Ecology

I INTRODUCTION

Ecology, the study of the relationship of plants and animals to their physical and biological environment. The physical environment includes light and heat or solar radiation, moisture, wind, oxygen, carbon dioxide, nutrients in soil, water, and atmosphere. The biological environment includes organisms of the same kind as well as other plants and animals.

Because of the diverse approaches required to study organisms in their environment, ecology draws upon such fields as climatology, hydrology, oceanography, physics, chemistry, geology, and soil analysis. To study the relationships between organisms, ecology also involves such disparate sciences as animal behavior, taxonomy, physiology, and mathematics.

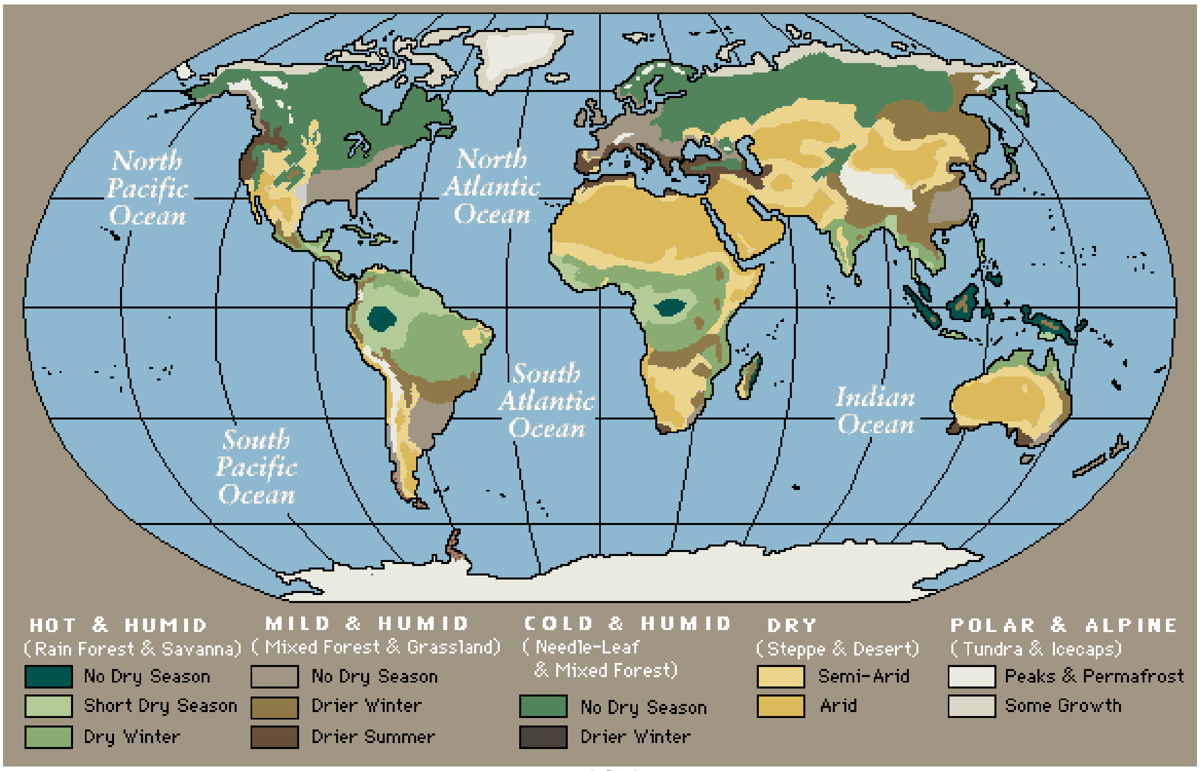
An increased public awareness of environmental problems has made *ecology* a common but often misused word. It is confused with environmental programs and environmental science. Although the field is a distinct scientific discipline, ecology does indeed contribute to the study and understanding of environmental problems.

The term *ecology* was introduced by the German biologist Ernst Heinrich Haeckel in 1866; it is derived from the Greek *oikos* (“household”), sharing the same root word as *economics*. Thus, the term implies the study of the economy of nature. Modern ecology, in part, began with Charles Darwin. In developing his theory of evolution, Darwin stressed the adaptation of organisms to their environment through natural selection. Also making important contributions were plant geographers, such as Alexander von Humboldt, who were deeply interested in the “how” and “why” of vegetation distribution around the world.

II THE EARTH'S BIOSPHERE

The thin mantle of life that covers the earth is called the biosphere. Several approaches are used to classify its regions.

A Biomes



Terrestrial Biomes

North American ecologists refer to the world's broad units of vegetation as biomes. Biomes include associated animal life, and are influenced by many factors, including latitude, altitude, moisture, and temperature. The major biomes use the dominant plant life for their names.

Desert Biome

An ecosystem with a dominant type of vegetation is called a biome. Besides the dominant vegetation, biomes, such as the desert biome represented here by the Namib Desert, have typical animal life, climates, and altitudes.

Grassland Biome

Grasslands form the ecological zone lying between the deserts and temperate woodlands and include a wide variety of plant communities. Generally occurring in the interior of continents, grasslands are composed of sod-forming grasses and perennial grasses and herbs. Grasslands have been cultivated and used for pasture. When overexploited, they can change into either woodlands or deserts.

The broad units of vegetation are called plant formations by European ecologists and *biomes* by North American ecologists. The major difference between the two terms is that biomes include associated animal life. Major biomes, however, go by the name of the dominant forms of plant life.

Influenced by latitude, elevation, and associated moisture and temperature regimes, terrestrial biomes vary geographically from the tropics through the arctic and include various types of forest, grassland, shrub land, and desert. These biomes also include their associated freshwater communities: streams, lakes, ponds, and wetlands. Marine environments, also considered biomes by some ecologists, comprise the open ocean, littoral (shallow water) regions, benthic (bottom) regions, rocky shores, sandy shores, estuaries, and associated tidal marshes.

B Ecosystems

A more useful way of looking at the terrestrial and aquatic landscapes is to view them as *ecosystems,* a word coined in 1935 by the British plant ecologist Sir Arthur George Tansley to stress the concept of each locale or habitat as an integrated whole. A *system* is a collection of interdependent parts that function as a unit and involve inputs and outputs. The major parts of an ecosystem are the *producers* (green plants), the *consumers* (herbivores and carnivores), the *decomposers* (fungi and bacteria), and the *nonliving,* or abiotic, component, consisting of dead organic matter and nutrients in the soil and water. Inputs into the ecosystem are solar energy, water, oxygen, carbon dioxide, nitrogen, and other elements and compounds. Outputs from the ecosystem include water, oxygen, carbon dioxide, nutrient losses, and the heat released in cellular respiration, or heat of respiration. The major driving force is solar energy.

C Energy and Nutrients

Ecosystems function with energy flowing in one direction from the sun, and through nutrients, which are continuously recycled. Light energy is used by plants, which, by the process of photosynthesis, convert it to chemical energy in the form of carbohydrates and other carbon compounds. This energy is then transferred through the ecosystem by a series of steps that involve eating and being eaten, or what is called a food web. Each step in the transfer of energy involves several trophic, or feeding, levels: plants, herbivores (plant eaters), two or three levels of carnivores (meat eaters), and decomposers. Only a fraction of the energy fixed by plants follows this pathway, known as the *grazing food web.* Plant and animal matter not used in the grazing food chain, such as fallen leaves, twigs, roots, tree trunks, and the dead bodies of animals, support the *decomposer food web.* Bacteria, fungi, and animals that feed on dead material become the energy source for higher trophic levels that tie into the grazing food web. In this way nature makes maximum use of energy originally fixed by plants.

The number of trophic levels is limited in both types of food webs, because at each transfer a great deal of energy is lost (such as heat of respiration) and is no longer usable or transferable to the next trophic level. Thus, each trophic level contains less energy than the trophic level supporting it. For this reason, as an example, deer or caribou (herbivores) are more abundant than wolves (carnivores).

Energy flow fuels the *biogeochemical,* or nutrient, cycles. The cycling of nutrients begins with their release from organic matter by weathering and decomposition in a form that can be picked up by plants. Plants incorporate nutrients available in soil and water and store them in their tissues. The nutrients are transferred from one trophic level to another through the food web. Because most plants and animals go uneaten, nutrients contained in their tissues, after passing through the decomposer food web, are ultimately released by bacterial and fungal decomposition, a process that reduces complex organic compounds into simple inorganic compounds available for reuse by plants.

D Imbalances

Within an ecosystem nutrients are cycled internally. But there are leakages or outputs, and these must be balanced by inputs, or the ecosystem will fail to function. Nutrient inputs to the system come from weathering of rocks, from windblown dust, and from precipitation, which can carry material great distances. Varying quantities of nutrients are carried from terrestrial ecosystems by the movement of water and deposited in aquatic ecosystems and associated lowlands. Erosion and the harvesting of timber and crops remove considerable quantities of nutrients that must be replaced. The failure to do so results in an impoverishment of the ecosystem. This is why agricultural lands must be fertilized.

If inputs of any nutrient greatly exceed outputs, the nutrient cycle in the ecosystem becomes stressed or overloaded, resulting in pollution. Pollution can be considered an input of nutrients exceeding the capability of the ecosystem to process them. Nutrients eroded and leached from agricultural lands, along with sewage and industrial wastes accumulated from urban areas, all drain into streams, rivers, lakes, and estuaries. These pollutants destroy plants and animals that cannot tolerate their presence or the changed environmental conditions caused by them; at the same time they favor a few organisms more tolerant to changed conditions. Thus, precipitation filled with sulfur dioxide and oxides of nitrogen from industrial areas converts to weak sulfuric and nitric acids, known as acid rain, and falls on large areas of terrestrial and aquatic ecosystems. This upsets acid-base relations in some ecosystems, killing fish and aquatic invertebrates, and increasing soil acidity, which reduces forest growth in northern and other ecosystems that lack limestone to neutralize the acid.

III POPULATIONS AND COMMUNITIES

The functional units of an ecosystem are the populations of organisms through which energy and nutrients move. A population is a group of interbreeding organisms of the same kind living in the same place at the same time. Groups of populations within an ecosystem interact in various ways. These interdependent populations of plants and animals make up the community, which encompasses the biotic portion of the ecosystem.

A Diversity

The community has certain attributes, among them dominance and species diversity. Dominance results when one or several species control the environmental conditions that influence associated species. In a forest, for example, the dominant species may be one or more species of trees, such as oak or spruce; in a marine community the dominant organisms frequently are animals such as mussels or oysters. Dominance can influence diversity of species in a community because diversity involves not only the number of species in a community, but also how numbers of individual species are apportioned.

The physical nature of a community is evidenced by layering, or *stratification*. In terrestrial communities, stratification is influenced by the growth form of the plants. Simple communities such as grasslands, with little vertical stratification, usually consist of two layers, the ground layer and the herbaceous layer. A forest has up to six layers: ground, herbaceous, low shrub, low tree and high shrub, lower canopy, and upper canopy. These strata influence the physical environment and diversity of habitats for wildlife. Vertical stratification of life in aquatic communities, by contrast, is influenced mostly by physical conditions: depth, light, temperature, pressure, salinity, oxygen, and carbon dioxide.

B Habitat and Niche

The community provides the habitat—the place where particular plants or animals live. Within the habitat, organisms occupy different niches. A niche is the functional role of a species in a community—that is, its occupation, or how it earns its living. For example, the scarlet tanager lives in a deciduous forest habitat. Its niche, in part, is gleaning insects from the canopy foliage. The more a community is stratified, the more finely the habitat is divided into additional niches.

C Population Growth Rates

Populations have a birth rate (the number of young produced per unit of population per unit of time), a death rate (the number of deaths per unit of time), and a growth rate. The major agent of population growth is births, and the major agent of population loss is deaths. When births exceed deaths, a population increases; and when deaths exceed additions to a population, it decreases. When births equal deaths in a given population, its size remains the same, and it is said to have zero population growth.

When introduced into a favorable environment with an abundance of resources, a small population may undergo geometric, or *exponential* growth, in the manner of compound interest. Many populations experience exponential growth in the early stages of colonizing a habitat because they take over an underexploited niche or drive other populations out of a profitable one. Those populations that continue to grow exponentially, however, eventually reach the upper limits of the resources; they then decline sharply because of some catastrophic event such as starvation, disease, or competition from other species. In a general way, populations of plants and animals that characteristically experience cycles of exponential growth are species that produce numerous young, provide little in the way of parental care, or produce an abundance of seeds having little food reserves. These species, usually short-lived, disperse rapidly and are able to colonize harsh or disturbed environments. Such organisms are often called *opportunistic* species.

Other populations tend to grow exponentially at first, and then logistically—that is, their growth slows as the population increases, then levels off as the limits of their environment or carrying capacity are reached. Through various regulatory mechanisms, such populations maintain something of an equilibrium between their numbers and available resources. Animals exhibiting such population growth tend to produce fewer young but do provide them with parental care; the plants produce large seeds with considerable food reserves. These organisms are long-lived, have low dispersal rates, and are poor colonizers of disturbed habitats. They tend to respond to changes in population density (the number of organisms per unit area) through changes in birth and death rates rather than through dispersal. As the population approaches the limit of resources, birth rates decline, and mortality of young and adults increases.

D Community Interactions

Major influences on population growth involve various population interactions that tie the community together. These include *competition,* both within a species and among species; *predation,* including parasitism; and *coevolution,* or adaptation.

D1 Competition

When a shared resource is in short supply, organisms compete, and those that are more successful survive. Within some plant and animal populations, all individuals may share the resources in such a way that none obtains sufficient quantities to survive as adults or to reproduce. Among other plant and animal populations, dominant individuals claim access to the scarce resources and others are excluded. Individual plants tend to claim and hold onto a site until they lose vigor or die. These prevent other individuals from surviving by controlling light, moisture, and nutrients in their immediate areas.

Many animals have a highly developed social organization through which resources such as space, food, and mates are apportioned among dominant members of the population. Such competitive interactions may involve *social dominance,* in which the dominant individuals exclude subdominant individuals from the resource; or they may involve *territoriality,* in which the dominant individuals divide space into exclusive areas, which they defend. Subdominant or excluded individuals are forced to live in poorer habitats, do without the resource, or leave the area. Many of these animals succumb to starvation, exposure, and predation.

Competition among members of different species results in the division of resources in a community. Certain plants, for example, have roots that grow to different depths in the soil. Some have shallow roots that permit them to use moisture and nutrients near the surface. Others growing in the same place have deep roots that are able to exploit moisture and nutrients not available to surface-rooted plants.

D2 Predation

One of the fundamental interactions is predation, or the consumption of one living organism, plant or animal, by another. While it serves to move energy and nutrients through the ecosystem, predation may also regulate population and promote natural selection by weeding the unfit from a population. Thus, a rabbit is a predator on grass, just as the fox is a predator on the rabbit. Predation on plants involves defoliation by grazers and the consumption of seeds and fruits. The abundance of plant predators, or herbivores, directly influences the growth and survival of the carnivores. Thus, predator-prey interactions at one feeding level influence the predator-prey relations at the next feeding level. In some communities, predators may so reduce populations of prey species that a number of competing species can coexist in the same area because none is abundant enough to control the resource. When predators are reduced or removed, however, the dominant species tend to crowd out other competitors, thereby reducing species diversity.

D3 Parasitism

Sea Lamprey Clings to a Fish

The sea lamprey, a vertebrate parasite, belongs to the most primitive group of living fish, the agnathans, or jawless fish. In this species the lower jaw is missing and the upper jaw is modified into a sucking disk. The lamprey feeds on blood by using this disk to attach to another fish and drilling a small hole into the fish’s side with its small, muscular tongue. The parasitic action rarely kills the host, but wounds caused by lampreys often become infected.

Closely related to predation is parasitism, wherein two organisms live together, one drawing its nourishment at the expense of the other. Parasites, which are smaller than their hosts, include many viruses and bacteria. Because of this dependency relationship, parasites normally do not kill their hosts the way predators do. As a result, hosts and parasites generally coevolve a mutual tolerance, although parasites may regulate some host populations, lower their reproductive success, and modify behavior.

D4 Coevolution

Coevolution is the joint evolution of two unrelated species that have a close ecological relationship—that is, the evolution of one species depends in part on the evolution of the other. Coevolution is also involved in predator-prey relations. Over time, as predators evolve more efficient ways of capturing or consuming prey, the prey evolves ways to escape predation. Plants have acquired such defensive mechanisms as thorns, spines, hard seed-coats, and poisonous or ill-tasting sap that deter would-be consumers. Some herbivores are able to breach these defenses and attack the plant. Certain insects, such as the monarch butterfly, can incorporate poisonous substances found in food plants into their own tissues and use them as a defense against predators. Other animals avoid predators by assuming an appearance that blends them into the background or makes them appear part of the surroundings. The chameleon is a well-known example of this interaction. Some animals possessing obnoxious odors or poisons as a defense also have warning colorations, usually bright colors or patterns, that act as further warning signals to potential predators.

Another coevolutionary relationship is mutualism, in which two or more species depend on one another and cannot live outside such an association. An example of mutualism is mycorrhizae, an obligatory relationship between fungi and certain plant roots. In one group, called ectomycorrhizae, the fungi form a cap or mantle about the rootlets. The fungal hyphae (threads) invade the rootlet and grow between the cell walls as well as extending outward into the soil from the rootlet. The fungi, which include several common woodland mushrooms, depend on the tree for their energy source. In return the fungi aid the tree in obtaining nutrients from the soil and protect the rootlets of the tree from certain diseases. Without the mycorrhizae some groups of trees, such as conifers and oaks, cannot survive and grow. Conversely, the fungi cannot exist without the trees.

E Succession and Climax Communities

Ecosystems are dynamic, in that the populations constituting them do not remain the same. This is reflected in the gradual changes of the vegetational community over time, known as succession. It begins with the colonization of a disturbed area, such as an abandoned crop field or a newly exposed lava flow, by species able to reach and to tolerate the environmental conditions present. Mostly these are opportunistic species that hold on to the site for a variable length of time. Being short-lived and poor competitors, they are eventually replaced by more competitive, longer-lived species such as shrubs, and then trees. In aquatic habitats, successional changes of this kind result largely from changes in the physical environment, such as the buildup of silt at the bottom of a pond. As the pond becomes more shallow, it encourages the invasion of floating plants such as pond lilies and emergent plants such as cattails. The pace at which succession proceeds depends on the competitive abilities of the species involved; tolerance to the environmental conditions brought about by changes in vegetation; the interaction with animals, particularly the grazing herbivores; and fire. Eventually the ecosystem arrives at a point called the *climax,* where further changes take place very slowly, and the site is dominated by long-lived, highly competitive species. As succession proceeds, however, the community becomes more stratified, enabling more species of animals to occupy the area. In time, animals characteristic of later stages of succession replace those found in earlier stages.