Chapter 2

Energy flow and nutrient cycles support life in ecosystems.

Less than 2.5 cm in length, krill such as *Euphausia pacifica* are tiny, shrimp-like organisms that play a big role in marine ecosystems. The mass of krill in the world's oceans is estimated to equal all the animal protein consumed by humans each year. Krill are found in vast numbers in the ocean along the coast of British Columbia. They are a main food source for salmon, squid, and many species of whale. Krill are such an essential energy source that some animals migrate thousands of kilometres to eat them.

Oceanographers at the University of Victoria have recently discovered that krill may play an important role in the recycling of nutrients in ocean ecosystems. Each night, krill travel from deeper waters beneath the ocean's surface to feed on algae. As the Sun begins to rise, they quickly return to these deeper waters to avoid predators. The daily movement of large numbers of krill stirs up nutrients, causing these nutrients to rise from the deep ocean to the surface. The availability of these nutrients in surface waters benefits algae, which are able to grow and reproduce, thereby providing krill with a continuous food source.

What You Will Learn

In this chapter, you will
- **explain** how energy flows through food chains, food webs, and food pyramids
- **describe** how nutrients are cycled in an ecosystem
- **explain** how chemicals can accumulate and cause harm to organisms in ecosystems
- **demonstrate** an understanding of how human activities affect biodiversity

Why It Is Important

Knowledge of energy flows and nutrient cycles can help us appreciate how our activities affect ecosystems and the organisms living in them. The more we learn about these effects, the better prepared we are to attempt to prevent environmental damage before it occurs. Scientific knowledge is leading to new technologies that will help us restore ecosystems and protect biodiversity.

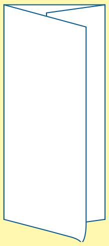
Skills You Will Use

In this chapter, you will
- **construct** energy pyramid models
- **simulate** the cycling of nutrients
- **analyze** the effects of altering the amount of nutrients in an ecosystem
- **model** the effects of human activities on ecosystems

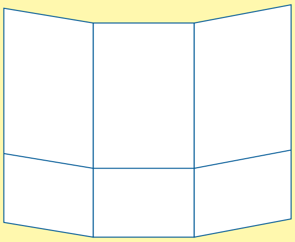
FOLDABLES™
Reading & Study Skills

Make the following Foldable to take notes on what you will learn in Chapter 2.

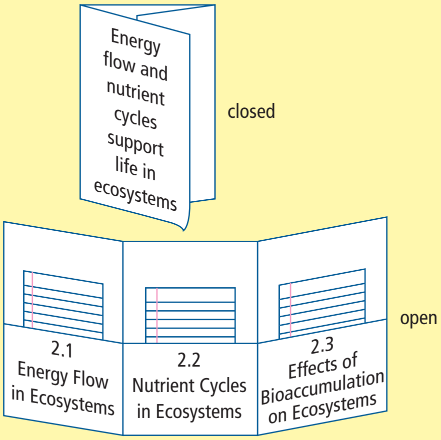
STEP 1 **Fold** a horizontal sheet of 28 cm by 43 cm paper into thirds. **Crease** well, and **open** the paper.



STEP 2 **Fold** the bottom edge up 5 cm, and **crease** well. **Glue** the outer edges of the 5 cm tab to create three pockets.



STEP 3 **Label** the exterior with the chapter title. **Label** each of the three pockets with the section titles.



Use index cards or quarter sheets of paper to record information, define terms, provide examples, and draw diagrams of cycles, food chains, and processes. Store your notes in the appropriate pockets.

2.1 Energy Flow in Ecosystems

In an ecosystem, energy flows from producers (plants) to primary consumers (herbivores) to secondary and tertiary consumers (carnivores). Food chains and food webs model this energy flow and these feeding relationships. Each step in a food chain is called a trophic level. Food pyramids model how energy is lost at each trophic level in an ecosystem.

Words to Know

biodegradation
consumers
decomposers
food chain
food pyramid
food web
producers
trophic level

Figure 2.1 The skeleton of a decomposed leaf

The eerie-looking skeleton of a leaf (Figure 2.1) reveals a canal system that once delivered water and minerals from the stem to the leaf. It also carried sugars made in the leaf to other parts of the tree. But how did the leaf tissue disappear, and where did it go? During photosynthesis, green leaves produce carbohydrates, which are an important energy source for plants and animals. Leaf litter (fallen leaves) forms an important energy source for organisms on the forest floor. Chemicals such as cellulose found in plant cell walls cannot be easily digested by most animals. However, fungi have finger-like projections that invade leaf tissue (Figure 2.2 on the next page). The fungi secrete enzymes that break down leaf tissue and cellulose into smaller nutrients. These nutrients can then be absorbed by the fungi. Some fungi secrete enzymes that change leaf litter into a food source for invertebrates such as beetles.

Scientists estimate that each year 28 billion tonnes of cellulose are produced in new leaves and each year fungi convert 80 percent of this cellulose back into usable nutrients.

This vast amount of leaf material forms part of the mass of all living organisms in the biosphere. To understand how much organic mass is produced in different parts of the biosphere, scientists estimate biomass. **Biomass** refers to the total mass of living plants, animals, fungi, and bacteria in a given area. Biomass can also refer to the mass of particular types of organic matter such as trees, plant crops, manures, and other organic materials that may be used to manufacture biofuels such as biogas. Estimates of biomass are usually expressed in grams or kilograms per square metre.

Did You Know?

The biomass of plants on Earth is over 100 times greater than the biomass of animals.

Figure 2.2 Star fungi growing on leaf litter break down the dead leaves into usable nutrients.

2-1A Raking in Profits from Leaf Biomass — Think About It

Each year, millions of leaves may fall in your neighbourhood. A single oak tree alone may drop 200 000 leaves. A British Columbia company that manufactures fertilizers made from organic materials is researching ways to turn the biomass of fallen leaves into a fertilizer. You have been asked to join the research team. Your team knows that decayed leaves are a good source of nutrients for other plants, but the natural process of leaf decay is slow. In this activity, you will investigate possible factors that may increase the rate of leaf decay.

What to Do

1. Working with your team, brainstorm a list of factors that you predict may increase the rate of leaf decay. (**Hint**: Think about what abiotic factors change during the fall.)
2. Choose one factor from your list that you think is worth investigating further.
3. Design an experiment that tests whether or not your prediction is correct. To help you design your experiment, consider the following questions.
   - What materials and equipment would you use to test your prediction?
   - What steps would you follow to carry out your experiment?
   - What type of data would you collect?
   - How would you measure and record the data?
   - How would you know if the factor you are investigating is increasing leaf decay?

What Did You Find Out?

1. If possible, compare your experiment's design to that of another team that investigated the same factor. Are there improvements that you could make to your design?

How Energy Flows in Ecosystems

In section 1.2, you learned that organisms have special roles, or niches, in the ecosystems in which they live. They compete for food and other resources or may be part of a predator-prey relationship. Within its niche, every organism in an ecosystem interacts with that ecosystem in two ways: (1) the organism obtains food energy from the ecosystem, and (2) the organism contributes energy to the ecosystem. The flow of energy from an ecosystem to an organism and from one organism to another is called **energy flow**. You are part of this flow of energy when you eat the food energy stored in plants and animals (Figure 2.3).

Figure 2.3 Plants in the form of grains, fruits, and vegetables provide you with energy in the form of carbohydrates.

Plants are called **producers** because they "produce" food in the form of carbohydrates during photosynthesis. Carbohydrates stored in plants become an energy source for other life forms. An insect such as a bee that feeds on a plant such as a sunflower is called a **consumer** (Figure 2.4A and Figure 2.4B). A consumer may also become an energy source if eaten by another consumer (Figure 2.4C).

Figure 2.4 Plants such as sunflowers are producers (A). Consumers such as bees obtain nutrients from sunflowers (B), and bees are an energy source for other consumers such as this crab spider (C).

Organisms continue to contribute to the energy flow in an ecosystem even after they die, in a process called decomposition. **Decomposition** is the breaking down of organic wastes and dead organisms. The action of living organisms such as bacteria to break down dead organic matter is called **biodegradation**. Organisms such as bacteria (Figure 2.5) and fungi are called decomposers. **Decomposers** change wastes and dead organisms into usable nutrients. The nutrients are then made available to other organisms in soil and water and link the biotic and abiotic components of an ecosystem.

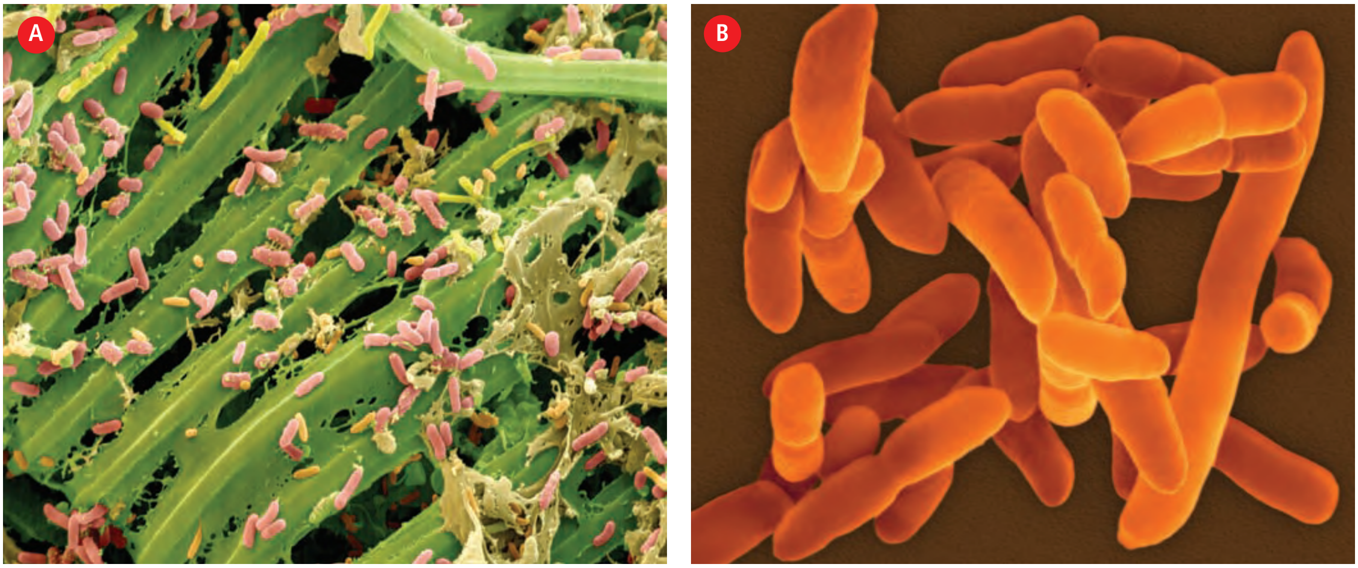


Figure 2.5 Bacteria on a decomposing cucumber (A). *Anthrobacter* is a type of decomposer bacteria (B).

Reading Check

1. What is biomass?
2. Why are plants called producers?
3. What is a consumer?
4. What is biodegradation?
5. What role do decomposers have in ecosystems?

Energy Flow and Energy Loss in Ecosystems

Scientists use different models to help them understand how energy flows through or is lost in an ecosystem. These models are food chains, food webs, and food pyramids. Each of these models reflects the feeding relationships of organisms within ecosystems.

Food chains and food webs

Food chains are models that show the flow of energy from plant to animal and from animal to animal (Figure 2.6). Each step in a food chain is called a **trophic level**. Trophic levels in a food chain show the feeding and niche relationships among organisms. Since plants and phytoplankton such as algae are the producers, they are at the first trophic level and are referred to as **primary producers**.

Figure 2.6 A terrestrial food chain and an aquatic food chain show the flow of energy up the trophic levels.

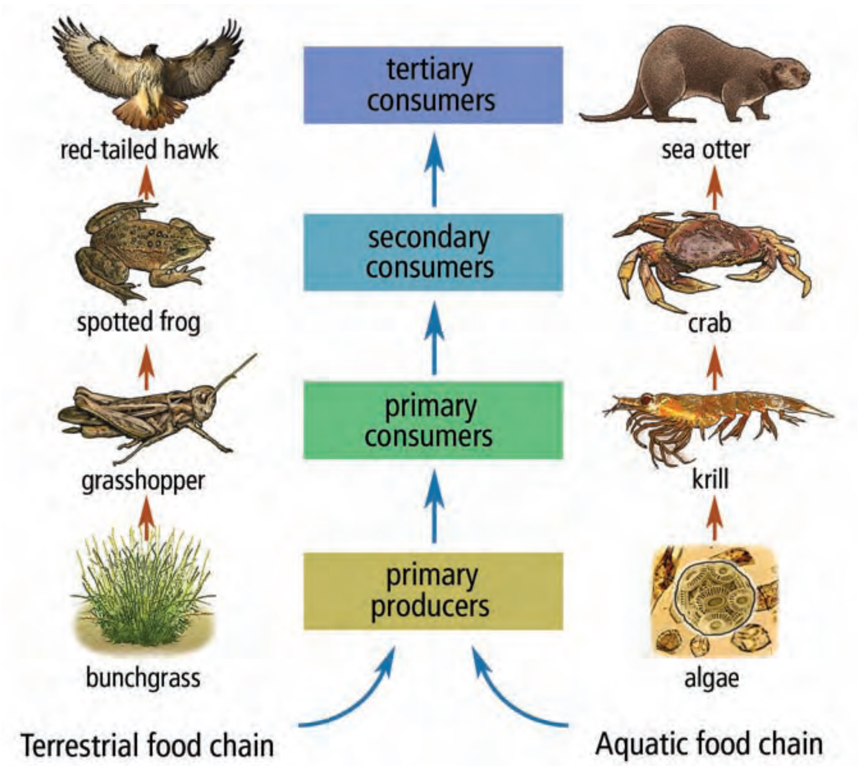


Figure 2.7 Detrivores in this forest ecosystem include carpenter ants, pill bugs, snails, and mites. Unseen are decomposer bacteria that vastly outnumber these detrivores.

In Figure 2.6, you can see that **primary consumers** such as grasshoppers and zooplankton (microscopic aquatic animals) are in the second trophic level. They obtain their energy by eating primary producers. **Secondary consumers** such as frogs and crabs are in the third trophic level and obtain their energy by eating primary consumers. In the fourth trophic level are **tertiary consumers** such as hawks and sea otters that feed on secondary consumers to obtain energy.

When ecologists discuss the diet or behaviour of organisms in a food chain, they often use the terms detrivores, herbivores, and carnivores. In terrestrial ecosystems, detrivores include small insects, earthworms, bacteria, and fungi (Figure 2.7).

Detrivores are consumers that obtain their energy and nutrients by eating the bodies of small dead animals, dead plant matter, and animal wastes. Detrivores feed at every trophic level (Figure 2.8) and make up their own important food chains. In fact, food chains based on dead plant and animal matter actually outnumber food chains based on living plants and animals. Detrivores such as earthworms and beetles are also an important energy source for consumers such as birds.

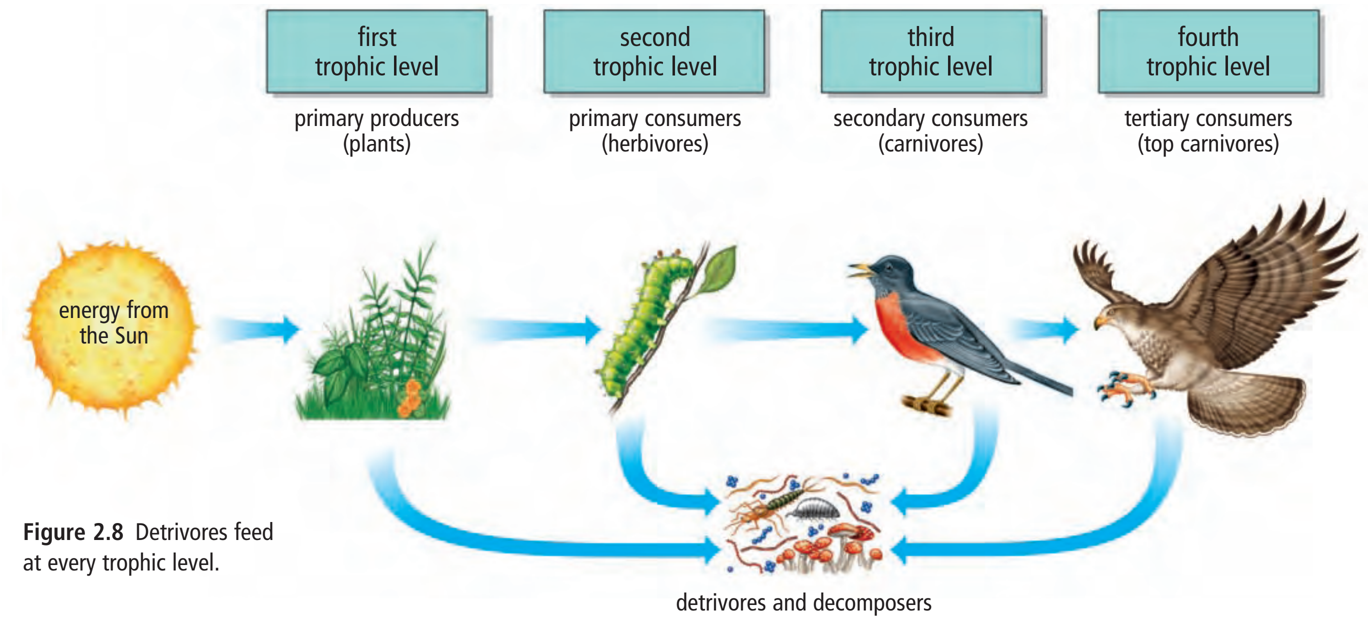


Figure 2.8 Detrivores feed at every trophic level.

Herbivores, such as grasshoppers, are primary consumers that eat plants. **Carnivores**, such as spotted frogs, are secondary consumers that eat primary consumers. Carnivores also eat other secondary consumers and are often at the tertiary level of a food chain. Carnivores at this level are often referred to as top carnivores, top consumers, or top predators. Figure 2.9 and Figure 2.10 on the next page show more examples of herbivores and carnivores.

Figure 2.9 Bighorn sheep (A) and western tiger swallowtail butterflies (B) are herbivores.

Figure 2.10 Grey wolves (A) and hobo spiders (B) are carnivores.

Many animals are part of more than one food chain and eat more than one kind of food in order to meet their energy requirements. For example, squirrels are primary consumers when they eat seeds or fruits. When they eat insects or young birds, squirrels are secondary or tertiary consumers. Consumers that eat both plants and animals are called **omnivores**. Interconnected food chains form a food web. **Food webs** are models of the feeding relationships within an ecosystem (Figure 2.11).

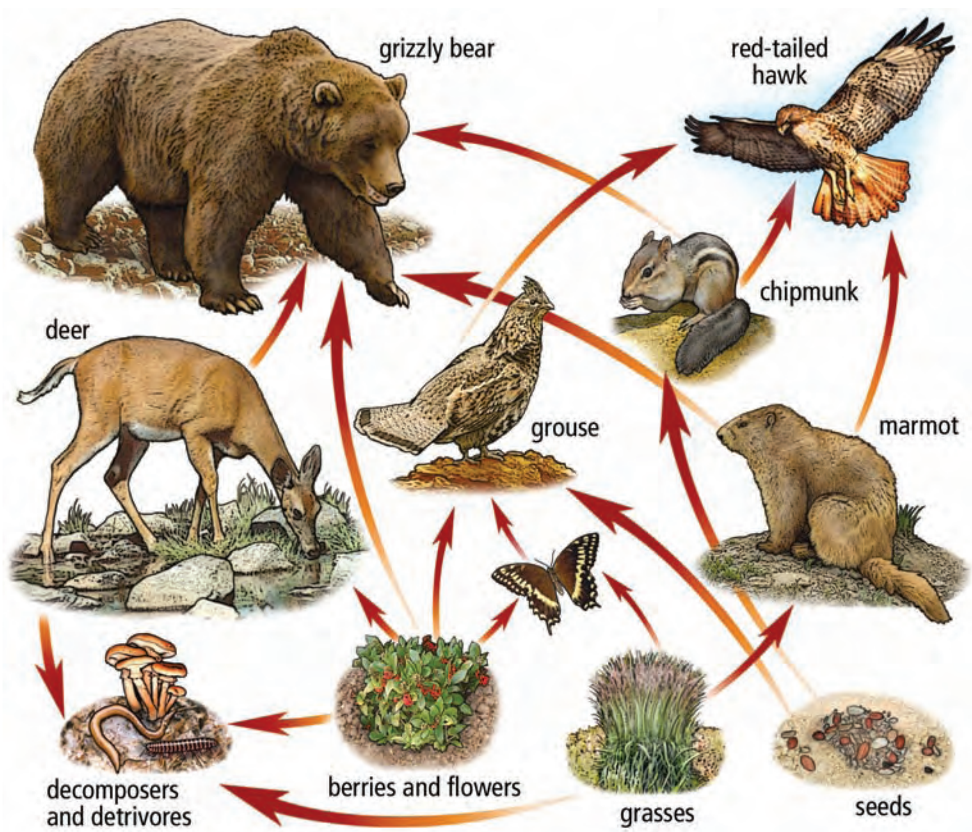


Figure 2.11 A food web in a terrestrial ecosystem

Food pyramids

When an insect eats leaves, energy stored in the leaves is transferred to the insect. When a bird eats the insect, energy stored in the insect is transferred to the bird. The same transfer of energy also occurs when killer whales eat salmon and when you eat meat, vegetables, and fruit. However, not all of the energy that organisms obtain by eating other organisms is stored (Figure 2.12). Food energy is used as you and all other living things work to obtain and digest food, repair damaged tissues, and move. Food energy is also lost when some food remains undigested and is excreted as feces. Between 80 and 90 percent of the food energy taken in by you and other organisms is used for chemical reactions in the body and eventually is lost to the ecosystem as heat. Very little food energy is used for growth or to increase biomass.

Did You Know?

Mammals and birds require a lot more food energy than most other animals to keep their body temperatures high and relatively stable.

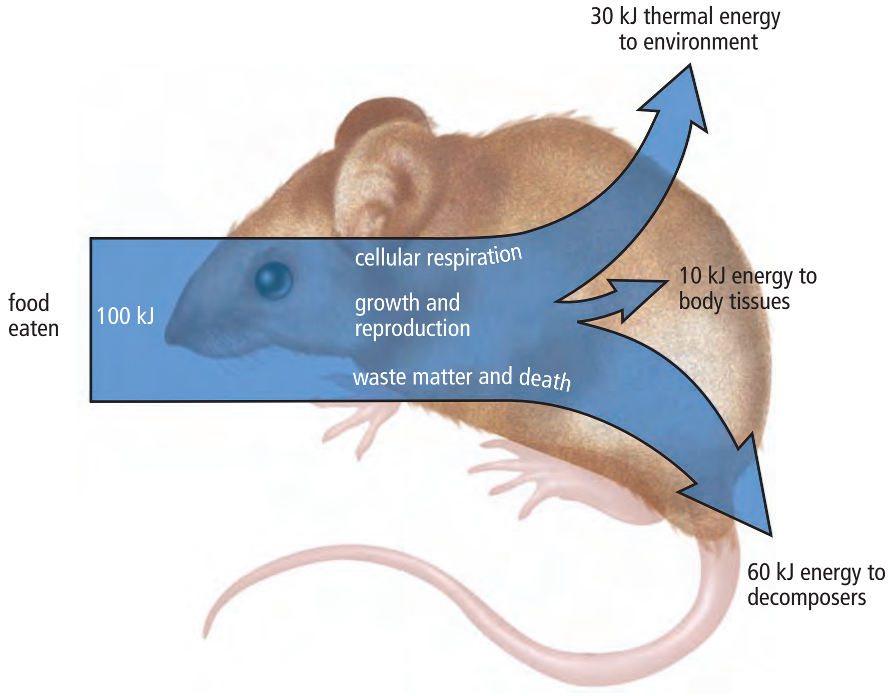


Figure 2.12 Ninety percent of the food energy taken in by this mouse is used to maintain its life functions.

A **food pyramid** is a model that shows the loss of energy from one trophic level to another (Figure 2.13 on the next page). Food pyramids are often referred to as ecological pyramids. There are several of types of **ecological pyramids** such as pyramids of biomass, numbers, and energy (see page 66). The amount of life that an ecosystem can support is determined by the amount of energy captured by producers. A desert or tundra ecosystem with little vegetation cannot support many organisms.

Explore More

In aquatic food chains, algae are primary producers that support marine life. Algae also produce 70 to 80 percent of Earth's oxygen and may be future producers of biofuels. Find out more about marine algae. Begin your search at **www.bcscience10.ca**.

Because of the 90 percent decrease in energy from trophic level to trophic level, an ecosystem supports fewer organisms at the higher trophic levels. Therefore, the lower the trophic level, the higher the number of organisms that can be supported by the ecosystem. Healthy grassland ecosystems can support many herbivores such as mice and jackrabbits, which, in turn can support large numbers of carnivores such as coyotes.

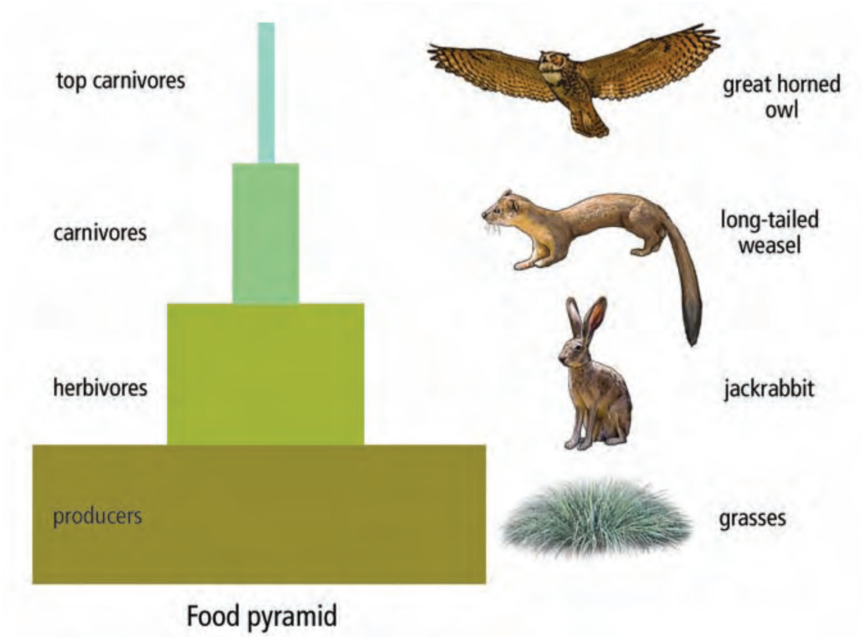


Figure 2.13 A food pyramid shows the loss of energy from one trophic level to another. This is represented by the decreasing size of the block at each level. Producers such as plants store the most energy. Carnivores such as great horned owls store the least.

Food pyramids illustrate that most of the Sun's energy that is trapped by plants flows out of an ecosystem. Food pyramids also show how important plant life is for making energy available in ecosystems. Maintaining the biodiversity of plants in an ecosystem is essential for maintaining viable food webs.

Reading Check

1. What is a food chain?
2. What is a trophic level?
3. What role do herbivores have in a food pyramid?
4. What happens to the food energy taken in by an organism?
5. What is the purpose of a food pyramid?

2-1B Comparing Available Energy

Find Out ACTIVITY

Burning firewood for heat is one of the oldest forms of using biomass energy. A temperate deciduous forest populated by trees such as maple, birch, and oak produces about 8000 kilocalories per square metre per year (kcal/m^2/y). A coniferous forest of evergreen trees such as pine, spruce, and hemlock produces about 3000 kcal/m^2/y. In this activity, you will construct two pyramids to compare the energy available in a coniferous forest and a deciduous forest.

Materials

- blank sheet of looseleaf paper
- calculator
- eight 2 cm wide strips of coloured paper
- ruler
- glue

What to Do

1. To construct a pyramid to illustrate the energy in a deciduous forest, you must use a scale for your model so that the pyramid will fit on half a sheet of looseleaf paper. Use a scale of 10 mm equals 400 kcal/m^2 to represent the amount of energy captured in a year by 1 m^2 of deciduous forest.
2. Copy the table into your notebook. In the Temperate Deciduous Forest Energy Pyramid section of your table, record 8000 kcal/m^2 of energy present for producers. Calculate how many millimetres in length a coloured strip of paper needs to be to represent 8000 kcal/m^2. Record this number in the appropriate column of your table.
3. Only 10 percent of the energy present in the biomass of the producers is converted into animal biomass. Calculate the amount of energy available to primary consumers, secondary consumers, and tertiary consumers in a deciduous forest. Record these amounts in your table.
4. Calculate how many millimetres in length a coloured strip of paper needs to be to represent each level of consumer in step 2. Record the data in your table.
5. Calculate and record the amount of energy lost at each trophic level.
6. Cut a strip of coloured paper to the correct length for plants and label it "Producers."
7. Cut a strip of coloured paper to the correct length and label it "Primary Consumers." Cut two more strips to the correct lengths and label them "Secondary Consumers" and "Tertiary Consumers."
8. Using the top half of the sheet of paper, glue the cut strips horizontally in a pyramid (the longest strip at the bottom of the pyramid, the shorter strips centred in a stack above it).
9. Repeat the above steps for the coniferous forest. Use the same scale (10 mm equals 400 kcal/m^2), and glue the pyramid to the bottom half of the sheet of paper.
10. Give each pyramid an appropriate title, and label each level in both pyramids.

Pyramids of Energy

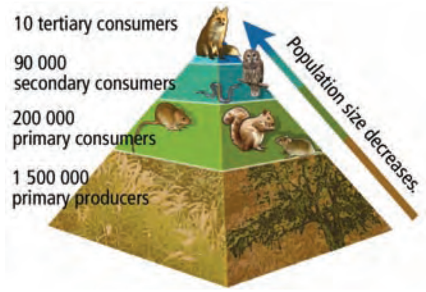
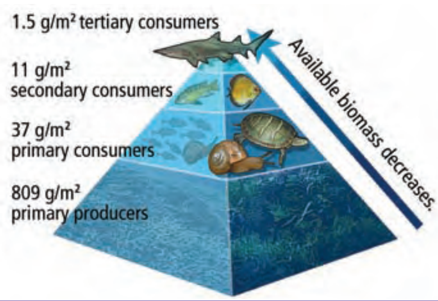
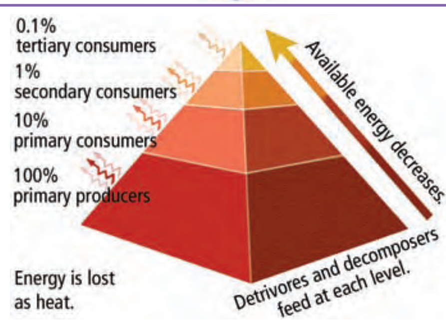
Temperate Deciduous Forest Energy Pyramid	Energy Present (kcal/m^2)	Length of Paper Strip (mm)	Energy Lost as Heat (kcal/m^2)
Producers			None
Primary consumers			
Secondary consumers			
Tertiary consumers			
Coniferous Forest Energy Pyramid	**Energy Present (kcal/m^2)**	**Length of Paper Strip (mm)**	**Energy Lost as Heat (kcal/m^2)**
Producers			None
Primary consumers			
Secondary consumers			
Tertiary consumers			

What Did You Find Out?

1. Which type of forest can support more primary consumers? More tertiary consumers?
2. Explain what happens to the energy that is not transferred at each trophic level.
3. Explain why the energy that is not transferred at each trophic level cannot be picked up by plants and cycled back through the system.

Science Math connect

Comparing Ecological Pyramids

Type of Ecological Pyramid	Diagram	Limitations
A **pyramid of numbers** shows the number of organisms at each trophic level.		The sizes of individual organisms vary greatly, therefore their energy needs vary greatly. The range of numbers from the producers to the tertiary consumers may be so great that it is impossible to represent the scale of the pyramid accurately.
A **pyramid of biomass** shows the number of organisms at each trophic level multiplied by their mass, which compensates for differences in size among organisms.		In some ecosystems, the biomass of lower trophic levels can be less than that of higher trophic levels. For example, in aquatic ecosystems, pyramids of biomass may be inverted because of the rapid reproduction rates of primary producers such as algae.
A **pyramid of energy** shows the amount of energy that is available at each trophic level.		It is difficult to obtain exact values of available energy in an ecosystem.

Questions

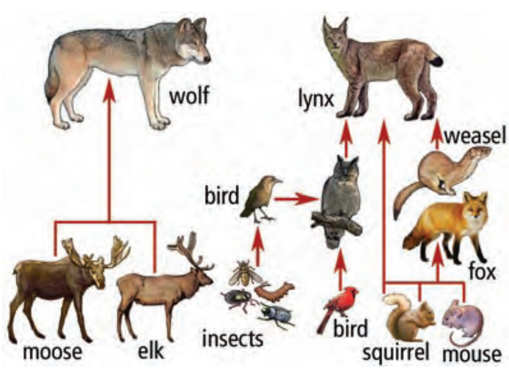
1. Data for ocean food chains are given in the table. Use graph paper and the data to construct:
   (a) a pyramid of numbers
   (b) a pyramid of biomass
   (c) a pyramid of energy
2. Are the pyramids you constructed for question 1 identical in appearance? Explain.

Trophic Level	Number of Organisms	Mass (g/m^2)	Energy ($kcal/m^2$)
Primary producers (phytoplankton)	4 000 000 000	807	36 380
Primary consumers	11	37	596
Secondary consumers	1	11	48

Check Your Understanding

Checking Concepts

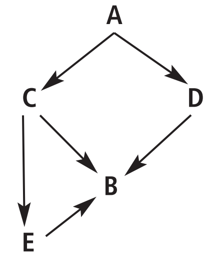
1. How do fungi decompose leaves?
2. What is decomposition?
3. Explain why plants are called primary producers.
4. Put the following organisms in order from lowest trophic level to highest trophic level.
   (a) snake (c) grass
   (b) eagle (d) mouse
5. (a) Are herbivores primary consumers? Explain why or why not.
   (b) Are carnivores primary consumers? Explain why or why not.
   (c) What is an omnivore?
6. Give an example of each of the following.
   (a) a secondary consumer
   (b) a tertiary consumer
   (c) an omnivore
7. How much energy is lost from producers to secondary consumers?
8. In the diagram below, identify each of the following.
   (a) producers
   (b) primary consumers
   (c) secondary consumers
   (d) tertiary consumers



9. Give an example of a food chain in a pond ecosystem.
10. What is the main difference between food chains and food webs?
11. Do detrivores return energy to an ecosystem? Explain.

Understanding Key Ideas

12. In the following diagram of a food web, identify which letter represents a species that:
    (a) is the producer
    (b) has the greatest biomass
    (c) has the smallest biomass
    (d) could be a caterpillar
    (e) could be a decomposer



13. If there are 1 000 000 kcal/m^2 in the producer level of a food pyramid, how many kilocalories will be incorporated into the bodies of the following, if there is a 90 percent energy loss at each level?
    (a) primary consumers
    (b) secondary consumers
    (c) tertiary consumers
14. (a) Describe a four-organism food chain that might be found in a desert community.
    (b) Identify the trophic level of each organism.
15. Explain why you do not gain weight every time you eat.
16. Explain why there cannot be an unlimited number of trophic levels.

Pause and Reflect

What would be the impact on life on Earth if less and less solar energy were able to reach Earth's surface?