Chapter 25
Ecology

OVERVIEW

This chapter explores some of the ecological topics not already discussed elsewhere in the text. An introduction to populations, communities, and ecosystems is followed by a brief look at producers, primary and secondary consumers, decomposers, and food chains or webs. Then energy flow through an ecosystem is considered, and the nitrogen, carbon, and water cycles are explored. Discussions of succession and fire ecology follow. The chapter concludes with a discussion of human impacts on plant communities at global and regional levels.

Some Learning Goals

1. Understand the relationships among populations, communities, and ecosystems.
2. Know the functions of producers, primary consumers, secondary consumers, and decomposers in an ecosystem.
3. Understand energy flow through an ecosystem.
4. Learn how nitrogen and carbon are cycled.
5. Define primary succession and provide examples.
6. Define secondary succession, eutrophication, and climax community.
7. Know at least 10 ways in which humans have impacted -ecosystems.

cology is the broad discipline of study involving the relationships of organisms to each other and to their environment. The term *ecology*, which has become a household word, was first proposed by Ernst Haeckel in 1869, but the discipline traces its origins back to early civilizations when humans learned to modify their surroundings through the use of tools and fire.

Various aspects of ecology were touched on throughout earlier chapters. For example, soils and organisms associated with them were discussed in Chapter 5. Some of the adaptations and modifications of leaves associated with specific environments were discussed in Chapter 7. The effects of light and temperature on plants were covered in Chapters 10 and 11. Other important ecological topics comprise the bulk of this chapter, but the reader is referred to the Additional Reading section at the end of the chapter for a sampling of works covering a number of these themes in greater depth.

In recent years, scientists, and increasingly the general public, have become alarmed about the effects of human carelessness on our environment. It wasn't until the 1970s, however, that damage to forests and lakes caused by acid deposition (acid rain), the "greenhouse effect," contamination of ground water by nitrates and pesticides, reduction of the stratospheric ozone shield, major global climatic changes, loss of biodiversity in general, loss of tropical rain forests in particular, and other aspects of ecology gained widespread publicity.

Since it is possible to review only a few of the major aspects of ecological study and environmental considerations in a text of this nature, this chapter will briefly explore some of the issues at several broad levels. These include (1) individual plants, plant populations, and plant communitites; (2) global matters; and (3) regional issues.

PLANTS AND THE ENVIRONMENT

The interactions between organisms and their environment determine whether or not a species, or an individual member of a species, can survive and reproduce in a particular habitat. The environment of each habitat is determined by both living and nonliving factors. Living, or *biotic*, factors include all of the other organisms in the habitat with which the organism interacts. If we consider a maple tree in the forest, the biotic factors include the other maple trees that might provide pollen for reproduction, or the animals that might eat its leaves, or the fungi and other microorganisms that are associated with its roots. The nonliving, or *abiotic*, factors in the environment include the wind, rain, sunlight, soil, and temperature to which the maple tree is exposed during its lifetime. Each habitat in the world has a different combination of biotic and abiotic factors, with different habitats favoring different kinds of plants and animals. Thus, maples might grow well in places where there are freezing winters while palm trees would not.

The fact that a particular species of plant can flourish in one habitat but not another suggests that plants reflect and respond to their environment. For example, when a seed germinates, it must be capable of growing into a mature plant and also must reproduce in the same environment. When the plant reproduces, its genes are passed along to the next generation; these genes allow it to grow in its environment. In other words, the plant is *adapted* to its environment. If the plant were not adapted to its environment, its seeds might germinate but the plants would die before reproduction could occur. By observing the plants growing in a particular habitat, one can tell the general nature of their environment. For example, cacti are indicative of desert conditions that normally include little precipitation. On the other hand, the presence of -natural grasslands -indicates that the environment provides higher levels of precipitation, but at insufficient levels to sustain the growth of trees.

Populations, Communities, and Ecosystems

We recognize that plants, animals, and other organisms tend to be associated in various ways with one another and also with their physical environment. For example, forests consist of **populations** (groups of individuals of the same species) of trees or other plants that form a **plant community** (unit composed of all the populations of plants occurring in a given area). The lichen and moss flora on a rock also constitute a community, as do the various seaweeds in a tidepool (Fig. 25.1). However, these communities also invariably have animals and other living organisms associated with them. It is preferable, therefore, to refer to the unit composed of all the populations of living organisms in a given area as a **biotic community.** Considered together, the communities and their physical environments, which interact and are interconnected by physical, chemical, and biological processes, constitute **ecosystems.** Some populations, communities, and ecosystems may be microscopic in extent, while others can be much larger, or even global.

Populations

Populations may vary in numbers, in density, in genetic diversity, and in the total mass of individuals. Depending on circumstances, a field biologist may investigate a population in various ways. If, for example, a conservation organization is concerned about the preservation of a rare or threatened species, the organization may simply count the *number* of individuals, although this may not always be feasible. If such a count is not feasible, the organization may estimate population *density* (number of individuals per unit volume—e.g., five blueberry bushes per square meter). If the individuals in a population vary greatly in size or are unevenly scattered, a better estimate of the population’s importance to the ecosystem may be calculated by determining the **biomass** (total mass of the living individuals present).

Communities

Communities are composed of populations of one to many species of organisms living together in the same location. Similar communities occur under similar environmental conditions, although actual species composition can vary considerably from one location to another. A community is difficult to define precisely, because species of one community may also occur in other communities. Furthermore, species of one community may have specific genetic adaptations to that community; therefore, if individuals are transplanted to a second, different community where the same species occurs, the transplanted individuals may not necessarily be able to survive alongside their counterparts that are themselves adapted to this second community.

Analysis and classification of communities are important in the preparation of maps that form the basis of activities such as land-use planning, forestry, natural resource management, and military maneuvers.

Ecosystems

Living organisms interacting with one another and with factors of the nonliving environment constitute an ecosystem. The nonliving factors of the environment (abiotic factors) include light, temperature, concentrations of oxygen and other gases, air circulation, fire, precipitation, rocks, and soil type. The distribution of a plant species in an ecosystem is controlled mostly by temperature, precipitation, soil type, and the effects of other living organisms (biotic factors). For example, in Mediterranean climates, such as those that occur in parts of California and Chile, nearly all precipitation occurs during the winter months, and the summers are dry. This type of climate favors spring annuals that complete their life cycles by summer and evergreen shrubs that can tolerate long periods of drought. Forests may occur in areas where melting heavy winter snowfall soaks deeply into the soil, compensating to a certain extent for the lack of summer moisture.

The distribution of plant species is influenced by the mineral content of soils. For example, serpentine soils occurring on the American west coast contain relatively high amounts of magnesium, iron, usually nickel, and chromium and low amounts of calcium. These soils often support species that are not found on nearby nonserpentine soils. Biotic interactions, such as competition for light and grazing by the animal members of the biotic community, and abiotic factors, such as mineral nutrients and available water, also influence the distribution of plant species.

The leaves and other parts of plant species that occur naturally in areas of low -precipitation and high temperatures (*xerophytes*) generally are adapted to their particular environment through modifications that reduce transpiration. These modifications are discussed under "Specialized Leaves" in Chapter 7 and "Regulation of Transpiration" in Chapter 9. Plants of arid areas may also have specialized forms of photosynthesis, such as CAM photosynthesis. Similarly, plants that grow in water (*hydrophytes*) are modified for aquatic environments.

Ecosystems may sustain themselves entirely through photosynthetic activity, energy flow through **food chains** (discussed in the next paragraph), and the recycling of nutrients. Organisms, called **producers,** are capable of carrying on photosynthesis (e.g., plants, algae) and store energy that may be released by other organisms. Animals such as cows, caribou, caterpillars, and other organisms that feed directly on producers are called **primary consumers. Secondary consumers,** such as tigers, toads, and tsetse flies, feed on primary consumers. **Decomposers** break down organic materials to forms that can be reassimilated by the producers. The foremost decomposers in most ecosystems are bacteria and fungi. Note that there is not necessarily a sharp distinction between consumers and decomposers. Decomposers, for example, depend just as much as consumers on organic matter for their nutrition.

In any ecosystem, the producers and consumers interact, forming food chains or interlocking *food webs* that determine the flow of energy through the different levels (Fig. 25.2). In such chains or webs, each link feeds on the one below and is consumed by the one above, with photosynthetic organisms at the bottom and the largest non-herbivorous animals at the top. Since most non-plant organisms have more than a single source of food and are themselves often consumed by a variety of consumers, there are considerable differences in the length and intricacy of food chains or webs, but there are rarely more than six links in any given chain.

Light energy itself, which enters at the producer level, can't be recycled in an ecosystem. Only about 1% of the light energy falling on a temperate zone community is involved in the production of organic material. As the organisms at each level respire, energy dissipates as heat into the atmosphere. Some parts of organisms may not be consumed at each level of the food chain. For example, leaves that are grazed by an herbivore are broken down and much of their energy is released within the animal. However, the energy stored within the uneaten leaves of the same plant isn't released until the leaves fall from the plant and decomposers (bacteria and fungi) break them down.

Only about 10% of the energy in one link of the food chain is passed on to the next link. This is because much of the energy at a lower food chain level is not even utilized (it is left unconsumed or undigested) and some of the energy is released as heat during metabolism. For example, a significant proportion of farmland is used to grow animal feed instead of food crops for humans. When cattle graze, however, only 10% of energy stored by the green plants they consume is stored in animal tissue. When we eat beef, only approximately 10% of its stored energy is used by our bodies to manufacture new blood cells and otherwise sustain life. The remaining energy is lost as heat. Obviously, then, in a long food chain, the final consumer gains only a tiny fraction of the energy originally captured by the producer at the bottom of the chain.

Conversely, there is proportionately much less loss of energy between levels in short food chains. Assume, for example, that for every 100 calories of light energy falling on corn plants each day, 10 calories are stored in corn tissue. Then suppose the corn is fed to cattle. Again, only 10%, or 1 calorie, of the original energy may be stored in animal tissue. If, as secondary consumers, we eat the beef, our bodies, in turn, may use 10% of the energy available in the beef, or only 0.1% of the original energy available. If, however, we eat the corn directly, we end up with the steer's percentage, which is 10 times more of the original solar energy than we would get if we ate the steer that ate the corn. (The actual amount of energy per gram of beef is considerably higher than that found in a gram of corn.)

From this, it follows that a vegetarian diet makes much more efficient use of solar energy than one that relies heavily on meats, and where food is scarce or humans are very abundant (as in India or Ethiopia), humans may be more or less forced to favor a vegetarian diet. It also follows that in terms of the numbers of individuals and the total mass, there is a sharp reduction at each level of the food chain. In a given portion of ocean, for example, there may be billions of microscopic algal producers supporting millions of tiny crustacean consumers, which, in turn, support thousands of small fish, which meet the food needs of scores of medium-sized fish, which are finally consumed by one or two large fish (Fig. 25.3). In other words, one large fish may very well depend on a billion tiny algae to meet its energy needs every day.

The interrelationships and interactions among the components of an ecosystem can be quite complex, but many function together in a somewhat regulatory fashion. An increase in food made available by producers can result in an increase in consumers, but the increased number of consumers and competition among them reduces the available food, which then inevitably leads to a reduction of consumers to earlier levels. While cyclical in nature, the net result is sustained self-maintenance of the ecosystem. This is the basis for the so-called *Balance of Nature.*

Interactions Among Plants, Herbivores, and Other Organisms

While it is easy to see the total mass of consumers is largely determined by the total mass of food made available by the producers, the interactions among different producers themselves, between predators and prey, and between the decomposers and the other members of the ecosystem are usually more subtle. Many flowering plants produce substances that either inhibit or promote the growth of other flowering plants. Black walnut trees, for example, produce a substance that wilts tomatoes and potatoes and injures apple trees that come in contact with black walnut roots. Desert plants have wide, shallow root systems. They often leach chemicals into the soil; the chemicals kill competitors, which results in cacti and other desert plants having more space for growth. Many other plants produce phytoalexins (chemicals that kill or inhibit disease fungi or bacteria), making them resistant to various diseases (see discussion under "Use of Resistant Varieties" in Appendix 2).

Conversely, some bacteria and fungi limit higher plant growth by producing various inhibitory chemical compounds. Population size in other bacteria, fungi, and flowering plants may be limited by nutritional needs and availability. The degree to which this occurs varies considerably with the organisms involved. Some of the species of the Figwort Family (Scrophulariaceae), which includes snapdragons and similar plants, have no chlorophyll, and depend entirely on their flowering plant hosts for their energy and other nutritional needs. Other related species, as well as mistletoes, do have chlorophyll but apparently also require supplemental food from their hosts. Still other species often parasitize the roots of certain plants but are also capable of existing independently.

Mycorrhizal fungi are intimately associated with the roots of most woody and many other plants in such a way that both organisms derive benefit (such associations, called *mutualisms,* are a major part of life in general; they are briefly discussed in Chapter 5). The fungi greatly increase the absorptive surface of the root, usually playing a major role in the absorption of phosphorus and other nutrients, while obtaining energy from root cells.

Thomas Belt, a naturalist of more than 100 years ago, first called attention to an association between tropical ants and thorny, rapidly growing species of *Acacia* (Fig. 25.4). The *Acacia* has large, hollow thorns at the base of each leaf and is host to ants that feed on sugars, fats, and proteins produced by petiolar nectaries and special bodies at the tip of each leaflet. The ants live within the hollow thorns and vigorously attack any other organism, from insects to large animals, that come in contact with the plant. They also kill, by *girdling,* any plant that touches the *Acacia* (girdling is discussed under "bridge grafting" in Appendix 4). Experiments have shown that when ants are removed from these *Acacia* species, the plants grow very slowly and usually soon die from insect attacks or from shading by other plants.

Large herbivorous animals, such as deer and moose, feed on a wide variety of plants, each differing in nutritional value. Each plant species also produces different combinations, types, and amounts of chemical compounds in addition to proteins, fats, and carbohydrates. Many of the chemical compounds may be toxic, but some animals grazing on the plants that produce these chemicals do not display symptoms of poisoning because their digestive systems are capable of breaking down the compounds and eliminating or excreting them to a limited degree. The limitations imposed by such compounds result in the consumers varying their diet, seeking familiar foods, and being wary of new ones.

Some plants are dependent for their existence on predators controlling populations of grazing animals. Populations of others such as oaks may become limited in extent when squirrels and acorn-consuming birds remove acorns that would potentially become trees. All plant species have some natural defense, such as chemical compounds or structural modifications (for example, spines). If this were not so, primary consumers of all kinds from insects to elephants could soon render a species extinct. In an ecosystem, the defenses that both producers and consumers have against each other have been developed through a process of coevolution resulting from natural selection and are more or less -balanced.

LIFE HISTORIES

In order for a species to maintain itself, it must be able to both survive and reproduce. It is critical that a proper balance between the use of resources for survival and those for reproduction be established. As you might expect, different strategies for allocating resources have developed. A species' *life history* is composed of the traits that control its survival and reproduction. Species adapted to regions with erratic weather conditions often develop the *big bang reproduction* strategy. These species devote all their resources toward growth for most of their lives. Then, when conditions are favorable, most of their energy goes into a final single reproductive burst. For example, desert agave plants grow vegetatively for many years and then, during a moist year, all the energy goes into producing huge flower stalks with many seeds. The plant then dies. In contrast, some species have *repeated reproduction,* producing seeds throughout their lifetimes. Most trees require several years to reach reproductive maturity, but produce seeds every year for the remainder of their lives.

Plants can be divided into three groups based on their reproductive strategies. As discussed in Chapter 8, annuals, biennials, and perennials differ in their seasonal growth cycles. During the growing season, annuals grow vegetatively, with reproductive growth occurring toward the end of the season. Once seeds have been produced, the plants die. Many weeds, wildflowers, and garden plants exhibit this type of growth. Biennials put all their energy into vegetative growth for one year. Then, during the second year, most energy is put into the production of reproductive structures, the plants dying after seeds are produced. Examples of biennial plants include parsley, carrots, celery, foxglove, and sweet William. Perennial plants produce vegetative structures that survive for many years. Herbaceous perennials grow actively during periods of adequate temperature and moisture, but die back during unfavorable growing conditions such as a cold winter or a dry season. They survive through underground structures such as roots, rhizomes, bulbs, or tubers, which remain dormant until conditions are favorable for growth again. Examples of herbaceous perennials include coneflowers, tulips, and most grasses. Woody perennials do not die back during unfavorable periods in the growing season, but they do become dormant. Examples include trees, shrubs, and vines.

NATURAL CYCLES

Water and elements such as carbon, nitrogen, and phosphorus are constantly cycling throughout nature. Such cycling involves transformation between organic and inorganic forms. We'll use the water, carbon, and nitrogen cycles as examples.

Nutrients constantly cycle and are recycled in the web of life. Carbon, nitrogen, water, phosphorus, and other molecules for eons have been passing through cycles. Some molecules that were a part of a primeval forest that became compressed and turned to coal may have become part of another plant after the coal burned. Then the new plant may have been eaten by an animal that, in turn, contributed molecules to a part of yet another living organism. Just think of where the molecules in your own body may have been in the past few billion years. They may well have been a part of some prehistoric seaweed, a saber-toothed tiger, a mighty dinosaur, or even all three!

The Water Cycle

Most of a living cell consists of water, and it is in this medium that the myriad of chemical reactions of living organisms takes place. In fact, life as we know it couldn't exist without water. The earth's water is constantly being recycled, and the total amount remains stable. However, as we will see later in this chapter, the distribution of water across the globe can change over time. Ninety-eight percent of the water is in oceans, rivers, lakes, and puddles that make up about two-thirds of the earth's surface. Most of the remaining water is in living organisms, glaciers, polar ice, water vapor, and the soil.

Some water that falls on land penetrates until it reaches an area of saturation known as the *water table.* Water in the water table may emerge from beneath the surface in the form of springs and artesian wells. Below the water table, porous rocks collect water and, when these rocks transmit water to wells and springs, they are called **aquifers.**

Water evaporates from bodies of water and is transpired from plants, which comprise more than 98% of the earth's biomass. Water also evaporates from the surfaces of animals and damp areas of the earth as the sun shines on them. The water vapor rises into the atmosphere, condenses, and falls back to earth in the form of rain, snow, and hail in a constant cycle—the *water cycle* (Fig. 25.5).

The Carbon Cycle

In the process of "feeding" (acquiring the energy they need to maintain themselves and grow; i.e., respire), bacteria process carbon (and nitrogen) in a way that allows these elements to be recycled (Fig. 25.6). Bacteria "eat" organic matter (carbohydrates), obtaining the energy present in the molecules. As a result of this activity (respiration), they convert carbohydrates to carbon dioxide. One of the two raw materials of photosynthesis, carbon dioxide constitutes 0.037% of our atmosphere. The combined plant life of the oceans and the land masses is estimated to use about 14.5 billion metric tons (16 billion tons) of carbon obtained from carbon dioxide every year. Respiration by all living organisms constantly replaces carbon dioxide, with perhaps as much as 90% or more of it being produced by the incredible numbers of decay bacteria and fungi as they decompose tissues.

The burning of fossil fuels by the internal combustion engines of industry and transportation releases lesser but significantly increasing amounts of carbon dioxide into the air, and a small amount originates with fires and volcanic activity. At the present rate of use by photosynthetic plants, it has been calculated that all of the carbon dioxide of our atmosphere would be used up in about 22 years if it were not constantly being recycled.

Scientists have found that plant growth initially can be accelerated by increasing levels of carbon dioxide in the air, and some commercial nurseries pump carbon dioxide along rows of bedding plants as a "fertilizer." However, the accelerated growth soon becomes limited by other factors in the environment and ultimately does not necessarily result in crop yield increases. Recent studies indicate that while C_3 plants may respond to increased carbon dioxide levels, C_4 plants may not, suggesting that in nature, the response of C_3 plants to higher levels of carbon dioxide may give them a competitive edge over C_4

plants.

Anaerobic bacteria produce large volumes of carbon-containing methane gas, which is discussed on page 490.

The Nitrogen Cycle

Most of the nitrogen in living organisms is in the protoplasmic proteins of their cells, with much of the protoplasm being water. Nitrogen gas makes up about 78% of our atmosphere but constitutes only about 18% of the protein in living cells. There are nearly 69,000 metric tons of nitrogen in the air over each hectare of land (35,000 tons per acre), but the total amount of nitrogen in the soil seldom exceeds 3.9 metric tons per hectare (2 tons per acre) and is usually considerably less. This discrepancy results from the nitrogen of the atmosphere being chemically inert, which is another way of saying that it will not combine readily with other molecules. It is, therefore, largely unavailable to plants and animals for their use in building proteins and other substances containing nitrogen.

Most of the nitrogen supply of plants (and indirectly, therefore, of animals) is derived from the soil in the form of inorganic compounds and ions taken in by the roots. These compounds and ions include those that contain nitrogen chemically combined with oxygen or hydrogen. Animals, through their digestive processes, and bacteria and fungi break down the more complex molecules of dead plant and animal tissues to simpler ones. Some nitrogen from the air is also *fixed*—that is, converted to ammonia or other nitrogenous compounds by various *nitrogen-fixing bacteria*. Some of these organisms gain access to various plants, particularly legumes (e.g., peas, beans, clover, alfalfa), through the root hairs, with the plant producing root nodules in which the bacteria multiply (root nodules are shown in Fig. 5.17). Others live free in the soil.

Figure 25.7 shows there is a constant flow of nitrogen from dead plant and animal tissues into the soil and from the soil back to the plants. Decay bacteria and fungi can break down enormous quantities of dead leaves and other tissues to tiny fractions of their original volumes within a few days to a few months. If they were abruptly to cease their activities, the available nitrogen compounds would be completely exhausted within a few decades and the carbon dioxide supply needed for photosynthesis seriously depleted. Forests and prairies would die as the accumulations of shed leaves, bodies, and debris buried the living plants and shielded their leaves from the light essential to photosynthetic activity. At present, even with the various bacteria involved in the nitrogen cycle functioning normally, the total amount of nitrogen in the soil is not being increased by their activities but is merely being recycled. Note, however, that addition of nitrogenous fertilizers will artificially increase soil nitrogen content.

Significant amounts of nitrogen are continually being lost as water leaches it out or carries it away through erosion of topsoil. More is lost with each harvest, the average crop removing about 25 kilograms per hectare (25 pounds per acre) per year. This nitrogen loss from the harvesting of crops can be sharply reduced if vegetable and animal wastes are recycled and returned to the soil each year. While bacteria are decomposing tissues, they use nitrogen, and little is available until they die and release their accumulations into the soil. Accordingly, until bacteria have completed their breakdown of organic matter, crops should not be planted in soils to which only partially decomposed materials have been added. Likewise, when sawdust, straw, or other organic mulches are spread around plants in a garden to control weeds and conserve soil moisture, the soil nitrogen will be less available to the growing plants until the mulches have been decomposed.

Weeds and stubble are often controlled by burning. Fire, however, causes serious loss of nitrogen, which has to be replaced. It has been estimated that the annual combined loss of nitrogen from the soil in the United States from fire, harvesting, and other causes exceeds 21 million metric tons (23 million tons), and only 15.5 million metric tons (17 million tons) are replaced by natural means. To offset the net loss, some 32 million metric tons (35 million tons) of inorganic fertilizers are applied to the soils each year. If organic matter is not added at the same time, however, this application of inorganic fertilizers, combined with the annual burning of stubble, may eventually result in the creation of a *hardpan* soil.

Hardpan develops through the gradual accumulation of salt residues, which dissolve humus and disrupt the structure of the soil, causing the clay particles to clump and also producing colloids that are impervious to moisture. In hardpan soils and others low in oxygen (e.g., flooded areas), denitrifying bacteria use nitrates instead of oxygen in their respiration, depleting the remaining soil nitrogen.

Precipitation returns a little nitrogen to the soil from the atmosphere, where it has accumulated as a result of the action of light on industrial pollutants, fixation by flashes of lightning, and diffusion of ammonia released through decay. The activities of nitrogen-fixing bacteria and volcanoes also contribute to the natural replenishment of nitrogen by converting it to forms that can be utilized by plants.

SUCCESSION

After a volcano spews lava over a landscape or after an earthquake or a landslide exposes rocks for the first time, there is initially no sign of life on the lava or rock surfaces. Within a few years or sometimes within a few months or even weeks, living organisms begin to appear, and a sequence of events known as **succession** takes place. During succession, the species of plants and other organisms that first appear gradually alter their environment as they carry on their normal activities, such as metabolism and reproduction. In time, the accumulation of wastes, dead organic material, and inorganic debris and other changes (such as of shade and water content in the habitat) favor different species that may replace the original ones. These, in turn, modify the environment further so that yet other species become established.

Succession occurs whenever and wherever there has been a disturbance of natural areas on land or in water. It proceeds at varying rates, depending on the climate, the soils, and the animals or other organisms in the vicinity. Prior to the 1970s, ecologists believed that each community could establish a state of balance that would remain stable unless disturbed by humans. We now realize that communities are constantly changing in response to an array of disturbances. Humans may cause disturbances, but so does nature, in the form of hurricanes, floods, drought, and fire.

Disturbances may appear to have a negative impact on communities, but their effects may not be as devastating as they first appear. In fact, they can help to enhance the species diversity that contributes to the survival of communities. For example, in 1988, forest fires burned 45% of Yellowstone National Park, which covers about 1 million hectares (2.5 million acres). While the scenes of destruction seemed horrific, long-term studies of the aftermath confirm that fires do not do long-term harm to forest ecosystems. In fact, for several reasons, the park has recovered more quickly than expected. Although the landscape looked uniformly barren after the fire, some areas were less severely damaged than others. The pockets of relatively unscathed ground even near the largest burn areas allowed the forest to regenerate more quickly than expected. In addition, roots and rhizomes of many wildflowers survived the fire because the soil was charred for only a few centimeters in depth. These plants were able to grow rapidly and disperse seeds throughout the burned areas. This allowed the charred areas to recover quickly because seeds did not need to be dispersed from untouched regions. As a result of the fires, uniform stands of old lodgepole pine trees have been replaced by a rich diversity of species undergoing a new round of succession. However, ecologists studying the recovery of Yellowstone are concerned that global warming will dramatically alter the course of succession in the park. Based on computer models, wetter winters caused by global warming could allow for the establishment of larch, scrub oak, and other non-native trees. And, of course, with additional warming, more fires can be expected, allowing new rounds of succession to take place.

Ecologists recognize a number of variations of two basic types of succession. *Primary succession* involves the actual formation of soil in the beginning stages, whereas *secondary succession* takes place in areas that had previously developed into a climax community (discussed in the next section, "Primary Succession") and had experienced a drastic environmental change such as a volcanic eruption, or conversion to farmland.

Primary Succession

One of the most universal types of primary succession begins with bare rocks and lava that have been exposed through glacial or volcanic activity or through landslides. Initially, the rocks are sometimes subjected to alternate thawing and freezing, at least in temperate to colder areas. Tiny cracks or flaking may occur on the surface as a result. Lichens often become established on such surfaces (Fig. 25.8). They produce acids that very slowly etch the rocks, and as they die and contribute organic matter, they are replaced by other, larger lichens. Certain rock mosses adapted to long periods of desiccation also may become established, and a small amount of soil begins to build up. This is augmented by dust and debris blown in by the wind. Eventually, enough of a mat of lichen and moss material is present to permit some ferns or even seed plants to become established, and the pace of soil buildup and rock breakdown accelerates.

If deep cracks appear in the rocks, the larger seeds may widen them further as they germinate and the roots expand in girth. It has been calculated that germinating seedlings can exert a force of up to 31.635 kilograms per square centimeter (450 pounds per square inch). Indeed, instances are known of seedlings splitting rocks that weigh several tons (Fig. 25.9).

As soil buildup continues, larger plants take over, and eventually the vegetation reaches an equilibrium in which the associations of plants and other organisms remain the same until another disturbance takes place or climatic changes occur.

These relatively stable plant communities may be referred to as **climax communities,** which differ from one part of the world to another, depending on climate and soil, or major disruptions such as fires or floods.

In parts of eastern North America, deciduous forests dominate the landscape. This climax community is comprised of maples, beeches, oaks, hickories, hemlocks, or other combinations of trees. In desert regions, cacti predominate, while large coniferous trees constitute the climax community in the Pacific Northwest. In parts of the Midwest, prairie grasses and other herbaceous plants form the climax vegetation, and in wet tropical regions, a complex association of trees and herbs predominates.

Occasionally, when a volcano produces ash that buries existing landscape and associated vegetation, some of the successional stages involving lichens and mosses may be bypassed, with larger plants colonizing the area and becoming the successional pioneers. This occurred following the series of ash eruptions, debris, and mudflows of Mount St. Helens in the state of Washington during the early 1980s (Fig. 25.10A). Most life in the path of destruction was destroyed (Fig. 25.10B). Within weeks, signs of life began to return to the area. However, it took two decades for vegetation to get a foothold. In the early 1990s, vegetation was limited to wetland areas, a few areas that escaped severe damage on the eastern side of the volcano, and areas where lupine became established. Lupine in turn promoted the establishment of other species because it is a legume and, therefore, capable of nitrogen fixation. It is interesting that several different community types have developed, but they do not appear to be related to landscape features. Instead, random factors associated with seed dispersal have determined community composition in the early stages of succession. Local features such as competition and soil conditions have not yet influenced the array of species in communities. It is expected that, as succession continues, competitive interactions will limit species to areas in which they are adapted.

Another important lesson from Mount St. Helens is that the volcano created many disturbances, not just one. The ash deposits, the lava flows, and the landslide affected plants in different ways, and, in turn, the plants responded differently. In areas where the ash deposits were not too deep, burrowing pocket gophers mixed up the soil, ash, seeds, plant parts, and microbes. This allowed mycorrhizal fungi to come into contact with plant roots and enabled them to take up critical nutrients. The variability in the patterns and rates of succession in different areas affected by the volcano indicates that succession is a complex phenomenon that cannot be interpreted as a single, linear, predictable set of events. In 1883, for instance, a powerful volcano on the island of Krakatau, Indonesia, covered the island and two neighboring islands with a thick layer of ash, destroying virtually all plant and animal life. Since Krakatau is an island, this event interested ecologists who study colonization. New plants reached the island from distances of over 40 kilometers (25 miles) and established themselves. The plants reached the island by air as light seeds or spores, by sea as floating seeds or by riding on logs, or by animals as hitchhikers on swimming or flying animals. Through these strategies, vascular plants recolonized the sterile islands without the establishment of lichens and mosses. The islands are now home to tropical rain forests containing over 400 species of vascular plants.

Succession may also take place in wet habitats. For example, ponds and lakes abound in the northern parts of midwestern states such as Michigan, Wisconsin, and Minnesota. Many of these bodies of water were left behind by retreating glaciers and often have no streams draining them. The water that evaporates from them is replaced annually by precipitation runoff. They also grow a tiny bit smaller each year as a result of succession (Fig. 25.11A).

This succession often begins with algae either carried in by the wind or transported on the muddy feet of waterfowl and wading birds. Although algae multiply throughout the upper sunlit levels of the entire pond, they tend to become concentrated in shallow water near the margin, and with each reproductive cycle, the dead parts sink to the bottom. Floating plants, such as duckweeds, may then appear, often forming a band around the body of water just offshore (Fig. 25.11B). When nutrients, oxygen, pH, and temperatures are low, peat mosses encroach from the sides and become the dominant floating plants. There are presently about 4 million square kilometers (1.5 million square miles) of peat bogs throughout the world.

Water lilies and other rooted aquatic plants with floating leaves often become established, each group of plants contributing to the organic material on the bottom, which slowly turns to muck. Cattails and other flowering plants that produce their inflorescences above the water often take root in the muck around the edges, and the accumulation of organic material accelerates.

Meanwhile, the algae, duckweeds, peat mosses, and other plants move farther out, and the surface area of exposed water gradually diminishes. Grasslike sedges become established along the damp margins and sometimes form floating mats as their roots interweave with one another. Dead organic material accumulates and fills in the area under the sedge mats, and herbaceous and shrubby plants then move in. As the margins become less marshy, coniferous trees whose roots can tolerate considerable moisture (e.g., tamaracks or eastern white cedars) gain a foothold, eventually growing across the entire site as the pond or lake disappears. The trees continue to contribute to the formation of new soil and, in due course, a stable climax community becomes established. At this point, no visible trace of the pond or lake remains, and the only evidence of its having been there lies beneath the surface, where fossil pollen grains, bits of wood, fossilized fish skeletons, and other material reveal the past history. Such succession can take up to a thousand or more years before it is complete. The evidence that it does occur, however, is extensive and compelling.

Under natural conditions, some stream-fed lakes and ponds eventually become filled with silt and debris, although this, too, may take hundreds of years to occur. The streams that feed these lakes bring in silt, and the nutrient content of the water rises as dissolved organic and inorganic materials (particularly nitrogen and phosphorus) are brought in. This gradual to relatively rapid enrichment, called **eutrophication,** facilitates the growth of algae and other organisms that add their debris to the bottom of the lake. When sewage and other pollutants enter the lake, the process of eutrophication may be greatly accelerated through stimulation of the growth of aquatic organisms. Eutrophication may also accelerate when trees are cleared from land surrounding lakes prior to the construction of summer homes and resorts. The cleared land erodes more readily, with precipitation runoff carrying soil into the water. Regardless of size, all bodies of water, including rivers, are subjected to these processes.

Secondary Succession

Secondary succession, which occurs more rapidly than primary succession, may take place if soil is already present and there are surviving species in the vicinity. In fact, survivors strongly condition subsequent succession. Many secondary successions follow human disturbances (e.g., land that was cleared when timber was harvested or land converted to farmland). Other secondary successions follow fires. Grasses and other herbaceous plants become established on burned or logged land. These usually are followed by trees and shrubs that have widely dispersed seeds (e.g., aspen and sumac in the Midwest and East, and chaparral plants, such as chamise and gooseberries, in the West). After going through fewer stages than are typical of primary succession, a climax community becomes established, often in less than 100 years.

Fire Ecology

Natural fires, started primarily by lightning and the activities of prehistoric humans, have occurred for thousands of years in

North America and other continents (Fig. 25.12A). Trees, such as the giant redwoods and ponderosa and lodgepole pines, although scarred by certain types of fires, often survive; the dates of fires can be determined by the proximity of the scars to specific annual rings (see Fig. 6.7). In the West, growth rings of ponderosa pines show that in the past, forests of such pines used to burn on an average of every 6 to 7 years. These fires and the climate, topography, and soil combined to have a profound effect on various biomes.

As human cultures developed, major and largely successful efforts to control fires were made, and this, in turn, significantly altered vegetational patterns. As knowledge of the role of fires in the maintenance of ecosystems has accumulated, it has become apparent that trying to eliminate fires, at least in certain areas, disrupts natural habitats more in the long run than allowing them to occur, and agencies such as the U.S. National Park Service may allow fires at higher elevations to run their natural course.

Fires also play a role in the composition of forests. In the mountains of east-central California, gooseberry and deerbrush appear in abundance after a fire, but their numbers stabilize within 15 to 30 years when larger trees return to the area. Ponderosa, jack and southern longleaf pines, and Douglas firs (which do not tolerate shade) are among the species that repeatedly replace themselves after fires; seeds of some species rarely germinate until they have been exposed to fire. The majority of chaparral species, both woody and herbaceous, are so adapted to fire that their seeds also will not germinate, as a rule, until fires remove accumulated litter and toxic wastes produced by the plants during growth.

Fires actually benefit grasslands, chaparral, and forests by converting accumulated dead organic material to mineral-rich ash, whose nutrients are recycled within the ecosystem. If the soil has been subjected to fire, some of its nutrients and organic matter may have been lost, and the composition of microorganisms originally present is likely to have been altered. Losses are offset, however, by the fact that soil bacteria, including cyanobacteria, which are capable of fixing nitrogen from the air, increase in numbers after a fire, and there is a decrease in fungi that cause plant diseases.

In some areas, such as the prairie states of the Midwest, grasses are better adapted to fire than are woody plants, producing seeds within a year or two after germination. Perennial grass buds that are at the tips of rhizomes close to or beneath the surface, where they escape the most intense heat of fires, usually survive, producing new growth the first season after a fire. Accordingly, a fire destroys only one season’s growth of grass, often after growth has been completed. Shrubs, however, have much of their living tissue above ground, and a fire may destroy several years’ growth. In addition, woody plants often do not produce seeds until several years after a seed germinates. Many shrubs do sprout from burned stumps, particularly in chaparral areas (Fig. 25.12B), but repeated burning keeps them small, thereby favoring grasses. There is evidence that at least some of the North American grasslands originated and were maintained because of fire. Since grassland fires have largely been controlled, many of the areas have now been invaded by shrubs that were once confined to watercourses.

THE IMPACTS OF HUMANS ON PLANT COMMUNITIES

At the Global Level

In the modern world, humans are found in almost every ecosystem on earth. Because of their large numbers and the huge amounts of resources they use on a daily basis, humans have a greater worldwide impact on ecosystems than any other living species. Among the many problems are strato-spheric ozone depletion, widespread climatic changes, and loss of biodiversity, all of which are global in scope and long lasting in impact. The origins of at least some of these problems have been traced to human activities. Strategies for attacking the problems emphasize the need for multinational dialogue and cooperation among specialists in fields as diverse as biology, chemistry, economics, and political science, and a need to conserve resources used.

GLOBAL WARMING

Although there is evidence that the earth has gone through cycles of warming and cooling in the prehistoric past, there seems to be little question that human activities are accelerating the rate at which global warming is now occurring. The hottest 10 years in the last century have all occurred since 1980. For instance, 1998 was the hottest year on record and 2001 was the second hottest. The 1990s were the hottest decade in the past 1,000 years. In 2003, the first-ever 37.8°C (100°F) temperatures in England were recorded, and thousands of human deaths were attributed to a summer heat wave that baked the area. Many scientists predict that such heat-related natural disasters will repeat themselves around the world as global warming pushes temperatures higher. As a result, glaciers are shrinking, permafrost is disappearing, and sea levels continue to rise as warm water expands and glaciers melt. This *greenhouse effect* is the accumulation in the atmosphere of gases that permit radiation from the sun to reach the earth’s surface but prevent the heat from escaping back into space, thus adding to the global rise in temperature. Carbon dioxide and methane, the two most common gases involved in potential global warming, have been part of our atmosphere for millions of years, but others, such as chlorofluorocarbons, are relatively recently produced by-products of the manufacture of refrigerants, plastics, and aerosol cans.

Carbon Dioxide

D. L. Lindstrom of the University of Illinois at Chicago and D. R. MacAyeal of the University of Chicago examined records of cores of ancient ice from Siberia, Scandinavia, and the Arctic Ocean. Using computers to simulate the status of ice and atmosphere going back 30,000 years, they found the earth's temperature had increased as the levels of carbon dioxide had increased. At the end of the most recent ice age, the rise in temperature was sufficient to melt the ice. Their findings suggest that cycles of ice ages followed by shorter warm periods may have been caused solely by rising and falling levels of carbon dioxide.

In 1986, worldwide carbon dioxide emissions from transportation and industrial sources totaled somewhat less than 4.5 billion metric tons (5 billion tons), but in 1987, the total rose to more than 5 billion metric tons (5.5 billion tons) and has continued to rise through the early 2000s to more than 7.2 billion metric tons (8 billion tons) in 2003. The burning of fossil fuels and deforestation has two significant effects on carbon dioxide content of the air: (1) it eliminates the photosynthesizing organisms that remove carbon dioxide from the atmosphere, and (2) it results in carbon stored in wood and other biological molecules being released into the air as carbon dioxide. Burning of fossil fuels and deforestation have been largely responsible for a 25% increase of carbon dioxide in the atmosphere since 1850. In the last 25 years alone, the earth's atmosphere has become 0.4°C (0.7°F) warmer, and between 1983 and 1990, the surface temperature of the ocean rose about 0.8°C (1.5°F).

Those may not seem to be significant amounts, but during the last ice age in North America when ice covered the northern United States and Canada, the average temperature of the earth at sea level was only 4°C (7°F) colder than it is now. In 1989, Mostafa Tolba, head of the United Nations Environment Program, estimated that if current levels of gas released into the atmosphere continue, the earth's temperature is likely to rise between 1.4°C and 4.3°C (2.5°F and 8°F) by 2039.

Higher temperatures melt ice at the poles and after melting cause water to expand. Higher ocean levels cause inundation of low-lying, often densely populated, coastal areas. The Environmental Protection Agency estimates that for each 30 centimeters (11.8 inches) the sea rises, it encroaches 30 meters (100 feet) inland, and already during the past century, worldwide ocean levels have risen 12.7 centimeters (5 inches). It is estimated that 7,000 square miles of land in the United States alone will be flooded if the temperatures rise as predicted. Major shifts in population to higher latitudes could follow, with the grain belts of the midwestern United States shifting into Ontario, and the fertile crescents of Asia shifting north into Russia. Higher temperatures can also have major effects on winds, currents, and weather patterns, causing droughts and creating deserts in some areas, while bringing about heavy rainfall in others.

Methane

Swamps and wetlands have long been known to be sources of methane produced by anaerobic bacteria. Many animals produce methane during digestive processes, and large amounts of this gas are produced by the wood-digesting organisms within the guts of termites. Anaerobic bacteria in rice paddies produce significant quantities of methane. The total annual production of methane in the atmosphere has been slowly increasing in recent years. A small part of this increase may stem from the prodigious mushrooming in numbers of termites in cleared tropical rain forest areas, which, in 1998, were being destroyed at the rate of more than 100 acres per minute, 24 hours a day.

Ozone Depletion

Methane gas and chlorofluorocarbons (CFCs), the inert chemicals used for refrigeration and other industrial purposes, are broken down into active compounds by sunlight at high altitudes. The breakdown products destroy ozone, a form of oxygen that in the stratosphere provides a natural shield for living organisms against ultraviolet radiation. Increased ultraviolet radiation correspondingly increases skin cancers. There is evidence the ozone shield has gone through lengthy cycles of expansion and contraction over millions of years, but there appears to be little question that ozone breakdown has been accelerated by industrial pollutants. The weakening of the ozone shield has been recognized as a serious global problem by North American countries and the European Economic Community. In 1987, the United States proposed a 50% reduction on production and uses of chlorofluorocarbons by the year 2000, and in 1989, the European Economic Community proposed a total ban on uses of chlorofluorocarbons, also by the year 2000. In 1998, however, developing nations, such as India, China, and Brazil, still had plans to expand the production of chlorofluorocarbons and contended that a ban would place them at an economic disadvantage. Since global cooperation is urgently needed, the major industrial nations have been seeking ways to allay the economic concerns of third-world countries. An international meeting, with mixed results, was convened in 1992 to try to foster global cooperation on this issue, but by the early 2000s, concrete evidence of such cooperation was still not in evidence.

Chlorofluorocarbons apparently are not the only force actively destroying the protective ozone layer. Bromine-based compounds called *halons,* which are commonly found in electronic equipment, such as computer protection systems, and in portable fire extinguishers, are reported to be as much as 3 to 10 times more destructive of ozone than chlorofluorocarbons. Halon concentrations in the atmosphere increased about 20% a year between 1980 and 1986, according to the Environmental Protection Agency. Some scientists believe the actual concentrations to be as much as 50% higher than that, and as a result of their strong recommendations, powders and other inert gases are being substituted for halons in fire extinguishers now being made.

EROSION

Beach erosion is a serious problem in many parts of the world. A dramatic example of the effects of erosion can be illustrated in the story of the Cape Hatteras, North Carolina, lighthouse. In 1870, the lighthouse was built 1,500 feet back from the shoreline and served to protect ships traveling through the Outer Banks. However, in 1999, the building had to be moved a quarter mile farther inland because erosion had brought waves lapping up to near its base. While beaches are constantly building up and eroding in response to waves and storms, we are now seeing a net loss in beach area. The sea level is rising and scientists expect it to continue to rise at an increasing rate over the next century, due in part to global warming.

Trees are critical for the prevention of coastal erosion. The significance of trees for the protection of shorelines was apparent during the December 26, 2004, Indian Ocean tsunami that killed 276,000 people. Dense growths of mangrove trees were especially effective at minimizing damage on land. It is estimated that 96% of the land occupied by dense tree growth was undamaged by the tsunami, while only 38% of the land without trees escaped serious damage. The trees were able to break the waves and absorb their energy (Fig. 25.13). Prior to the tsunami, about one--quarter of the mangroves in the Indian Ocean region had been destroyed to make room for agriculture, aquaculture, and development. Land managers in the area are now reconsidering the wisdom of the trend.

In August 2005, Hurricane Katrina hit the Gulf Coast, causing more devastation than any hurricane in U.S. history. Over 1,800 people died and tens of thousands were displaced as a result of the hurricane and its aftermath. Although the devastation is shocking, it did not come as a surprise to scientists. A number of ecological factors contributed to the events that transpired in the late summer of 2005. First of all, much of the damage occurred in New Orleans, the only major metropolitan area in the United States that is below sea level. Before the 1800s, the Mississippi Delta on which New Orleans was built was regularly replenished by floods that brought sediment from the Mississippi River. However, in the past 200 years, a series of dams were constructed on the Mississippi River, preventing most sediment from reaching the delta. In addition, the levees that were built to protect New Orleans channel any sediment that does reach the South directly into the Gulf of Mexico. The levees also direct sediment away from barrier islands between New Orleans and the Gulf of Mexico. These islands are important because they provide a buffer against hurricane winds and storm surges. Finally, the sea level continues to rise and is expected to rise another 50 to 100 centimeters (20–40 inches) in the next century, compounding the effects of storm surges. Certainly, the hurricane was a natural disaster, but the effects of human intervention compounded the devastation.

The world human population now exceeds 6.5 billion. Amazingly, it has doubled in less than 50 years. The United Nations has developed high, medium, and low population growth estimates. Based on the medium estimate of 9 billion people by 2050, food production will need to increase by 50% in the next 40 years. With current farming methods, each person needs a half hectare (1.24 acres) to produce a food supply equivalent to that eaten by Western Europeans and North Americans. However, there is only half that amount of arable land in the world. It is obvious that there is critical need to continue to increase agricultural production to keep up with the demand for food.

The most significant limitation to sustainable productivity is soil erosion. The Midwest Dustbowl of the 1930s provides an illustration of the severe effects of soil erosion. Farmers moving west plowed the grasslands in the Great Plains and planted wheat. The crops grew well until a drought set in during the early 1930s. When the crops dried up, there was nothing to hold the soil and it blew into the air in huge billows of dust. Settlers were forced westward in an attempt to find another region with productive soil. While the Dustbowl is an extreme example, soil erosion continues to be a major conservation issue. One millimeter (0.04 inches) of soil lost in a rainstorm is equivalent to 15 metric tons (16.5 tons) of soil in a hectare (2.47 acres). That valuable topsoil is not easily replaced. The soil that is washed or blown away takes with it organic matter that is important, directly and indirectly, for the ability of the soil to soak up water. Without that sponge-like quality, water runs off the land. In addition to carrying away soil, the water may carry fertilizers and pesticides, resulting in pollution.

Soil erosion is the single largest source of water pollution in the United States and commonly occurs at construction sites, roadways, and farm fields. In order to reduce soil erosion, some lands have been permanently removed from production, while others are given temporary reprieves through the Conservation Reserve Program. Erosion rates have been reduced as a result of these and other erosion control programs, but the erosion rate is still 10 times the sustainability level.

AQUIFER DEPLETION

While soil erosion is visible as gullies in fields or billowing clouds of dust, another serious resource issue often goes undetected until it is too late to address. The overpumping of aquifers is probably the most underestimated ecological problem worldwide. Roughly 70% of water pumped from underground is used for irrigation, 20% is used by industry, and 10% is used for homes. However, the demand for water from all three uses is increasing rapidly. The United Nations has predicted that by the year 2050, 1.7 billion people will not have enough water to satisfy their basic needs. Most of the world water deficit is in China, India, the Middle East, North Africa, and North America. This problem is relatively recent, since the use of water has tripled since 1950. The demand for water is growing while the sustainable yield of aquifers is fixed, so water deficits grow larger every year. For example, in the Chenaran Plain of northeastern Iran, the water table has been dropping by 2.8 meters (9 feet) per year. However, in 2001, the aquifer plummeted 8 meters (26 feet) due to a drought and additional development.

LOSS OF BIODIVERSITY

Most plants and animals are adapted, sometimes in subtle ways, to the habitats in which they occur. When their natural habitats are destroyed, a few species may be able to adapt to new habitats, but most are not capable of doing so and ultimately perish. Ever since living organisms first appeared on this planet, various species have become extinct as climates and other environmental factors changed. However, the rates of extinction have accelerated enormously in just the last half-century as many types of habitats, from tropical rain forests and swamps to deserts, have been damaged or destroyed. Literally thousands of species are now facing extinction, many within the next 10 years.

If food and fiber plants are not particularly endangered by loss of natural habitats, why should we be concerned if seemingly unimportant wild species disappear? One of the many consequences of such losses pertains to the origins of our crop plants. Virtually all food, fiber, medicinal, and other useful plants have been developed from wild species, and keeping crops from succumbing to diseases often depends on our ability to breed new disease-resistant strains by tapping the gene pools of the plants' wild cousins. The gene pools usually have developed over thousands or even millions of years, and if they disappear, the most skillful plant breeders may be no match for rapidly mutating fungal and other diseases that attack our crops.

At the Regional Level

Although funding for solving many types of ecological problems is considered by citizens interested in the environment to be inadequate, the allocations to regional issues usually gain better public support because they are highly visible, and progress in dealing with them can be followed.

In the past two decades alone, concern about the effects of pollution on lands, waters, and peoples has been widely reported in the media and in scientific journals. During this time, attempts to correct or stem environmental damage have resulted in requirements that many construction projects file environmental impact reports before proceeding. These reports provide information that helps various agencies evaluate the possible effects a proposed project may have on the flora, fauna, and physical environment and determine what *mitigations* (alleviations of the problem) may be necessary before the project can or should be approved. The process has sometimes resulted in a great deal of controversy and emotional debate between landowners who believe their rights are being usurped and those who are convinced that preservation of the environment should supersede material considerations. Brief discussions of some regional issues follow.

Acid Deposition

Acid deposition occurs after fossil fuels are burned. The burned fuels release sulfur and nitrogen compounds into the atmosphere. There, chemical reactions brought about by sunlight and rain convert the compounds to nitric acid (HNO_3). Burning may result in the conversion of sulfur dioxide (SO_2) to sulfuric acid (H_2SO_4). These may combine with moisture droplets and become a liquid acid deposition (*acid rain*), which has a pH of less than 5.5 as compared with a pH of about 5.7 for unpolluted rain water. Some of the acid deposition, however, may be in the form of solid particulates. The acid deposition, in turn, adversely affects or even kills many living organisms on which it falls and increases the concentration of other toxic elements. Mycorrhizal fungi are beneficially associated with the roots of many trees, and are susceptible to acidified soil, which may be linked to acid deposition. Higher acidity of soil water also reduces the capacity of plant roots to obtain needed mineral nutrients.

Trees have been dying prematurely in parts of the world's forests. Some have died because of a lack of water during successive years of low rainfall or from other causes, such as insect infestations. Salt scattered to melt ice and snow on roads has affected trees in the immediate vicinity. There seems to be little question that acid deposition has had a major role in stunting or destroying trees downwind from industrial sites. In recent years, there has been increasing international attention and cooperation in reducing industrial and automobile emissions that play a role in the production of acid deposition.

Acid deposition also affects nonliving materials. Dr. Merle Robertson, an authority on pre-Colombian art, reported that the natural weathering of ancient Mayan ruins in southern Mexico had been accelerated by acid deposition over the past decade or two. The acid deposition apparently originates when moisture-laden winds blow over major oil refineries and other industrial sites located upwind from the ruins.

Water Contamination

Water becomes contaminated in different ways. Much of the pollution in our lakes and streams comes from the dumping of toxic industrial wastes and from runoff over polluted land. Other sources include the spraying of pesticides, the exhaust and other emissions of aircraft and ships, and airborne pollutants originating with the combustion of fossil fuels. Ground water supplies become polluted from pesticides and wastes trickling through the soil, from septic tanks, and from garden and farm fertilizers. Even deep wells, which seldom became polluted in the past, are increasingly becoming contaminated with unacceptably high levels of nitrates and other substances that harm the health of water-dependent humans and animals. Blue-baby syndrome is one example of the effects of high nitrate levels in drinking water. In response to the problem, many communities are improving their water treatment plants, and many families are installing water filtration systems in their homes.

Long-range goals for curbing water pollution include a tightening of restrictions on the dumping of wastes and greater improvements in municipal water purification plants and systems. Genetic engineering and bacteria also probably will play a major role in the future. For example, a bacterium that can remove more than 99% of 2,4,5-T (a major component of Agent Orange—discussed in Chapter 11) from a contaminated environment has already been bred, and several other bacteria are being genetically engineered to enhance their capacities for breaking down other toxic wastes.

Wetlands

Swamps, marshes, lagoons, river margins and estuaries, floodplains, and other wetland areas have historically been regarded as wastelands and have routinely been drained and converted to drier, more "productive" agricultural and industrial sites. For example, only 6% of California's original wetlands, 2% of Iowa's original wetlands, and less than 10% of the wetlands once along the shores of Lake Ontario remain today. Wetlands are, however, far from the wastelands they were once thought to be. Consider that the plants, algae, and other organisms in just 1 hectare (2.47 acres) of tidal wetland can perform the same recycling functions that about $150,000 of the latest wastewater treatment equipment is capable of—at no cost to taxpayers. The wetlands (Fig. 25.14), at the same time, provide habitat, shelter, and breeding grounds for a wide variety of wildlife, many species of which are now threatened with extinction.

Some attitudes toward wetlands have begun to change as the public has slowly become aware of the folly of eliminating them. City and regional planners in many areas now either ban new developments on wetlands or require a proposed development that would encroach on a wetland to provide mitigation measures such as the creation of new wet areas equal in extent and quality to those that may be lost. In addition, projects now in progress in many areas involve the restoration of damaged or lost wetlands.

Hazardous Waste

Members of earlier generations routinely drained the oil from their vehicle crankcases directly on to the ground or into storm drains or took the used oil and other hazardous wastes to the dump. Highly toxic industrial wastes were also disposed of both within and at the outskirts of cities and towns. In 1996, it was estimated that some 12 million children in the United States were living less than 4 miles from a hazardous waste site. Disasters have occurred when living organisms (including humans) have not been properly isolated from radioactive wastes produced by atomic energy plants. Even when hazardous wastes aren't unceremoniously dumped, serious accidents and spills take place, with the effects sometimes lingering indefinitely, as, for example, in and around the former Soviet Union's Chernobyl atomic meltdown site.

Today, there are concerted efforts to curb the disposal of hazardous wastes and to greatly reduce the probabilities of accidents and spills. At most solid-waste dumps, it is illegal to dispose of even empty latex paint cans, let alone more toxic materials, and heavy fines are levied on those found disposing of industrial wastes in an improper manner. Monies from a U.S. government "superfund" are being used, with some success, to clean up selected old hazardous waste sites. The process thus far is slow and inadequate, but the increased restrictions on disposal methods, and, as previously noted, the genetic engineering of bacteria that can dismantle and render harmless many types of wastes hold promise for the future.

Invasion of Foreign Species

Each year, alien plants, animals, and pathogens cause billions of dollars in damage in the United States alone, entering the country as stowaways in airplanes, trucks, or ships, and sometimes escaping from the gardens, fields, and yards of people who unwittingly contribute to the problem. These invasive species are often aggressive weeds, reproducing quickly and crowding out native plants and crops. Hawaii, which is home to about 10,000 endemic species, is vulnerable to invasive species since it is one of the most isolated groups of islands in the world. As a trade and tourist hub, Hawaii is visited by countless ships and planes each year, each potentially carrying foreign plants. Indeed, Hawaii is now home to 47 of the 100 most invasive species in the world. When these alien plants are introduced in the areas where there are no natural pests or herbivores, they will experience selection for individuals that devote more energy to reproduction and less to defense, allowing them to outcompete native plants. Most established foreign species are successful because they exhibit more phenotypic plasticity (physiological tolerance) or genetic differentiation (rapid evolution) than do their natural counterparts.

Kudzu, a legume from Japan, was brought into the United States in the late 19th century to help control soil erosion. Today, the climbing vine affects millions of acres of forests and farmland all over the southern United States, -killing other plants with shade and weight, and covering houses, light poles, and electric lines. The tamarisk (salt cedar) was brought to the United States from its native western Asia habitats in the 1830s as an ornamental plant that could also be used as a windbreak. In the United States, the tamarisk has no natural enemies, can withstand heat and drought, and can grow in extremely salty soils. Each shrub produces 500,000 to 1 million seeds each year, which has helped the tamarisk to spread throughout the dry areas of many western states. Because each plant can use up to 300 gallons of water per day—much more than the native plants that it is replacing—the tamarisk is threatening the water resources of the areas it has invaded.

Summary

1. Ecology is the study of the relationships of organisms and their environment. It is a vast field with many facets.
2. The environment of a plant's habitat is determined by both living and nonliving factors. Plants reflect and respond to their environment.
3. Populations vary in numbers, density, and in the total mass of individuals. Populations of one community may also occur in another community, and ecotypes may be specifically adapted to a single community.
4. Precipitation, temperature, soils, and biotic factors play roles in determining the distributions of plant species in an ecosystem.
5. Xerophytes and hydrophytes have modifications of leaves and other organs.
6. Species distribution is influenced by soil mineral content and biotic factors, such as competition for light, nutrients, and water.
7. Ecosystems sustain themselves through photosynthetic activity, energy flow through food chains, and the recycling of nutrients. Producers carry on photosynthesis; consumers feed on producers. Primary consumers feed directly on producers, and secondary consumers feed on primary consumers.
8. Decomposers break down organic materials to forms that can be reassimilated by the producers. In any ecosystem, the producers and consumers comprise food chains that determine the flow of energy through the different levels. Food chains vary in length and intricacy and, because of their interconnections, form food webs.
9. Energy itself is not recycled in an ecosystem; it escapes in the form of heat as it passes from one level to another. In a long food chain, the final consumer gains only a tiny fraction of the energy originally captured by the producer at the bottom of the chain.
10. When producers increase the amount of food available, consumers may increase correspondingly and compete for the food; this reduces what is available, resulting in a self-maintaining ecosystem. The composition of an ecosystem may be influenced by its living components through the secretion of growth-inhibiting and growth-promoting substances.
11. Annual plants complete their life cycle in one year, while biennials require two years. Perennial plants live for more than two years.
12. Some nitrogen from the air is fixed by the nitrogen--fixing bacteria found in legumes and other plants. In the nitrogen cycle, there is a constant flow of nitrogen from dead plant and animal tissues into the soil and from the soil back to the plants.
13. Water leaches nitrogen from the soil and carries it away when erosion occurs. Other nitrogen is lost from harvesting crops, but the loss can be reduced if wastes are decomposed and annually returned to the soil. Fire also causes nitrogen loss.
14. Replacement of nitrogen loss by the application of chemical fertilizers may eventually create hardpan by altering the soil structure.
15. Bacteria also recycle carbon and other substances, such as water and phosphorus.
16. Succession occurs whenever there has been a disturbance of natural areas on land or in water.
17. Primary succession involves the formation of soil in the beginning stages, while secondary succession takes place in areas previously covered with vegetation. When a primary succession begins with bare rock or lava, the activities of lichens, plants, and physical forces convert the rock or lava to soil in an orderly progression of events over a period of time.
18. A climax community becomes established at the conclusion of succession and remains until or unless a disturbance disrupts it.
19. A primary succession can be initiated in a wet habitat and culminates in a climax community. As a lake or other body of water is filled in with silt and debris, eutrophication facilitating the growth of algae and other organisms occurs.

20. Secondary succession, which proceeds more rapidly than primary succession, may take place if soil is present. It may occur after fires.
21. Impacts of humans on plant communities occur at both global and regional levels.
22. A global rise in temperature due to carbon dioxide, methane, and other gases preventing the sun's radiant heat from escaping back into space is referred to as the greenhouse effect.
23. The carbon dioxide and methane levels in the earth's atmosphere and the earth's temperature have been rising. It is predicted that polar ice will, as a result, melt, and flooding of low-lying coastal areas will occur.
24. In the stratosphere, sunlight converts methane, chlorofluorocarbons, and halons into active compounds that destroy the ozone shield that protects us from intense ultraviolet radiation.
25. Beach and soil erosion are increasingly serious environmental problems with no simple solutions.
26. The depletion of aquifers may lead to serious water shortages in the near future.
27. Loss of biodiversity has serious consequences, including the potential loss of means with which to combat crop diseases.
28. Regional ecological issues include acid deposition, water contamination, wetlands, hazardous waste, and invasion of foreign species.
29. Acid deposition damages or kills living organisms; it is produced when sulfur and nitrogen compounds released by the burning of fossil fuels are converted to nitric acid and sulfur dioxide by sunlight and rain.
30. Water contamination occurs when toxic wastes, pesticides, septic tanks, and fertilizers wash or leach into surface and ground water. Bacteria may in the future be used to break down various contaminants.
31. Wetlands were once considered wastelands. They have been drained but now increasingly are being protected.
32. Hazardous waste sites are gradually being detoxified, but progress is slow.
33. Foreign invasive species may crowd out or destroy native vegetation.

Review Questions

1. How does acid deposition occur?
2. What are the principal threats to global drinking-water sources?
3. Distinguish among a plant community, a biotic community, an ecosystem, and a biome.
4. What is the difference between a primary consumer and a secondary consumer?
5. How are short food chains more efficient in the use of solar energy than long ones?
6. Why is the diet of larger herbivorous animals varied?
7. What types of checks and balances exist in an ecosystem?
8. How are nitrogen and carbon recycled in nature?
9. What is primary succession as opposed to secondary succession?
10. What are general characteristics of climax vegetation as compared with nonclimax vegetation?
11. What is the greenhouse effect?
12. What is the ozone shield, and what significant role does it play? What threats are there to its existence?

Discussion Questions

1. Humans have disrupted ecosystems almost everywhere they have established themselves, at least in industrialized countries. Do you believe that humans could also improve an ecosystem?
2. If a vegetarian diet makes more efficient use of solar energy, should we all strive to become vegetarians for this reason?
3. Besides the hypothetical example given (in which it was observed that eating corn directly was a more efficient use of solar energy than feeding it to cattle and then eating the beef), can you think of other ways in which food chains might be shortened?
4. Peanut butter has many of the nutrients needed in human nutrition. On the basis of what you have learned about the diet of animals in an ecosystem, do you think it would be a good idea to live on peanut butter and water as a means of saving money?
5. Could succession take place in an abandoned swimming pool?

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An alpine ecosystem near Mount Ranier, Washington. *(© Craig Tuttle/CORBIS)*

Figure 25.1 A tidepool community at low tide.

Figure 25.2 A food web.

Figure 25.3 An energy pyramid of an ecosystem. There is much more energy at the bottom than at the top.

Figure 25.4 A species of *Acacia* that is host to ants that live in its hollow stipules. The ants attack any organisms, large or small, that come in contact with the plant. The plant provides food for the ants through nectaries at the bases of the stipules (*A*) and nitrogenous bodies at the tips of the leaflets (*B*).

A.

B.

Figure 25.5 The water cycle.

Figure 25.6 The carbon cycle.

Figure 25.7 The nitrogen cycle.

Unlike any other single species, explosive human population growth has disrupted ecosystems across the entire planet. These disruptions have included changes in atmospheric composition, over-enrichment of ecosystems with nutrients, and large-scale land clearing, which threatens to produce a massive extinction of species. Knowledge of the basic ecology of populations (groups of individuals of the same species), communities (all the populations occurring in a given area), and ecosystems (communties and the physical environments with which they interact) is necessary to understand the magnitude and significance of the ecological changes produced by the growing human population. Plant population ecology includes processes such as pollination, seed dispersal, germination, and seedling survival and establishment. Plant community classification and analysis is an important aspect of land-use planning, natural resource management, and conservation of biodiversity. Knowledge of succession, energy flow, and nutrient cycling is critical to assessing ecosystems and managing them for health and sustainability.

Figure 25.8 Early stages of succession on a Hawaiian road after an earthquake produced cracks and a hole. Ferns have become established in the cracks and hole less than 3 years after the disruption.

Figure 25.9 A blue oak that grew from an acorn lodged in a small crack of the rock. Over the years, the oak has split the rock apart.

Figure 25.10B The slopes of Smith Creek valley, east of Mount St. Helens, show trees blown down by a lateral blast. The direction of the blast, shown here from left to right, is apparent in the alignment of the downed trees. Over four billion board feet of usable timber, enough to build 150,000 homes was damaged or destroyed. *(Photograph by Lyn Topinka, USGS/CVO)*

Figure 25.11 *A.* Succession in a pond in northern Wisconsin. *B.* Duckweeds floating on a pond in early stages of succession. *(A. Courtesy Robert A. Schlising)*

A.
B.
A.
B.

Figure 25.12 *A.* Fires appear to be devastating, but they can be beneficial to forest ecosystems. *B.* Secondary succession on a burned area. California bay trees are resprouting the first season after a burn. *(A. Courtesy of John McColgan, Alaska Fire Service/Bureau of Land Management)*

Figure 25.13 Trees help to absorb the impact of a tsunami. *(National Geophysical Data Center, NOAA)*

Figure 25.14 A view of Florida wetlands as seen from the air. *(© Vol. 16/PhotoDisc/Getty Images)*

John Muir, Father of America's National Park System

Today, America's national parks are overcrowded as some 270 million people enjoy their beauty each year, relaxing in the great outdoors, hiking in fields and mountains, or navigating their rivers. Whether it is Yosemite, the Grand Canyon, Acadia, or one of the many others, each park has a unique and special appeal. These magnificent parks are the result of many people's vision and foresight; however, perhaps none more so than John Muir, who lived from 1838 to 1914. Often called the "Father of the National Park System," he influenced presidents, members of Congress, and "just plain folks" by his love of nature and his writings about it. Always traveling and exploring various ecosystems, he visited Alaska five times, walked 1,000 miles from Indianapolis to the Gulf of Mexico, as well as walking across California's San Joaquin Valley to explore the Sierra Nevada. Later he wrote of viewing the Sierra Nevada range for the first time, "Then it seemed to me the Sierra should be called not the Nevada, or 'Snowy Range,' but the Range of Light, the most divinely beautiful of all the mountain chains I have ever seen."

Wherever he roamed in the wilderness, he noticed increasing waste and destruction from various sources, whether overgrazing by cattle and sheep or overcutting by loggers. It was his love for the American forest that drove him to work tirelessly for its preservation. He wrote some 300 articles and 10 books that told of his travels and contained his naturalist philosophy. He called to everyone to "climb the mountains and get their good tidings." He wrote that the wilderness should be preserved, viewed as a treasure rather than a resource to be exploited. Through his writing, he drew attention to the destruction forests were facing and worked to find remedies.

One solution was the formation of national parks. Largely through Muir's efforts, Congress, in 1890, created Yosemite National Park. He was also personally involved in the creation of Sequoia, Grand Canyon, Mount Ranier, and Petrified Forest national parks. He went one step further by founding the Sierra Club in 1892 and served as its first president until his death in 1914. He and his friends conceived the Sierra Club with the mission to "do something for wilderness and make the mountains glad." His idea was to form an association that would work to protect Yosemite National Park.

This brought him to the attention of President Theodore Roosevelt, who visited Muir in Yosemite in 1903. Together with Muir, under the trees of the park, Roosevelt's innovative conservation programs began to take form.

John Muir's words and life inspire environmental activism today; they also teach the importance of enjoying nature and protecting it. Muir wrote a warning that is just as timely today as it was 100 years ago.

> The axe and saw are insanely busy, chips are flying thick as snowflakes and every summer thousands of acres of priceless forests, with their underbrush, soil, springs, climate, scenery and religion, are vanishing away in clouds of smoke, while, except in the national parks, not one forest guard is employed. Any fool can destroy trees. They cannot run away; and if they could, they would still be destroyed—chased and hunted down as long as fun or a dollar could be got out of their bark hides, branching horns or magnificent bole backbones. Few that fell trees plant them; or would planting avail much towards getting back anything like the noble primeval forest.[1]

A living memorial to John Muir is located 12 miles north of San Francisco, Muir's home in his later years. Muir Woods is a 560-acre national monument consisting of a grove of majestic coastal redwoods along a canyon floor. The towering redwoods and lush canyon ferns growing along Redwood Creek make this a forest of tranquility. Only a 30-minute drive from San Francisco, Muir Woods is visited by over 1.5 million people each year. He declared that this grove of coastal redwoods was the "best tree-lovers' monument that could possibly be found in all the forests of the world."

John Muir—lover of America's forests, roamer of the wilderness, inspired writer, and fighter for conservation.

D. C. Scheirer

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1. *Atlantic Monthly, No. 80,* 1897.

Box Figure 25.1 Shafts of light penetrate the coastal redwoods of Muir Woods.

Figure 25.10A Five explosive eruptions of Mount St. Helens occurred during 1980, including this spectacular event of July 22. This eruption sent pumice and ash 6 to 11 miles into the air, and was visible in Seattle, Washington, 100 miles to the north. The view here is from the south. *(Photograph by Michael P. Doukas, USGS)*