about ecosystems and how much we have to gain from closed ecosystem experiments.

Even with the use of careful monitoring and direct control of the systems within the enclosure—through the use of the most modern computers, materials, and control systems—it was easy for the delicate balance within this system to get out of phase.

OUTSIDE Biosphere 2, in the original, natural biosphere of the Earth, we do not have such elaborate monitoring and control systems. Life has persisted on the Earth for $3\frac{1}{2}$ billion years without a pilot at the controls and without computers to ensure that everything is working. How is it possible that our planetary life-support system has been self-sustaining for such a long time? To obtain an answer, we must first consider what it is that sustains life on Earth.

6.1 WHAT SUSTAINS LIFE ON EARTH?

We tend to associate life with individual organisms, for the obvious reason that it is individuals that are alive. But *sustaining* life on the Earth requires more than individuals or even single populations or species. Life is sustained by the interactions of many organisms functioning together, interacting through their physical and chemical environments. To understand important environmental issues, such as conserving endangered species, sustaining renewable resources, and minimizing the effects of toxic substances, we must know certain basic principles about a collection of organisms of different kinds that function together. That is, we must understand the concepts of the ecosystem (introduced in Chapter 3) and the ecological community. An ecosystem is an ecological community, along with its nonliving environment, functioning as a unit. An **ecological community** is a set of interacting species that occur in the same place. The purpose of this chapter is to develop these two important concepts as they relate to sustaining life on Earth.

6.2 THE ECOSYSTEM

The ecosystem concept is at the heart of the management of natural resources. When we try to conserve species or manage natural resources so that they are sustainable, we must focus on their ecosystem and make sure that it continues to function. If it doesn't, we must replace or supplement ecosystem functions with our own actions.

At its simplest, an ecosystem consists of several species—at least one species that produces its own food from inorganic compounds in its environment and one species that decomposes the wastes of the first species—plus a fluid medium (air, water, or both). Two basic kinds of processes must occur in the ecosystem: a cycling of chemical elements and a flow of energy.

Given these qualities needed for life, we recognize that *sustained life on Earth is a characteristic of ecosystems, not of individual organisms or populations.*[3] No species exists that both produces all its own food and decomposes all its wastes so that the materials can be reused to produce food. No individual cell, population, or community of populations forms a sufficient system to support life.

In the presence of light, green plants, algae, and photosynthetic bacteria produce sugar from carbon dioxide and water; from sugar and inorganic compounds they make many other organic compounds, including proteins and woody tissue. But no green plant can decompose woody tissue back to its original inorganic compounds. Living things, such as bacteria and fungi, that decompose organic matter do not produce their own food, but instead obtain their energy and chemical nutrition from the dead tissues on which they feed. For complete recycling of chemical elements to take place, several species must interact.

As discussed in Chapter 4, chemical cycling is complex. All chemical elements required for growth and reproduction must be made available to each organism at the right time, in the right amounts, and in the right ratios to each other. These chemical elements must be recycled, that is, converted to a reusable form by the system. So wastes are converted into food, which is converted into wastes, which must be converted into food once again.

Basic Characteristics of Ecosystems and Ecological Communities

Ecosystems have several fundamental characteristics. First, an ecosystem has structure—nonliving and living parts. Nonliving parts include rocks, water, and

A CLOSER LOOK 6.1

YELLOWSTONE HOT SPRINGS FOOD CHAIN

Perhaps the simplest natural ecosystem is a hot spring, such as those found in a geyser basin in Yellowstone National Park, Wyoming.[4] Few organisms can live in these hot springs, because the environment is so severe. Water in parts of the springs is close to the boiling point. Also, some springs are very acid and others are very alkaline; either extreme makes a harsh environment.

Some of the organisms that can live in hot springs are brightly colored and give these pools a striking appearance for which they are famous (Figure 6.2*a*). Typically, the springs have a wide range of water temperatures, from almost boiling near the source to much cooler near the edges, especially in the winter when there may be snow on the ground next to a spring. In a typical alkaline hot spring, the hottest waters, between 70° and 80°C (158°–176°F), are colored bright yellow green by photosynthetic blue-green bacteria, one of the few kinds of photosynthetic organisms that can survive in hot springs. In slightly cooler waters, 50° to 60°C (122°–140°F), thick mats of bacteria and algae accumulate, some becoming 5 cm thick.

First trophic level. These mats are formed by long strings of photosynthetic bacteria and algae. As the flowing springwater passes over the mats, the long strings of cells trap and hold single-cell algae. Photosynthetic bacteria and algae make up the spring's first trophic level, which is composed of **autotrophs**, organisms that make their own food from inorganic chemicals and a source of energy. In the hot springs, as in most communities, the source of energy is sunlight (Figure 6.2*b*).

Second trophic level. Some flies, called *Ephydrid* flies, live in the cooler areas of the springs. One species, *Ephydra bruesi*, lays bright orange pink egg masses on stones and twigs that project above the mat. Another species, *Aracoenia turbida*, lays white eggs in the mat. The fly larvae feed on the bacteria and algae. Since these flies eat only plants, they are herbivores, and they form the second trophic level.

Third trophic level. Another fly, called the *Dolichopodid* fly, is carnivorous and feeds on the eggs and larvae of the herbivorous flies. Dragonflies, wasps, spiders, tiger beetles, and one species of bird, the killdeer, also feed on the herbivorous flies. The herbivorous *Ephydrid* flies also have a parasite, a red mite, which feeds on fly eggs and travels by attaching itself to the bodies of the adult flies. Another parasite, a small wasp, lays its eggs within the fly larvae. The dolichopodid fly, dragonfly, wasp, spider mites, and killdeer are **predators** that feed on herbivores; these, along with the parasitic mite and wasp form the third trophic level.

Fourth trophic level. Wastes and dead organisms of all trophic levels are fed on by **decomposers**, which in the hot springs are primarily bacteria. These form the fourth trophic level.

Trophic level terminology seems

FIGURE 6.2 (*a*) One of the many hot springs in Yellowstone National Park. The bright greenish color is photosynthetic bacteria, one of the few kinds of organisms that can survive in the hot temperatures and chemical condition of the springs.

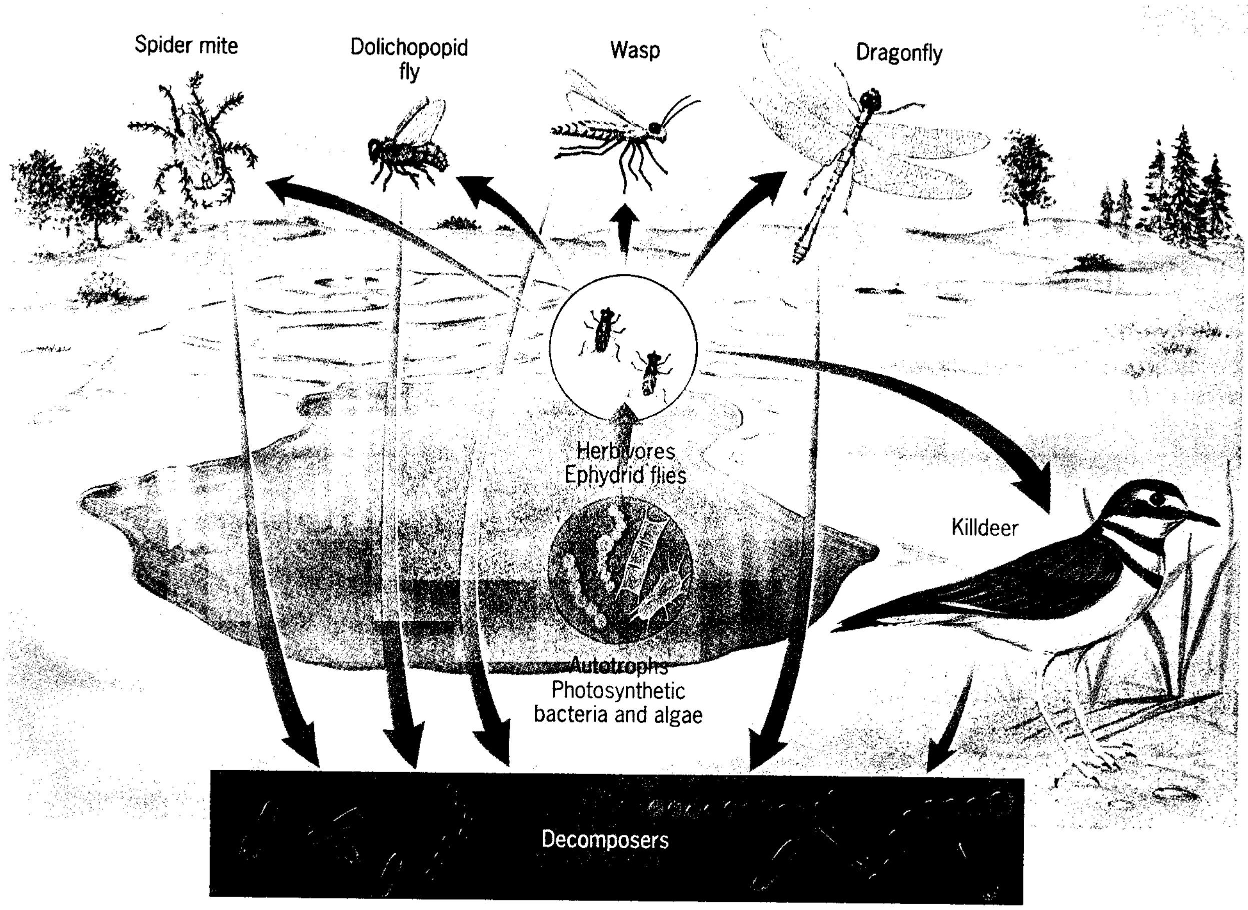


FIGURE 6.2 (*b*) Food web of a hot spring.

clear and simple when it is applied to organisms that feed on only one trophic level, but it is more confusing for the decomposers, because they feed on several trophic levels. If a species feeds on several trophic levels, the convention is to assign that species to the highest trophic level of which it is a member (the level above that of any of its food sources).

The entire hot springs community of organisms—photosynthetic bacteria and algae, herbivorous flies, carnivores, and decomposers—is maintained by two factors: (1) sunlight that provides an input of usable energy for the organisms, and (2) a constant flow of hot water that provides a continual new supply of chemical elements required for life and a habitat in which the bacteria and algae can persist. Even though this is one of the simplest ecological communities in terms of the numbers of species, a fair number of species are found, including eight species of animals (two species of herbivorous flies, five species of carnivorous invertebrates [see Chapter 7] and one species of birds). In high-temperature, alkaline springs there are two or three dominant species of photosynthetic bacteria and algae, especially *Synechococcus*, the blue-green bacteria that live at the highest temperatures, *Mastigocladus*, found in intermediate temperatures, and *Microcoleus*, found in the cooler (but still very hot) waters. The decomposing bacteria include a number of species. The total number of species important in this ecosystem is about 20. These form an ecological community, with a food web and trophic structure, which has been sustained for long periods in these unusual habitats.

Another interesting aspect of the hot springs ecosystem is species dominance. **Dominance** refers to the species that are most abundant or otherwise most important within the community. (We discuss this in connection with diversity in Chapter 7.) As noted earlier, in the hot springs community the species of photosynthetic bacteria or algae that is dominant changes with the temperature; one species dominates the hotter springs and hottest regions within a spring, and another species dominates cooler waters. Because the algae are so brightly colored, this spatial patterning in dominance is readily apparent to visitors. It was striking to one of the earliest explorers of Yellowstone, a trapper named Osborne Russell who visited the springs in the 1830s and 1840s and wrote that one boiling spring about 100 m (328 ft) across had three distinct colors. "From the west side for one-third of the diameter it was white, in the middle it was pale red, and the remaining third on the east light sky blue."[5] This passage also illustrates spatial variations in the relative importance of species within springs and between springs.

air. The living part is the community, which is a set of interacting species. Second, an ecosystem has processes, including the two already mentioned—energy flows through it and chemical elements cycle within it. Third, an ecosystem changes over time and can undergo development through a process called succession, which is discussed in Chapter 9.

In practice, an ecological community—the set of interacting species that are the living part of an ecosystem—is defined by ecologists in two ways. The first, which is simply pragmatic definition, is that the community consists of all the species found in an area, whether or not they are known to interact and affect one another. Animals in different cages in a zoo could be called a community according to this approach.

The second method is to define the community as a set of *interacting* species found in the same place and functioning together to make possible the persistence of life. This seems more meaningful as an idea, but it is usually difficult in practice to know the entire set of interacting species. Therefore it is difficult in practice to obtain a definitive understanding of a particular community using this definition.

Food Chains and Trophic Levels

One way individuals in a community interact is by feeding on one another. Energy, chemical elements, and some compounds are thus transferred from creature to creature along **food chains** (the linkage of who feeds on whom), which in more complex cases are called **food webs.**

Ecologists group the organisms in a food web into trophic levels. A **trophic level** consists of all those organisms in a food web that are the same number of feeding levels away from the original source of energy. The original source of energy in most ecosystems is the sun. Green plants produce sugars through the process of photosynthesis, using only the energy of the sun and CO_2 from the air, so they are grouped into the first trophic level. *Herbi-*

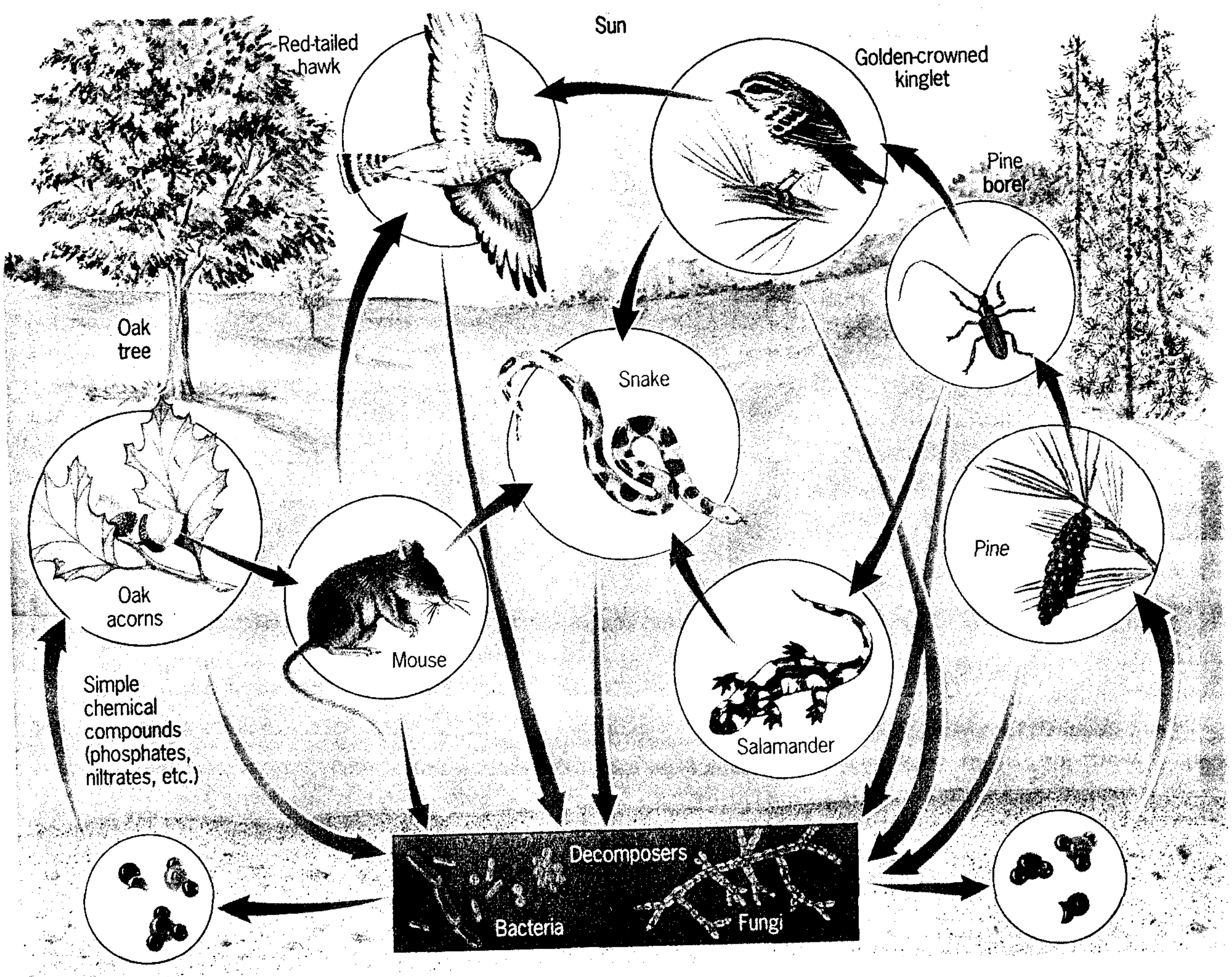


FIGURE 6.3 Food webs. (*a*) A typical terrestrial food web.

vores, organisms that feed on plants, are members of the second trophic level; *carnivores* (meat eaters) that feed directly on herbivores are in the third trophic level; carnivores feeding on third-level carnivores are in the fourth trophic level; and so on.

Food chains and webs are often quite complicated and thus difficult to analyze. A detailed look at one of the simplest food chains is provided in A Closer Look 6.1: Yellowstone Hot Springs Food Chain. We also look briefly at several more complicated food chains.

A Terrestrial Food Chain

An example of terrestrial food chains and trophic levels is shown in Figure 6.3*a*. This is a north temperate woodland food web that existed in North America before European settlement and includes human beings. The first trophic level includes grasses, herbs, and trees. The second trophic level, herbivores, includes mice, the pine borer insect, and other animals such as deer not shown here; the third trophic level, carnivores, includes foxes and wolves, hawks and other predatory birds, spiders, and predatory insects. People are *omnivores* (eaters of both plants and animals) and feed on several trophic levels. In Figure 6.3a, people would be listed on the fourth trophic level, which is the highest trophic level in which they would take part. Decomposers also feed on several trophic levels, and are shown here on the fourth level, since they feed on all the other trophic levels.

An Oceanic Food Chain

In the oceans, food webs involve more species and tend to have more trophic levels than they do in the hot springs or the terrestrial ecosystem just considered. In a typical oceanic ecosystem (Figure 6.3*b*), microscopic single-cell planktonic algae are in the first trophic level. Small invertebrates called *zoo-*

FIGURE 6.3 (*b*) An oceanic food web.

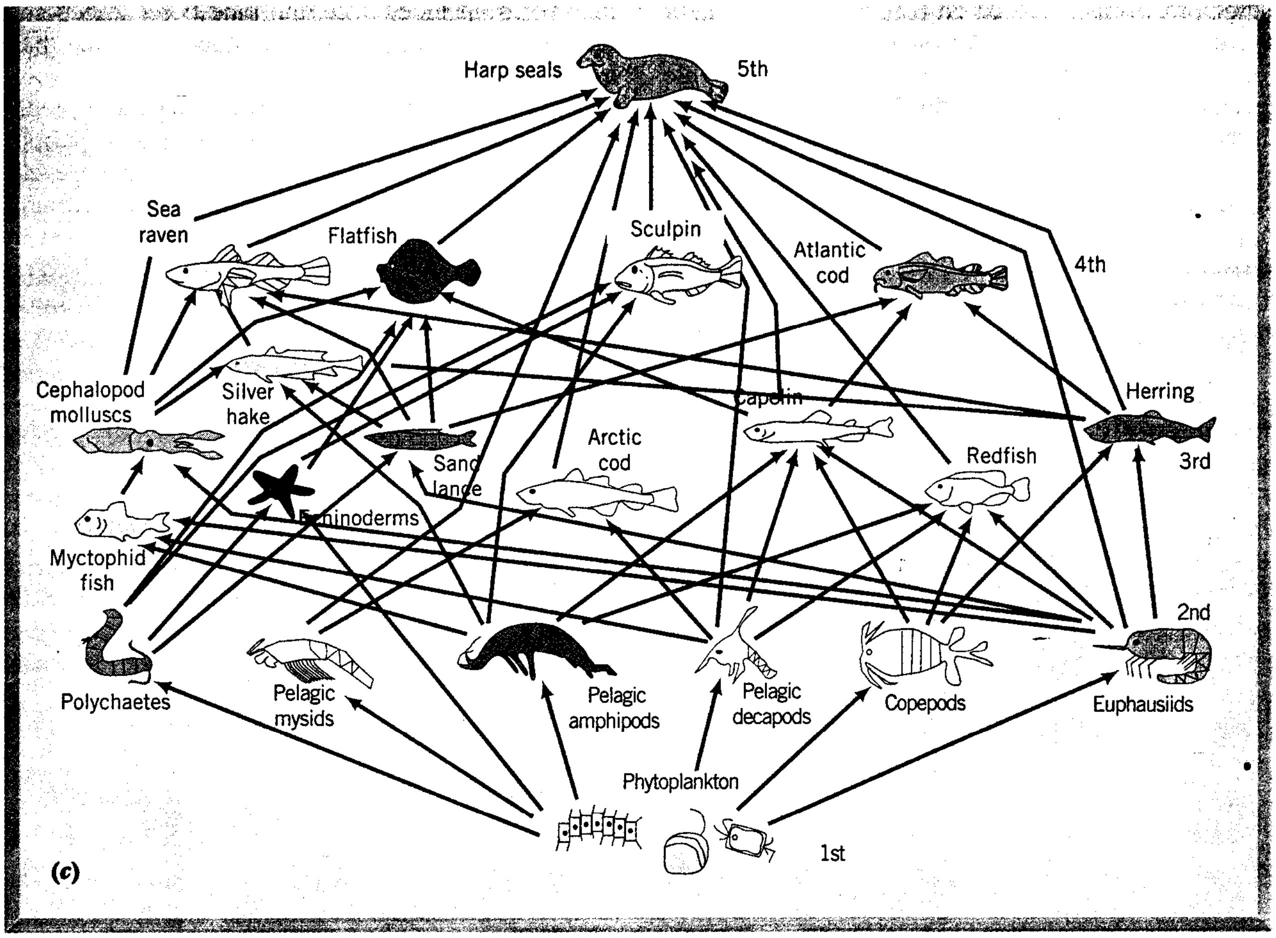


FIGURE 6.3 (c) The food web of the harp seal.

plankton and some fish feed on the algae, forming the second trophic level. Other fish and invertebrates feed on these herbivores and form the third trophic level. The great baleen whales filter seawater for food, feeding primarily on small herbivorous zooplankton (mostly crustaceans), and thus the baleen whales are also in the third level. Some fish and marine mammals, such as killer whales, feed on the predatory fish and form higher trophic levels.

The Food Web of the Harp Seal

In the abstract, a diagram of trophic levels seems simple and neat, but in reality food webs are complex, because most creatures feed on several trophic levels. For example, consider the food web of the harp seal (Figure 6.3*c*). The harp seal is shown at the fifth level.[6] It feeds on flatfish (level 4), which feed on sand lances (level 3), which feed on euphausiids (level 2), which feed on phytoplankton (level 1). But the harp seal feeds at several trophic levels, from the second through the fourth, and it feeds on predators of some of its prey and thus is a competitor with some of its own food.[6] Since a species that feeds on several trophic levels typically is classified as belonging to the trophic level above the highest from which it feeds, we consider the harp seal on the fifth trophic level.

6.3 THE COMMUNITY EFFECT

Species can interact directly through food chains and in other ways, such as symbiosis and competition, which are discussed in the next chapter. One species can also affect other species indirectly, by influencing members of the community that, in turn, affect another set of species in the community. One species can also affect the environment, which then affects a group of species in the community. Changes in that second group affect a third group. Such indirect and more complicated interactions are referred to as **community-level interactions**.

Sea Otters and the Community Effect

Interactions at the community level are illustrated by the sea otters of the Pacific Ocean. In fact,

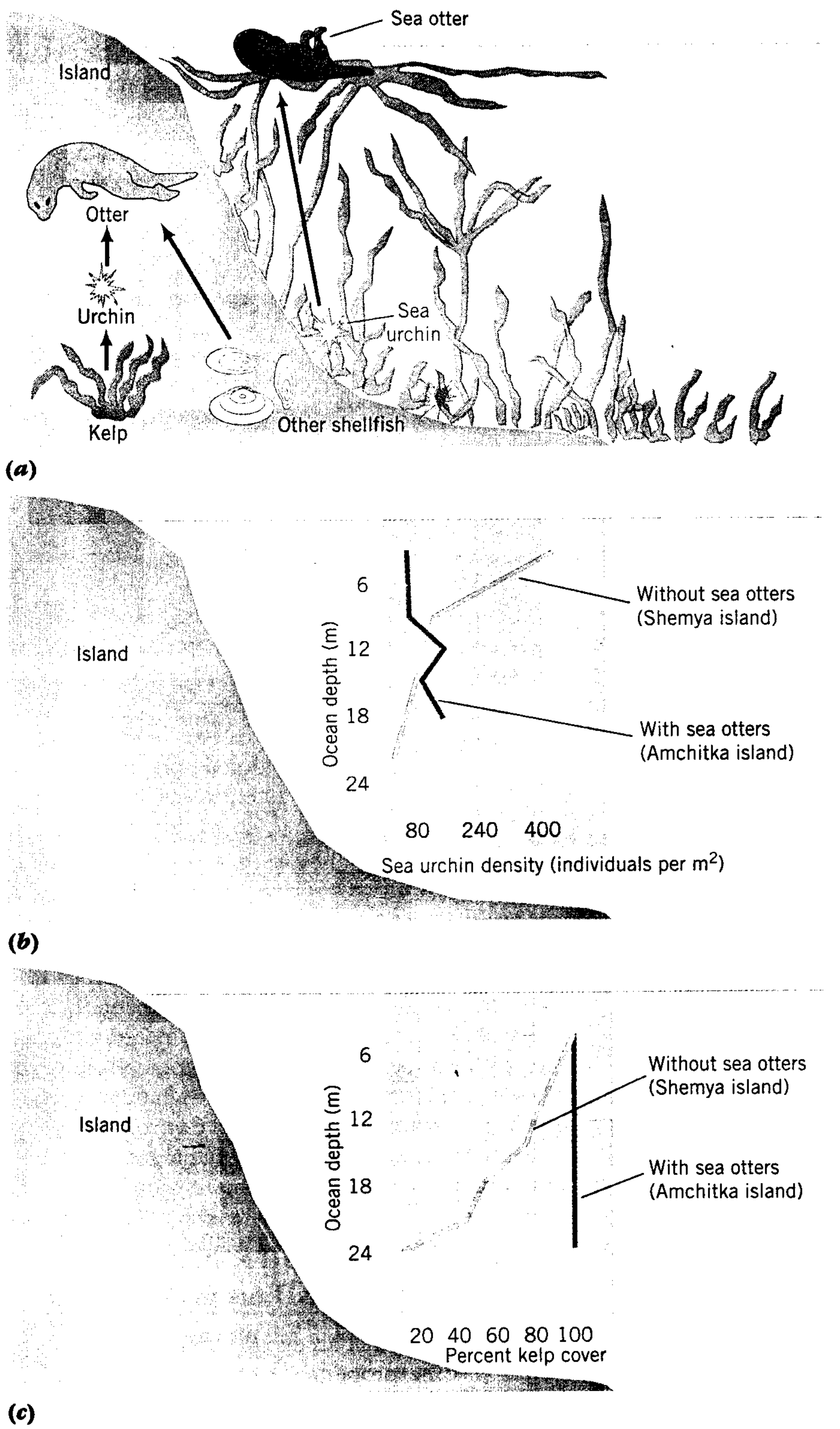


FIGURE 6.4 The effect of sea otters on kelp.

the community-level interactions of the sea otter are at the heart of some arguments in favor of conservation of this species. Sea otters feed on shellfish, including sea urchins and abalone (Figure 6.4). Sea otters originally occurred throughout a large area of the Pacific Ocean coasts, from northern Japan, northeastward along the Russian and Alaskan coasts, and southward along the coast of North America to Morro Hermoso in Baja California, Mexico.[7] The otters were brought almost to extinction by commercial hunting for their fur during the eighteenth and nineteenth centuries—they have one of the finest furs in the world. By the end of the nineteenth century there were too few otters left to sustain commercial exploitation, and there was concern that the species would become extinct. A small population survived and has increased since then, so that today there are approximately 4000 sea otters. Now sea otters occur in just two areas in North America: along the chain of Aleutian Islands of Alaska and along the California coast from Monterey Bay south to Point Conception.

Legal protection of the sea otter by the U.S. government began in 1911 and continues under the U.S. Marine Mammal Protection Act of 1972 and the Endangered Species Act of 1973. This animal has been a focus of controversy and research. On the one hand, fishermen argue that there are too many sea otters today and that they take large amounts of abalone and compete with commercial fishing.[8]

On the other hand, conservationists argue that sea otters have an important community role, necessary for the persistence of many oceanic species. What is this important role? One of the preferred foods of sea otters is the sea urchin. Sea urchins feed on kelp, the large brown algae that form undersea forests. Kelp beds are an important habitat for many species and are the location for reproduction of some of these species. Sea urchins do not eat the entire kelp. Instead, they graze along the bottoms of the beds, feeding on the base of the kelp, called holdfasts. When the holdfasts, which attach the kelp to the bottom, are eaten through, the kelp float free and die.

Where sea otters are abundant, as on Amchitka Island in the Aleutian Islands of Alaska, kelp beds are also abundant and there are few sea urchins (Figure 6.4*b*). At nearby Shemya Island, which lacks sea otters, sea urchins are abundant and there is little kelp (Figure 6.4*c*).[7] Experimental removal of sea urchins led to an increase in kelp.[9]

The otters affect the abundance of kelp, but the influence is indirect. Sea otters do not feed on kelp, nor do they protect individual kelp plants from attack by sea urchins. The sea otters reduce the number of sea urchins. With fewer sea urchins, there is less destruction of the kelp. With more kelp, there is a larger habitat for many other species—so, indirectly, sea otters increase the diversity of species.[9,10] Thus sea otters have a community-level effect.

This example shows that community-level effects occur through food chains. These community-level effects can alter the distribution and abundance of individual species. When a species such as the sea otter has a large effect on its community or ecosystem, it is called a **keystone species**, or a key species.[11] The balance of the entire system is keyed to the activities of this species; its removal or the alteration of its role within the ecosystem would change the basic nature of the community.

The existence of community-level effects tells us that there is a reality to an ecological community; there are processes that can take place only because of the existence of a set of species interacting along a food chain.

The Holistic View of the Community

As we have indicated before, the ecological community is a difficult concept: How do we know if and how species interact? If every single species were completely essential to the organization of the community, the whole community could be viewed as a superorganism whose component species could not easily be replaced by others. This view, that the whole is more than the sum of its parts, is often called the *holistic view of the community*. However, this idea of the community, first developed by Frederick E. Clements at the beginning of the twentieth century,[12] has been shown not to be realistic.[13]

Species associations are not constant—they vary from site to site and they also change over time. Nevertheless, every additional species in a community adds more species interactions: it may be prey or predator or contribute to chemical cycling; it may be a partner in a symbiosis or a competitor with other species. In this sense, even in a more realistic *individualistic view of the community*, the whole is indeed more than just the sum of its parts.[14] (Remember the discussion of environmental unity in Chapter 3.) The conflicting ideas about the nature of communities are of major importance in the discussion of ecological succession and biological conservation (see Chapter 9).[15] However, whatever view one takes, it is clear that the idea of environmental unity—that everything is tied to everything else—is basic to the philosophy of ecosystems.

6.4 HOW DO YOU KNOW WHEN YOU HAVE FOUND AN ECOSYSTEM?

We have said that an ecosystem is the minimal entity that has the properties required to sustain life. This implies that an ecosystem is real and important and, therefore, that we should be able to find one easily. However, the key to ecosystems is in the processes that occur in them, and ecosystems vary greatly in structural complexity and in the clarity of their boundaries. Thus we have applied the term *ecosystem* to areas of the Earth that differ greatly in size, from the smallest puddle of water to a large forest. We have also seen that ecosystems differ greatly in composition, from a few species in the small space of a hot spring to many species interacting over a large

(a) (b)

Figure 6.5 (*a*) Sometimes the transition from one ecosystem to another is sharp and distinct, as in the transition from lake to forest at Lake Moraine in Banff National Park, Alberta, Canada; (*b*) Sometimes the transition is gradual and fuzzy, as in the transitions among vegetation types and their associated ecosystems on the slopes of Humphreys Peak, one of the San Francisco Peaks in Coconio National Forest near the Grand Canyon in Arizona.

area of the ocean. In addition, ecosystems differ in the kinds and relative proportions of their nonbiological constituents and in their degree of variation in time and space.

Sometimes the borders of the ecosystem are well-defined, like the border between a lake and the surrounding countryside. Sometimes the transition is gradual as the transition from desert to forest on the slopes of the San Francisco Mountains in Arizona (Figure 6.5). Sometimes the borders are vague, as in the subtle gradations from grasslands to savannas in East Africa, and from boreal forest to tundra in the far north, where the trees thin out gradually (Figure 6.6).

A commonly used practical definition of the boundary of an ecosystem on land is the **watershed**. A watershed is defined most simply as follows: within a watershed, any drop of rain that reaches the ground flows out in the same stream. Topography—the lay of the land—determines the watershed. When a watershed is used to define the boundaries of an ecosystem, then the ecosystem is unified in terms of chemical cycling. This, of course, is the idea introduced in the story about two drops of water in Chapter 4—they fall into different watersheds and thus enter different ecosystems with different chemical cyclings.

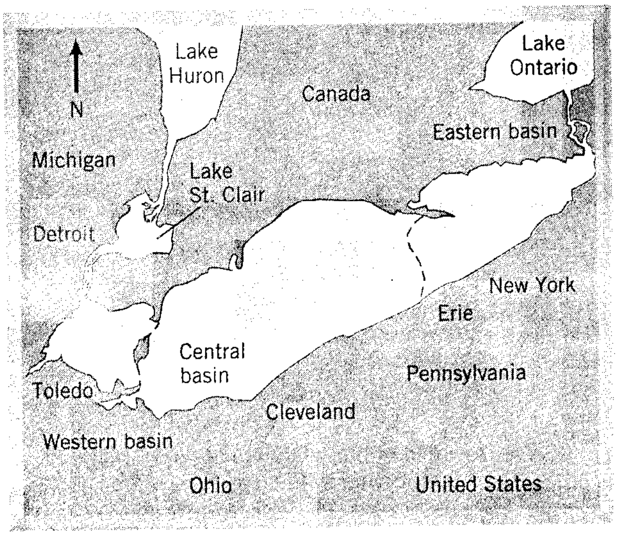
Figure 6.6 The transition between boreal forest and tundra is often subtle and occurs over a large area. Here we see thinly scattered, small trees interspersed among tundra vegetation, within the transition in Kluane Park, Yukon, Canada.

ENVIRONMENTAL ISSUE

Can Damaged Ecosystems be Restored?

In the 1960's, Lake Erie was pronounced dead, its oxygen depleted in deep waters, its surface choked by overgrowth of algae, and some of its top predators endangered. Scientists concluded that the major cause of the destruction of the Lake Erie ecosystem was too much phosphorus from municipal waste. Overcoming the problems of Lake Erie required cooperation between the United States and Canada and led to the establishment of the International Joint Commission. Working together, the governments of the two countries improved waste treatment in communities surrounding Lake Erie. By 1985, the annual release of phosphorus from these sources had been reduced by 84%, and phosphorus levels in the Detroit River, which feeds Lake Erie, by 65%.

Bordered by New York, Pennsylvania, Ohio, Michigan, and the Province of Ontario (see map), Lake Erie is the world's twelfth largest lake. It is 388 km long and covers an area of 25,690 square km. Water enters the lake from three other Great Lakes, Huron, Superior, and Michigan, through the Detroit River, and leaves by way of the Niagara River to Lake Ontario. Lake Erie is divided by natural features into three main portions: the western basin (average depth 7.4 m), the central basin (average depth 29 m), and the eastern basin (average depth 24.4 m). As the water quality improved with phosphorus abatement, algal growth declined and oxygen levels improved. The small planktonic crustacea that feed on the algae became less abundant, and fish that feed on them, such as the undesirable alewife and shiners, also decreased. Populations of fish that feed on other fish, particularly the walleye, rebounded, and programs to stock the lake with salmon were successful.



On the other hand, blue pike, once a commercially valuable species, may have become extinct. And increases in some elements, such as potassium, sodium, and calcium, which come in runoff from developments and farms, cannot be reduced. Furthermore, development of the shoreline, including wetlands, and contamination with toxic chemicals from nearby industries continue.

By 1991, the total phosphorus in Lake Erie had been reduced to close to the target levels set by scientists, except on some occasions when sediments are resuspended. Oxygen depletion, which scientists had predicted would lag behind phosphate reduction by as much as 10 years, has decreased significantly, except in the central basin, and oxygen levels are expected to continue to improve through the end of the century. With a decline in algae in the lake, water clarity has improved as well and by 1993 had improved dramatically.

Critical Thinking Questions

1. Why do high phosphorus levels lead to overgrowth of algae? Why does this lead to oxygen depletion?
2. The western basin of Lake Erie was the most seriously damaged part of the lake. Give at least two reasons for this.
3. Draw a food web of the organisms mentioned in this Environmental Issue.
4. Would you say that Lake Erie has been restored to its former condition? Explain.
5. Recently Lake Erie has been invaded by the zebra mussel, a European species introduced accidentally into the Saint Lawrence seaway by ocean-going vessels. Zebra mussels are extremely prolific (there may be as many as 70,000 individuals in a square meter), and they are voracious algae feeders. What effect would you predict the mussels will have in Lake Erie? On the ecosystem?

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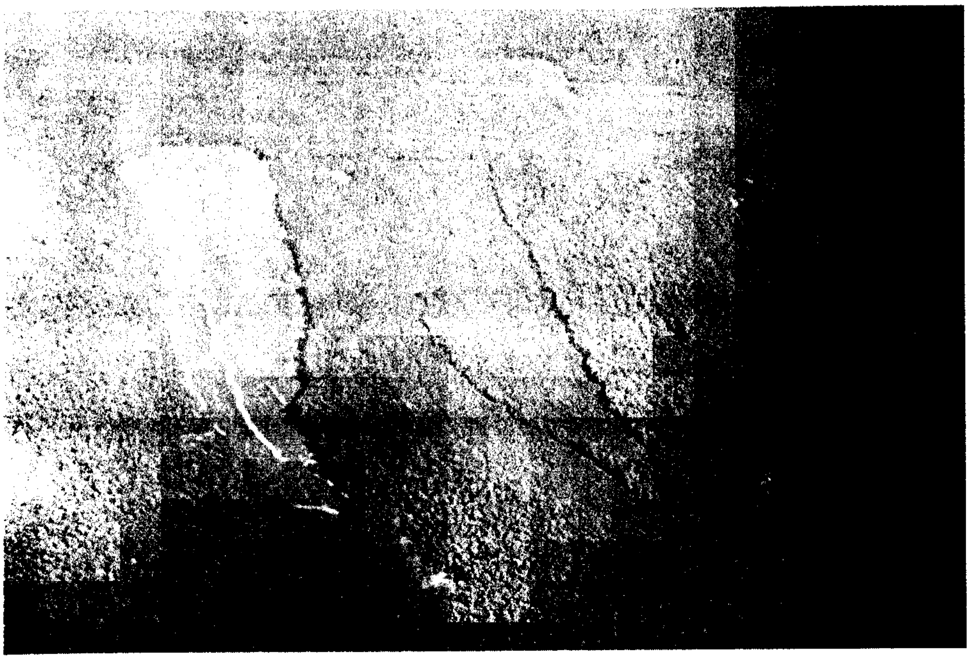

FIGURE 6.7 The v-shaped logged area in this picuture is the famous Hubbard Brook ecosystem study. Here, a watershed defined the ecosystem, and the v-shape is an entire watershed cut as part of the experiment.

Some classic experimental studies of ecosystems have been conducted on forested watersheds in U.S. Forest Service experimental areas, including the Hubbard Brook experimental forest in New Hampshire (Figure 6.7) and the Andrews experimental forest in Oregon.

What all ecosystems have in common is not a particular physical size or sharp boundaries, but the existence of the processes we have mentioned—the flow of energy and the cycling of chemical elements. The ecological community—the living part of an ecosystem—is characterized by food webs, food chains, and trophic levels.

Ecosystems can be natural or artificial or a combination of both. An artificial pond that is a part of a waste treatment plant is an example of an artificial ecosystem, as is Biosphere 2. Ecosystems can also be managed, and the management can vary over a large range of actions. Agriculture can be thought of as partial management of certain kinds of ecosystems, as can forests managed for timber production. Wildlife preserves are examples of partially managed ecosystems. Sometimes, when we manage or domesticate individuals or populations, we separate them from their ecosystems. When we do this, we must replace the ecosystem functions of energy flow and chemical cycling with our own actions. This is what happens in a zoo, where we must provide food and remove the wastes for individuals separated from their natural environments.

SUMMARY

- An ecosystem is the simplest entity that can sustain life. At its most basic, an ecosystem consists of several species and a fluid medium (air, water, or both); it sustains two processes, the cycling of chemical elements and the flow of energy.
- The living part of an ecosystem is the ecological community, which is a set of species connected by food webs and trophic levels. A food web or chain is a diagram showing who feeds on whom. A trophic level consists of all the organisms that are the same number of feeding steps from the initial source of energy.
- Community-level effects are the result of indirect interaction between species, such as occurs when sea otters influence the abundance of urchins. These effects would not occur if there were only direct interactions between pairs of species, without involvement of the environment or of a set of species on different trophic levels.
- Ecosystems are real, and important, but it is often difficult to define the limits of a system or to pinpoint all the interactions that take place. Creating an artificial ecosystem requires an understanding and balancing of many complex interactions.

KEY TERMS

autotrophs *100*
community-level interactions *104*
decomposers *100*
dominance *101*
ecological community *99*
food chains *102*
food webs *102*
keystone species *106*
predators *100*
trophic level *102*
watershed *107*
wetlands *108*

STUDY QUESTIONS

1. Distinguish between an ecosystem and an ecological community.
2. In what ways would an increase in the number of sea otters and a change in their geographic distribution benefit fishermen? In what ways would these changes be a problem for fishermen?
3. Based on the discussion in this chapter, would you expect a highly polluted ecosystem to have many species or few species?
4. Is our species a keystone species? Explain.
5. What factors do you think are most important to monitor in Biosphere 2?
6. Suppose you were asked to set up a monitoring system for a natural ecosystem, such as a forested watershed. Would you monitor the same factors that you listed in response to question 5?
7. Which of the following are ecosystems? Which are ecological communities? Which are neither?
   a. Chicago
   b. a 1000-ha farm in Illinois
   c. a sewage treatment plant
   d. the Illinois River
   e. Lake Michigan

FURTHER READING

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