**Ecological Communities**

**Guiding Question:** How do energy and nutrients move through communities?

**Knowledge and Skills**

- Explain the difference between a producer and a consumer.
- Explain the effect of inefficient energy transfer on community structure.
- Describe how feeding relationships can have both direct and indirect effects on community members.

**Reading Strategy and Vocabulary**

- **Reading Strategy** As you read, generate a concept map using each of the boldface words highlighted in the lesson.
- **Vocabulary** primary producer, photosynthesis, chemosynthesis, consumer, cellular respiration, herbivore, carnivore, omnivore, detritivore, decomposer, trophic level, biomass, food chain, food web, keystone species

**Life Requires Energy** to organize matter into complex forms such as carbohydrates, to build and maintain cellular structures, to power interactions among species, and to power the geological forces that shape our planet. Energy is somehow involved in nearly every biological, chemical, and physical event. So, where does all this energy come from? And what, exactly, is energy?

**Producers and Consumers**

Organisms are classified as either producers or consumers based on how they obtain energy and nutrients.

Energy is the ability to do work. It is energy that changes the position, composition, or temperature of matter. The first law of thermodynamics states that energy cannot be created or destroyed, only changed from one form to another. For example, solar energy is converted to thermal energy when absorbed by a sandy beach or a dark t-shirt. Just like matter, the total energy in the universe remains constant. However, unlike matter, energy is not recycled in the biosphere. It moves in a one-way stream, shaping communities in the process.

**Primary Production** Energy cannot be created or destroyed, but it has to enter an ecosystem somehow. Organisms called autotrophs or primary producers, like the plant shown in Figure 18, capture energy from the sun or from chemicals and store it in the bonds of sugars, making energy available to the rest of the community.

**Guiding Question:** How do energy and nutrients move through communities?

**Figure 18 Primary Producers** Green plants, like this spring pea, can capture radiant energy from the sun and store it in the bonds of sugar molecules.
Energy From the Sun
For nearly all of Earth’s ecological systems, the sun is the ultimate source of energy. The sun releases radiation from large portions of the electromagnetic spectrum, shown in Figure 19. Earth’s atmosphere filters much of this out, and we see only some of this radiation as visible light. Some primary producers, such as green plants, algae, and cyanobacteria, can turn light energy from the sun into chemical energy in a process called photosynthesis. Photosynthesis is the process by which primary producers use sunlight to convert carbon dioxide and water into sugars, releasing oxygen along the way. Photosynthesis is a complex process, but the overall reaction can be summarized with the following equation:

\[ 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{the sun’s energy} \rightarrow C_6\text{H}_{12}\text{O}_6 \text{(sugar)} + 6\text{O}_2 \]

Energy From Chemicals
Not all communities are powered by the sun’s energy. On the floor of the ocean, jets of water heated by magma under Earth’s crust gush into the icy-cold depths. In one of the more amazing scientific discoveries of recent decades, scientists realized that these deep-sea vents host entire communities of organisms. Deep-sea vents are deep enough underwater that they completely lack sunlight. Instead, primary producers such as bacteria use energy stored in the bonds of hydrogen sulfide (H\(_2\)S) to convert carbon dioxide and water into sugars in a process called chemosynthesis. Chemosynthesis can be summarized as:

\[ 6\text{CO}_2 + 6\text{H}_2\text{O} + 3\text{H}_2\text{S} \rightarrow C_6\text{H}_{12}\text{O}_6 \text{(sugar)} + 3\text{H}_2\text{SO}_4 \]

Photosynthesis and chemosynthesis use different energy sources, but each uses water and carbon dioxide to produce sugars. Energy from chemosynthesis supports many organisms including enormous clams and tubeworms, and various species of mussels, shrimp, crabs, and fish. These organisms have adaptations that enable them to live in the extreme high-temperature, high-pressure conditions of deep-ocean vents.

Reading Checkpoint
What is the primary difference between photosynthesis and chemosynthesis?

Consumers
Organisms that rely on other organisms for energy and nutrients are called heterotrophs, or consumers. Consumers, like those in Figure 20, make use of the chemical energy stored by photosynthesis or chemosynthesis in a process called cellular respiration.

FIGURE 19  Energy From the Sun
The sun emits radiation from many portions of the electromagnetic spectrum. All photosynthesis is powered by just a small portion of the visible light that reaches Earth.

ANSWERS

Reading Checkpoint  The main difference is the source of energy. For photosynthesis, it is the sun. For chemosynthesis, it is energy stored in chemical bonds.

FIGURE 20  Consumers  Most communities contain many kinds of consumers, including a variety of herbivores, carnivores, omnivores, detritivores, and decomposers.
Cellular respiration is the process by which organisms use oxygen to release the chemical energy of sugars such as glucose, releasing carbon dioxide and water as a byproduct. The summary equation for cellular respiration is the exact opposite of that for photosynthesis:

\[
C_6H_{12}O_6 \text{(sugar)} + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}
\]

Cellular respiration does not only occur in consumers—primary producers also use cellular respiration to release energy and nutrients they themselves have stored. In fact, the term autotroph literally means “self-feeder.” Heterotroph, on the other hand, means “other feeder.”

**Herbivores, Carnivores, and Omnivores** Organisms that consume producers are known as primary consumers. Most primary consumers, such as deer and grasshoppers, eat plants and are called herbivores. Wolves that prey on deer are considered secondary consumers, as are rodents and birds that prey on grasshoppers. Tertiary consumers eat secondary consumers, and so on. Most secondary and tertiary consumers kill and eat other animals and are called carnivores. Animals that eat both plant and animal food are called omnivores.

**Detritivores and Decomposers** Recall that nutrients, such as carbon, nitrogen, and phosphorus, are recycled in ecosystems. When animals eat plants, they break down plant tissues into their components. Then, the animals’ bodies use the nutrients to build their own tissues. What happens when animals die? How do nutrients re-enter the ecosystem? Luckily, ecosystems have recyclers called detritivores and decomposers. Detritivores, such as millipedes and soil insects, consume detritus—nonliving organic matter including leaf litter, waste products, and the dead bodies of other community members. Large detritivores, like vultures, are often called scavengers. Decomposers, such as fungi and bacteria, break down nonliving matter into simpler parts that can then be taken up and reused by primary producers. If it were not for detritivores and decomposers, nutrients would be lost to an ecosystem when organisms die.
Energy and Biomass

Inefficient energy transfer between organisms shapes the structure of a community.

As organisms feed on one another, matter and energy move through the community’s trophic levels. An organism’s trophic level is its rank in a feeding hierarchy. Primary producers always make up a community’s first trophic level. Primary, secondary, and tertiary consumers make up the second, third, and fourth levels. In theory, a community can have any number of trophic levels. However, the relative amounts of energy and nutrients available at each trophic level put restrictions on a community’s structure. Consequently, there are typically only three or four trophic levels in any community.

Energy in Communities

Although the overall amount of energy is conserved in any process of energy transfer, the second law of thermodynamics states that energy tends to change from a more-ordered state to a less-ordered state. That is, systems tend to move toward increasing disorder, or entropy. The result of the second law of thermodynamics is that no process involving energy conversion is 100% efficient. When gasoline is burned in an automobile engine, for example, only about 14% of the energy is used to move the automobile down the road—most of the rest is converted to thermal energy and released as heat, as shown in Figure 21. Thermal energy has high entropy and is very hard to capture and convert to something else. In other words, thermal energy is generally “lost” when released as heat.

Energy Transfer in Communities

Organisms are not that different from car engines. They take in food through predation, herbivory, or parasitism, and “burn it” using cellular respiration. Energy needed for life activities is released, but in the process much of the original energy is lost as waste heat. Due mainly to heat loss, only a small amount of the energy consumed by an organism in one trophic level is available to be transferred to the next trophic level.
The Ten Percent Rule A general rule of thumb is that each trophic level contains just 10% of the energy of the trophic level below it, although the actual proportion can vary greatly. So, if the primary producers represent 100 calories of a community’s energy, 10 calories (10% of 100 calories) will be available to level two, 1 calorie (10% of 10 calories) to level three, and 0.1 calories (10% of 1 calorie) to level four. Most communities, therefore, do not contain enough energy to support consumers above the third or fourth trophic level. Energy transfer in a community can be visualized as a pyramid, shown in Figure 22.

This pyramid-like pattern illustrates why eating at lower trophic levels—eating vegetables and fruit rather than meat, for instance—decreases a person’s ecological footprint. When we eat meat, we are taking in the end product of far more energy consumption, per calorie of energy that we gain, than when we eat plant products.

Numbers and Biomass in Communities
Similar to the amount of available energy, there are generally fewer organisms at higher trophic levels than at lower ones. Look at Figure 23. A mouse eats many plants in its lifetime, a snake eats many mice, and a hawk eats many snakes. Thus, for every hawk in a community there must be many snakes, still more mice, and a huge number of plants. Because the difference in numbers of organisms among trophic levels tends to be large, the same pyramid-like relationship also often holds true for biomass. A trophic level’s biomass is the total amount of living tissue it contains. So, although a snake weighs more than a mouse, the total snake biomass is much less than the total biomass of mice.

Reading Checkpoint What happens to energy that is not passed from one trophic level to the next, or used to power life processes?
Food Webs and Keystone Species

Feeding relationships have both direct and indirect effects on organisms in the community.

As energy is transferred from species on lower trophic levels to species on higher trophic levels, it is said to pass up a food chain. A food chain is a linear series of feeding relationships. For example, a small fish eats algae, a larger fish eats the smaller fish, a bird eats the large fish, and an alligator eats the bird, as shown in Figure 24.

Figure 24 Food Chains Food chains are a linear illustration of energy transfer through feeding relationships in a community.

One member of a community can have a direct effect on another, for example, when one organism eats another as part of a food chain. Organisms have indirect effects, too. Consider the zebra mussel’s effects, shown in Figure 25. The mussels’ waste products promote bacterial growth and disease pathogens that harm native mussels and clams. Zebra mussels can also contain high levels of toxic chemicals that can make animals at higher trophic levels sick. On the other hand, they provide nutrients that nourish crayfish and other invertebrate animals. The mussels also clarify the water by filtering out phytoplankton, which are photosynthetic algae that live in water. As a result, sunlight penetrates more deeply into the water and plants flourish.

Reading Checkpoint Food webs show the many different paths that matter and energy take as they move through a typical community. Food chains show only one path.

ANSWERS

Figure 25 It would likely harm the plants, because the mussels would not be filtering phytoplankton and clarifying the water.

Reading Checkpoint Food webs show the many different paths that matter and energy take as they move through a typical community. Food chains show only one path.

Food Webs Thinking in terms of food chains can be useful, but in reality, ecological systems are far more complex than simple linear chains. For one thing, most organisms have more than one source of food! A more accurate representation of the feeding relationships in a community is a food web. A food web is a visual map of feeding relationships and energy flow, showing the many paths by which energy and nutrients pass among organisms as they consume one another. Figure 26 shows a simplified food web from Florida’s Everglades region. Note that even within this simplified diagram we can pick out a number of different food chains involving different sets of species.

Reading Checkpoint Why are most communities best represented with a food web instead of a food chain?
FIGURE 26 Food Webs Food webs illustrate the feeding relationships in a community. In this food web from Florida’s Everglades, arrows are drawn from one organism to another to indicate the direction of energy flow as a result of predation or herbivory. For example, an arrow leads from the algae to the flagfish to indicate that flagfishes consume algae. Most food webs, like this one, are simplified to make them easier to read and interpret.
**ANSWERS**

**Lesson 3 Assessment**  
For answers to the Lesson 3 Assessment, see page A–7 at the back of the book.

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**1. Compare and Contrast**  
Explain the difference between a producer and a consumer. Then, explain the differences among an herbivore, carnivore, omnivore, detritivore, and decomposer.

**2. Calculate**  
If there are 1623 calories available at the first trophic level, approximately how many calories of energy would be available to a third-level consumer (fourth trophic level)?

**3. Infer**  
Describe three effects a sudden decrease of pig frogs have might have on the community structure shown in Figure 26. *(Hint: Think about what pig frogs eat and what eats them.)*

**4. Explore the BIG QUESTION**  
Identifying a community’s keystone species is not always easy. In fact, some ecologists think that a community can have many keystone species or none at all. Ecologists all agree, however, that decomposers, as a category of consumers, have a huge impact on a community’s structure. Write a paragraph in which you argue that decomposers are a “keystone group.”

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**Keystone Species**  
Ecologists have found that in communities, some species exert greater influence than do others. A species that has strong or wide-reaching impact on a community is called a **keystone species**. Shown in Figure 27a, a keystone is the wedge-shaped stone at the top of an arch that holds the structure together. If the keystone is removed, the arch will collapse. In an ecological community, removal of a keystone species can alter a large portion of the food web.

Consider the ecosystem shown in Figure 27b. Sea otters, a keystone species, eat urchins, which in turn, eat kelp. In the 1990s, sea otter populations off the coast of Alaska declined when orcas (killer whales) ate large numbers of otters. Fewer otters meant more urchins. The increased urchin population caused a huge decline in the kelp “forests” offshore. The kelp had served as habitat for many animals and plants. This is an example of a **trophic cascade**: Predators at high trophic levels (sea otters) indirectly help organisms at low trophic levels (kelp) by limiting populations at intermediate trophic levels (urchins).