Sixth Edition

Geosystems

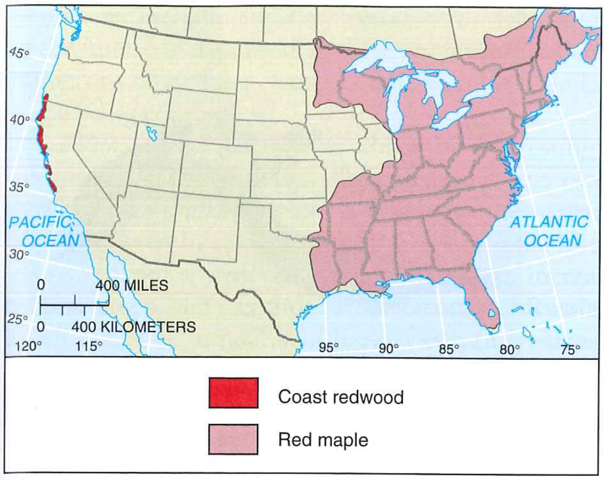
An Introduction to Physical Geography

Annotated Instructor's Edition

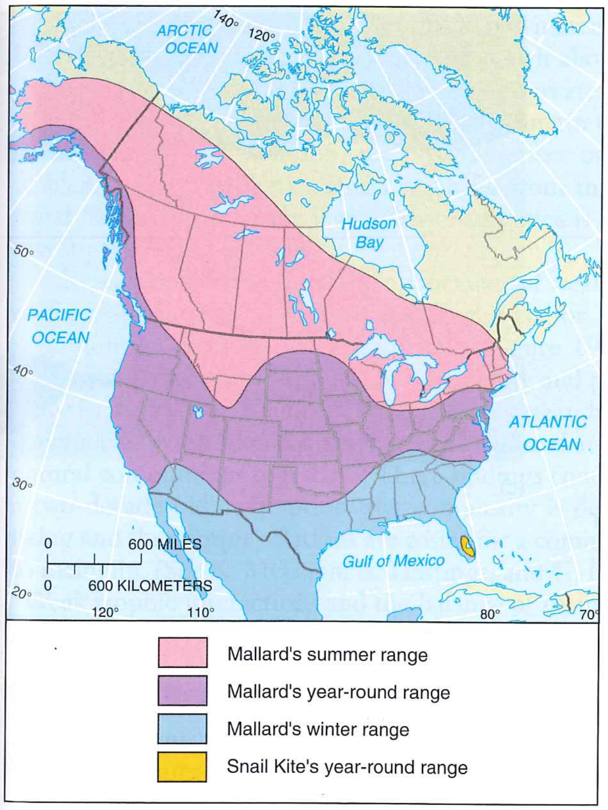
Robert W. Christopherson

PEARSON
Prentice Hall

Upper Saddle River, New Jersey 07458



(a)



(b)

FIGURE 19.12 Limiting factors affect the distribution of every plant and animal species.
(a) Distributions of coast redwood and red maple demonstrate the effect of limiting factors, (b) as do the distributions of the Mallard Duck and the Snail Kite across North America. The Mallard is a generalist and feeds widely. In contrast, the range of its food, a single type of snail, limits the Snail Kite.

Biotic Ecosystem Operations

The abiotic components of energy, atmosphere, water, weather, climate, and minerals make up the life support for the biotic components of each ecosystem. The flow of energy, cycling of nutrients, and trophic (feeding) relations determine the nature of an ecosystem. As energy cascades through this process-flow system, it is constantly replenished by the Sun. But nutrients and minerals cannot be replenished from an external source, so they constantly cycle within each ecosystem and through the biosphere (Figure 19.13). Let us examine these biotic operations.

Producers, Consumers, and Decomposers

Organisms that are capable of using carbon dioxide as their sole source of carbon are called *autotrophs* (self-feeders), or **producers.**These are the plants. They chemically fix carbon through photosynthesis. Organisms that depend on producers as their carbon source are called *heterotrophs* (feed on others), or **consumers**. Generally, these are animals.

Autotrophs are the essential producers in an ecosystem—capturing light energy and converting it to chemical energy, incorporating carbon, forming new plant tissue and biomass, and freeing oxygen. Solar energy enters each food chain through the producer plant or producer phytoplankton, subsequently flowing through higher and higher levels of consumers.

From the producers, which manufacture their own food, energy flows through the system along a circuit called the **food chain**, reaching consumers and eventually *detritivores*. Organisms that share the same basic foods are said to be at the same *trophic level*. Ecosystems generally are structured in a **food web**, a complex network of interconnected food chains. In a food web, consumers participate in several different food chains, comprising both *strong interactions* and *weak interactions* between species in the food web.

In Figure 19.13b crabeater seals rest on a bergy bit, or small iceberg, in Antarctic waters where they feed on krill that feed on phytoplankton that harvest sunlight. Nearby is the blood-stained ice where one of the seals was taken and eaten by a leopard seal. Figure 19.13c shows the dominant Arctic predator, a marine mammal, the polar bear, on the pack ice many kilometers from land. Here in the Arctic Ocean the male bear killed a harp seal, hiding it temporarily in an ice burrow. Later he retrieved the carcass and dragged it across the ice to feed. The polar bear consumes most of the seal except for the bones and intestines. Figure 19.14 illustrates simple terrestrial and oceanic food chains.

Primary consumers feed on producers. Because producers are always plants, the primary consumer is called an **herbivore**, or plant eater, like the krill. A **carnivore** is a secondary consumer and primarily eats meat, as in the leopard seal and polar bear examples. A tertiary consumer eats primary and secondary consumers and is referred to as the "top carnivore" in the food chain. A consumer that feeds on both producers (plants) and consumers (meat) is called an **omnivore**—a role occupied by humans, among others.

In the Arctic region, the walrus (*Odobenus rosmarus*) has a special diet and adaptation to obtain it (Figure 19.14c). They feed on clams in the shallows near land, brushing aside sand and sediment with their tusks and whiskers, pulling up the clam in to their mouth and, with a powerful

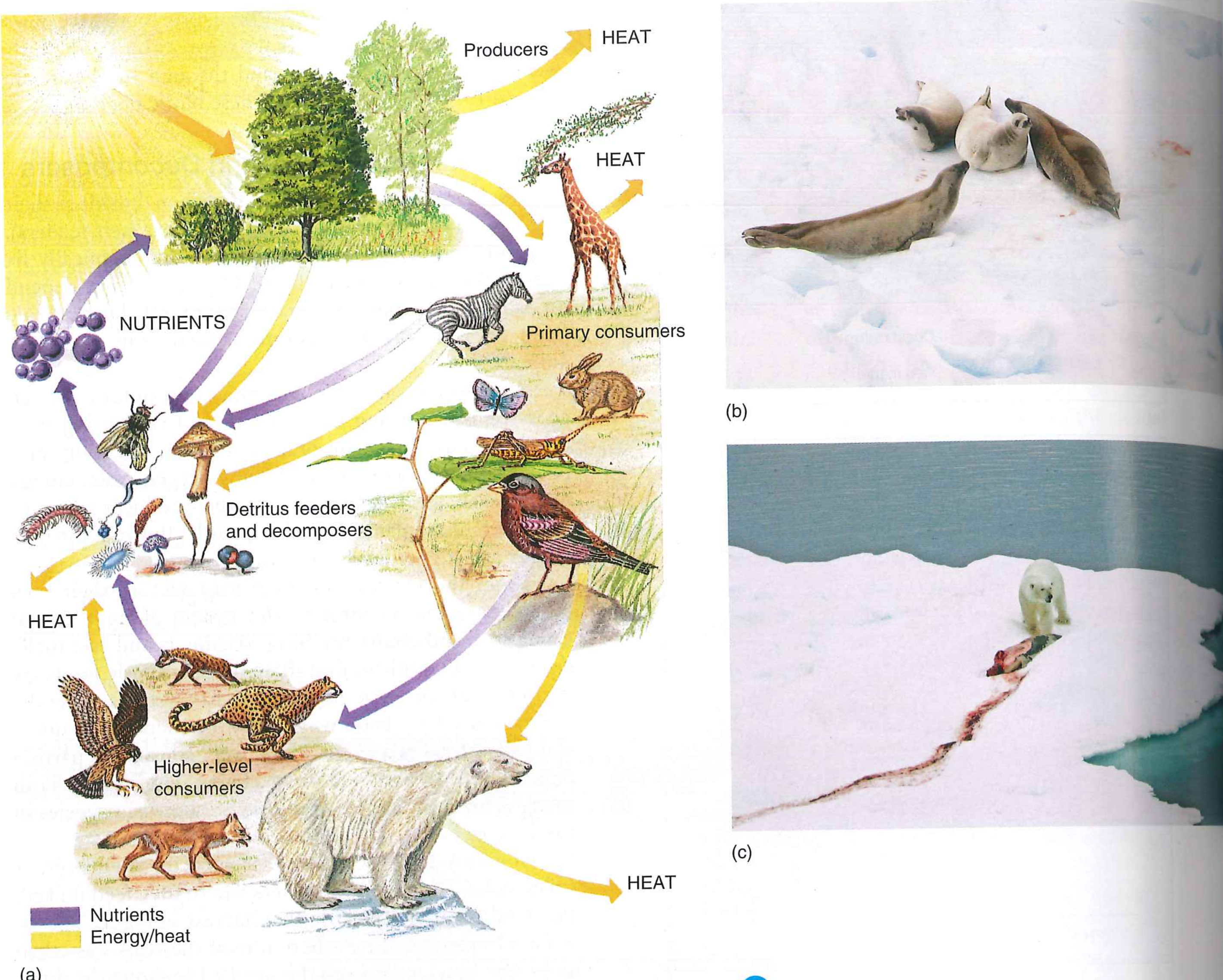


FIGURE 19.13 Energy, nutrient, and food pathways in the environment. **(a) The flow of energy, cycling of nutrients, and trophic (feeding) relationships portrayed for a generalized ecosystem. The operation is fueled by radiant energy supplied by sunlight and first captured by the plants. (b) Crabeater seals (*Lobodon carcinophaga*) on a bergy bit off the coast of Antarctica. The blood on the ice probably marks an earlier leopard seal kill of one of the crabeaters. (c) A polar bear drags its harp seal feast across pack ice in the Arctic Ocean, many kilometers from land.** [From T. Audesirk and G. Audesirk, *Biology: Life on Earth,* 4th ed., Figure 45-1, p. 892. © 1996 Prentice Hall Inc. Used by permission. Photos (b) and (c) by Bobbé Christopherson.]

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sucking action, pulling out the meat. Walrus will occasionally eat squid and fish if needed to sustain their huge calorie requirement. In the photo a female walrus places a protective flipper on her pup on a precarious piece of pack ice.

Detritivores (detritus feeders and decomposers) are the final link in the endless chain. Detritivores renew the entire system by releasing simple inorganic compounds and nutrients with the breaking down of organic materials. Detritus refers to all the dead organic debris, remains, fallen leaves, and wastes, that living processes leave. Detritus feeders—worms, mites, termites, centipedes, snails, crabs, even vultures, among others—work like an army to consume detritus and excrete nutrients that fuel an ecosystem. **Decomposers** are primarily bacteria and fungi that digest organic debris outside their bodies and absorb and release nutrients in the process. This metabolic work of microbial decomposers produces the rotting that breaks down detritus. Detritus feeders and decomposers, although different in operation, have a similar function in an ecosystem.

Examples of Complex Food Webs

An example of a complex community is the oceanic food web that includes krill, a primary consumer (Figure 19.15a). Krill (*Euphausia sp.*, at least a dozen species) is a shrimplike crustacean that is a major food for an interrelated group of organisms, including whales, fish, seabirds, seals, and squid in the Antarctic region. All of these organisms participate in numerous other food chains as well, some consuming and some being consumed.

Phytoplankton begin this chain by harvesting solar energy in photosynthesis. Phytoplankton are eaten by *herbivorous zooplankton* such as krill and other organisms. Krill are eaten by consumers at the next trophic level. Because krill are a protein-rich, plentiful food, increasingly factory ships, such as those from Japan and Russia, seek them out. The annual krill harvest currently surpasses a million tons, principally as feed for chickens and livestock and as protein for human consumption. Many of the Antarctic dwelling birds depend on krill and on fish that eat krill. News Report 19.3 follows a penguin colony along the Antarctic Peninsula through a summer.

The impact on the food web of further increases in the krill harvest is uncertain, for little is known about the krill reproduction rate. Their long life span (greater than 8 years) and slow growth rate limit the ultimate extent of the resource. In addition, the possible effect on krill of increased ultraviolet radiation resulting from the seasonal "hole" in the ozone layer above Antarctica is under investigation.

Researchers determined the importance of weak (secondary) interactions in a complex food web for island communities in the Gulf of California (Figure 19.15b). The complexity they found produced stability and persistence in the system. Kevin McCann and his research team concluded, "weak interactions may be the glue that binds natural communities together." These findings countered a two-decade-old assumption that complexity is destabilizing and that simple relations are easier for a community to maintain. (See K. McCann, A. Hastings, and G. Huxel, "Weak trophic interactions and the balance of nature," in *Nature* 395 (October 22, 1998: 794–798.)

Efficiency in a Food Web

Any assessment of world food resources depends on the level of consumer being targeted. Let us use humans as an example. Many people can be fed if wheat is eaten directly. However, if the grain is first fed to cattle (herbivores) and then we eat the beef, the yield of available food energy is cut by 90% (810 kg of grain is reduced to 82 kg of meat); far fewer people can be fed from the same land area (Figure 19.16).

In terms of energy, only about 10% of the kilocalories (food Calories, not heat calories) in plant matter survive from the primary to the secondary trophic level. When humans consume meat instead of grain, there is a further loss of biomass and added inefficiency. More energy is lost to the environment at each progressive step in the food chain. You can see that an omnivorous diet such as ours is quite expensive in terms of biomass and energy.

Food web concepts are becoming politicized as world food issues grow more critical. Today, approximately half of the cultivated acreage in the United States and Canada is planted for animal consumption—beef and dairy cattle,

(a)
(b)
(c)

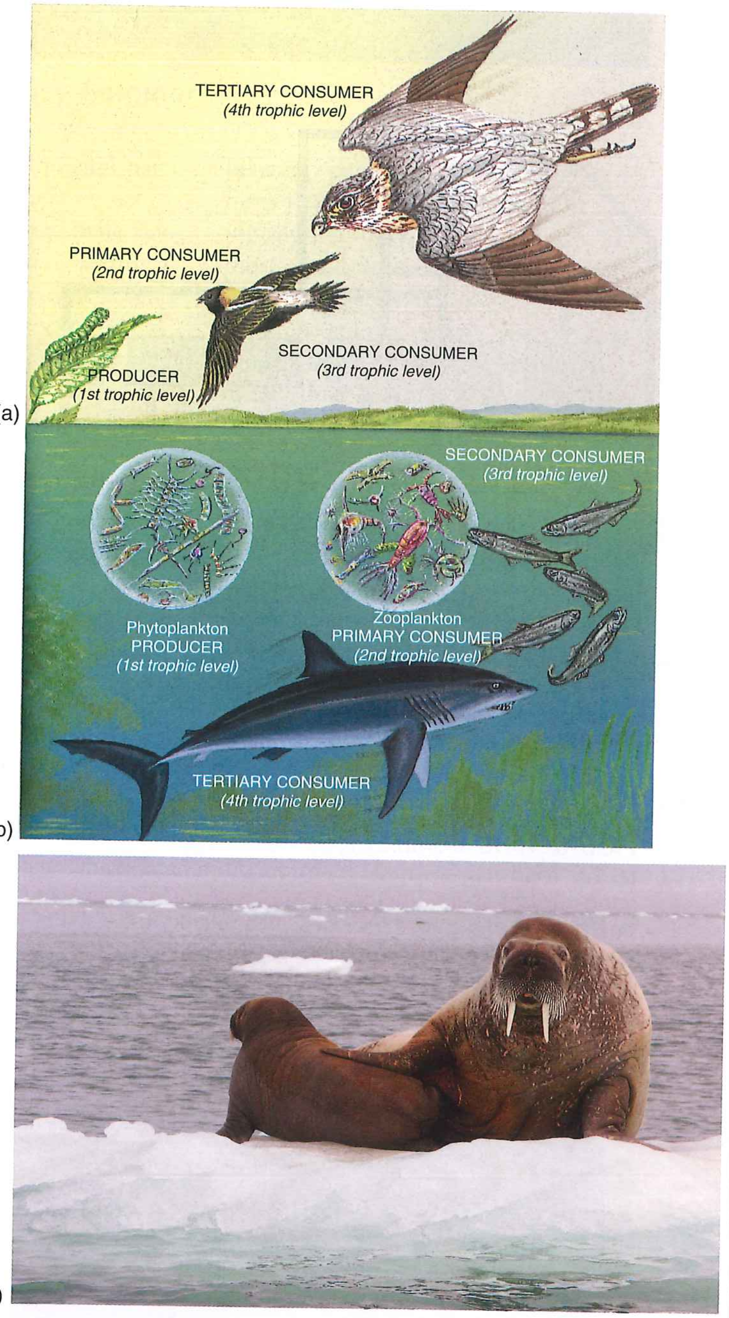

FIGURE 19.14 Food chains.
(a) A simplified terrestrial food chain, from leaf to caterpillar to Bobolink to a fast-moving Merlin Hawk. (b) A simplified aquatic food chain from phytoplankton to zooplankton to schooling fish and to a mako shark. (c) A female walrus and her pup rest on Arctic Ocean pack ice. [(a) and (b) From T. Audesirk and G. Audesirk, *Biology: Life on Earth,* 4th ed., Figure 45-4, p. 895. © 1996 Prentice Hall Inc. Used by permission. Photo (c) by Bobbé Christopherson]

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hogs, chickens, and turkeys. Livestock feed includes approximately 80% of the annual corn and nonexported soybean harvest. In addition, some lands cleared of rain forest in Central and South America were converted to pasture to produce beef for export to restaurants, stores,

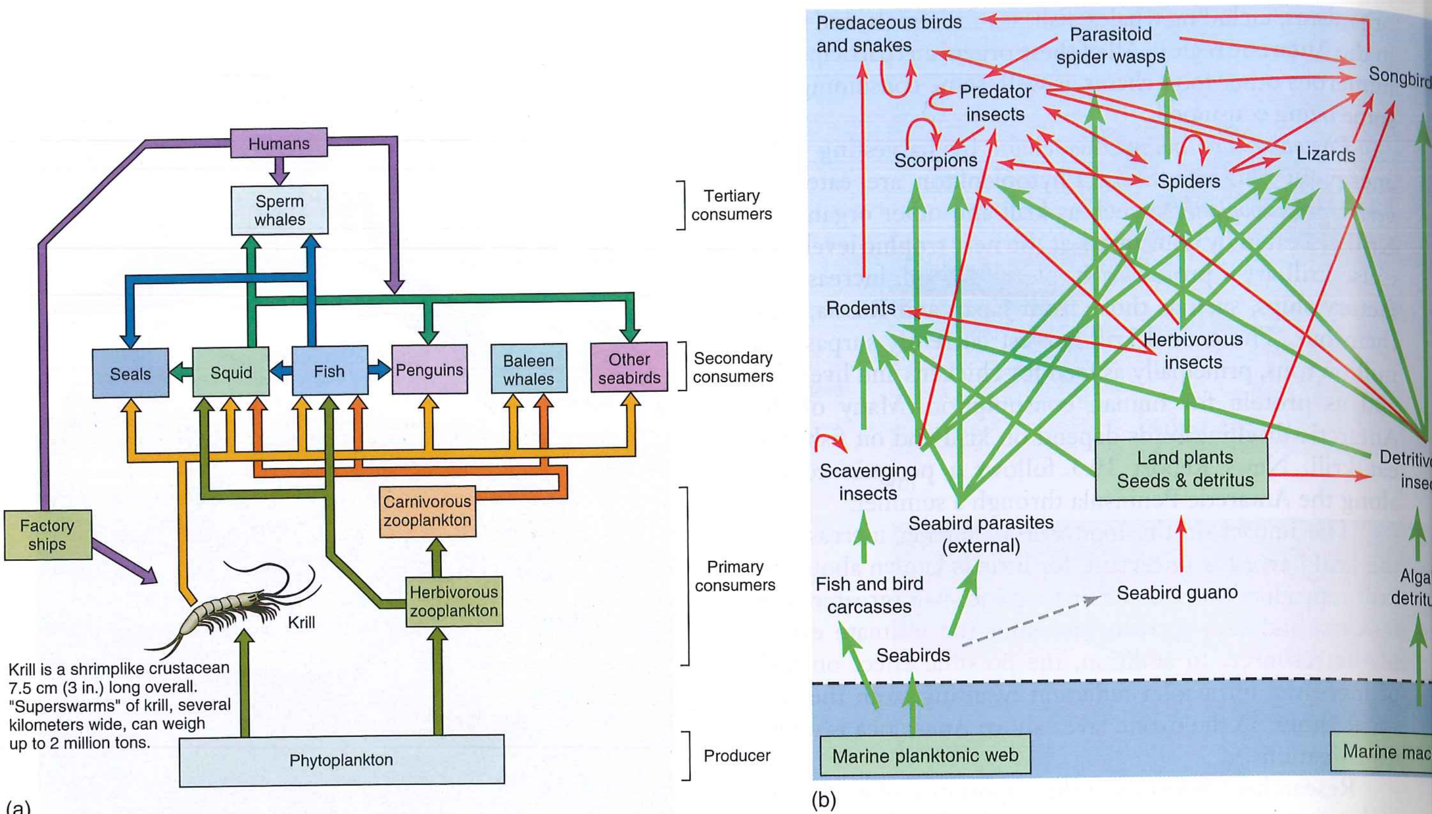


FIGURE 19.15 Complex food webs.
(a) The food web in Antarctic waters, from phytoplankton producers (bottom) through various consumers. Phytoplankton begin this chain using photosynthesis to store solar energy. Krill and other herbivorous zooplankton eat the phytoplankton. Krill in turn are consumed by the next trophic level. (b) A complex food web on islands in the Gulf of California, featuring relationships through both strong (green color) and weak (red color) interactions. [(b) From Gary A. Polis, "Stability is woven by complex webs," in *Nature* 395 (October 22, 1998): 744–745.]

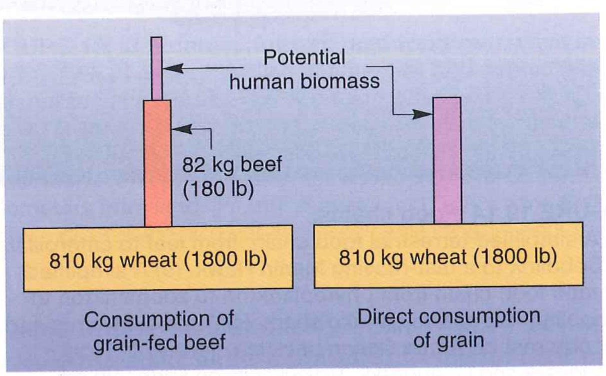


FIGURE 19.16 Efficiency and inefficiency in biomass consumption.
Biomass pyramids illustrate a great difference in efficiency between direct and indirect consumption of grain.

and fast-food outlets in developed countries. Thus, lifestyle decisions and dietary patterns in North America and Europe are perpetuating inefficient food webs, not to mention the destruction of valuable resources, both here and overseas. Scientists are studying the impact on world grain supplies from the spread of American meat-based fast-food restaurants across the globe and the dietary changes these foster.

Clearly, some food webs are exceptionally simple, such as eating grains directly, whereas others are more complex. The home gardener's tomatoes may be eaten by a tomato hornworm, which is then plucked off by a passing Robin, which is later eaten by a hawk—and so it goes, in endless cycles.

Ecological Relations

A study of food webs is a study of who eats what and where they do the eating. Figure 19.17 charts the summertime distribution of populations in two ecosystems, grassland and temperate forest. The stepped population pyramid is characteristic of summer conditions in such ecosystems. You can see the decreasing number of organisms supported at successively higher trophic levels. The base of the temperate forest pyramid is narrow, however, because most of the producers are large, highly productive trees and shrubs, which are outnumbered by the consumers they can support.

One approach to ecological study is to analyze a community's metabolism. *Metabolism* is the way in which a

News Report 19.3

Chinstrap Penguins and Their Short, Busy Summer

Summers are brief at Hannah Point, Livingston Island, Antarctica (63° 15′ S), when temperatures in calm air range from −2°C to +2°C (28°F to 35.6°F) and ocean temperatures are at +1°C (34°F). Chinstrap Penguin pairs build rock nests (done for drainage) and mate in early November (Figure 19.3.1a). By December, the female lays an average of two eggs, and the parents alternate sitting on the nest, keeping the eggs warm in a brood pouch (Figure 19.3.1b). Incubation takes from 31 to 39 days. The pair take turns hiking back and forth between the ocean and the nest, sometimes this is quite a distance, to feed on crustaceans, such as krill and occasionally small fish. Penguin pairs form long-lasting bonds.

To a casual observer, male and female penguins appear identical. Only a detailed examination reveals sexual differences between genders. In visually identifying which species of penguin you are seeing, about 95% of the characteristics differentiating them are from the neck up. Can you see why these are called Chinstraps?

Predators are Sheathbills and Brown Skuas that try to snatch an egg or chick from the nest. The hatchlings are fed by regurgitation from the parents (Figure 19.3.1c). The chicks leave the parents after just 4 weeks and join a crèche, or group of other juvenile penguins. These flightless birds fledge 48 to 59 days from hatching. By February, the juveniles are almost as tall as the parents. The lively scene in December is gone, as the penguin colony stands almost motionless for about 10 days while they moult their feathers. Penguins have some 80 feathers per square inch.

In Figure 19.3.1d, note the snow is gone from the colony, the surface muddy, and all the rock nests dispersed. By March or early April when molting is complete, the colony returns to the ocean for the entire winter, staying just beyond the pack ice as it freezes.


(a)


(b)


(c)


(d)

FIGURE 19.3.1 Chinstrap Penguins at Hannah Point, Antarctica. Chinstrap Penguins (*Pygoscelis antarctica*) (a) singing a loud squawking song for recognition from its mate; (b) incubating two eggs on a rocky nest in early December; (c) feeding chicks through regurgitation of food by the adult; and (d) juveniles and adults must molt feathers and replace with new feathers to prepare for a winter at sea in late February. The photos span a brief summer season (2003–2004) in their lives. [All photos by Bobbé Christopherson.]

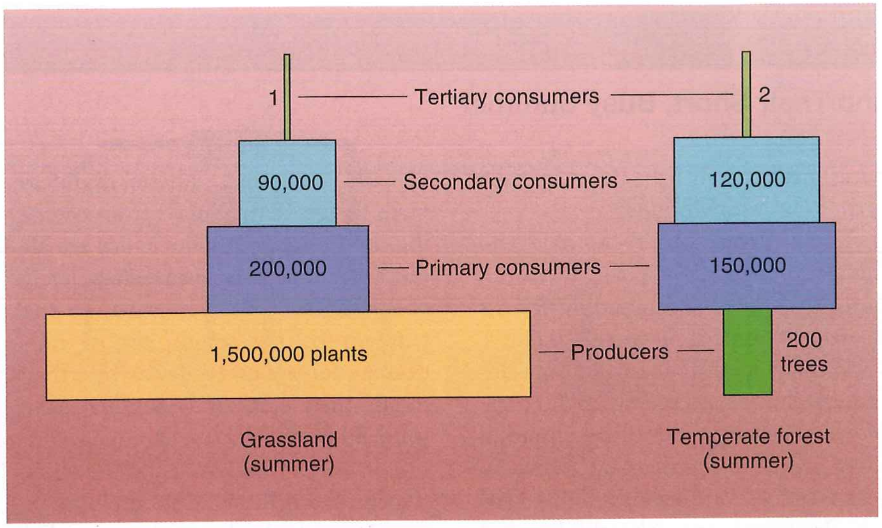


FIGURE 19.17 Population distribution in two ecosystems. Ecological pyramids for 0.1 hectare (0.25 acre) of land show the difference in producers and consumers between grassland and forest in the summer. [From E. P. Odum, *Fundamentals of Ecology,* 3rd ed., reprinted with permission of Brooks/Cole an imprint of the Wadsworth Group, a div. of Thomson Learning.]

community uses energy and produces food for continued operation (the sum of all its chemical processes). In 1957, Howard T. Odum completed one of the best-known studies of this type for Silver Springs, Florida.

Figure 19.18a, an adaptation of his work, shows that the energy source for the community is insolation. The amount of light absorbed by the plants for photosynthesis is 24% of the total amount arriving at the study site. Of the absorbed amount, only 5% is transformed into the community's gross photosynthetic production—and this is only 1.2% of the total insolation input. The net plant production (gross production minus respiration) is 42.4% of the gross production, or 8833 kilocalories per square meter per year. That amount then moves through the food chain of herbivores and carnivores, with the top carnivores receiving only 0.24% of the net plant production of the system.

You can see that, at each trophic level, some of the biomass flows to the decomposers. The largest portion of the biomass is exported from the system in the form of community respiration. In addition, a relatively small portion leaves the system as organic particles by downstream export out of this system. The biomass pyramid shown in Figure 19.18b portrays the same community from the viewpoint of a *standing crop* (all the biomass in a particular environment at one time), which is another way of examining the existing biomass at each trophic level.

Concentration of Pollution in Food Chains

Many farms freely use pesticides on producers to reserve them for eating by selected consumers—such as humans or the animals we feed. When an ecosystem of producers and consumers has chemical pesticides applied, the food web concentrates some of these chemicals. Many chemicals are degraded or diluted in air and water and thus are rendered relatively harmless. Other chemicals, however, are long-lived, stable, and soluble in the fatty tissues of consumers. They become increasingly concentrated at each higher trophic level. Figure 19.19 illustrates this *biological amplification*, or *magnification*.

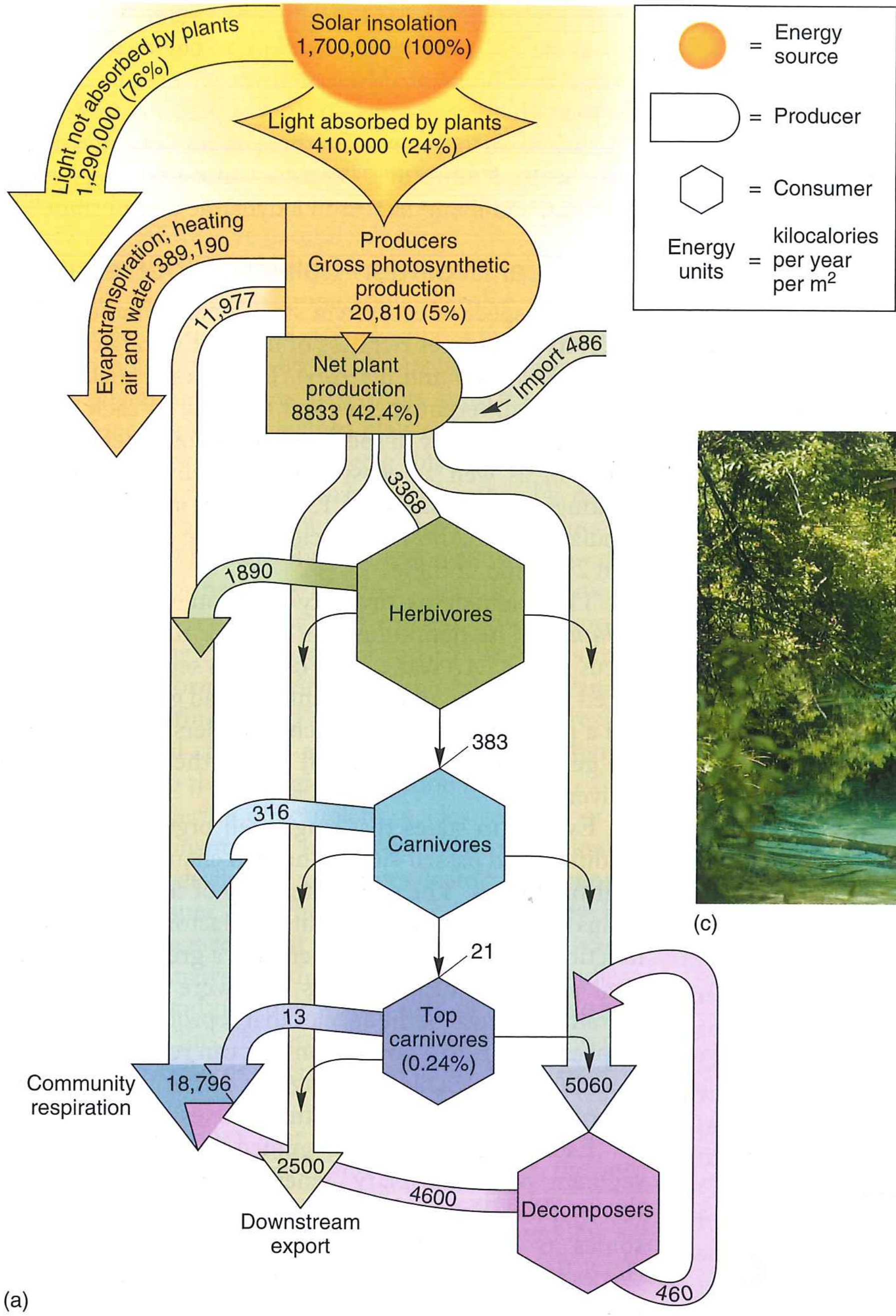
DDT is one such chemical. As an insecticide, it saved millions of human lives in the tropics by killing the mosquitoes that spread malaria. Crop-destroying insects also were brought under control. However, the persistence of the chemical in the environment and its destruction of established food webs brought many unwanted consequences—death and illness to animals and humans alike. Although banned in some countries (the United States banned it in 1973), it still is widely used in less-developed countries. In addition, some other organic and synthetic chemicals, radioactive debris, and heavy metals such as lead and mercury become concentrated in food webs.

Thus, pollution in a food web can efficiently poison the organism at the top. Many species are threatened in this manner, and, of course, humans are at the top of many food chains and can ingest concentrated chemicals in what is consumed; consider this relative to the Kesterson Wildlife Refuge example discussed in Focus Study 18.1.

Ecosystems, Evolution, and Succession

Far from being static, Earth's ecosystems are dynamic (vigorous and energetic) and ever changing from the beginning of life on the planet. Over time, communities of plants and animals have adapted, evolved, and in turn shaped their environments to produce great diversity. Regardless of the time frame considered over the past billion years, a constant interplay exists between increasing growth in a community and decreasing growth caused by resistance factors that create limits and disruptions (Figure 19.20). Each ecosystem is constantly adjusting to changing conditions and disturbances in the struggle to survive. The concept of change is key to understanding ecosystem stability.

The nature of change in natural ecosystems can range from smooth with gradual transitions from one equilibrium



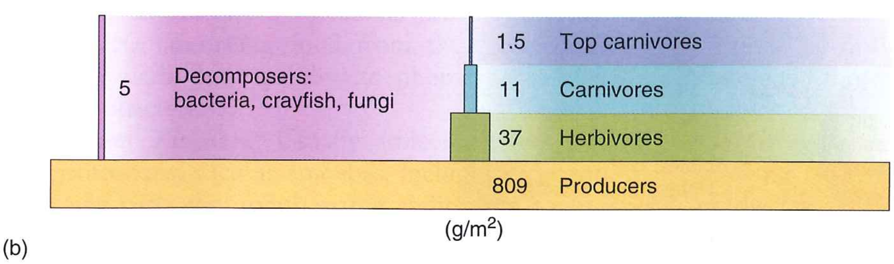


FIGURE 19.18 How energy and nutrients flow through a community. (a) Analysis of community metabolism. (b) Standing crop distribution in grams per square meter for Silver Springs, Florida. (c) A similar nearby swampy forest ecosystem. [From E. P. Odum, *Fundamentals of Ecology,* 3rd ed., reprinted with permission of Brooks/Cole an imprint of the Wadsworth Group, a div. of Thomson Learning. (c) Photo by Bobbé Christopherson.]

to another, balancing the factors in Figure 19.20, all the way to extreme catastrophes such as an asteroid impact or severe volcanism, among other events. In the evolution of life, or the physical and chemical evolution of Earth's systems, such sudden changes created a punctuated equilibrium. Following each of the five major extinctions of life over the past 450 million years, there were great bursts of diversity and proliferation of new and different species, a process known as *speciation.* Although the extinctions (noted in Figure 11.1) temporarily limited biodiversity, each created evolutionary opportunities into which life diversified into differentiated populations.

For most of the last century, scientists thought that an undisturbed ecosystem—whether forest, grassland, aquatic, or other—would progress to a stage of equilibrium, a stable point, with maximum chemical element storage and biomass. Modern research has determined, however, that ecosystems do not progress to some static conclusion. In other words, there is no "balance of nature," instead think of a "constant interplay of physical, chemical, and living factors in a dynamic equilibrium."

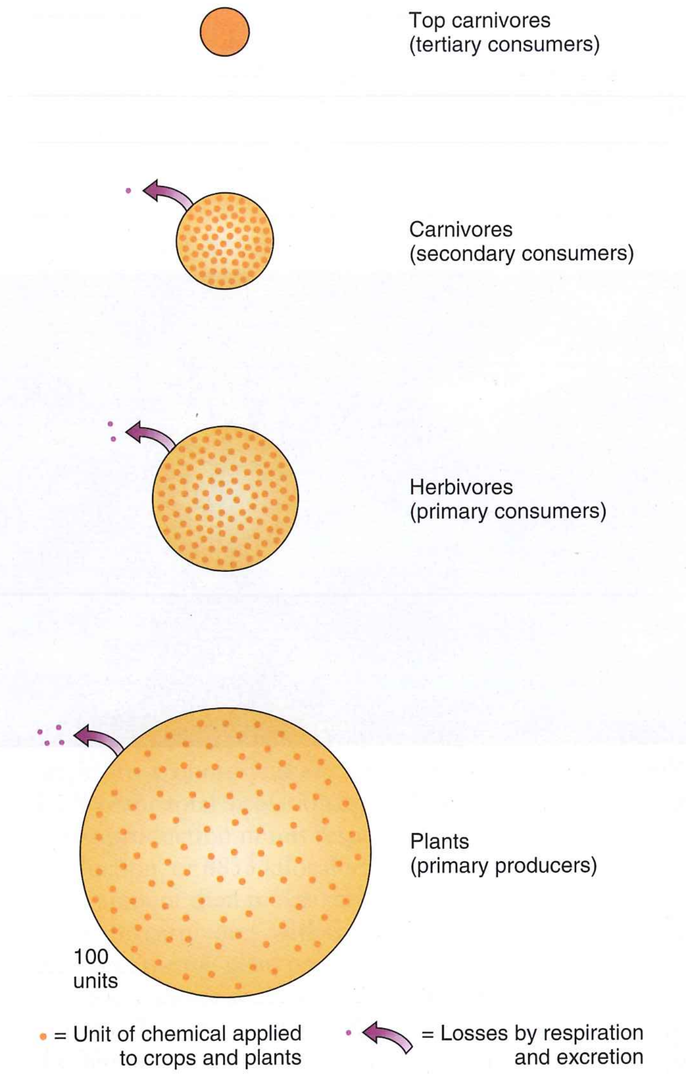


FIGURE 19.19 Concentration of chemical toxins in food chains.
Chemical residues are passed along a simple food chain to the top carnivores, where the accumulation becomes concentrated. This phenomenon is *biological magnification.*

Biological Evolution Delivers Biodiversity

A critical aspect of ecosystem stability and vitality is **biodiversity**, or species richness of life on Earth (a combination of *bio*logical and *diversity*). Biodiversity includes the number of different species and quantity of each species, the genetic diversity in species (number of genetic characteristics), as well as ecosystem and habitat diversity. A working estimate says that 13.6 million species presently populate Earth; however, scientists have classified less than 2 million of these.

The origin of this diversity is embodied in the *theory of evolution.* (The definition of a *scientific theory* is given in Focus Study 1.1.) A theory is based on several extensively tested hypotheses and represents a broad general principle and a powerful tool with which to understand nature and the general laws in operation across the planet and the Universe.

Evolution states that single-cell organisms adapted, modified, and passed along inherited changes to multicellular organisms. The genetic makeup of successive generations was shaped by environmental factors, physiological functions, and behaviors that created a greater rate of survival and reproduction, traits that were passed along—literally, "survival of the species that reproduces the most." A species refers to a population that can reproduce sexually and produce viable offspring. By definition, this means reproductive isolation from other species.

Each inherited trait is guided by a *gene* that is a segment of the primary genetic material called *DNA* (deoxyribonucleic acid) that resides in the nest of chromosomes in every cell nucleus. These traits are passed to successive generations, especially those traits that are most successful at maximizing niches different from those of other species or traits that help the species adapt to environmental changes. Such differential reproduction

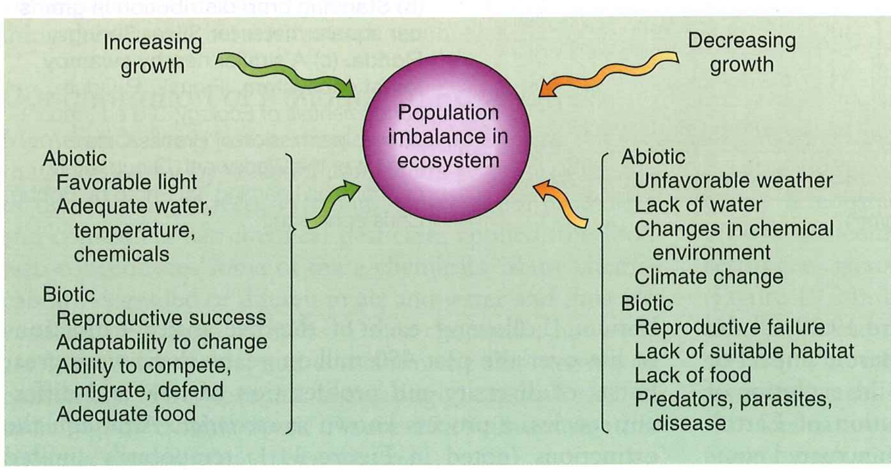


FIGURE 19.20 Factors controlling the population balance of an ecosystem.
Potential factors and resistance factors ultimately determine the population of an ecosystem.

and adaptation passes along successful genes or groups of genes in a process of genetic favoritism called *natural selection.* The process of evolution follows generation after generation and tracks the passage of inherited characteristics that were successful—the failures passed into extinction. Thus, it is not an understatement to say that today's humans are the result of billions of years of positive change and affirmative natural selection.

New mixes in the *gene pool,* or all genes possessed by individuals in a given population, involve mutations. Mutation is a process that occurs when a random action, or perhaps an error as the DNA reproduces, forms new genetic material and sets new traits into the inherited stream. Geography comes into play, as spatial effects are important. A species may disperse through migration to different environments, or may be separated by natural vicariance (fragmentation of the environment) events that establish natural barriers. Such isolation allows natural selection to evolve new sets of genes. Imagine the migrations across ice bridges or land connections at times of low sea level, or the slowly evolving rise of a mountain range, or the formation of an isthmus such as Panama connecting continents and separating oceans. To restate, the physical and chemical evolution of Earth's systems is closely linked to the biological evolution of life.

The deciphering of complete species *genomes,* or the total genetic constituents of an organism, is a scientific triumph and is disclosing a complex history and geography of each species—where species originated, how species are dispersed, what diseases and traumas were of consequence. Analysis of the human genome has indicated our origins and provided a road map of how we got to where we are. Thus, the intricate interplay that led to present biodiversity across myriad ecosystems, both terrestrial and aquatic, is here in Chapters 19 and 20.

All life falls into one of five major groups, called *kingdoms.* Focus Study 20.1 and Table 20.1 in the next chapter provide a specific count of the tremendous diversity of life within the five kingdoms. These kingdoms are classified based on source of nutrition, cellular structure (lacking a nucleus–the *prokaryotes,* or having a membrane-enclosed nucleus–the *eukaryotes*), and numbers of cells. The five kingdoms of life are:

- —*Monera Kingdom:* Unicellular prokaryotes, such as bacteria; absorbing food from their environment, some with the capability to photosynthesize (e.g., cyanobacteria).
- *Protista Kingdom:* Usually unicellular eukaryotes, protozoans, such as amoebas; includes slime molds, some with photosynthesizing ability, and some mobile members with simple cilia for propulsion.
- *Fungi Kingdom:* Multicellular eukaryotes, fungi, mushrooms, bread molds, with specialized cells for reproduction and feeding.
- *Plant Kingdom:* Multicellular eukaryotes, dominated by flowering plants including trees, not mobile; photosynthesis for food production, interrelationships with animals for nutrient supplies and pollination; mosses, liverworts, ferns, coniferous trees, food plants, among others.
- *Animal Kingdom:* Multicellular eukaryotes, ingest food, many specialized organs and tissues, specialized cells, sensory ability and mobile; includes vertebrates, worms, mollusks, among other types; largest group of animals are invertebrates such as anemones.

Ecosystem Stability and Diversity

In an ecosystem the tendency of species populations to remain stable (*inertial stability*) does not necessarily foster the ability to recover from change (*resilience*). Several of the dramatic asteroid impact episodes that triggered partial extinctions over the past 440 million years tested communities of plants and animals and their resilience. Think of resilience as an ecosystem's ability to recover from disturbance, its ability to absorb disturbance up to some threshold point before it snaps to a different set of relations, thus altering some logical ecological progression.

Examples of communities with high inertial stability include a redwood forest, a pine forest at a high elevation, and a tropical rain forest near the equator. But, cleared forest tracts recover slowly and therefore have poor resilience. Figure 19.21 shows how clear-cut tracts of former forest have drastically altered microclimatic conditions, making regrowth of the same species difficult. In contrast, a midlatitude grassland is low in stability; yet, when burned, its resilience is high because the community recovers rapidly.

In the context of ecosystem stability and resilience, consider the elimination of a full section of forest ecosystem, shown in Figure 19.21, on private land in southern Oregon, south-southeast of Crater Lake. Note the high road density, the inadequate buffers along watercourses to prevent sedimentation of streams, the drag lines and skid trails to each pickup spot that pockmark the landscape. On nearby U.S. Forest Service land, the rules are clear: a full 95-m (312-ft) tree buffer is left on either side of a stream, road densities are minimized, and harvesting regimes that include partial removals, commercial thinning, group selection harvests, among others, are all in contrast to the devastation on private lands in the photo. The forest service in that region has not allowed a clear-cut on government land of more than 10 acres for several decades, according to local authorities. Scientists have concluded that for sustainable forests, the sole objective should never be the complete removal of timber.

Greater biodiversity in an ecosystem results in greater stability and greater productivity. In other words, the strength of **biodiversity** is that it spreads risk over the entire community, because several food sources exist at each trophic level. Therefore, biodiversity matters. Consider more than just the diversity of species, rather think of all the positive interactions of species embodied in the *facilitation concept.* Facilitation describes how a diverse community manages nutrient dynamics among the populations, and pest resistance, and resilience to events such as fire. News Report 19.4 presents exciting confirmation of biodiversity.

(a)

(b)

FIGURE 19.21 Poor practices disrupt stable forest communities.
(a) An example of clear-cut timber harvesting that has devastated a stable forest community and produced drastic changes in microclimatic conditions. Full exposure to sunlight and wind is different from former shade conditions. With few riparian buffer strips of uncut forest along streams, sedimentation will clog streams as soils erode. (b) A logged pine forest and disruptive logging road. About 10% of the Northwest's old-growth forests remain, as identified through satellite images and GIS analysis. [Photos (a) by Bobbé Christopherson; (b) by author.]

The present loss of biodiversity is irreversible, and yet, here we are in the midst of the biosphere's sixth major extinction episode (see Figure 11.1). Extinction is final no matter how complex the organisms or how long it lived since it evolved. E. O. Wilson, the famed biologist, stated,

> Biological diversity—the full sweep from ecosystems to species within ecosystems, thence to genes within species—is in trouble. Mass extinctions are commonplace, especially in tropical regions where most of the biodiversity occurs. Among the more recent are more than half the exclusively freshwater fishes of peninsular Asia, half of the fourteen birds of the Philippines island of Cebu, and more than ninety plant species growing on a single mountain ridge in Ecuador. In the United States an estimated 1 percent of all species have been extinguished; another 32 percent are imperiled.*

Agricultural Ecosystems Humans simplify communities by eliminating biodiversity, and in this way we place more ecosystems at risk of harmful change and perhaps failure. An artificially produced monoculture community, such as a field of wheat, is singularly vulnerable to failure owing to weather or attack from insects or plant disease. In some regions, simply planting multiple crops brings more stability to the ecosystem. This is an important principle of sustainable agriculture, a movement to make farming more ecologically compatible.

A modern agricultural ecosystem not only is vulnerable to failure because of its lack of ecological diversity but also because it creates an enormous demand for energy, chemical pesticides and herbicides, artificial fertilizer, and irrigation water. The practice of harvesting and removing biomass from the land interrupts the cycling of materials into the soil (Figure 19.22). This net loss of nutrients must be artificially replenished. The type of plantation agriculture in Figure 19.22b is depleting of soil nutrients over time; this farming practice requires subsidies of chemical fertilizers and herbicides to eliminate competing vegetation.

Climate Change Obviously, the distribution of plant species is affected by climate change. Many species have survived wide climate swings in the past. Consider the beginning of the Tertiary Period, 75 million years ago. Warm, humid conditions and tropical forests dominated the land as far north as southern Canada, pines grew in the Arctic, and deserts were few. Then, between 15 and 50 million years ago, deserts began developing in the southwestern United States. Mountain-building processes created higher elevations, which created rain-shadow aridity that affected plant distribution.

Recall, too, that the movement of Earth's tectonic plates created climate changes important in the evolution and distribution of plants and animals (see Figure 11.17a–e). Europe and North America were joined in Pangaea and positioned near the equator, where vast swamps formed (the site of coal deposits today). The southern mass of Gondwana was extensively glaciated as it drifted at high latitudes in the Southern Hemisphere. Such glaciation left matching glacial scars and specific distributions of plants and animals across South America, Africa, India, and Australia. The diverse and majestic dinosaurs dispersed with the drifting continents.

The key question for our future is: As temperature patterns change, how fast can plants either adapt to new conditions or migrate through succession (location change) to remain within their shifting specific habitats? Rapid changes in vegetation patterns in northern latitudes since 1980 are indicated from satellite observations.

*E. O. Wilson, *Consilience, The Unity of Knowledge* (New York: Knopf, 1998), p. 292.

News Report 19.4

Experimental Prairies Confirm the Importance of Biodiversity

Little of the original midlatitude prairies remains. Only a few widespread areas of unaltered prairie are protected. Iowa was once 80% prairie, and now 99.9% of the prairie is gone, converted to other uses. One such plot of 240 acres (97 ha) is in Howard County, Iowa, south of the Minnesota border. The Hayden Prairie State Preserve sits quietly, almost missed by passing cars as they kick up pale dust from the gravel county road (Figure 19.4.1). Grasses and shooting star flowers (*Dodecatheon sp.*), and a blocked former road and trails, mark this pristine place in Iowa.

Field experiments have confirmed an important scientific assumption: that greater biological diversity in an ecosystem leads to greater stability, productivity, and soil nutrient use within that ecosystem. For instance, during a drought, some species of plants will be damaged. In a diverse ecosystem, however, other species with deeper roots and better water-obtaining ability will thrive.

Ecologist David Tilman at the University of Minnesota tracked the operation of 147 grassland plots, each 3 m (9.8 ft) square. Species diversity was carefully controlled on each plot (Figure 19.4.2). Plots were sown with different numbers of native North American prairie plant seeds and cared for by a team of 50 people. The results demonstrated that the plots with a more diverse plant community were able to retain and use nutrients more efficiently than the plots with less diversity. This efficiency reduced the loss of soil nitrogen through leaching, thus increasing soil fertility. Biodiversity improved the nutrient dynamic in the prairie ecosystem.

Greater plant diversity led to both higher productivity and better resource utilization. Also, total plant cover was found to increase with species richness. Tilman and his colleagues affirm:

> This extends the earlier results to the field, providing direct evidence that the current rapid loss of species on Earth, and management practices that decrease local biodiversity, threaten ecosystem productivity and the sustainability of nutrient cycling. Observational, laboratory, and now field experimental evidence, supports the hypothesis that biodiversity influences ecosystem productivity, sustainability, and stability.*

*D. Tilman, D. Wedin, and J. Knops, "Productivity and sustainability influenced by biodiversity in grassland ecosystems," *Nature* 379 (February 22, 1996): 720. Also see the summary in *Science* 271 (March 15, 1996): 1497.

FIGURE 19.4.1 One of the few remaining tracts of prairie. The Hayden Prairie State Preserve in Howard County, Iowa, is 240 acres of tallgrass prairie named after Dr. Ada Hayden, a former botany professor at Iowa State University. [Photo by Bobbé Christopherson.]

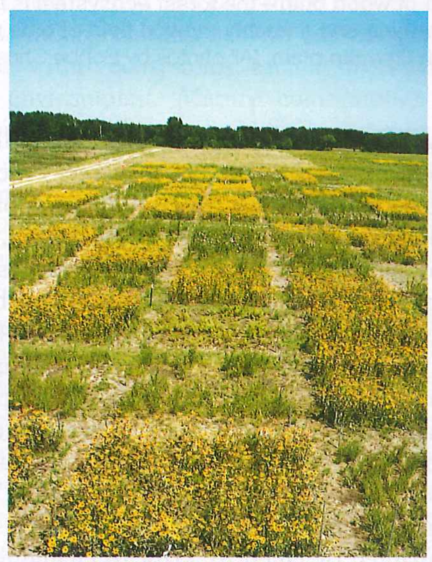


FIGURE 19.4.2 Biodiversity experiment. Experimental plots are planted with native North American prairie grasses. A total of 147 plots were sown with random seed selections of 1, 2, 4, 6, 8, 12, or 24 species. Experimental results confirm many assumptions regarding the value of rich biodiversity. [Photo by David Tilman/University of Minnesota, Twin Cities Campus.]


(a)


(b)


(c)


(d)

FIGURE 19.22 Agricultural ecosystems.
(a) The Sacramento Valley of California is one of the most intensively farmed regions of the world. Field crops including irrigated rice, an irrigation canal, and the Sacramento River are in the scene. (b) A pine tree plantation (farm) in Georgia, principally for the production of wood pulp—the forest ecosystem is reduced to efficient rows for clear-cutting when mature. (c) Modern mechanized farming and a freshly mowed field of oats near Dokka, Norway. (d) Highly fragmented, fertile agricultural land along the north German plain. [All photos by Bobbé Christopherson.]

Global warming is reducing spring snow cover, allowing spring greening to occur earlier, up to 3 weeks sooner in some high-latitude locations. Likewise the onset of fall is delayed to a later date than previously experienced.

Nina Leopold Bradley is studying the Wisconsin setting her father, Aldo Leopold, made famous in his book *A Sand County Almanac* (Oxford University Press, 1949). He kept detailed records of all things dealing with nature and seasonal change on his tract of land. Her findings show that more than one-third of animal and plant species start spring activities 4 weeks earlier than they did 50 years ago.

Adaptation to changing conditions is key to evolution. Through mutation and natural selection, species have either adapted or failed to adapt to changing environmental conditions over millions of years. Current global change is occurring rapidly, at the rate of decades instead of millions of years. Thus, we see die-out and succession of different species along disadvantageous habitat margins. The displaced species may colonize new regions made more hospitable by climate change. Also shifting will be agricultural lands that produced wheat, corn, soybeans, and other commodities. Society will have to adapt to different crops growing in different places.

A study completed by biologist Margaret Davis on North American forests suggests that trees will have to respond quickly if temperatures increase. Changes in the climate inhabited by certain species could shift 100–400 km (60–250 mi) during the next 100 years. Some species, such as the sugar maple, may migrate northward, disappearing from the United States except for Maine, and moving into eastern Ontario and Québec. Davis prepared a map showing the possible impact of increasing temperatures on the distribution of beech and hemlock trees (Figure 19.23).

> Changes in the geographical distributions of plant and animal species in response to future greenhouse warming threaten to reduce biotic diversity. . . . The risk posed by CO_2-induced warming depends on the distances that regions of suitable climate are displaced northward [in the Northern Hemisphere] and on the rate of displacement. . . . If the change occurs too rapidly for colonization of newly available regions, population sizes may fall to critical levels, and extinction will occur.*

*M. B. Davis and C. Zabinski, "Changes in the geographical range resulting from greenhouse warming: Effects on biodiversity in forests," in R. L. Peters and T. E. Lovejoy, eds., *Global Warming and Biological Diversity* (New Haven, CT: Yale University Press, 1992), p. 297.