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.

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 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—that 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.

### Section 3–2

#### 1 FOCUS

**Objectives**

3.2.1 Identify the source of energy for life processes.

3.2.2 Trace the flow of energy through living systems.

3.2.3 Evaluate the efficiency of energy transfer among organisms in an ecosystem.

#### 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
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.

#### Guide for Reading

**Vocabulary Preview**

To help students understand related terms in this section, write the following sets of words and word parts on the board.

Set 1: photo-, chemo-, synthesis

Set 2: herb-, carn-, omni-, detritus, -vore

Have students look up the meaning of all words and parts in a dictionary and list them. As students read the section and make notes about the terms, they can check the text’s definitions against this list.

**Reading Strategy**

Students’ concept maps could be titled “Energy Flow” and begin with autotrophs, or producers, which make food through photosynthesis or chemosynthesis. Then, students should add the various types of heterotrophs to their concept maps and show how the various types of organisms are interrelated, using the terms food chain, food web, trophic level, and ecological pyramid.

#### 2 INSTRUCT

**Producers**

**Building Science Skills**

**Measuring** Have groups of students cut out one-square-meter pieces of heavy wrapping or butcher paper. Next, let each group use a balance and various common objects in the classroom to measure out 3.5 kg of mass, and then place the objects on the paper square. Encourage the groups to examine one another’s piles of objects. Emphasize that each pile represents the amount of living tissue produced per square meter each year in a tropical forest.

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3–2 (continued)

Make Connections

Chemistry On the board, write the chemical equation for photosynthesis:

\[6\text{CO}_2 + 6\text{H}_2\text{O} \xrightarrow{\text{Light}} \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2\]

Ask: Which element does each letter in the formulas stand for? (C for carbon; O, oxygen; H, hydrogen)

Explain that the equation can be read as “Six molecules of carbon dioxide and six molecules of water combine in the presence of light energy to yield one molecule of glucose and six molecules of oxygen.” Ask: Why are the numbers needed in the equation? (Without numbers, the equation wouldn’t be balanced.) If students are not familiar with this concept, write the equation on the board, and then cross out the balanced pairs—6 carbon atoms (C6) on the left and 6 carbon atoms (C6) on the right; 18 oxygen atoms (6O2) on the left and 6 oxygen atoms (6O2) on the right; 12 hydrogen atoms (6H2) on the left and 12 hydrogen atoms (6H2) on the right. 12

Consumers

Build Science Skills

Classifying Divide the class into small groups, and provide each group with photocopies of a wide variety of organisms, including plants, multicellular algae, invertebrates, and vertebrates. Then, have each group sort its organisms into two piles—producers and consumers—and then sort the consumers into piles representing the four subcategories of herbivores, carnivores, omnivores, and decomposers. 13 12

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.

Inclusion/Special Needs

To engage students’ interest in feeding relationships and ecological pyramids, ask students about feeding relationships with which they may have some familiarity. For example, most students will know that birds in their neighborhood feed on either seeds and berries or small animals such as worms and insects. Elicit from students ideas about relative numbers at different trophic levels, energy transfer, and biomass comparisons.

Advanced Learners

Point out to interested students this sentence on page 68 about chemosynthetic bacteria: “Surprisingly, these bacteria represent a large proportion of living autotrophs.” Challenge students to find out about such bacteria, including those that live in hot springs and those that live in the deep ocean around vents. Have students prepare reports about what they find and present them to the class when students study bacteria in Chapter 19.
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**, (deh-TRY-tiv-awrz), 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.

**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 carnivores, such as sharks. In this food chain, the top carnivore is four steps removed from the producer.

**Feeding Relationships**

Use Visuals

**Figure 3–7** After students have studied the figure, ask: Among the organisms shown, which are autotrophs and which are heterotrophs? (The algae are autotrophs; the others are heterotrophs.) Among the heterotrophs, which are herbivores and which are carnivores? (The zooplankton are herbivores; the other heterotrophs are carnivores.)

**What kind of heterotroph might enter this food chain when the shark dies and falls to the ocean floor? (Detritivores and decomposers)**

Build Science Skills

**Applying Concepts** Show students some acorns, sunflower seeds, or other common type of seed, and ask: Where did these seeds come from? (A plant!) What kind of animal might eat these seeds? (Depending on the type of seeds used, a squirrel, chickadee, mouse, or chipmunk might eat them.) What kind of animal might eat the animal that ate the seeds? (A larger carnivore such as a fox, hawk, or coyote) What is the feeding relationship that you just described called? (A food chain) What happens to energy in the food chain? (Energy is transferred from the organism being eaten to the organism doing the eating. Some energy from lower trophic levels is lost as heat.) What was the original source of energy in the food chain? (The sun)

**FACTS AND FIGURES**

**Energy moves up the chain**

In nature, simple “straight line” food chains are rare, primarily because few species eat or are eaten by only one other species. Nevertheless, a food chain is a useful model for studying the transfer of energy and materials in an ecosystem.

All food chains on land begin with producers that use light energy to synthesize organic compounds. Primary consumers are herbivores that feed directly on the producers. Above the primary consumers are secondary consumers, then tertiary consumers, and, in some food chains, quaternary consumers. Not many food chains extend beyond four consumer levels. Decomposers (also known as saprotrophs), detritivores, and parasites—organisms that live in or on other organisms and obtain energy from them—can occupy any level of a food chain.

Answers to . . .

**Cyanobacteria** Photosynthesis uses light energy. Chemosynthesis uses the energy stored in chemical bonds.

**Figure 3–6** A consumer

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3–2 (continued)

Quick Lab

**Objective**  Students will be able to describe the organization of a simple food chain.

**Skill Focus** **Classifying**

**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

**Time**  15 minutes for initial setup, 5 minutes per day for one week to observe and record

**Advance Prep**
- About two weeks before students do this activity, plant bean seeds in pots or paper cups. Each group will need two seedlings. Plant extras in case some plants do not thrive.
- Aphids and ladybird beetles may be collected outdoors or ordered from a biological supply house. Ladybird beetles also may be available at garden centers as natural pest-controls. If the organisms are collected outdoors, make sure they are returned to their original locations at the conclusion of the activity.
- Because it may be difficult to obtain pea aphids and ladybird beetles, you may want to use crickets and praying mantises instead.

**Safety**  Caution students to handle organisms without harming them. Make sure they wash their hands with soap and warm water before leaving the lab.

**Strategies**
- Make the aphids and ladybird beetles available to students in a central distribution center.
- You may want to let students examine the aphids with magnifiers before they place them in the jars.

**Expected Outcome**  See Analyze and Conclude number 1 below.

**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.

**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.

**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 snails 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.

**Word Origins**

<table>
<thead>
<tr>
<th>Trophic</th>
<th>Trophic originates from the Greek word trophē, which means “food or nourishment.” What do you think are the original meanings of the words heterotroph and autotroph?</th>
</tr>
</thead>
</table>

**Two types of food webs**

There are two basic types of food webs: grazing food webs and detrital food webs. A grazing food web begins with photosynthesizing plants, algae, or phytoplankton. A detrital food web begins with decomposers and detritivores. It is the detrital type of food web that enables nutrients to be recycled in ecosystems.

Decomposers and detritivores obtain energy by breaking down organic wastes and the remains of dead organisms. This process releases simple inorganic molecules such as mineral salts, carbon, nitrogen, phosphorous, and potassium, making these nutrients available for reuse by producers and, eventually, all other organisms in the ecosystem. Without decomposers and detritivores, such essential elements would remain in animal wastes and dead organisms.
Use Visuals

**Figure 3–8** To help students deal with the complexity of the food web, call on different students in turn to name the organisms in one food chain, beginning with a producer and working upward to the final consumer. For example, students might identify a food web including algae, zooplankton, plankton-eating fishes, and heron.

Build Science Skills

**Making Models** Obtain at least 25 pictures of organisms—producers and different-level consumers—that could be found in an ecosystem other than the one shown in Figure 3–8. Tape the pictures in random order on the classroom walls, desktops, and other surfaces. Give each student a small ball of colored yarn and several small pieces of masking tape. Then, let four or five students at a time connect pictures with yarn to show different food chains. Students may crisscross the room with the yarn so the food web becomes quite complex. When every student has had a turn, let the class examine the results. Ask: What is the name for this pattern of feeding relationships? (A food web) How is a food web different from a food chain? (A food web contains many overlapping food chains, so it is much more complex than a single food chain.)

Word Origins

**Hetero-** means “other, different,” and **auto-** means “self.” Thus, **heterotroph** refers to an organism that feeds on other organisms, and **autotroph** refers to one that produces its own food.

**Answers to . . .**

**Ecotone** A food web is the network of feeding relationships in an ecosystem.

**Figure 3–8** Birds and small mammals

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**TEACHER TO TEACHER**

I have students make a food-web poster for a particular ecosystem or biome. The food web must contain at least five food chains consisting of a producer, a primary consumer, and a secondary consumer. Each consumer must be labeled as an herbivore, carnivore, omnivore, or decomposer. At least one predator-prey relationship must be shown. Five abiotic factors also must be included and labeled.

The posters may be drawn free-hand, or students may cut and paste pictures from magazines or computer printouts. I usually have students explain their posters to the class in oral presentations.

—LouEllen Parker Brademan
Teacher
Potomac Senior High School
Dumfries, Virginia

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**Interpreting Graphics** What does the marsh hawk feed on?

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**Answers to . . .**

**Ecotone** A food web is the network of feeding relationships in an ecosystem.

**Figure 3–8** Birds and small mammals

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Ecological Pyramids

Mathematics  Draw students’ attention to the energy pyramid in Figure 3–9. Explain that the amount of energy available in food is measured in calories. One calorie is the amount of energy needed to raise the temperature of 1 gram of water 1°C. Scientists usually refer to the energy content of food in units of kilocalories. One kilocalorie equals 1000 calories. A kilocalorie is also expressed as a Calorie, with a capital C. Then, pose the following problem: Suppose that the base of this energy pyramid consists of plants that contain 450,000 Calories of food energy. If all the plants were eaten by mice and insects, how much food energy would be available to those first-level consumers? (45,000 Calories) If all the mice and insects were eaten by snakes, how much food energy would be available to the snakes? (4500 Calories) If all the snakes were eaten by a hawk, how much food energy would be available to the hawk? (430 Calories) How much food energy would the hawk use for its body processes and lose as heat? (405 Calories—90 percent of 450) How much food energy would be stored in the hawk’s body? (43 Calories) (2)

Build Science Skills

Applying Concepts  Point out the exception described in the text of a numbers pyramid. Ask: What would be the shape of a numbers pyramid for the forest? (The pyramid’s base, representing the trees, would be much smaller than the second section, representing the insects that feed on the trees.) LT 1 2

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 tissue 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.

The rule of 10

The textbook’s discussion of energy pyramids states that only about 10 percent of the energy available at each trophic level in a food chain is transferred to organisms at the next higher trophic level. This “rule of 10,” which was based on early studies of aquatic ecosystems, is useful as a general approximation. However, it does not apply uniformly to all food chains. More recent studies have demonstrated that energy efficiency varies between trophic levels in a food chain and between different food chains. In fact, these recent studies have yielded approximations of energy efficiency ranging from a low of 0.05 percent to a high of 20 percent.
Evaluate Understanding

Have each student draw and label a food web for a specific ecosystem of his or her choice. Tell students that the web should contain at least four food chains and that each food chain should consist of at least three organisms.

Reteach

Display a list of organisms that would be found in a specific ecosystem. Call on students in turn to identify each organism as a producer or a consumer. Write P or C next to each organism’s name. Then, have students further classify each consumer as an herbivore, a carnivore, or an omnivore; write H, C, or O next to each name. As a final step, have students in turn link together any three organisms—a producer, an herbivore, and a carnivore—in a food chain.

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!

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 has only about one tenth of the energy from the level below, it can support only about one tenth the amount of living tissue.

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.

Focus on the BIG Idea

Students may choose to describe any of the several food chains shown in Figure 3–8. A typical choice might begin with marsh grass as the producer. The marsh grass is eaten by the grasshopper, which is eaten by the harvest mouse, which is eaten by the marsh hawk. All three animals should be identified as consumers. Students might suggest that any or all of these organisms eventually die and are consumed by decomposers.

If your class subscribes to the iText, use it to review the Key Concepts in Section 3–2.