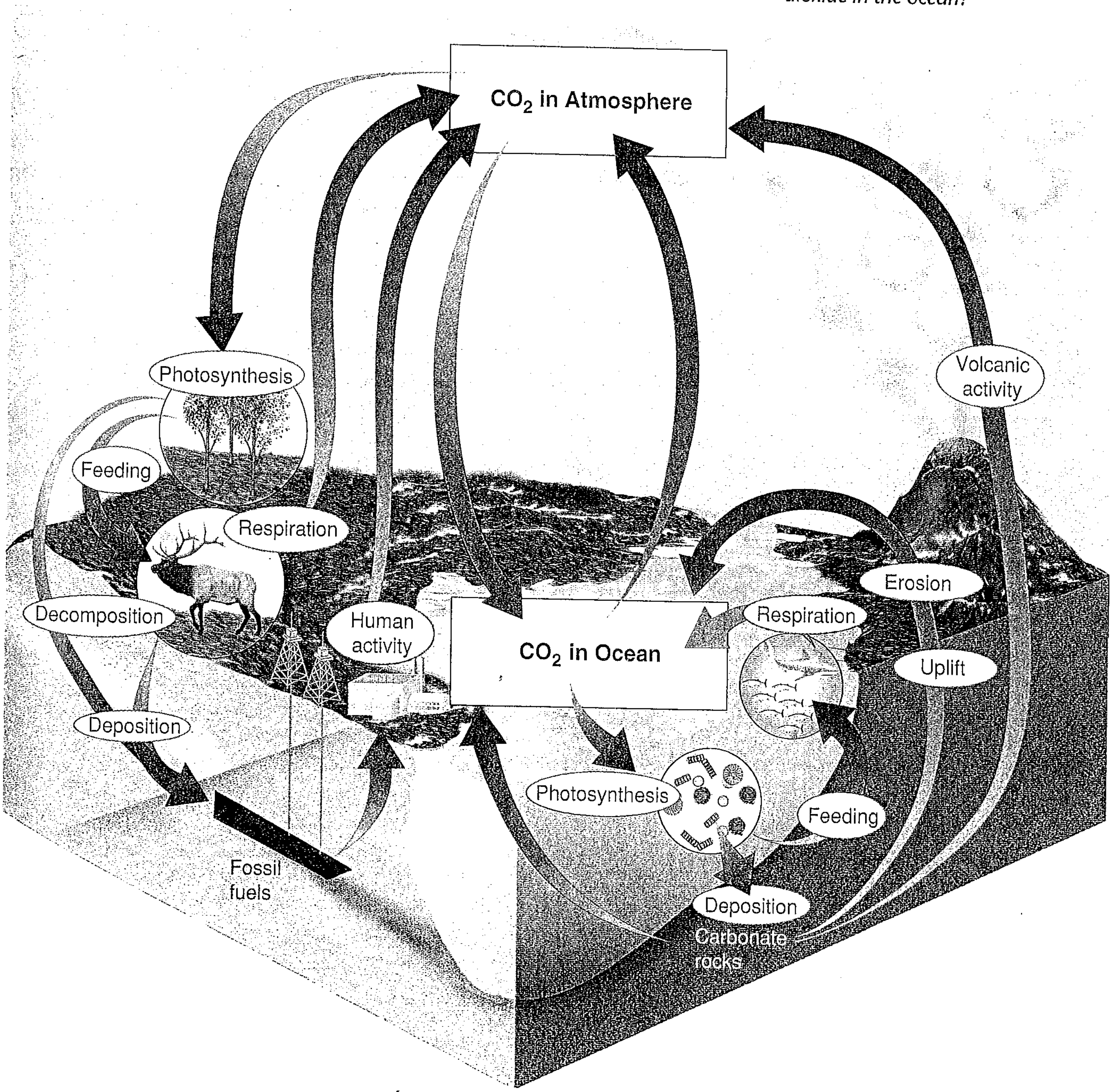
Figure 3–13 shows how these processes move carbon through the biosphere. In the atmosphere, carbon is present as carbon dioxide gas. Carbon dioxide is released into the atmosphere by volcanic activity, by respiration, by human activities such as the burning of fossil fuels and vegetation, and by the decomposition of organic matter. Plants take in carbon dioxide and use the carbon to build carbohydrates during photosynthesis. The carbohydrates are passed along food webs to animals and other consumers. In the ocean, carbon is also found, along with calcium and oxygen, in calcium carbonate, which is formed by many marine organisms. Calcium carbonate can also be formed chemically in certain marine environments. This chalky, carbon-based compound accumulates in marine sediments and in the bones and shells of organisms. Eventually these compounds break down and the carbon returns to the atmosphere.

▼ **Figure 3–13** Carbon is found in several large reservoirs in the biosphere. In the atmosphere, it is found as carbon dioxide gas; in the oceans as dissolved carbon dioxide; on land in organisms, rocks, and soil; and underground as coal, petroleum, and calcium carbonate rock. **Interpreting Graphics** *What are the main sources of carbon dioxide in the ocean?*

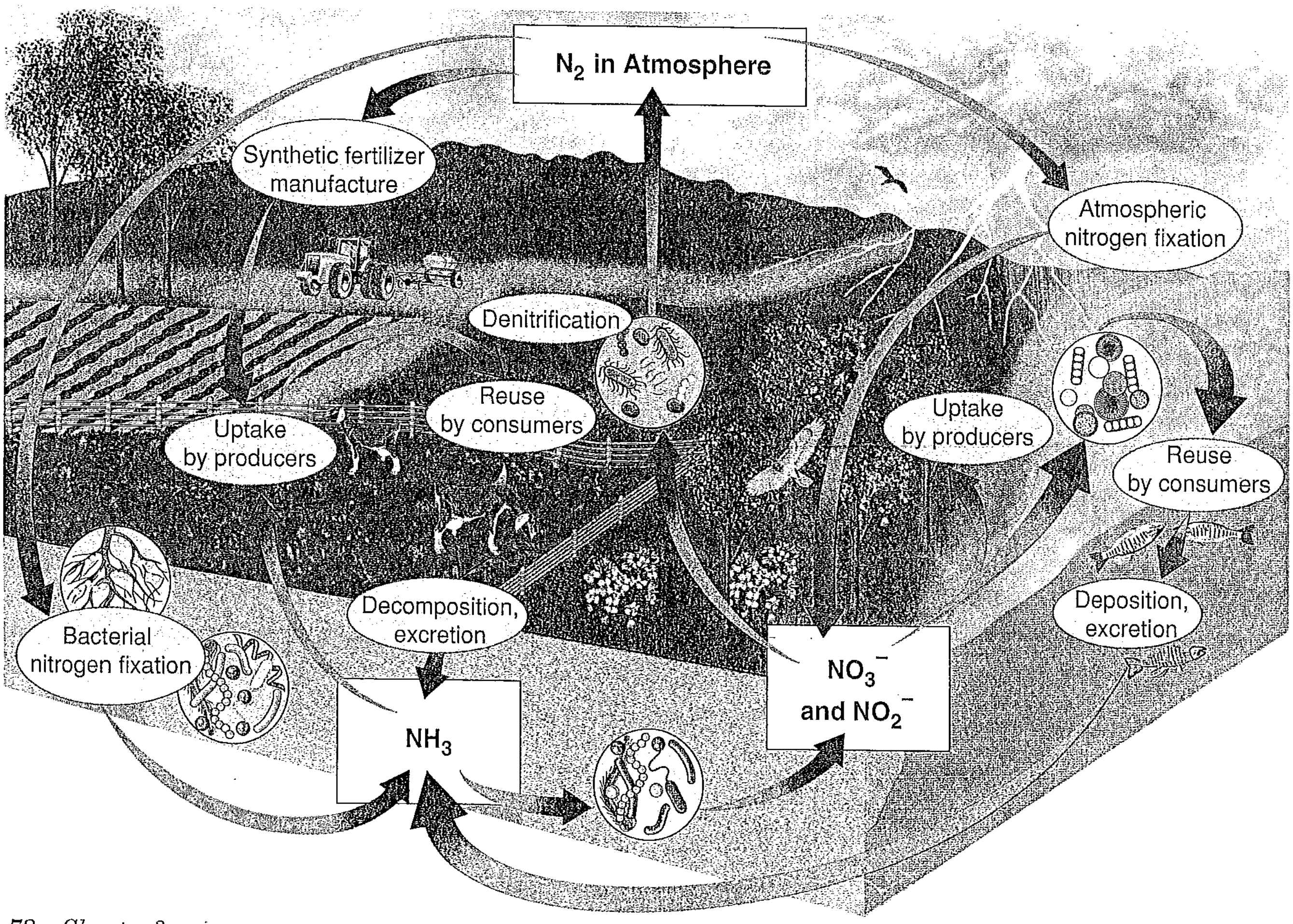


The Nitrogen Cycle All organisms require nitrogen to make amino acids, which in turn are used to build proteins. Many different forms of nitrogen occur naturally in the biosphere. Nitrogen gas (N_2) makes up 78 percent of Earth's atmosphere. Nitrogen-containing substances such as ammonia (NH_3), nitrate ions (NO_3^-), and nitrite ions (NO_2^-) are found in the wastes produced by many organisms and in dead and decaying organic matter. Nitrogen also exists in several forms in the ocean and other large water bodies. Human activity adds nitrogen to the biosphere in the form of nitrate—a major component of plant fertilizers.

Figure 3–14 shows how the 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. Such bacteria, which live in the soil and on the roots of plants called legumes, convert nitrogen gas into ammonia in a process known as **nitrogen fixation.** Other bacteria in the soil convert ammonia into nitrates and nitrites. Once these products are available, producers can use them to make proteins. Consumers then eat the producers and reuse the nitrogen to make their own proteins.

When organisms die, decomposers return nitrogen to the soil as ammonia. The ammonia may be taken up again by producers. Other soil bacteria convert nitrates into nitrogen gas in a process called **denitrification.** This process releases nitrogen into the atmosphere once again.

▼ **Figure 3–14** The atmosphere is the main reservoir of nitrogen in the biosphere. Nitrogen also cycles through the soil and through the tissues of living organisms. **Interpreting Graphics** *What are the main nitrogen-containing nutrients in the biosphere?*



Analyzing Data

Farming in the Rye

Sometimes, farmers grow crops of rye and other grasses and then plow them under the soil to decay. This practice helps to increase crop yields of other plants. Farmers may also plow under legumes such as peas, vetch, and lentils. Legumes are plants that have colonies of nitrogen-fixing bacteria living in nodules on the plant roots.

In an effort to determine which practice produces the best crop yields, scientists performed an experiment in Georgia. They grew corn on land that had previously received one of five treatments. Three fields had previously been planted with three different legumes. A fourth field had been planted with rye. The fifth field was left bare before the corn was planted. None of the fields received fertilizer while the corn was growing. The table shows how much corn was produced per hectare of land (kg/ha) in each field. One hectare is equivalent to 10,000 square meters.

Corn Production

Previous Crop	Average Yield of Corn (kg/ha)
Monantha vetch	2876
Hairy vetch	2870
Austrian peas	3159
Rye	1922
None	1959

1. **Using Tables and Graphs** Use the data in the table to create a bar graph.
2. **Comparing and Contrasting** Compare the effect of growing legumes to that of growing grass on the yield of corn. How do the yields differ from the yield on the field that had received no prior treatment?
3. **Using Tables and Graphs** Which treatment produced the best yield of corn? The worst yield?
4. **Applying Concepts** Based on your knowledge of the nitrogen cycle, how can you explain these results?

The Phosphorus Cycle Phosphorus is essential to living organisms because it forms part of important life-sustaining molecules such as DNA and RNA. Although phosphorus is of great biological importance, it is not very common in the biosphere. Unlike carbon, oxygen, and nitrogen, phosphorus does not enter the atmosphere. Instead, phosphorus remains mostly on land in rock and soil minerals, and in ocean sediments. There, phosphorus exists in the form of inorganic phosphate. As the rocks and sediments gradually wear down, phosphate is released. On land, some of the phosphate washes into rivers and streams, where it dissolves. The phosphate eventually makes its way to the oceans, where it is used by marine organisms.

As **Figure 3–15** shows, some phosphate stays on land and cycles between organisms and the soil. When plants absorb phosphate from the soil or from water, the plants bind the phosphate into organic compounds. Organic phosphate moves through the food web, from producers to consumers, and to the rest of the ecosystem.

✓CHECKPOINT *Where is most of the phosphorus stored in the biosphere?*

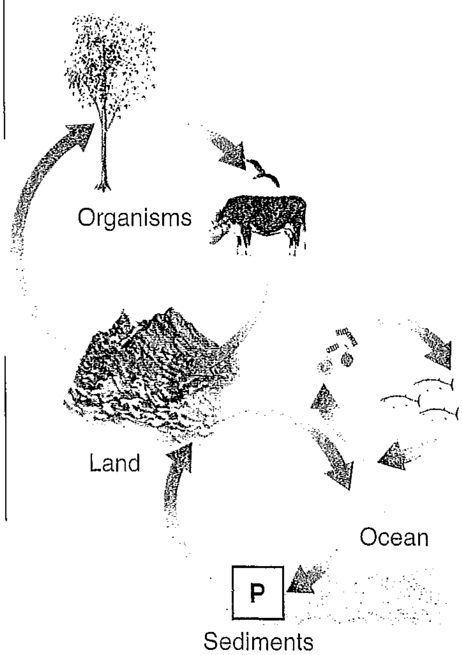
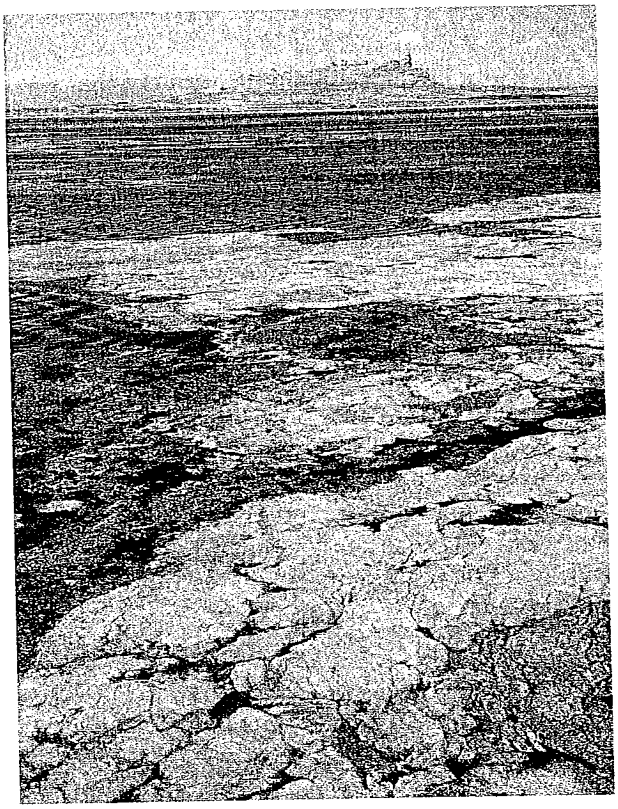


Figure 3–15 Phosphorus in the biosphere cycles among the land, ocean sediments, and living organisms. **Interpreting Graphics** *How is phosphorus important to living organisms?*



▲ **Figure 3–16** When an aquatic ecosystem receives a large input of a limiting nutrient, the result is often an increase in the number of producers. Here, an extensive algal bloom covers the shoreline of Tule Lake in California. **Using Analogies** *How is this situation similar to the one that occurs in a fish tank in which the fish have been overfed?*

Nutrient Limitation

Ecologists are often interested in the **primary productivity** of an ecosystem, which is the rate at which organic matter is created by producers. One factor that controls the primary productivity of an ecosystem is the amount of available nutrients. If a nutrient is in short supply, it will limit an organism's growth. When an ecosystem is limited by a single nutrient that is scarce or cycles very slowly, this substance is called a **limiting nutrient.**

Because they are well aware of this phenomenon, farmers apply fertilizers to their crops to boost their productivity. Fertilizers usually contain three important nutrients—nitrogen, phosphorus, and potassium. These nutrients help plants grow larger and more quickly than they would in unfertilized soil.

The open oceans of the world can be considered nutrient-poor environments compared to the land. Seawater contains at most only 0.00005 percent nitrogen, or 1/10,000 of the amount typically found in soil. In the ocean and other saltwater environments, nitrogen is often the limiting nutrient. In some areas of the ocean, however, silica or even iron can be the limiting nutrient. In streams, lakes, and freshwater environments, phosphorus is typically the limiting nutrient.

When an aquatic ecosystem receives a large input of a limiting nutrient—for example, runoff from heavily fertilized fields—the result is often an immediate increase in the amount of algae and other producers. This result is called an **algal bloom.** Why do algal blooms occur? There are more nutrients available, so the producers can grow and reproduce more quickly. If there are not enough consumers to eat the excess algae, conditions can become so favorable for growth that algae cover the surface of the water. Algal blooms, like the one shown in **Figure 3–16,** can sometimes disrupt the equilibrium of an ecosystem.

3–3 Section Assessment

1. **Key Concept** How does the way that matter flows through an ecosystem differ from the way that energy flows?
2. **Key Concept** Why do living organisms need nutrients?
3. Describe the path of nitrogen through its biogeochemical cycle.
4. Explain how a nutrient can be a limiting factor in an ecosystem.
5. **Critical Thinking Predicting** Based on your knowledge of the carbon cycle, what do you think might happen if vast areas of forests are cleared?
6. **Critical Thinking Applying Concepts** Summarize the role of algal blooms in disrupting the equilibrium in an aquatic ecosystem.

Thinking Visually

Making a Flowchart

Use a flowchart to trace the flow of energy in the carbon cycle. *Hint*: You may wish to refer to **Figure 3–13,** especially to the labels Photosynthesis, Feeding, Respiration, and Decomposition. Also, you may want to refer to **Figure 3–7** in Section 3–2 for a description of energy flow in an ecosystem.