NATURAL FORCES OF DECAY AND RENEWAL

BIODEGRADATION

When a tree dies in the wilderness, there is no natural force that hauls it off to a landfill. Instead, the dead tree slowly decays. Woodpeckers make holes in their search for beetles and other insects that tunnel their way through the dead wood. Bacteria, fungi, and a wide variety of insects and other invertebrates feed on the wood, gradually breaking it down. As the trunk becomes hollow, it provides shelter for owls, raccoons, chipmunks, and many other forms of wildlife. Eventually, the tree falls, and the cycle of decay continues until the wood crumbles and blends in with the surrounding soil.

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Topic: biodegradation
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What would happen if this natural process of decay did not take place? Piles of dead plants and animals would cover the earth. Each year, as leaves fell and plants and animals reached the ends of their lives, the piles would become deeper until nothing more could grow. Eventually, the chemicals needed for life would be tied up in dead plants and animals, and the thickening cover of fallen logs, animal carcasses, and other plant and animal remains would choke out new life.

Fortunately, decay does occur. Decomposition continually renews and enriches the earth, returning carbon, hydrogen, and nutrients to the soil, water, and air and providing the conditions needed for new life to thrive. This natural decomposition process is called *biodegradation.* "Degradation" means decay, and "bio-" refers to the fact that it is carried out by biological forces—by the huge assortment of bacteria, fungi, insects, worms, and other organisms that eat dead material and recycle it into new forms.

***Biodegradation* refers to the biological processes that cause decay.**

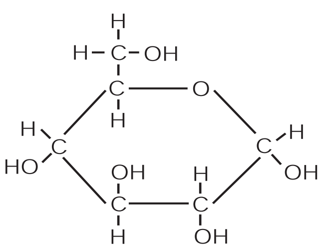
Organic matter **includes living and dead organisms and the wastes they produce.**

Through biodegradation, dead plants and animals get broken down and so do the waste products they produce while living. For plants, these waste products include dead leaves and the remnants of seeds and blossoms. For animals, wastes include excrement and any feathers, fur, hair, antlers, shells, skin, or other parts that get shed. All of these wastes are examples of *organic matter,* material that has been created by living things.

Although all organic matter eventually will decay, some types will break down much faster than others. Depending on the type of material and the environmental conditions, decay may take place within hours or over many years. Why is biodegradation important? Not only does it clean up the mess left behind by dead bodies and other wastes, it also plays an essential role in nutrient cycling and energy flow—key processes that sustain life on Earth.

Organic compounds **are chemicals that contain chains of two or more carbon atoms.**

In order to live and grow, all living things need a source of energy and a source of nutrients, especially carbon. Why carbon? Life is based on carbon because this element is the basis for the sugars, proteins, starches, and other compounds that make up living things. All of these compounds consist of chains of carbon atoms linked together and combined with hydrogen, oxygen, and sometimes a few other key elements. Compounds that contain chains of two or more carbon atoms per molecule are called *organic compounds.* Organic matter is made up of organic compounds.



Glucose is an organic compound.

In addition to carbon and other nutrients, all living things need a source of energy to sustain life. When you need energy, you eat food. All organisms need nutrition, but they get it in a variety of ways, depending on whether they are producers or consumers.

PRODUCERS AND CONSUMERS

Green plants are called *producers* because they can make their own food. Using energy from the Sun, producers create organic matter from carbon dioxide and water. This process is called *photosynthesis*—from "photo," the Latin word for light, and "synthesis," meaning to create.

Producers **use energy from the Sun to make their own food.**

Through photosynthesis, green plants convert solar energy into chemical energy in the form of glucose and other simple sugars (Figure 1.1). These sugars are organic compounds, made up of carbon, hydrogen, and oxygen. Plants build them using carbon from carbon dioxide and hydrogen and oxygen from water. The leftover oxygen gets released to the atmosphere.

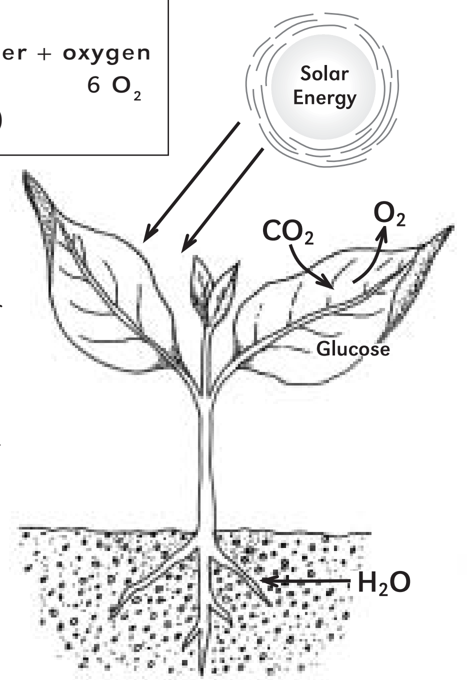
When plants grow, they build complex compounds such as starches and proteins by combining the simple sugars produced through photosynthesis with nutrients such as nitrogen, phosphorus, and sulfur that they take up from soil and water. Through this process, they also create *enzymes,* specialized proteins that are used to accelerate or control the rates of biochemical reactions. For example, one type of enzyme plays a crucial role in regulating the rate at which carbon dioxide is used in photosynthesis.

Animals and other organisms that cannot produce their own food are called *consumers.* Instead of absorbing carbon dioxide and converting it to

FIGURE 1.1
Through Photosynthesis, Green Plants Create Organic Matter

Photosynthesis:

carbon dioxide + water + solar energy → organic matter + oxygen
$6\ CO_2$ $6\ H_2O$ $C_6H_{12}O_6$ (glucose) $6\ O_2$



organic matter, consumers obtain their energy and nutrients by eating organic matter that has been produced by other organisms. Consumers are classified according to the kinds of food that they eat. For example, herbivores eat plants, and carnivores eat animals. Consumers that get their nutrition and energy by eating wastes are called *decomposers.* Their food consists of dead bodies, animal droppings, leaves, and all sorts of other wastes produced by living things.

Through a process that looks like the reverse of photosynthesis, both producers and consumers break down organic matter into carbon dioxide, water, and energy. This process is called *respiration.* Respiration is a confusing term because it is used in a couple of different ways. One way refers to the exchange of gases that occurs in lungs or gills as organisms breathe. But what we are referring to here is a process that takes place within each cell, including cells of plants and other organisms that don't have lungs or gills. In this process of cellular respiration, organic matter gets broken down and used as a source of energy to sustain life.

Respiration:

organic matter + oxygen → carbon dioxide + water + energy

Many people think that plants use photosynthesis to create food and animals use respiration to break it down. This is partly correct, but it ignores the fact that respiration is carried out by all living things—green plants included. When green plants are exposed to light, they produce their own food through photosynthesis. But just like animals, plants carry out respiration constantly, throughout the day and night, to support growth, reproduction, and all of the day-to-day functions of life.

Consumers **get energy by eating other organisms or organic wastes.**

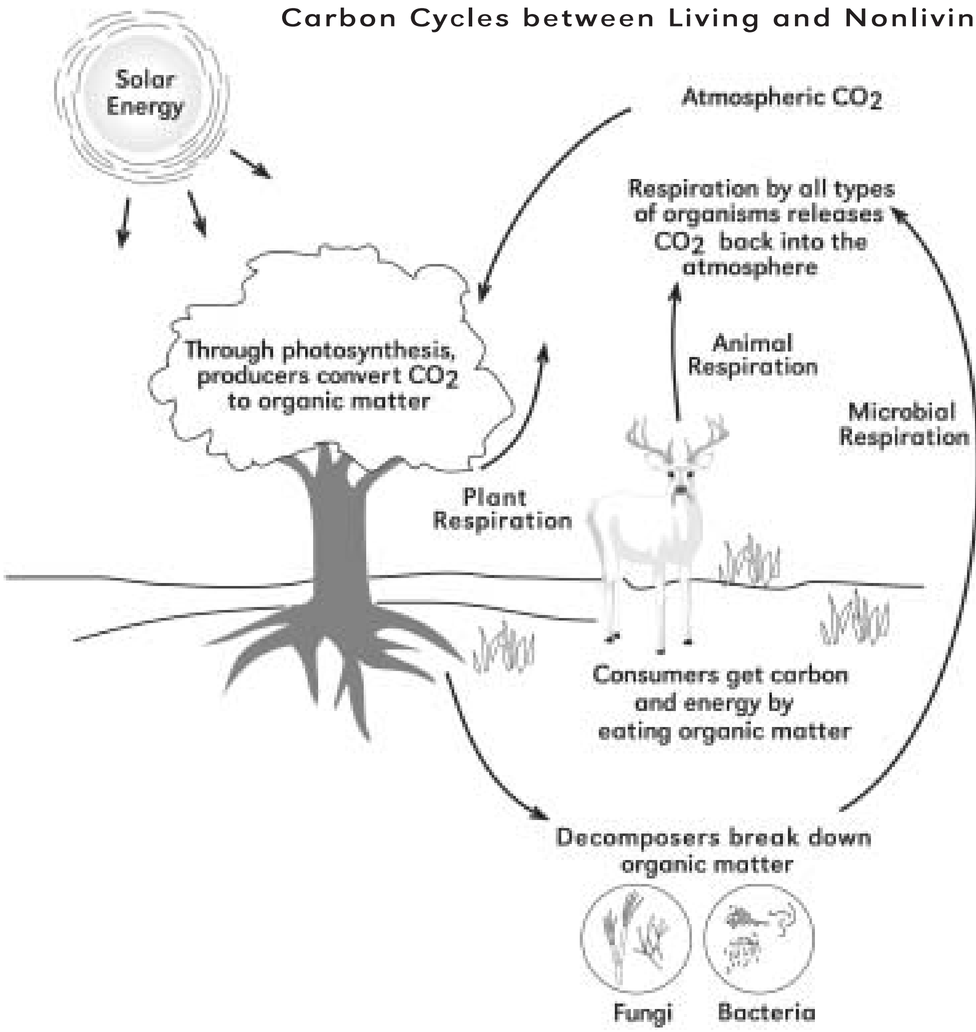
Decomposers **get energy by eating dead organisms and wastes.**

Respiration **is the process through which living things use the chemical energy that is stored in organic matter.**

NUTRIENT CYCLES AND ENERGY FLOWS

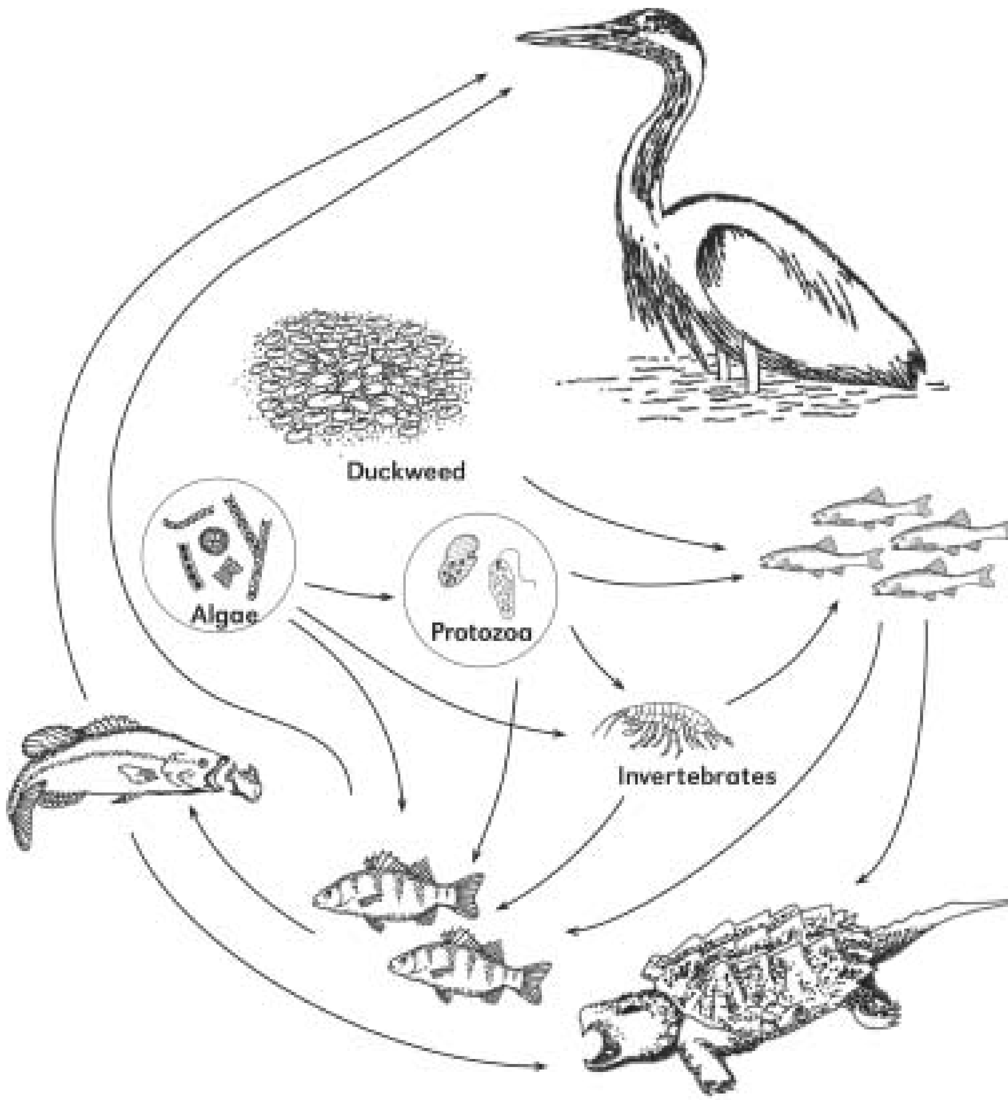
Through the processes of photosynthesis and respiration, carbon continuously cycles through living and nonliving forms (Figure 1.2). Carbon gets incorporated into organic matter by green plants through photosynthesis. Then these organic molecules are broken down through respiration by all types of organisms—plants, animals, and microbes. Respiration provides organisms with energy, and it also releases carbon dioxide back into the atmosphere where it once again becomes available for uptake by plants.

FIGURE 1.2
Carbon Cycles between Living and Nonliving Forms



You may be familiar with diagrams of a typical food web showing who eats what in a lake or pond (Figure 1.3). The producers in this aquatic food web include single-celled algae as well as rooted and floating plants such as water lilies and duckweed. The smallest consumers are tiny organisms such as protozoa that get energy by eating algae, other tiny organisms, and particles of organic matter. Then they in turn are eaten by secondary consumers such as aquatic invertebrates, which get eaten by higher-level consumers such as fish, frogs, turtles, and birds.

FIGURE 1.3
A Typical Food Web in a Lake or Pond



At each step in a food web, organisms obtain energy from the food that they eat. However, energy does not cycle through the living and nonliving environment like carbon does. Instead, it flows in one direction, from producers to consumers at various levels of food webs. At each level, organisms use cellular respiration to release the chemical energy stored in sugars, starches, and other organic compounds. Some of this energy gets used to support life processes, but much is lost to the environment in the form of heat.

Think about how you get hot when you exercise vigorously. This heat is caused by the cellular respiration that fuels your exercise. Cellular respiration accomplishes this same sort of energy conversion in all types of organisms, from microbes to mountain lions. That's why energy flow through an ecosystem commonly is represented as a pyramid—at each step there is less chemical energy available because of the losses in the form of heat (Figure 1.4).

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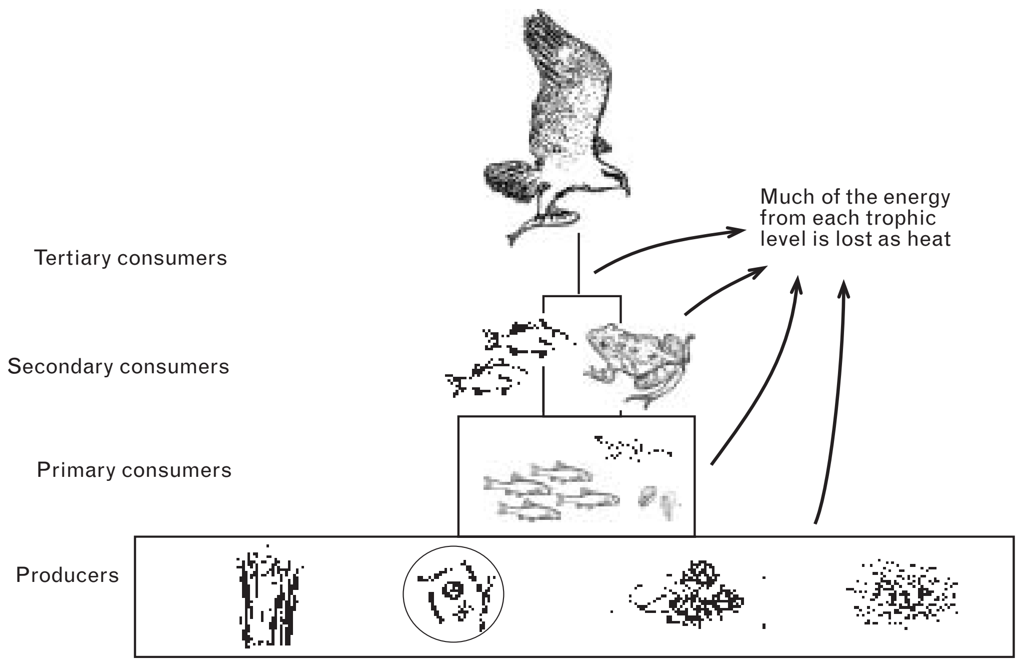
FIGURE 1.4
A Typical Energy Pyramid in a Lake or Pond



Something is missing from the food web and energy pyramid represented in Figures 1.3 and 1.4. What happens to the nutrients and chemical energy contained in organisms when they die, or in the wastes that they produce while alive? Decomposers use these sources of energy and nutrients. At each level of a food web or energy pyramid, decomposers take care of the wastes that are produced. In the process of obtaining nutrition by eating organic wastes, they provide a vital link in global nutrient cycles. For example, decomposers convert carbon that is tied up in organic compounds back into carbon dioxide, making it available to once again be taken up by plants and used in photosynthesis.

Waste or Resource?

We humans may have a hard time imagining eating animal droppings, but these wastes provide valuable sources of protein and other nutrients to dung beetles and a wide range of other decomposer microorganisms.

If you were a dung beetle, your life would be devoted to finding, storing, and eating the dung of larger animals. There are thousands of species of dung beetles in the world, native to every continent except Antarctica. All of them specialize in eating animal droppings of one sort or another. To store food away from competing decomposers, these beetles carve out pieces of dung and roll them into balls. They lay their eggs inside these balls and bury them underground. When the eggs hatch, the dung provides food for the larvae as they grow and develop into adults.

Although dung beetles are an obvious type of decomposer, they have lots of company in the invertebrate world. For example, worms, millipedes, slugs, and sow bugs all are decomposers that feast on decaying organic matter.

The most important organisms in the biodegradation process are ones you cannot see—the *microscopic* organisms called microorganisms or *microbes*. Among leaves and logs on the forest floor, in a steaming pile of hay or manure, or in a compost pile, a huge assortment of these less visible decomposer organisms are at work. All decomposers use dead organic matter as a source of energy and nutrients; then they in turn may become food for a wide variety of other consumer organisms.

***Microbes* include all organisms that are too small to be seen without a microscope.**

Decay-causing microbes are present in every type of habitat, even on living things. Have you ever wondered why an apple core will quickly rot when buried in moist soil, but a carrot growing in the same soil will not? As long as an organism is alive, its natural defenses hold back the forces of decay. But as soon as a plant or animal dies, it becomes food for a wide array of decomposers. Who are these decomposers? Most are classified as either fungi or bacteria.

***Biodegradation* is carried out primarily by microbes.**

CLASSIFICATION OF LIVING THINGS

Ever since the 1700s, scientists have been interested in naming organisms and organizing them into broad groups called *kingdoms*. Within each kingdom, the organisms share some important characteristics and are thought to have evolved from common ancestors. At first, all living things were classified into either plant or animal kingdoms. Over the years, scientists have proposed modifications to this classification scheme based on new discoveries about living things. In 1784, for example, scientists proposed adding a third kingdom—the fungi—including mushrooms as well as a vast world of less visible organisms such as molds and yeasts.

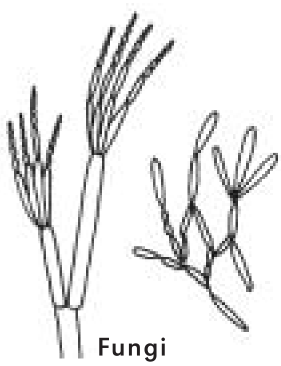
In some ways, fungi are similar to plants. When you look at a mushroom, it certainly seems more like a plant than an animal. However, when Anton van Leeuwenhoek and other scientists first started using microscopes to study living things, they discovered that fungi have some characteristics that set them apart from the plant kingdom. For example, fungal cells do not contain chlorophyll, the chemical that enables green plants to carry out photosynthesis. Instead, fungi release specialized proteins called *enzymes* that break down organic matter into substances that get absorbed into their cells and then further digested. Once this discovery was made, scientists proposed assigning fungi to their own kingdom.

Various two- or three-kingdom classification systems were used for almost 200 years. This changed in 1969, when Dr. Robert Whittaker, an ecologist at Cornell University, proposed that life could best be organized into five kingdoms. In addition to plants, animals, and fungi, he proposed two new kingdoms:

- the Protista, including simple organisms such as amoebas that have a nucleus, and
- the Monera, including bacteria and similar single-celled organisms that don't have true nuclei.

In recent years, this five-kingdom classification scheme has once again come under scientific debate. The classification system will continue to change as new discoveries about DNA and genetics help to trace the evolutionary relationships connecting all forms of life.

The group of organisms that we call *microbes* or *microorganisms* is defined according to size rather than kingdoms. The only feature that they have in common is that they are too small to be seen without a microscope. Microorganisms include bacteria, fungi, and single-celled plants and animals—clearly representing a broad range of kingdoms. The group that we call *decomposers* also is found in more than one kingdom. Decomposers are defined by function—they are the organisms that cause biodegradation.



Fungi

BIODEGRADATION ON LAND

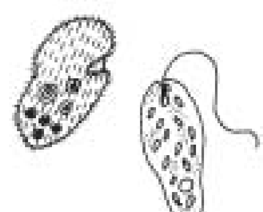
In a soil food web, microorganisms are the most numerous living things and also play the largest role in decomposition. A single spoonful of soil can contain up to a billion bacteria and hundreds of thousands of fungi.

Fungi are visible in the form of mushrooms, molds, and yeasts, but they also grow long microscopic threads that stretch throughout soil and decaying vegetation such as rotting logs. Fungi serve a vital role in biodegradation of plants. Plant cell walls contain cellulose, a complex compound that cannot be digested by most animals. Lignin, another hard-to-degrade compound, forms long chains that link cells together in wood, straw, and other plant stems. Fungi provide the first line of attack in breaking down these tough compounds, turning them into forms that are usable by bacteria and other organisms.

Bacteria

A few types of fungi are predators, specialized to capture and digest nematodes, tiny roundworms that are described below. These fungi create sticky nets or noose-like loops to trap their prey. Then thread-like filaments from the fungi extend into the captured nematodes and digest them as a source of energy and nitrogen.

Bacteria are microscopic, single-celled organisms shaped like rods, spheres, or spirals. They are among the most abundant organisms on earth. Most bacteria are decomposers, although some species are able to create their own food through photosynthesis. Before bacteria can digest chemical compounds, they need to absorb the compounds into their cells. Many compounds are too large to be absorbed directly, so microbes release enzymes to pre-digest these substances into smaller pieces that can be absorbed and used as food.

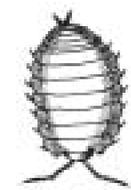


Protozoa

If you drain water from a sample of moist soil or compost and observe it under a microscope, you are likely to see tiny, single-celled organisms called protozoa. Members of the Protista kingdom, protozoa such as amoebas live in the thin films of water surrounding soil particles. They feed on bacteria, fungi, other protozoa, and dissolved organic matter. Because they digest organic matter and then get eaten by higher organisms, protozoa can provide important links in decomposer food chains.

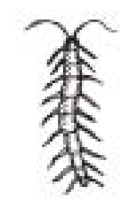
Nematode

Nematodes are another type of tiny organism you are likely to find in water drained from soil or compost. Nematodes are nonsegmented worms, about the width of a human hair. They are extremely abundant and diverse. Some species eat decaying vegetation, some eat bacteria or fungi, and others prey on protozoa or other nematodes.



Sow Bug

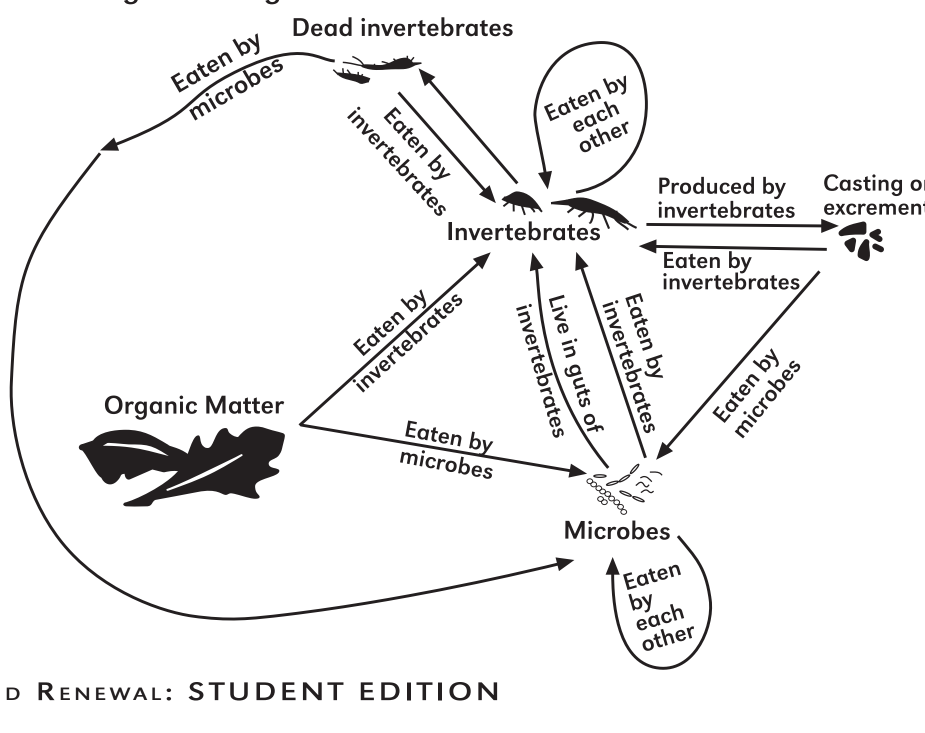
Larger organisms also help to break down organic matter in soil. If you sift through the layer of leaves and other decaying vegetation at the soil surface, you are likely to find an assortment of invertebrates such as millipedes, sow bugs, snails, slugs, and earthworms. These organisms shred decaying vegetation, breaking it down both physically and chemically. The **Soil Invertebrate Identification Sheet** (p. 38) describes common invertebrates found in soil and compost.



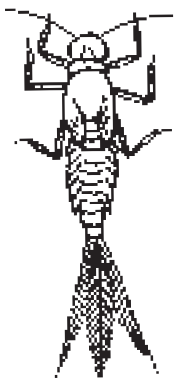
Centipede

Together all of these organisms make up complex decomposer food webs (Figure 1.5). Organisms such as slugs and sow bugs eat dead plants and animals. Others such as dung beetles prefer wastes that have already passed through the guts of other organisms. Microbes play a central role in decomposer food webs. As they digest wastes to meet their own nutritional needs, microbes also convert the organic matter into chemical forms that are more usable by a wide range of invertebrates. When worms eat decaying vegetation, they get their nutrition primarily by digesting the microbes growing on the organic matter rather than from the vegetation itself. Decomposer food webs also include predators such as centipedes that use poison glands in their jaws to paralyze prey such as small worms, insect larvae, insects, and spiders.

FIGURE 1.5
Food Web among Soil Organisms



In soil, the end product of decomposition is humus, a stable mixture of complex compounds. Humus does continue to biodegrade, but the process occurs slowly over a period of years because the easier-to-degrade compounds have already been broken down. Topsoil consists mostly of humus. You may have seen it for sale at garden centers—it is valuable for plant growth because it acts like a sponge, helping to hold water and nutrients in the upper soil layers where they remain available for uptake by plants.



Mayfly Nymph

BIODEGRADATION IN WATER

Biodegradation takes place in every type of habitat, even in the purest mountain streams. If you flip over rocks in a swift mountain stream, you are likely to find mayfly nymphs and other aquatic invertebrates scurrying for cover. What do these organisms find to eat? The rocks may be coated with a layer of algae, but other plants are likely to be scarce because of the low nutrient concentrations. Instead, stream organisms rely on input of organic wastes from surrounding land. Leaves, twigs, and other organic materials fall into the water or are washed in by runoff or snowmelt. These materials form the base for the food web in streams.

Many of the invertebrates that live in mountain streams are scavengers, adapted to eating organic debris left behind by other animals and plants. Some of these invertebrates gradually shred the leaves that enter the stream from the surrounding land. Others catch particles from the current as the water flows by. Still others feed by scraping bacteria and algae off the surfaces of rocks. Finally, all of these types of invertebrates become food for trout and other higher-level consumers in aquatic food webs.

The same forces of decomposition that take place in flowing water also occur in ponds and lakes. Each year, plants and animals grow and then die and decompose, continuing the cycling of nutrients through the ecosystem.

Organic Pollution

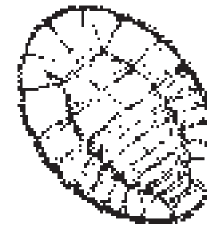
Through the work of decomposer organisms, organic matter in lakes and streams gets broken down and used to support new life. This sounds useful to humans—why not just dump our organic wastes into the water and let natural biodegradation processes take care of them? Although this sounds like a reasonable idea, there is a limit to the biodegradation capacity of natural waterways.

If too much manure or untreated sewage enters a stream, drastic changes in stream life will occur. Populations of decomposer bacteria will grow rapidly because of the increased food supply. As bacteria work to break down the organic wastes, they use up oxygen and produce carbon dioxide. As a result, dissolved oxygen levels may drop so low that sensitive species of fish such as salmon and trout will be wiped out.

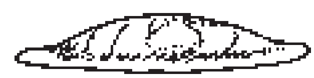
Aquatic invertebrates also are affected by dissolved oxygen. Stonefly nymphs and beetle larvae called "water pennies" are examples of stream invertebrates that cannot live in streams that have become polluted with too much organic matter. These organisms cling to rocks in streams where the rapidly flowing currents normally carry high levels of dissolved oxygen. When oxygen levels drop too low, sensitive invertebrates such as these will not be able to survive.

Gradually, a few types of organisms that are adapted to life under low-oxygen conditions will begin to move into stream sections that are polluted with too much organic matter. For example, sludge worms are adapted to living with very little dissolved oxygen, and they commonly are found in water with organic pollution. These worms live with their heads buried in muddy sediments and their bodies waving through the water to capture as much oxygen as possible. Because few types of organisms are adapted to life in polluted waters, the diversity of organisms tends to be much lower there than in areas with higher oxygen concentrations.

As sewage-polluted water flows downstream, natural purification gradually occurs. Although the stream remains highly impacted at the pollution source, this impact diminishes with distance downstream. This occurs because the organic matter gradually breaks down and dissolved oxygen levels gradually return to normal. The section of the stream in which this occurs is called the *zone of recovery* (Figure 1.6). The length of this zone depends on the size of the river or stream and the amount of organic pollution it receives. A small stream with a large input of organic pollution can be impacted for many miles downstream of the pollution source.



Water Penny (top view)



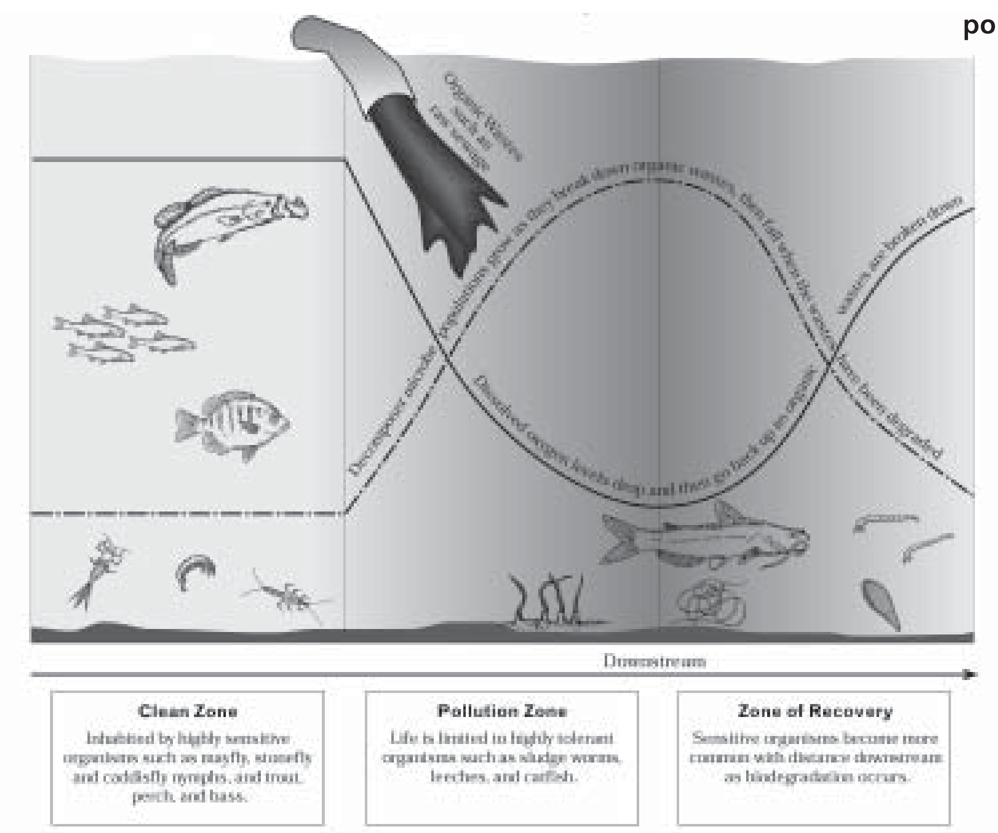
Water Penny (side view)

Sludge Worm

In the *zone of recovery,* natural biodegradation processes gradually clean up the organic pollution in a stream.

FIGURE 1.6

Stream Life Gradually Recovers as Organic Matter Biodegrades Downstream of a Pollution Source



Eutrophication

A slightly different form of organic pollution occurs when excess vegetation grows in lakes, rivers, or coastal waters. Rather than input of organic matter such as manure or untreated sewage, in this case the problem is caused by input of too much fertilizer. The fertilizer causes algae and other aquatic plants to grow out of balance with the natural forces of decay and renewal. This over-fertilization process is called *eutrophication,* derived from Greek words meaning "well fed."

Fertilizers commonly contain three essential plant nutrients: nitrogen, phosphorus, and potassium. Just as these nutrients increase the growth of crops, lawns, golf courses, and gardens, they also stimulate growth of algae and other aquatic vegetation. When water bodies receive nutrient-rich run-off from fertilized land, they may become eutrophic.

When *eutrophication* occurs, high rates of biodegradation use up dissolved oxygen in aquatic systems.

In fresh water, plant growth usually is limited by the amount of available phosphorus. In oceans and estuaries, nitrogen is more likely to be the nutrient in shortest supply. When extra nutrients are provided, they trigger faster growth of algae and other aquatic plants. Within certain limits, increased growth causes no harm. But if nutrient levels become too high, lakes, rivers, or coastal waters will become choked with mats of algae or beds of rooted vegetation.

Aquatic plants add oxygen to the water through photosynthesis, so you might think that the more they grow, the better. However, plants and animals also use oxygen through respiration. As a result, dissolved oxygen levels in eutrophic waters tend to fluctuate widely, with high levels during the day but low levels at night. Another problem is that photosynthesis occurs only in the surface layers where plants have access to sunlight. When the mats of algae and other plants and animals die, they sink. Oxygen gets used up in the deeper waters as all of this organic matter decomposes. As a result, the fish and other organisms that live in cool, deep waters may no longer be able to survive.

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Over a period of hundreds or thousands of years, water bodies may naturally become more eutrophic due to natural inputs of nutrient-rich sediments. Human-caused eutrophication occurs much more rapidly, causing ecological problems by throwing off the natural balance between rates of growth and decay. In the worst cases, this results in masses of rotting organic matter, and habitats that no longer can support sensitive species of fish and other aquatic life.

CONCLUSION

Biodegradation is a natural process that is essential to the continuation of energy flow and nutrient cycling in ecosystems. Energy is neither created nor destroyed, but we think of it as flowing rather than cycling through ecosystems because life on Earth requires continual input of energy from the Sun. Photosynthetic organisms convert solar energy to chemical energy, which is used by the producers themselves and by all types of consumers and decomposers. Without continued input of solar energy, life as we know it would end because at each level of every food web much of the chemical energy gets lost in the form of heat. Energy flow through an ecosystem is represented as a pyramid because of these losses in chemical energy at each level.

Unlike energy, the Earth does not receive new inputs of nutrients such as carbon. Instead, carbon and other nutrients constantly cycle between living and nonliving forms. For example, organisms incorporate carbon into organic compounds such as sugars, carbohydrates, and proteins. Through cellular respiration by all types of organisms, these organic compounds get broken down and carbon dioxide is released back into the environment.

On land and in water, decomposers work to break down plant and animal debris, releasing nutrients needed for new growth. These continuous cycles of growth and decomposition form the basis for all life on Earth. However, it is possible to overwhelm the natural forces of decay and renewal. For example, if too much manure, sewage, or other organic matter is dumped into a stream, dissolved oxygen concentrations drop too low to support sensitive forms of aquatic life. Over-fertilization causes similar problems in nutrient-rich waterways that become eutrophic when excessive growth of aquatic plants creates more organic matter than the system can decompose without ecological harm.

The following chapters focus on ways in which people use natural forces of biodegradation to clean up wastes and prevent pollution problems such as these.

DISCUSSION QUESTIONS

- Could we live without microbes? How do they affect the environment?
- Why do we say that nutrients "cycle" but that energy "flows" in ecosystems? What roles do decomposers play in these processes?
- If matter can be neither created nor destroyed, where does it go when plants or animals decompose?