1.2 The Biosphere and Energy

Key Terms
photosynthesis
trophic level
biomass
trophic efficiency
bioaccumulation

All activities require a source of energy—a fuel. For example, to sustain a campfire, you need to keep it supplied with wood. To reach a destination by car, you need to have enough gas in the tank. To migrate successfully, hummingbirds need to burn the fat that is stored in their tissues.

In each of these examples, the fuel is different—wood for the campfire, gasoline for the car, and nectar stored as fat for the hummingbirds. In a different sense, however, the three fuels are the same. They all come from the same source—solar energy that has been converted to and stored as chemical energy. Solar energy is energy from the Sun, as shown in **Figure 1.11**. This energy is given off by nuclear reactions in the Sun. Some organisms in the biosphere trap solar energy and use it to make food, which is then used by all organisms to fuel activity and growth.

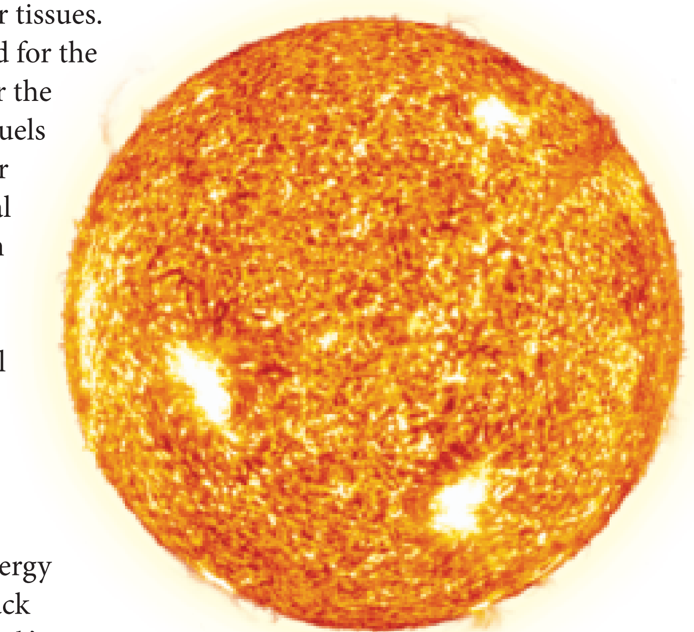


Figure 1.11 Nuclear reactions in the Sun are the energy source for almost all life on Earth. Although only a small fraction of the Sun's energy reaches Earth's surface, this is enough to sustain the biosphere.

Photosynthesis and the Sun's Energy

An enormous amount of energy reaches Earth from the Sun. At the same time, there is a never-ending loss of energy from Earth. The energy is lost as heat when it spreads back out from Earth's surface, beyond Earth's atmosphere. Earth's atmosphere is able to trap some of the heat, warming the atmosphere and making Earth habitable.

Matter is used over and over as it moves through Earth's four spheres. The nutrient cycles you read about in Section 1.1 show this concept. The nutrients may change form or take millions of years to complete their cycle, but no matter is lost as they move through Earth's four spheres.

Chlorophyll and Photosynthesis

The conversion of solar energy to chemical energy, in the form of food, is important to life for two reasons. First, the Sun will continue to supply Earth with energy for billions of years. Second, many organisms on Earth, including plants, algae, and some bacteria, contain chlorophyll, which allows the biosphere to harvest some of this reliable solar energy.

Chlorophyll is the central player in **photosynthesis**, a process that is crucial to life on Earth. The terms "chlorophyll" and "photosynthesis" are both built from ancient Greek words. *Chloros* means green, and *phyllon* means leaf. Chlorophyll is a pigment that gives leaves their green colour. *Photo* means light, and *synthesis* means putting together. Photosynthesis refers to putting something together using light. What does photosynthesis put together using chlorophyll and light? Photosynthesis puts together carbon, hydrogen, and oxygen to make life's universal energy supply—sugar. You may already know that there are different types of sugars. Photosynthesis produces one specific type of sugar, called glucose.

photosynthesis a process that changes solar energy into chemical energy

Suggested Investigation

Inquiry Investigation 1-B, The Chemistry of Photosynthesis, on pages 38–39

What Happens During Photosynthesis?

Sugars, including glucose, are in a class of molecules called carbohydrates. Carbohydrates are made from carbon, oxygen, and hydrogen. Thus, to make glucose, plants need ready supplies of these three elements. They get the hydrogen from water, mostly through their roots. They get the carbon and oxygen from carbon dioxide gas, through tiny pores in their leaves called stomata (singular, stoma or stomate), as shown in **Figure 1.12**.

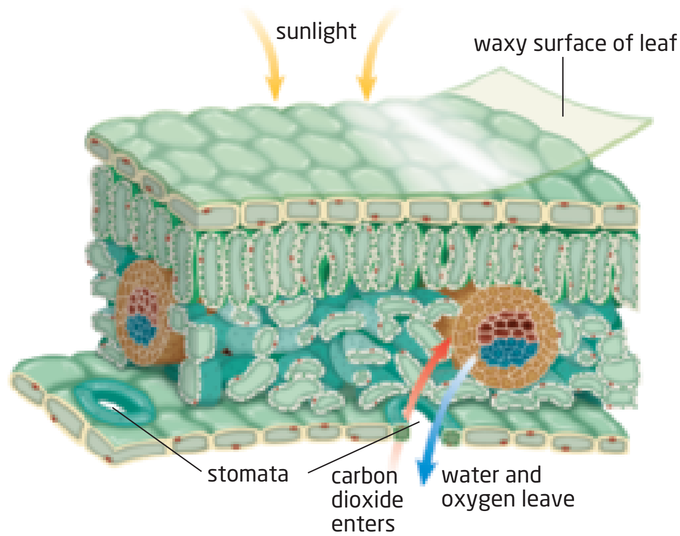


Figure 1.12 Plants take in carbon dioxide and release oxygen through small pores in their leaves called stomata.

In the process of photosynthesis, shown in **Figure 1.13**, the chlorophyll in plant leaves uses solar energy to assemble glucose molecules from water and carbon dioxide. Oxygen is also produced by photosynthesis. The chemical formula for photosynthesis is shown below.

$$\underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} \xrightarrow{\text{light energy}} \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2}$$

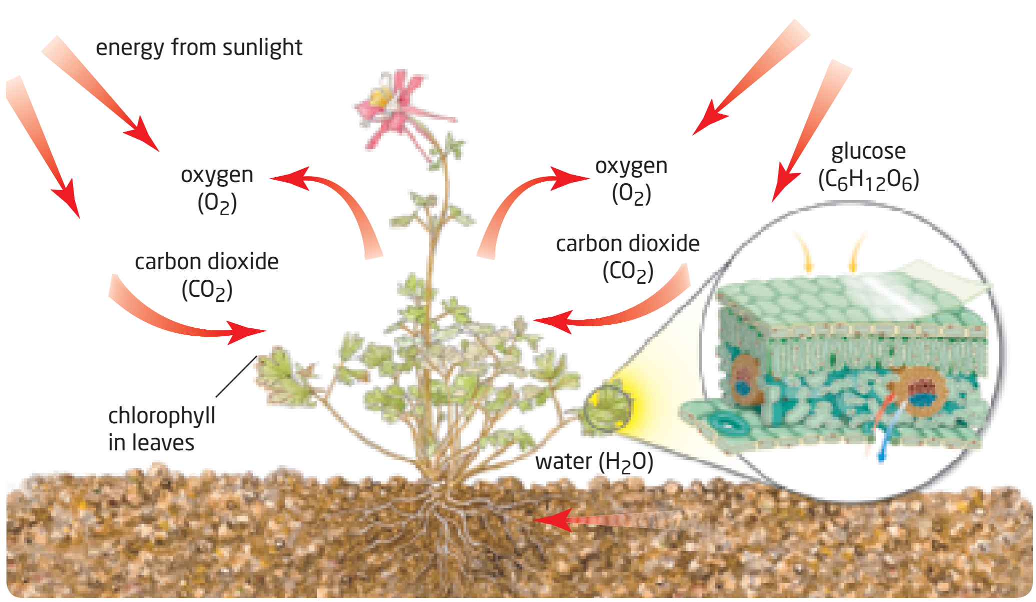


Figure 1.13 Without light energy, photosynthesis cannot occur.

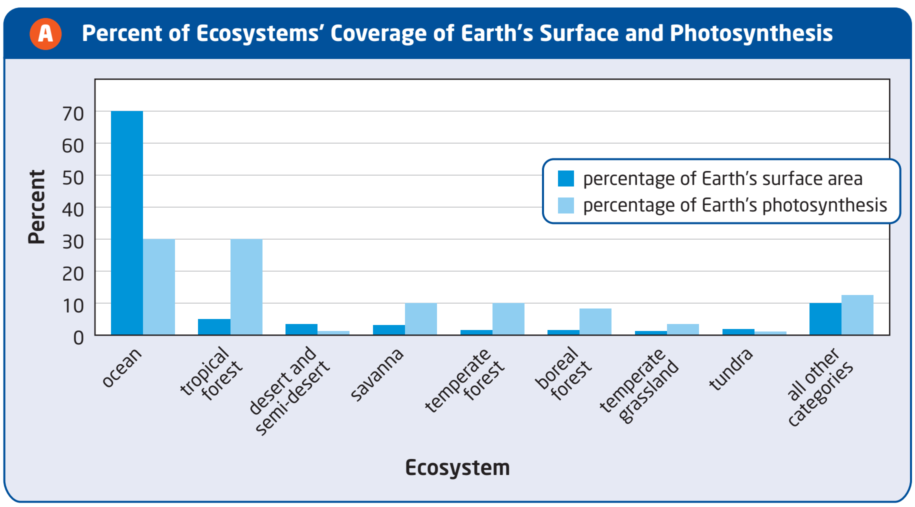
Sources of Oxygen

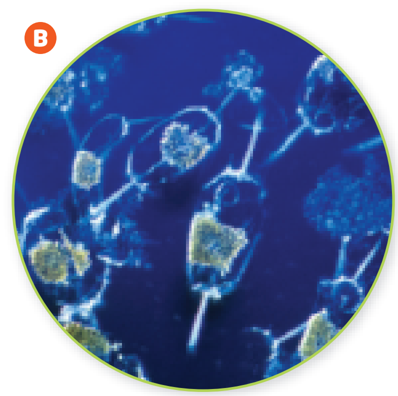
Photosynthesis is vital for the biosphere. Photosynthesis produces glucose, an energy supply that plants, and the organisms that eat them, require for all of life's essential activities. As well, photosynthesis continuously adds oxygen to the atmosphere, which many organisms breathe. Finally, photosynthesis continuously removes carbon dioxide from the atmosphere.

Wherever there are chlorophyll-containing organisms, oxygen is generated. Not all parts of the biosphere produce oxygen at the same rate, however. **Figure 1.14A** shows that two ecosystems are particularly important. One of these ecosystems is tropical forests. Even though they cover only about 5 percent of Earth's surface, tropical forests are responsible for about 30 percent of Earth's photosynthesis. The second ecosystem is the world's oceans, which are also responsible for about 30 percent of Earth's photosynthesis. In aquatic ecosystems, photosynthesis is mainly performed by algae and chlorophyll-containing microscopic organisms, known as phytoplankton. Phytoplankton are shown in **Figure 1.14B**.

Sense of scale

Photosynthesis produces the equivalent of 100 to 200 billion tonnes of sugar each year. This amount of sugar is enough to make about 3.0×10^{17} sugar cubes!





phytoplankton

Figure 1.14 In **A**, the dark blue bars represent the percentage of Earth's surface area that each ecosystem covers. For example, the oceans cover about 70 percent of Earth. The light blue bars represent the percentage of photosynthesis in each ecosystem. **B** shows phytoplankton, which carry out photosynthesis in aquatic ecosystems.

Learning Check

1. What is chlorophyll?
2. Write the word equation for photosynthesis. Indicate the source of each material.
3. Draw a diagram of a leaf, and label the stomata. If the stomata of a leaf are damaged, what are some possible effects?
4. In the winter, very little photosynthesis occurs in Canada. Explain how, on a January day, you may directly benefit from tropical forests.

Trophic Levels

trophic level a category of organisms that is defined by how the organisms gain their energy

Matter and energy are transferred between trophic levels within the biosphere. A **trophic level** is a category of organisms that is defined by how the organisms gain energy. Examples of trophic levels include primary producers and consumers. *Primary producers* are organisms that can make their own food, such as plants. *Consumers* are organisms that cannot make their own food. Consumers must eat other organisms to get the matter and energy they need to survive.

Study **Figure 1.15**, which shows a sample food chain. Notice that there are four trophic levels in this food chain. The primary producers are at the first trophic level. The grasshopper is the primary consumer, at the second trophic level. The barn swallow is the secondary consumer, at the third trophic level. Secondary consumers eat primary consumers to obtain energy. The hawk, a tertiary consumer, is at the fourth trophic level. Tertiary consumers feed on secondary consumers to obtain energy.

Since the grasshopper only eats plants, it is called a herbivore. Consumers that only eat other animals, such as the barn swallow and the hawk, are called carnivores. Consumers that eat both plants and other animals are called omnivores. Both energy and matter, including nutrients, move through the trophic levels of this food chain.

Notice that all the levels of this food chain are linked to decomposers. Ultimately, decomposers move the nutrients in the decaying bodies and wastes of producers and consumers back to the abiotic parts of the ecosystem as they take in the nutrients they need to survive.

Study Toolkit

Comparing and Contrasting
Making a Venn diagram can help you compare and contrast primary producers and consumers.

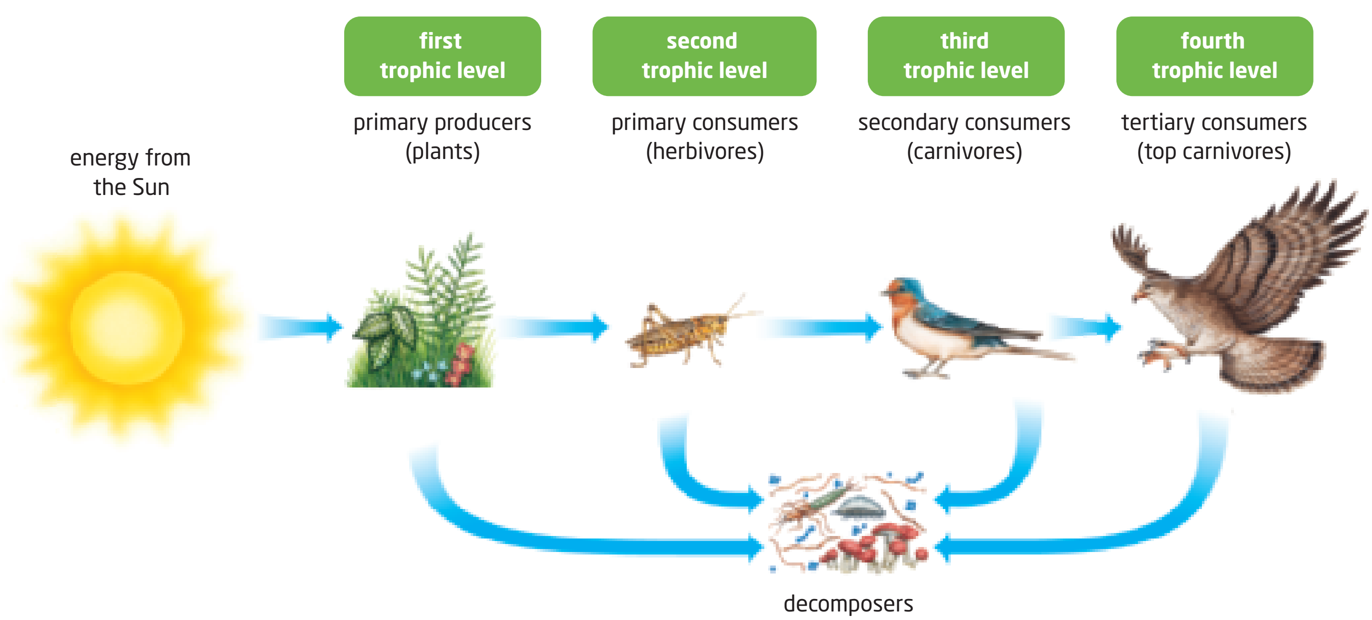


Figure 1.15 Matter moves through the biosphere by travelling from one trophic level to the next in a cycle.

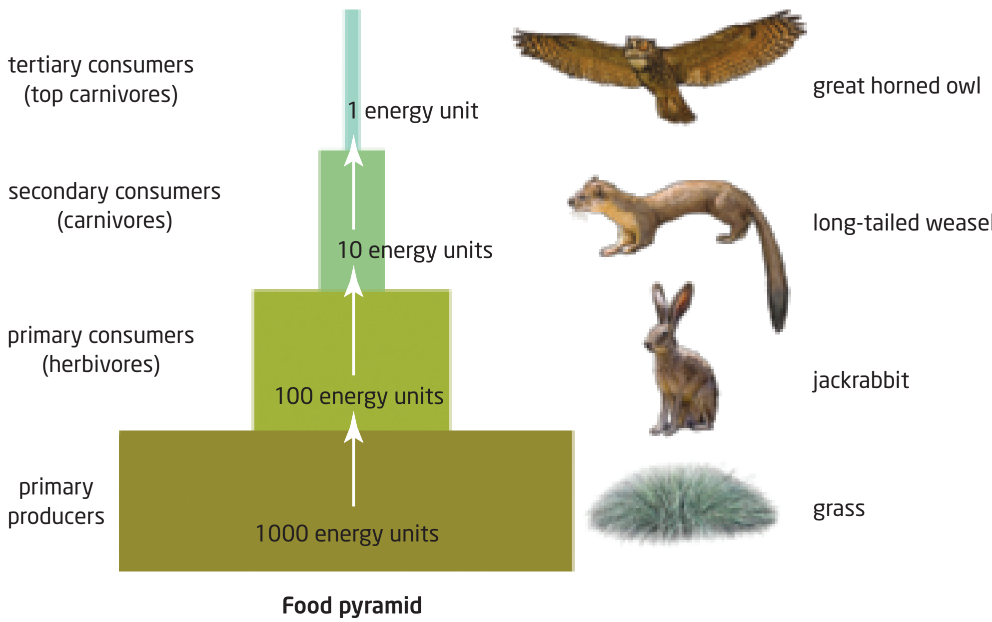


Figure 1.16 Energy that is stored in biomass at one trophic level moves to the next trophic level through a food chain.

Trophic Efficiency

Biomass is the mass of living cells and tissues that has been assembled by organisms using solar energy. Leaves, stems, wood, roots, and flower nectar are all packed with chemical energy that has been converted from solar energy. Animals indirectly rely on solar energy too, by eating plants or other animals that eat plants.

Trophic efficiency is a measure of how much of the energy in organisms at one trophic level is transferred to the next higher trophic level. This percentage is always less than 100 percent because organisms use much of the energy from the biomass they consume for their life functions, and they produce wastes as well. In fact, trophic efficiencies are usually quite inefficient—only about 10 percent.

Figure 1.16 shows a sample food chain from a primary producer, grass, to a tertiary consumer, the great horned owl. Suppose that the grass biomass contains 1000 units of energy. If only 10 percent of this energy is transferred to the jackrabbit, only 100 units of energy will reach the jackrabbit. Of these 100 units, only 10 will be transferred from the jackrabbit to the long-tailed weasel. Of the 10 units that reach the weasel, only 1 unit of energy will reach the great horned owl.

There are several reasons why biomass decreases from one trophic level to the next. Herbivores may not eat all the parts of a plant; for example, they may eat only the tops of the plants and leave the roots. Not everything that is eaten is digested; for example, fur may not be digested. Also, at every level, energy is lost as heat from the bodies of organisms. Because of the inefficiency of energy transfer among trophic levels, there are usually fewer carnivores than herbivores, and fewer herbivores than plants.

biomass the total mass of living organisms in a defined group or area

trophic efficiency a measure of the amount of energy or biomass transferred from one trophic level to the next higher trophic level

Water Pollution and Bioaccumulation

The monarch butterfly is poisonous to eat. It does not make its own poison, however. As a caterpillar, it feeds on a plant called milkweed. It ingests toxins, or poisonous substances, from the milkweed. The toxins are stored in the butterfly, in tissues where they do not harm it. The ingestion of toxins at a rate faster than they are eliminated is called **bioaccumulation**.

bioaccumulation a process in which materials, especially toxins, are ingested by an organism at a rate greater than they are eliminated

In this example, bioaccumulation works to the advantage of the species. If fewer individuals of the species are eaten because they are poisonous, more individuals will survive to reproduce. In contrast, the bioaccumulation of toxins from human-made pollution can be devastating to a species. These toxins can cause health problems or death. *Biomagnification* is a process that is related to bioaccumulation. Biomagnification is the increase in the concentration of a toxin as it moves from one trophic level to the next.

DDT

DDT (**d**ichloro-**d**iphenyl-**t**richloroethane) is an agricultural insecticide that was once used in North America. When DDT entered the environment in run-off from land, it was absorbed by algae in the water. Microscopic animals ate the algae, and small fish ate the microscopic animals. At each trophic level in the food chain, the concentration of DDT in the tissues of the organisms increased. At high concentrations, the DDT affected reproduction in fish-eating birds. Following the ban on DDT in the 1970s, populations of DDT-vulnerable birds slowly increased in numbers in Canada.

PCBs

PCBs (**p**oly**c**hlorinated **b**iphenyls) were previously used by industries. PCBs entered water, air, and soil while they were being used and disposed of. **Figure 1.17** shows how the concentration of PCBs, given in parts per million (ppm), is biomagnified in higher-level consumers in the Great Lakes. Peregrine falcons were affected by both DDT and PCBs. Exposure to PCBs also affected reproduction in these birds. After PCBs were banned, peregrine falcons were brought back from the brink of extinction by having captive birds produce young, which were then raised by humans in boxes on nesting cliffs or tall downtown buildings.

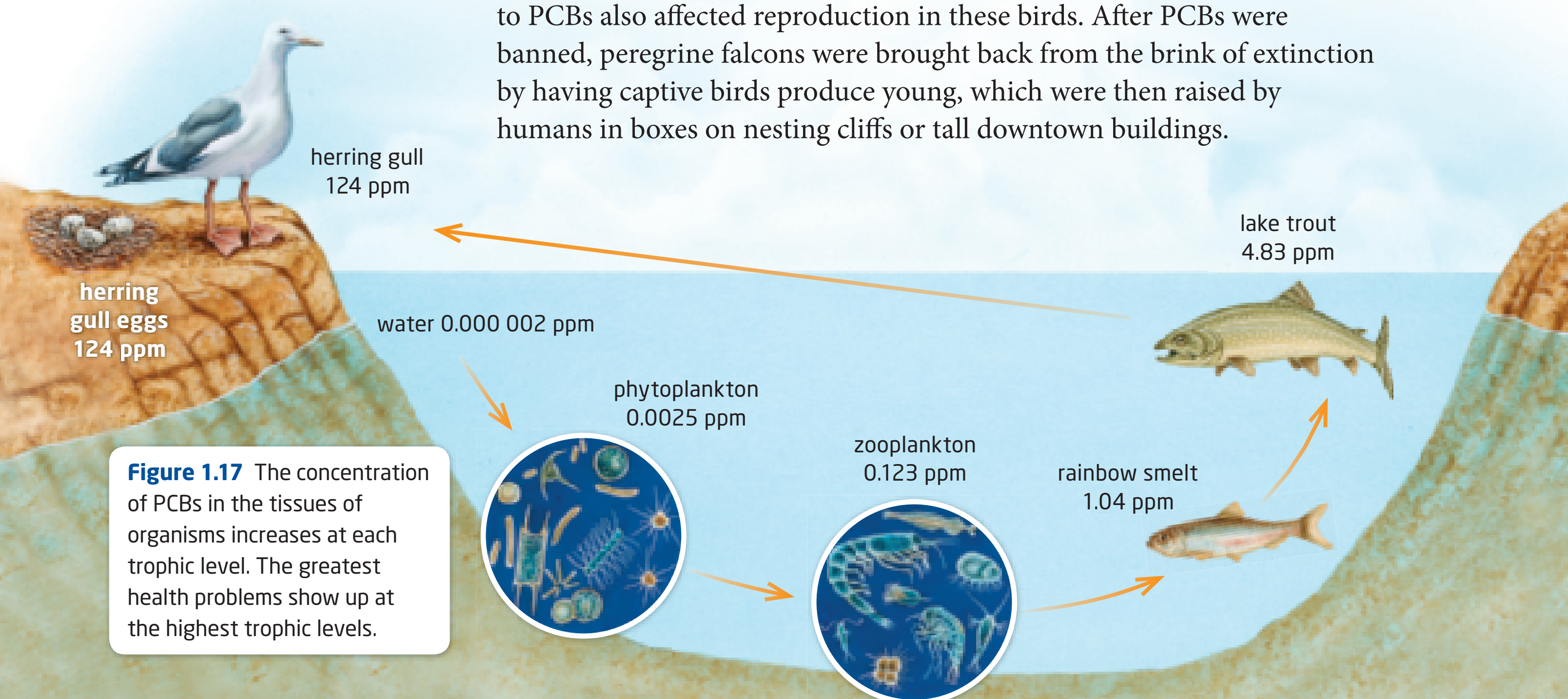


Figure 1.17 The concentration of PCBs in the tissues of organisms increases at each trophic level. The greatest health problems show up at the highest trophic levels.

Section 1.2 Review

Section Summary

- The biosphere relies on a constant source of solar energy.
- Chlorophyll in primary producers converts solar energy to chemical energy through photosynthesis.
- Most of the stored energy in one trophic level does not move to the next trophic level.
- Bioaccumulation and biomagnification can result in unhealthy levels of pollutants in organisms.

Review Questions

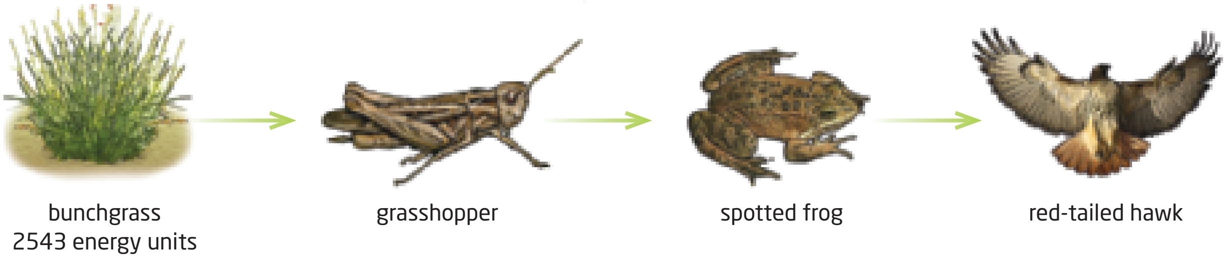
K/U **1.** Explain the process of photosynthesis.

K/U **2.** What three chemical elements are the building blocks of carbohydrates?

C **3.** Should photosynthesis win the "Most Important Chemical Reaction on Earth" award? Explain your answer.

K/U **4.** What is the difference between a producer and a consumer?

A **5.** Calculate the units of energy at each trophic level in the food chain below, assuming that the trophic efficiency at each level is 10 percent.



K/U **6.** Trophic efficiency is usually only 10 percent. What happens to the energy that does not move up to the next trophic level?

C **7.** Use a Venn diagram to compare and contrast bioaccumulation and biomagnification. Give one example of each.

T/I **8.** Refer to **Figure 1.17**. Suppose that a lake is located beside an abandoned manufacturing plant. Someone discovers that the plant is leaking chemicals into the lake. The chemicals are absorbed by phytoplankton, which are consumed by zooplankton. Which size of fish would you expect to have higher levels of chemicals in their tissues: smaller fish that eat zooplankton or larger fish that eat the smaller fish? Explain your answer.