Florida panther *(Puma concolor coryi)*. Fewer than 100 individuals of this endangered subspecies survive.

JH Pete Carmichael/Getty Images Inc.

Study Plan

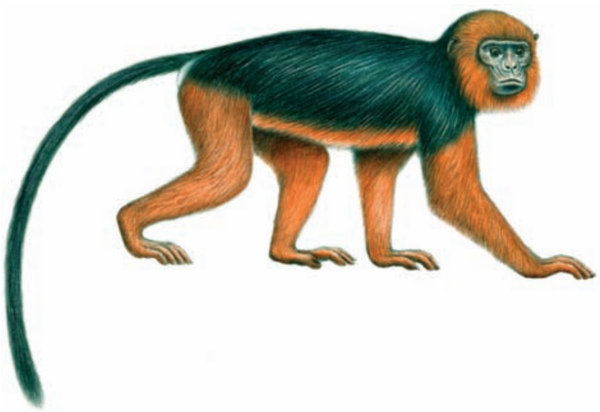
53 Biodiversity and Conservation Biology

Why It Matters

Someone seems to be missing. Investigators thoroughly checked the subject's known haunts, but found no trace. They questioned others in the neighborhood, but came up with few leads. The case is especially difficult because the subject was last seen alive in 1978. With so cold a trail to follow, investigators reluctantly marked the case file "Missing and Presumed Extinct."

The subject in this case was Miss Waldron's red colobus monkey, *Procolobus badius waldroni* **(Figure 53.1).** Named for a traveling companion of the taxonomist who first described it in 1933, this distinctively colored subspecies lived in large and noisy social groups in a remote forest on the border between Ivory Coast and Ghana in West Africa.

John Oates of the City University of New York recently led a research team that tried to locate Miss Waldron's red colobus. They used every imaginable method, including visual and auditory censuses, searching for scat (dung) in natural habitats, interviewing local people, and looking in marketplaces where monkey meat is commonly traded. In 2000, more than 20 years after the last confirmed sighting, the researchers concluded that this monkey is probably extinct. A later



Stephen D. Nash/Conservation International

Figure 53.1
Miss Waldron's red colobus. *Procolobus badius waldroni*, which weighed about 10 kg, may be the first primate subspecies to become extinct in more than 100 years.

search by a member of the team, William S. McGraw of Ohio State University, did find the skin of one monkey that a hunter had shot 6 months before. But McGraw searched in vain for a living monkey, and he concluded that even if a few are still alive, the population is so small that continued hunting will surely eliminate it.

Procolobus badius waldroni may be the first primate subspecies to become extinct in more than 100 years—and only the second in the last 500 years. Monkeys and other primates are among the most closely monitored and protected species on Earth. Nonetheless, Oates and his colleagues concluded, these monkeys probably became extinct because they were hunted locally for food by a growing human population and because humans have destroyed their natural habitats.

C-GH/Grant Heilman Photography, Inc.

Figure 53.2
The Pacific yew tree. The slow-growing Pacific yew *(Taxus brevifolia)* is the original source of Taxol, a compound that effectively fights several cancers.

Miss Waldron's red colobus is just one of many species driven to extinction every year. Current threats to biodiversity, all of which ultimately result from human activities, are massive. The likely loss of this monkey should warn us that many taxa are at risk, even those that are most rigorously protected.

When ecologists speak of **biodiversity**, they are referring to the richness of living systems. At the most fundamental level of biological organization, biodiversity encompasses the *genetic variation* that is raw material for adaptation, speciation, and evolutionary diversification (see Chapters 20 and 21). At a higher level of organization, biodiversity includes *species richness* within communities (see Section 50.3). The number and variety of species within a community influences its overall characteristics, population interactions, and trophic structure. Finally, biodiversity exists at the *ecosystem level*. Complex networks of interactions bind species in an ecosystem together, and because different ecosystems interact within the biosphere, damage to one ecosystem can reverberate through others.

In this chapter we reflect on the importance of biodiversity and describe how human activities threaten it. We also consider theoretical and practical approaches to conservation biology, the scientific discipline that focuses on preserving Earth's biological resources.

53.1 The Benefits of Biodiversity

What is the value of biodiversity, and why should humans preserve it? Arguments for conserving biodiversity fall into three general groups: its direct benefit to humans, its indirect benefit to all living systems, and its intrinsic worth.

Biodiversity Benefits Humans Directly

Scientists constantly search for natural products that might provide humans with better food, clothing, or medicine. The development of a new medicine often begins when a scientist analyzes a traditional folk remedy or screens naturally occurring compounds for curative properties. Chemists then isolate and purify the active ingredient and devise a way to synthesize it in the laboratory. More than half of the 150 most commonly prescribed drugs were developed from natural products in this manner.

For example, *Taxol,* a drug treatment for breast and ovarian cancer, was isolated from the narrow strip of vascular cambium beneath the bark of the Pacific yew tree, *Taxus brevifolia* **(Figure 53.2).** Unfortunately, a fully grown, 100-year-old tree produces only a tiny amount of Taxol, and six trees must be destroyed to extract enough to treat one patient. Pacific yew trees are not abundant, and they grow slowly. Harvesting them for Taxol extraction could quickly lead to their extinction—and an end to the natural source of this life-saving compound. However, after much research, scientists can now synthesize this widely used drug in the laboratory.

Wild plants and animals also serve as sources of genetic traits that may improve agricultural crops and domesticated livestock. For example, corn *(Zea mays)* is an annual plant. Its cultivation requires yearly tilling of the soil, a labor-intensive activity that leads to erosion and loss of topsoil. Farmers have yearned for a perennial strain of corn, one that would produce grain for years after a single planting. In 1978, botanists discovered teosinte *(Zea diploperennis)* a perennial plant closely related to corn, in the mountains of western Mexico. Researchers crossed the two species, producing a *perennial* corn. If they can increase the yield of this hybrid, it may prove to be an economically valuable crop **(Figure 53.3).**

Today, many agricultural researchers use genetic engineering, the transfer of selected genes from one species into another (see Section 18.2), to alter crop plants more precisely than they can using hybridization. The transferred genes may be chosen to increase resistance to pests or environmental stress, promote faster growth, or increase shelf life after harvesting. However, many scientists and environmentalists fear that genetically modified crops may create environmental hazards that will inadvertently endanger biodiversity. For example, a genetically modified plant or animal that escaped into a natural habitat might compete with naturally occurring species. Or a genetically modified plant might poison harmless animals as well as insect pests.

John Doebley

Figure 53.3
Teosinte and domesticated corn. Ears of domesticated corn (*Zea mays*, right) are much larger than those of its wild relative teosinte (*Zea diploperennis*, left). Scientists crossed the two species in the hope of producing a perennial corn; the hybrids produce ears of an intermediate size (middle).

Ecosystem Services Benefit All Forms of Life

Humans and other species derive indirect benefits when ecosystems perform the ecological processes on which all life depends. These **ecosystem services,** as they are called, include the decomposition of wastes, nutrient recycling, oxygen production, maintenance of fertile topsoil, and air and water purification.

Some ecosystem services can even mitigate environmental damage caused by humans. As you may recall from *Focus on Applied Research* in Chapter 51, the combustion of fossil fuels produces CO_2 and other waste products that accumulate in the atmosphere, increasing the greenhouse effect and fostering global warming. Photosynthetic organisms use CO_2 for essential metabolic processes; thus, forests and, even more importantly, communities of marine phytoplankton withdraw CO_2 from the atmosphere and incorporate it into living organisms (see Figure 51.13), a phenomenon called *carbon sequestration*. Recent research indicates that these organisms are essential for limiting the damage caused by the burning of fossil fuels. In the long run, biodiversity's indirect benefits, provided in the form of ecosystem services, may be even more valuable to humans than the direct benefits.

Biodiversity Has Intrinsic Worth beyond Its Utility to Humans

Some ethicists argue that we should preserve biodiversity because it has intrinsic worth, independent of its direct or indirect value to humans. They note that humans are just one species among millions in the remarkable network of life. Countering this position is the view that our immediate needs should always rank above those of other species and that we should use them to maximize our own welfare. The latter view inevitably leads to the disruption of natural environments and the loss of biodiversity. Framed in this way, the debate lies more within the realms of philosophy and public policy than biology. Nevertheless, many people feel an emotional or spiritual connection to natural landscapes and the plants and animals they harbor. Thus, biodiversity enhances human existence in intangible ways.

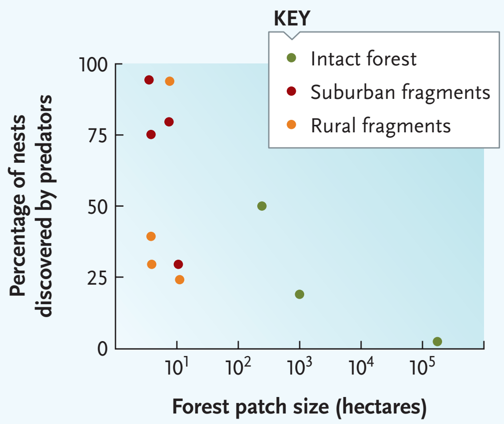
Figure 53.4 Experimental Research

Predation on Songbird Nests in Forests and Forest Fragments

QUESTION: Are songbird nests in small forest fragments more likely to be found by predators than nests in large forest patches?

EXPERIMENT: Wilcove placed between 13 and 50 artificial bird nests, each containing three quail eggs, in three habitat types: large areas of intact forest, rural forest fragments, and suburban forest fragments. He placed about half the nests at each study site on the ground at the base of a tree or shrub and half the nests 1 to 2 m above the ground in a sapling or shrub. He checked the nests after 7 days to determine what proportion of the nests had been subjected to predation.

RESULT: Predators generally found a larger proportion of the artificial bird nests in small forest fragments than they did in large forest patches.



CONCLUSION: Songbirds' nests are much more likely to suffer from predation in small forest fragments than they are in large patches of intact forest.

Study Break

1. How does biodiversity serve as a storehouse of genetic information that is potentially useful to humans?
2. How do naturally occurring organisms provide humans with ecosystem services?

53.2 The Biodiversity Crisis

Earth's biodiversity is currently declining dramatically. Although the proximate causes of the decline may vary from one group of organisms to another, the ultimate cause is always the same: human disruption of natural communities and ecosystems.

Human Activities Disturb and Fragment Habitats

When humans first enter undisturbed habitats, they typically build roads to gain access to resources, such as oil, wood, or game animals, or to begin agricultural development. The roads bring in settlers, who clear isolated areas for specific uses. Nonnative organisms are often introduced by humans or migrate into the now-disturbed area under their own power. These invaders then consume, parasitize, or compete with the native plants and animals. As the land is further changed and degraded, the habitat is altered dramatically, possibly forever. Although this pattern of development initially affects only locally distributed species, the negative effects spread rapidly to a regional scale. The remaining areas of *intact* habitat are inevitably reduced to small, isolated patches, a phenomenon that ecologists describe as **habitat fragmentation.**

Habitat fragmentation is a threat to biodiversity because small habitat patches can sustain only small populations. As you learned in Section 49.5, a habitat's *carrying capacity*, the maximum population size that it can support, varies with available resources. Populations that occupy small habitat patches inevitably experience low carrying capacities, a problem that is especially acute for species at the higher trophic levels (see Section 51.1). Furthermore, fragmented habitat patches are often separated by unsuitable habitat that organisms may be unable or unwilling to cross. As a result, individuals from one isolated population are unlikely to migrate into another, reducing gene flow between them. The combination of small population size and genetic isolation fosters genetic drift, which reduces genetic variability and fosters extinction (see Section 20.3).

Habitat fragmentation not only reduces the amount of undisturbed habitat; it also jeopardizes the quality of the habitat that remains. Human activities create noise and pollution that spread into nearby areas. The removal of natural vegetation disrupts the local physical environment, exposing the borders of the remaining habitat to additional sunlight, wind, and rainfall. Increased runoff compacts the soil and makes it waterlogged. These phenomena are collectively described as **edge effects.**

The effects of habitat fragmentation are often profound. For example, populations of forest-dwelling, migratory songbirds have declined markedly in eastern North America since the late 1940s, largely because of habitat fragmentation in their North American breeding grounds and in their Caribbean and South American wintering grounds.

In 1994, Scott K. Robinson of the Illinois Natural History Survey and David S. Wilcove of the Environmental Defense Fund identified three factors that decrease populations of migratory songbirds in fragmented breeding habitats. First, small forest patches often lack specific habitat types—such as streams, cool ravines, or dense ground cover—that many songbird species require.

Second, songbirds breeding in forest patches are more likely to suffer from brood parasitism (described in the opening of Chapter 50) by brown-headed cowbirds *(Molothrus ater)* than are those breeding in intact forests. Brown-headed cowbirds, which prefer open habitats, were rare in eastern North America before European settlers converted forests to farmland. Today, cowbirds are abundant in open agricultural fields and suburban gardens, and they locate the nests of unwitting "foster parents" in nearby forest fragments where the host species breed. Parasitized songbirds rear fewer than half as many young as they might otherwise raise, and their populations decline accordingly.

The third factor that reduces songbird numbers in forest fragments is increased nest predation by blue jays *(Cyanocitta cristata)*, American crows *(Corvus brachyrhynchus)*, common grackles *(Quiscalus quiscula)*, squirrels (genus *Sciurus*), raccoons *(Procyon lotor)*, and domestic dogs and cats. These predators, which feed on songbird eggs and young, are now superabundant in rural and suburban areas, and they enter adjacent forest fragments in search of an easy meal. Wilcove tested the predation hypothesis experimentally by placing artificial nests with quail eggs in intact forests and in forest fragments. Although he did not observe predation directly, he found that predators discovered only 2% of the nests in the largest intact forest, but they often found 50% or more of the nests placed in small, suburban forest fragments **(Figure 53.4).**

Deforestation May Lead to Desertification

Forests are among the habitats that humans most frequently clear and convert. According to the United Nations Forest Resources Assessment released in 2005, global deforestation is occurring at a rate of about 13 million hectares per year, or 25 hectares per minute. In other words, an area of forest equivalent to 42 football fields is cleared of all trees every minute of every day.

Deforestation does not occur uniformly across the globe. Today, more than 90% of the deforestation occurs in tropical regions, mostly to clear land for grazing. Brazil has experienced the most extensive recent damage, accounting for 25% of all deforestation during the late twentieth century **(Figure 53.5).** This assessment is particularly troubling because Brazil contains approximately 27% of the planet's total aboveground woody biomass. Compounding the environmental damage, most tropical forests are burned as they are cleared, a process that adds CO_2 to the atmosphere, enhancing the greenhouse effect and increasing the rate of global warming (see *Focus on Applied Research* in Chapter 51).

Once a forest has been cut, heavy grazing or farming drains nutrients from the soil. To remain productive, even the best agricultural or grazing lands require either the application of fertilizers or long periods during which the land is fallow, allowing plants to replenish the soil naturally. Unfortunately, the soil where tropical forests grow is often of marginal value right from the start (for reasons described in Chapter 52), and it is rapidly degraded; it becomes hard, even more nutrient-poor, unable to retain water, and likely to wash away.

When large tracts of subtropical forest are cleared and overused, the land often undergoes **desertification:** the groundwater table recedes to deeper levels; less surface water is available for plants; soil accumulates high concentrations of salts (a process called *salinization*); and topsoil is eroded by wind and water. In other words, the habitat is converted to desert.

Desertification speeds the loss of biodiversity locally and can eliminate entire ecosystems. For example, desertification has decimated habitats in the Sahel re-

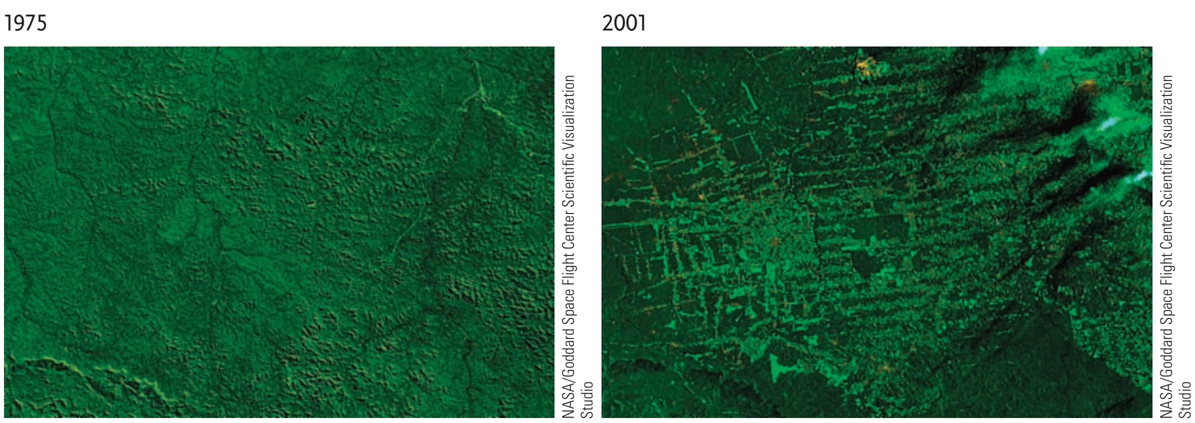


Figure 53.5
Deforestation in the Amazon Basin. Satellite photos of Rondonia, in the Brazilian Amazon, show how much of the Amazon forest was cut (light green) between 1975 and 2001. Each photo illustrates an area approximately 60 by 85 km.

a. The Sahel region of Africa **b.** Women preparing millet, a grain, in the Sahel

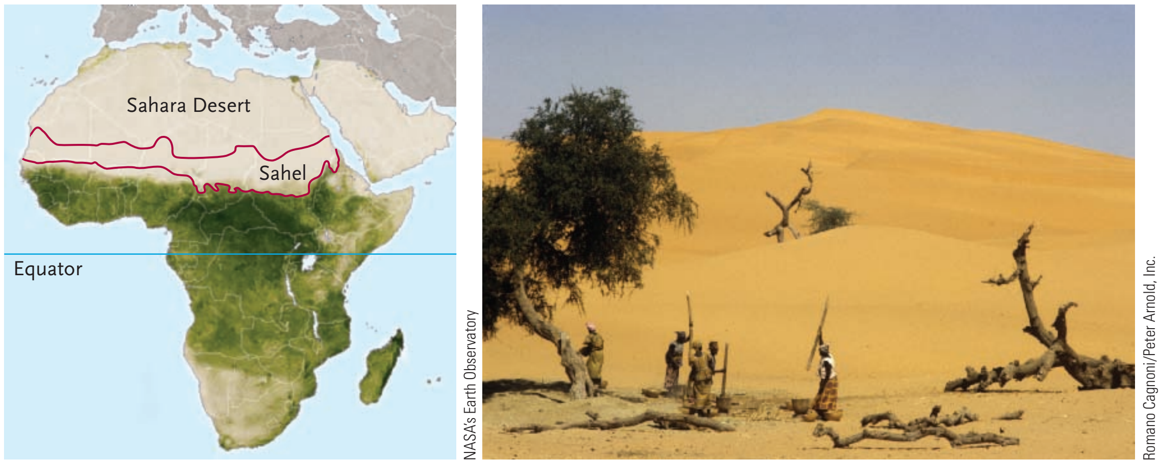


Figure 53.6
Desertification in the Sahel. **(a)** A satellite photo taken near the end of the dry season in June 2005 illustrates the severe desertification in parts of the Sahel region of Africa. Dark green areas are densely vegetated; light green areas are sparsely vegetated, and sand-colored areas are barren. **(b)** People who live in this region can barely eke out a living on the land.

gion of Africa, just south of the Sahara Desert **(Figure 53.6).** Excessive grazing of cattle and goats by an ever-expanding human population is the main reason for the Sahara's southward expansion at a rate of 5.5 to 8 km per year. Because the sand dunes of the expanding desert shift constantly, agriculture and grazing are nearly impossible, resulting in frequent famines among the people of the Sahel.

Desertification and salinization have also begun in the Everglades, a unique, shallow "river of grass" that covers much of southern Florida. The amount of fresh water flowing through South Florida to the Everglades has decreased approximately 70% since 1948, when an extensive network of canals and levees was built to reduce flooding. The rapidly growing human population in South Florida contributes directly to desertification, as groundwater is tapped for domestic use and to irrigate lawns, golf courses, and agricultural fields. Salt water from the Gulf of Mexico now intrudes into the water table, causing salinization of the soil. The Comprehensive Everglades Restoration Plan (CERP), approved by the U.S. Congress in 2000, seeks to restore the natural flow of the Everglades over the next 30 years. This project may halt or reverse the desertification process.

Sadly, deforestation, desertification, and global warming reinforce each other in a positive feedback cycle (see *Focus on Applied Research* in Chapter 51). If scientists' projections are correct, desertification will lead to an increase in the average global temperature, speeding evaporation and the retreat of forests, which, in turn, will increase rates of desertification. If deforestation and desertification continue, we will soon lose a large proportion of Earth's forests and face a decrease in the area of habitable land.

Many Forms of Pollution Overwhelm Species and Ecosystems

The release of **pollutants**—materials or energy in forms or quantities that organisms do not usually encounter—poses another major threat to biodiversity.

Although chemical pollutants, the by-products or waste products of agriculture and industry, are released locally, many spread in water or air, sometimes on a continental or global scale. Within North America, for example, winds carry airborne pollutants from coal-burning power plants to the Northeast **(Figure 53.7).** Sulfur dioxide (SO_2), which dissolves in water vapor in the air and forms sulfuric acid, falls as **acid precipitation,** acidifying soil and bodies of water. Many lakes in northeastern North America have experienced a precipitous drop in pH from historical readings near 6 to values that are now well below 5—a 10-fold increase in acidity. Although the lakes once harbored lush aquatic vegetation and teemed with fishes, they are now crystal clear and nearly devoid of life.

As residents of major cities and industrial areas know all too well, carbon wastes from factories and automobile engines cause terrible local pollution, increasing rates of asthma and other respiratory ailments. Some airborne pollutants, notably CO_2, also join the general atmospheric circulation, where they contribute to the greenhouse effect and global warming.

Like air pollution, water pollution originates locally but has a much broader impact. Oil spills, for example, disrupt local ecosystems, killing most organisms near the spill. Because oil floats on water, it spreads rapidly to nearby areas. The wreck of an oil tanker off the coast of Spain in 2002 destroyed many fertile fishing grounds within a few weeks. Scientists

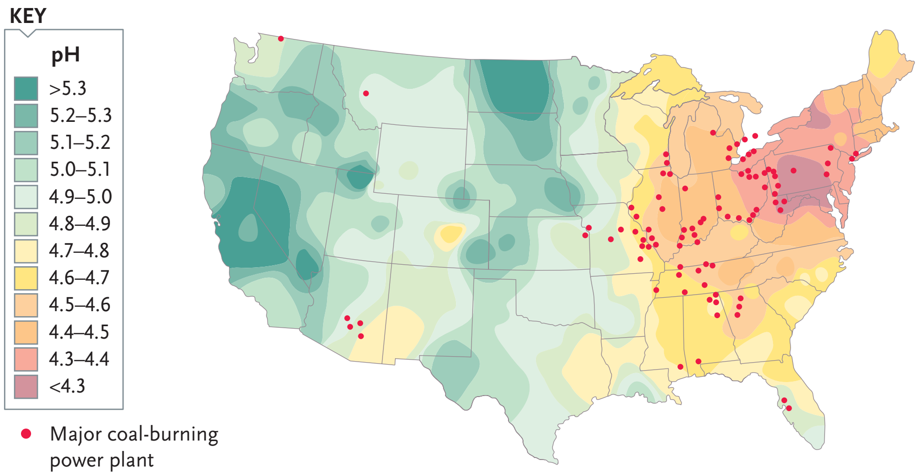


Figure 53.7
Acid precipitation. Coal-burning power plants (indicated by red dots) release air pollution that is carried northeast, where it falls as acid precipitation. The map shows the average pH of rainfall.

expect oil to continue leaking from the sunken ship for another 50 years; the effects of the long-term leakage may linger for centuries.

Pollution can also have serious effects on terrestrial ecosystems. As a recent disaster in India, Nepal, and Pakistan illustrates, the application of synthetic compounds to agricultural fields or livestock can have dire and far-reaching consequences. For thousands of years, gigantic populations of vultures (several *Gyps* species)—estimated at more than 40 million birds—performed an important ecosystem service by consuming the abandoned carcasses of farm animals across South Asia. In the early 1990s, however, farmers began to administer diclofenac, a new and inexpensive anti-inflammatory drug, to injured livestock. Within a few years, vultures began to disappear; in 2006, scientists estimated that their populations had declined by more than 97%. Recent research revealed that diclofenac, which causes fatal kidney failure in birds, was responsible for the deaths: vultures were ingesting substantial doses of the drug from the livestock carcasses they ate. All vulture species in South Asia are now on the verge of extinction, and although governments in the region have banned the sale of diclofenac, wildlife experts say that the vulture populations are unlikely to recover soon, if ever.

The decline in vulture populations has had a disastrous impact on urban and rural communities in South Asia. Livestock carcasses are now consumed by growing populations of wild dogs, many of which carry rabies. India has the world's highest human death toll from rabies—30,000 per year—and two-thirds of the cases are caused by dog bites. Populations of rats and flies also appear to be increasing. *Focus on Research* (p. 1236) describes another example of how pesticides and other chemicals accumulate at lethal concentrations in organisms living at higher trophic levels.

Some forms of pollution have more subtle effects. Light and noise pollution disrupt the activities of nocturnal animals or those that rely on vision or hearing for orientation. For example, light pollution in beachfront communities disrupts the reproduction of marine turtles, all species of which are declining in numbers **(Figure 53.8).** Female turtles crawl up on beaches at night to lay their eggs in the sand; after the eggs hatch, the young dig their way out of the nest and head for the ocean. But female turtles are reluctant to come ashore on beaches with artificial light. And lights may later confuse and misdirect their hatchlings, making them even easier prey for predators, or cause them to stay too long on shore, where they dehydrate and die.

Exotic Species Often Eliminate Native Species

As humans travel from one habitat to another, we inevitably carry other species with us. Seeds cling to our legs, insects accompany us in our food and possessions, and some organisms hitch a ride on boats or cars. The introduction of nonnative organisms, called

a. Female green turtle digging a nest **b.** Heron eating hatchling green turtle

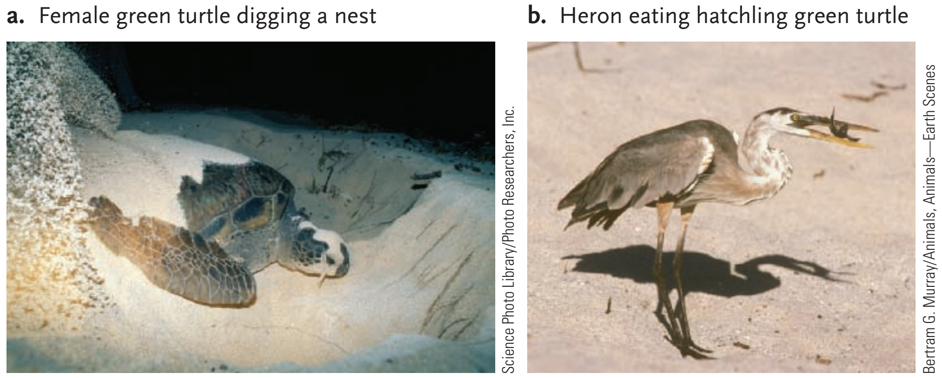


Figure 53.8
Light pollution disrupts green turtle reproduction. (a) Female green turtles *(Chelonia mydas)* are reluctant to nest on beaches affected by light and noise pollution. **(b)** Artificial light confuses hatchling turtles, hindering their escape from eager predators like this great blue heron *(Ardea herodias).*

Focus on Research

Applied Research: Biological Magnification

The synthetic organic pesticide DDT (dichloro-diphenyl-trichloroethane) was first used widely during World War II. In the tropical Pacific, it killed the mosquitoes that transmitted malarial parasites (*Plasmodium* species) to soldiers. In war-ravaged European cities, it controlled body lice that carried the bacteria causing typhus *(Rickettsia rickettsii)*. After the war, people started using DDT to kill agricultural pests, disease vectors, and insects in homes and gardens.

Although DDT is a stable hydrocarbon compound that is nearly insoluble in water, it is more mobile than its users expected. Winds carry it as a vapor, and water transports it as fine particles. DDT is also highly soluble in fats, accumulating in animal tissues—and it travels with animals wherever they go.

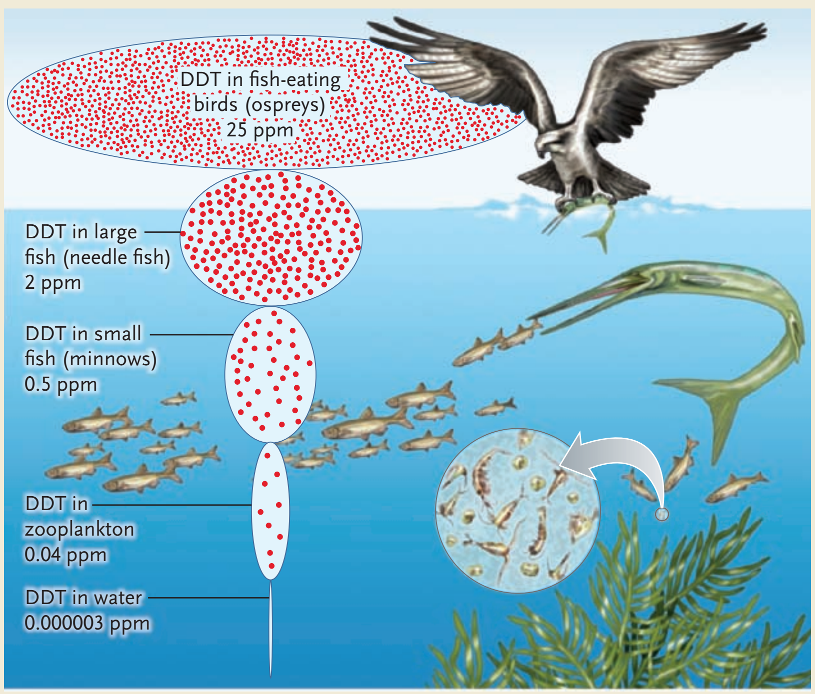
Unfortunately, consumers accumulate the DDT from all of the organisms they eat in their lifetimes. Primary consumers, like herbivorous insects, may ingest relatively small quantities. But a songbird that eats many insects will accumulate a moderate amount, and a predator that feeds on songbirds will accumulate even more. Thus, DDT and other nondegradable poisons become concentrated in organisms at higher trophic levels, a phenomenon called **biological magnification** (see **figure**). Although many organisms can partially metabolize DDT to other compounds, these products are also toxic or physiologically disruptive.

After the war, DDT moved rapidly through ecosystems, affecting organisms in ways that no one had predicted. In cities where DDT controlled Dutch elm disease, songbirds died after eating contaminated insects and seeds. In streams flowing through forests where DDT killed spruce budworms, salmon died because runoff carried the pesticide into their habitat. And in croplands around the world, new pests flourished because DDT indiscriminately killed the natural predators that had kept their populations in check.

Eventually, the effects of biological magnification began to show up in places far removed from the sites of DDT application. Top carnivores in some food webs were pushed to the brink of extinction. The reproduction of bald eagles, peregrine falcons, ospreys, and brown pelicans was disrupted because one DDT breakdown product interferes with the deposition of calcium in their eggshells. When birds tried to incubate their eggs, the shells cracked beneath the parents' weight. Even today, traces of DDT are found in the bodies of nearly all species, including in human fat and breast milk.

Since the 1970s, DDT has been banned in the United States, except for restricted applications to protect public health. Many hard-hit species have partially recovered, but some birds still lay thin-shelled eggs because they pick up DDT at their winter ranges in Latin America. As recently as 1990, the California State Department of Health recommended that a fishery off the coast of California be closed; DDT from industrial waste discharged 20 years earlier was still moving through that ecosystem. Moreover, DDT is still used in other countries, and some enters the United States on imported fruit and vegetables.

Biological magnification is a problem that applies to many compounds that humans release into the environment. For example, polychlorinated biphenyls (PCBs), commonly used in the manufacture of plastics and electrical insulation, enters aquatic ecosystems in factory wastes. Their use has been banned in the United States since the 1970s. But these compounds break down very slowly, and vast deposits have accumulated in the bottom sediments of rivers and lakes. Once bottom-feeding organisms ingest them, the toxins work their way up food webs, accumulating at higher and higher concentrations in consumers. The effects on humans can be severe; pregnant women who regularly eat fish from the Great Lakes often give birth to children with below-average weight and neonatal behavioral problems. The pollution in some areas of New York State was so severe that the Department of Health advised people to avoid eating freshwater fish more than once a month. PCBs can be removed from aquatic ecosystems by dredging, but the dredging activity itself stirs up the polluted sediments, releasing the toxins into the water that flows above.



In this food web near Long Island Sound, New York, DDT concentration (measured in parts per million, ppm) was magnified nearly 10 million times between zooplankton and the osprey.

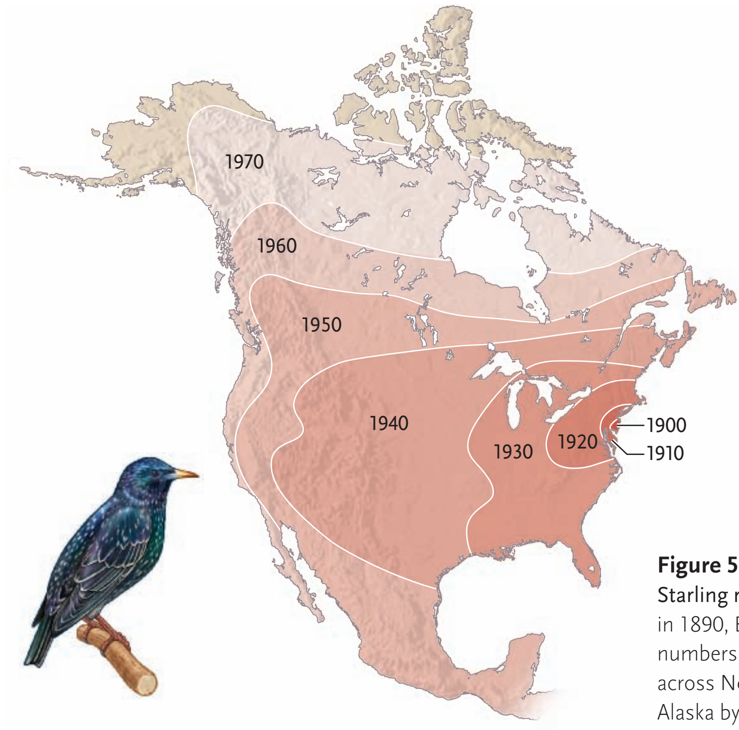


Figure 53.9
Starling range expansion. After being introduced in New York City in 1890, European starlings *(Sturnus vulgaris)* increased their numbers and quickly extended their breeding range westward across North America. They reached the west coast by 1960 and Alaska by 1970.

exotic species, into new habitats poses one of the most serious threats to biodiversity.

Exotic species often prey upon, parasitize, or outcompete native species, leading to their extinction. Many have *r*-selected life histories (see Section 49.6); they mature quickly and reproduce prodigiously, and they thrive in the degraded habitats that humans so frequently create. In the absence of natural checks on population growth—such as competitors, predators, and parasites—exotics often experience exponential population growth (see Section 49.5).

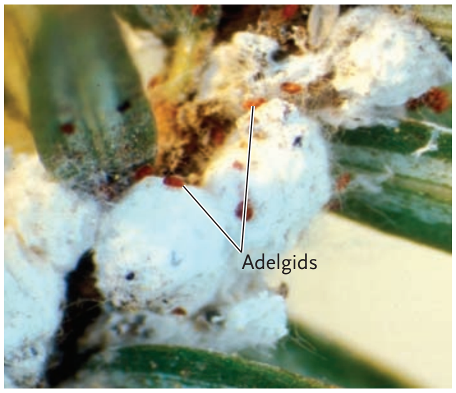
The European starling *(Sturnus vulgaris)* provides an example of the explosive population growth and range expansion of an exotic species. These birds were released in North America in 1890 when a misguided individual, who wanted to introduce all of the bird species mentioned by Shakespeare into North America, imported them into Brooklyn, New York. Within 70 years, they had spread across the continent **(Figure 53.9);** their population size is now estimated at 200 million. Starlings pose a serious threat to native birds, including several woodpecker species, because they successfully compete with them for nesting sites in natural cavities in trees.

Introduced plants often transform entire ecosystems. One of the best-known examples is kudzu *(Pueraria lobata),* a fast-growing species from Asia. In the early 1900s, it was widely planted in the southeastern United States as a source of animal feed. Later, a government agency promoted it as a plant that could stabilize soils and decrease erosion on deforested hillsides; we now know that it does not perform those functions effectively. But when kudzu has access to abundant nutrients and water, its branches can grow up to 30 cm per day. It spread quickly across the South, literally overgrowing almost all native plants **(Figure 53.10).**

Exotic insects often become pests of agricultural crops and native plants. The hemlock woolly adelgid *(Adelges tsugae)* was accidentally introduced into North America from Asia. The adelgid kills eastern hemlocks *(Tsuga canadensis)* by feeding on their sap. It now threatens the trees from North Carolina to Massachusetts **(Figure 53.11).** But adelgids endanger far more than these evergreen trees. Hemlocks buffer the physical

Figure 53.10
Kudzu, the vine that ate the South. Kudzu *(Pueraria lobata)*, an introduced vine, grows so quickly that it often covers living trees or even abandoned buildings.

a. Woolly adelgids



b. Hemlocks killed by woolly adelgids

c. Eastern hemlock and woolly adelgid ranges

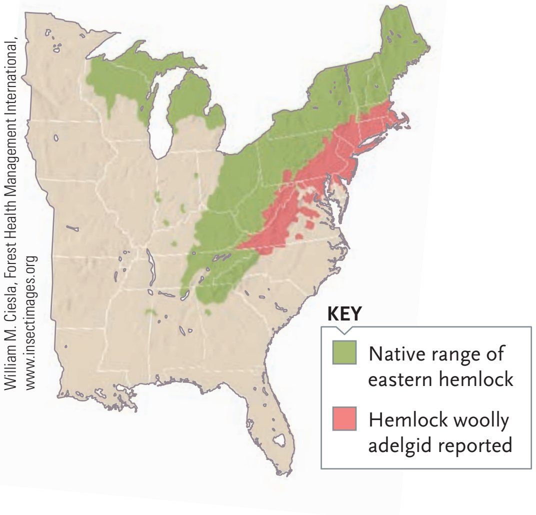


Figure 53.11
Hemlock woolly adelgid. **(a)** The aphidlike woolly adelgid *(Adelges tsugae)* feeds on the sap of **(b)** eastern hemlock *(Tsuga canadensis)*, often killing the tree. This insect pest is spreading northward **(c)** and may someday endanger hemlocks throughout their geographical range.

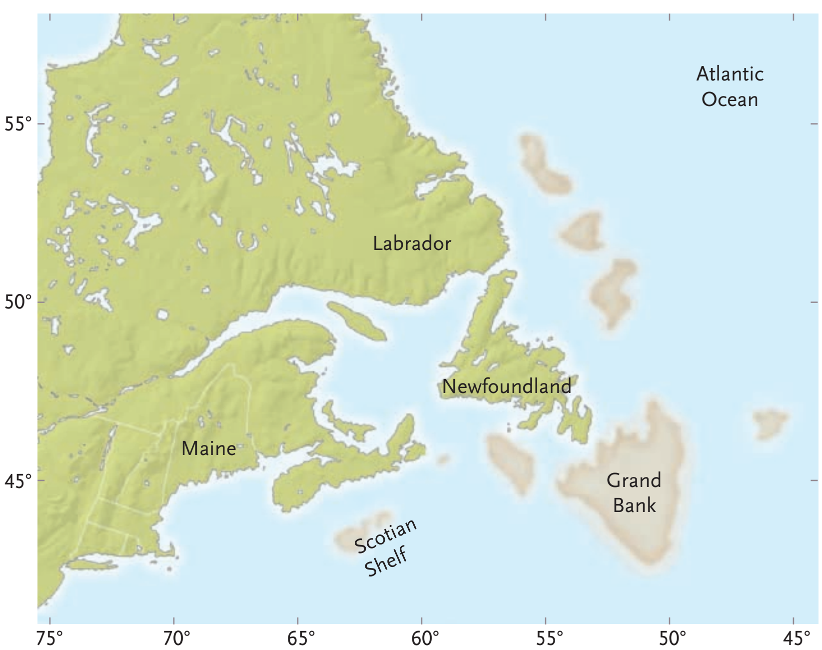
conditions below them: hemlock stands are cool in summer and warm in winter, sustaining a unique community of organisms that includes ruffed grouse *(Bonasa umbellus)*, turkey *(Meleagris gallopavo)*, white-tailed deer *(Odocoileus virginianus)*, and snowshoe hare *(Lepus americanus)*. Infested stands rarely survive more than a few years, and the communities established under pure stands of eastern hemlock will likely become extinct because of feeding by the adelgid.

Overexploitation Greatly Reduces Population Sizes

Many local extinctions result from **overexploitation**, the excessive harvesting of an animal or plant species. At a minimum, overexploitation leads to declining population sizes in the harvested species. In the most extreme cases, a species may be wiped out completely. Overexploitation also can foster evolutionary changes in the exploited population, much the way guppies respond to natural predators in the streams of Trinidad (described in *Focus on Research* in Chapter 49).

The fishery on the Grand Banks off the coast of Newfoundland, Canada, provides a sad example of overexploitation **(Figure 53.12).** For hundreds of years, fishermen used traditional line and small-net fishing to harvest a large but sustainable catch. During the twentieth century, however, new technology allowed them to locate and exploit schools of fishes more efficiently. As a result, 45% of the fish species harvested there are now overfished. Haddock *(Melanogrammus aegelfinus)* and yellowtail flounder *(Limanda ferruginea)*

a. The Grand Banks



b. Atlantic cod

Figure 53.12
Overexploitation of North Atlantic fisheries. **(a)** The Grand Banks (sand-colored shading) were severely overfished in the late twentieth century, leading to the near extinction of many species, including the **(b)** Atlantic cod *(Gadus morhua)*.

have been essentially eliminated from the Grand Banks, and their populations will probably never recover. And because fishermen preferentially harvest the oldest and largest individuals, which fetch a higher market price, Atlantic cod *(Gadus morhua)* now mature at a younger age (3 years compared with 5 or 6 years) and smaller size.

As a consequence of overfishing, the average yield of the Grand Banks has declined to less than 10% of the highest historic levels. In the mid-1960s, Atlantic cod yielded a minimum of 350,000 tons per year. By the mid-1970s, the catch dropped to 50,000 tons per year. The Canadian government finally closed the fishery in 1993, after the cod catch fell below 20,000 tons for several consecutive years. But the damage had already been done: the most heavily exploited species are less marketable because of their smaller size, fish populations have decreased to dangerously low levels, and the fishing industry is itself imperiled. This sequence of events has been replicated in fisheries around the world. Indeed, in a report published in 2003, Ransom A. Myers and Boris Worm of Dalhousie University in Nova Scotia estimated that modern fishing techniques have reduced the biomass of large predatory fishes by about 90% in marine ecosystems.

Overexploitation is not inevitable; careful management of fisheries can achieve sustainable harvests. Many approaches are possible, such as providing supplemental food or shelter; maintaining captive breeding populations, from which individuals are introduced into the wild; limiting the times of harvest to avoid disrupting reproductive cycles; and limiting the size and character of the catch. Similar strategies can be devised for other resource populations.

Human Activities Are Causing a Dramatic Increase in Extinction Rates

As you may remember from Section 22.5, extinction has been common in the history of life: roughly 10% of the species alive at any time in the past became extinct within 1 million years. These *background extinction rates* eliminated perhaps seven or eight species per year. Paleobiologists have also documented at least five *mass extinctions,* during which extinction rates increased greatly above the background rate for short periods of geological time (see Figure 22.18).

At present, Earth appears to be experiencing the greatest mass extinction of all time. According to Edward O. Wilson of Harvard University, extinction rates today may be 1000 times the historical background rate, meaning that thousands of species are being driven to extinction each year. The vast majority of extinctions are a direct result of habitat fragmentation, desertification, rising levels of pollution, the introduction of exotic species, and the overexploitation of natural populations.

If humans are the cause of the current mass extinction, why has it taken so long to occur? Why didn't the mass extinction begin long ago? The answer lies in our increased rate of population growth (see Section 49.7). During the nineteenth and twentieth centuries, improvements in food production, sanitation, and health care increased human life expectancy. Our ever-increasing population consumes resources and produces wastes at an escalating rate. As global population continues to increase, so will the habitat destruction that inevitably accompanies population growth.

Study Break

1. How has habitat fragmentation affected breeding songbird populations in eastern North America?
2. What factors have increased the likelihood of desertification in southern Florida?
3. What are the consequences of the overexploitation of fish populations?
4. How do extinction rates today compare with the background extinction rate evident in the fossil record?

53.3 Biodiversity Hotspots

Given the detrimental effects of human activities on biodiversity and natural environments, conservation biologists are constantly seeking ways to minimize or reverse the damage.

Conservation Biologists Focus Their Efforts in Areas Where Biodiversity Is both Concentrated and Endangered

If we are to limit the effects of human activities and preserve biodiversity, we must know how and where biodiversity is distributed. Although species richness generally increases from the poles to the tropics within many communities (see Section 50.7), these large global patterns do not help biologists pinpoint those areas where conservation efforts will have the greatest impact.

In a survey published in 2000, Norman Myers of Oxford University and his colleagues in England and the United States pinpointed 25 **biodiversity hotspots**, areas where biodiversity is both concentrated and endangered **(Figure 53.13).** As defined by the Endangered Species Act, adopted by the U.S. Congress in 1973, an **endangered species** is one that is "in danger of extinction throughout all or a significant portion of its range." (Species that are likely to become endangered in the near future are designated as *threatened*.) Thus, to qualify as a biodiversity hotspot, an

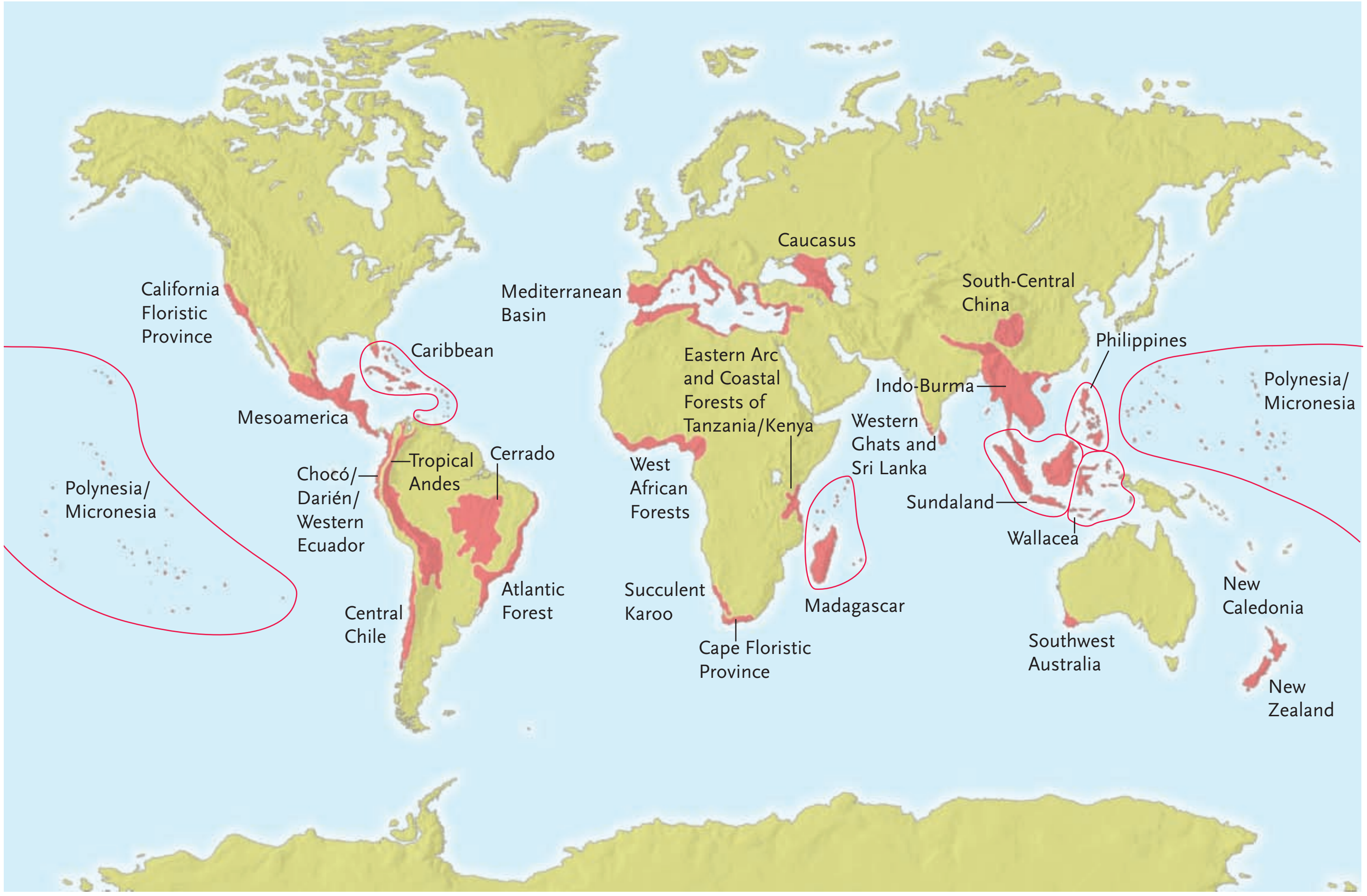


Figure 53.13
Biodiversity hotspots. Norman Myers and his colleagues identified 25 places that harbor many endemic species that are threatened by human encroachment.

area must harbor a large number of **endemic species** (those that are found nowhere else), and it must have already lost much of its natural vegetation to human encroachment.

Endemic species tend to have highly specific habitat or dietary requirements, low dispersal ability, and restricted geographical distributions. Myers used the number of endemic species as a criterion for identifying hotspots because locally distributed species account for much of Earth's biodiversity; and if the local habitats where these species occur are at risk of development, the species are also at risk. Although the 25 hotspots occupy only 1.4% of Earth's land surface, they include the only remaining habitat for approximately 45% of all terrestrial plant species and 35% of all terrestrial vertebrate species.

Sixteen of the 25 hotspots are in the tropics, where humans have already cut much of the natural vegetation. For example, until the mid-1900s, the Brazilian Atlantic Forest stretched undisturbed along the southern coast of Brazil and parts of Paraguay and Argentina. Since then, 93% of the forest has been cleared for agriculture and grazing, making it one of the most endangered ecosystems on Earth. Today more than 70% of Brazil's population lives within the historical distribution of the Atlantic Forest, and most of its endemic species are threatened. Yet the Atlantic Forest still harbors more than 5% of Earth's butterfly species, 7% of the primate species, and more than 430 tree species per hectare.

Nearly all tropical islands fall within one of the designated hotspots, and 9 of the 25 hotspots are mostly or completely made up of tropical islands. As you may recall from Chapter 21, island clusters often harbor many species because their geography fosters adaptive radiations. By definition, because island-dwelling species have limited geographical ranges, their population sizes tend to be small; and small populations always face a high likelihood of extinction. Because most tropical islands also house dense human populations, it is not surprising that they are well represented on the hotspot list.

Study Break

1. What criteria do ecologists use to identify biodiversity hotspots?
2. Why are conservation biologists especially concerned about the rapid rate of deforestation in the tropics?

53.4 Conservation Biology: Principles and Theory

Conservation biology is an interdisciplinary science that focuses on the maintenance and preservation of biodiversity. Conservation biologists use theoretical concepts from systematics, population genetics, behavior, and ecology to develop ways to protect threatened wildlife. We introduce theoretical aspects of conservation biology in this section and practical applications in the next.

Systematics Organizes Our Knowledge of the Biological World

To develop a conservation plan for any habitat, scientists must start with an inventory of its species. Their primary tool is systematics, the branch of biology that discovers, describes, and organizes our knowledge of biodiversity (see Chapter 23).

Cataloguing the diversity of life may be the most daunting task that biologists face. After more than 200 years of work, systematists have described and named approximately 1.6 million species. However, they realize that this number represents only a fraction of existing species.

In 1982, Terry Erwin of the Smithsonian Institution studied beetle biodiversity at the Tambopata National Reserve in Southern Peru. He sprayed biodegradable insecticide into the canopy of one large tree and collected 15,869 individual beetles, which he sorted into 3429 species. More than 90% of the individual beetles he collected belonged to species that had not yet been described. Erwin used this astounding result and a complex mathematical model to predict that approximately 30 million species currently exist.

Nigel Stork of the Natural History Museum in London later questioned Erwin's conclusions. Using additional data and a modified set of assumptions, he estimated that the actual number of living species was closer to 100 million. If his figure is correct, more than 98% of species—most of them arthropods, nematodes, bacteria, and archaeans—are still unknown to science. Regardless of whether biodiversity encompasses 30 million species or 100 million, systematists clearly have much work to do.

Recently, conservation biologists and systematists have begun to develop a new technology that will simplify the identification of species in the field, thereby facilitating the creation of a catalog of biodiversity. *Insights from the Molecular Revolution* describes the effort to develop a "DNA barcode scanner."

Population Genetics Informs Strategies for Species Preservation

When populations are reduced to small size, genetic drift inevitably reduces their genetic variability (see Section 20.3) and the evolutionary potential to adapt to changing environments. Thus, the loss of even a small fraction of a species' genetic diversity reduces its survival potential. To avoid this problem, conservationists strive not only to increase the population sizes of threatened or endangered species but to maintain or increase their genetic variation, both within and between populations.

For example, the whooping crane *(Grus americana)* was once an abundant bird in wet grassland environments through much of central North America **(Figure 53.14).** By the early 1940s, excessive hunting and habitat destruction had caused their numbers to decline to just 21 individuals in two isolated populations. This population bottleneck and the resultant loss of genetic variability apparently contributed to developmental deformities of the spine and trachea that had not been seen previously.

During the 1970s, biologists began an aggressive conservation program. In addition to preserving habitats in the crane's summer and winter ranges, they initiated a carefully controlled captive breeding program designed to minimize the effects of inbreeding. Although more than 300 whooping cranes now survive in several wild and captive populations, recent research reveals that they still have a remarkably low level of genetic variability. As expected, the genetic effects of a severe population bottleneck may persist long after a population begins to increase in size.


Brian K. Miller/Animals, Animals—Earth Scenes

Figure 53.14 **Whooping cranes.** Endangered whooping cranes *(Grus americana)* winter in the Aransas National Wildlife Refuge in Corpus Christi, Texas.

INSIGHTS FROM THE MOLECULAR REVOLUTION

Developing a DNA Barcode System

Everyone is familiar with the checkout scanners at supermarkets and other stores. The cashier quickly passes an item's barcode over the scanner, and the register identifies it and records its price. The system works because the barcode on every item contains unique identifying information. Some biologists have proposed an analogous method, called DNA barcoding, for identifying animal and plant species quickly and accurately. The researchers envision using a handheld device to rapidly analyze DNA in the field; the resulting data would be sent to a database by cell phone, and minutes later an identification and a description of the species would appear on the instrument's screen.

While the analytical device is not yet ready for use in the field, DNA barcoding is now being tested. This technique is the brainchild of Paul Hebert, a population geneticist at the University of Guelph, Ontario, Canada. His idea has caught on, and in 2004 a consortium of major natural history museums and herbariums started the Barcode of Life Initiative, with the goal of creating a database of DNA barcodes linked to specimens already identified in their collections. The approach potentially could replace the traditional methods of systematic analysis using organismal and genetic characters to identify species.

Hebert proposed using the first part of the *COI* (cytochrome oxidase 1) gene—a sequence of about 500 nucleotides—as the DNA barcode to distinguish animal species. This mitochondrial gene tends to vary greatly between species. Moreover, it appears to have no inserted or deleted DNA segments in most animal species, making the alignment and comparison of sequences straightforward. Hebert's hope is that any *COI* gene sequence obtained in the field will provide a unique identifier for the species from which the DNA sample was obtained.

Early tests of Hebert's barcode approach have been promising. He and his collaborators first analyzed the *COI* gene sequence in the skipper butterflies of Costa Rica. Although adult skippers look pretty much alike, their caterpillars vary in appearance and in their food plant preferences, leading researchers to wonder if butterflies that had been assigned to one species *(Astraptes fulgerator)* might actually represent several. Analyses of the *COI* gene sequence sampled from 484 adults allowed Hebert and his colleagues to identify 10 distinctive DNA barcodes, suggesting that there are at least 10 species of skipper in Costa Rica rather than just one.

In early 2007, Hebert and his colleagues reported that they had used the DNA barcode to analyze 2500 specimens of 643 North American bird species. The results were impressive: barcode differences between species were an order of magnitude greater than the differences within species, allowing the unambiguous identification of species from a short DNA sequence. Interestingly, the barcode analysis identified 15 probable new species that had not been previously identified and revealed that 8 supposed species of gull may be variants of just one species.

Taken together, the results of the two research studies provide support for the use of DNA barcodes, and for using the *COI* gene sequence specifically for the barcode analysis, as a means of identifying animal species.

Can DNA barcodes be used to identify plant species? The mitochondrial *COI* gene sequence used for barcoding animals is not suitable for barcoding plants because the gene has evolved much more slowly in plants and therefore exhibits less variability among species. However, in 2005, researchers reported on a study that used two different DNA sequences, one from the nuclear genome and the other from the chloroplast genome, to barcode flowering plants. Trials involving 53 plant families, with a total of 99 species from 80 genera, suggested that the two sequences could distinguish a large number of flowering plant species, making barcoding of flowering plants a feasible proposition.

Despite these early successes, many skeptics believe that DNA barcoding will prove to be inaccurate and may, in fact, produce false conclusions about species designations and incorrect counts of biodiversity. The skeptics argue that the approach has not been tested sufficiently in closely related species, which may exhibit only small differences in the barcode sequence. They also point out that the assumption that organisms have a fixed genetic characteristic—like the barcodes on items at the supermarket—contradicts fundamental ideas about genetic variability that are at the core of contemporary evolutionary theory. The DNA barcoding efforts continue nonetheless, and new data will continue to fuel the debate between the supporters of this approach and the naysayers.

Studies of Population Ecology and Behavior Are Essential Elements of Conservation Plans

Conservation programs also require data about target species' ecology and behavior, including their feeding habits, movement patterns, and rates of reproduction.

Sea otters *(Enhydra lutris)* are predatory marine mammals that live along the coastline of the North Pacific Ocean. In the early 1700s, they numbered approximately 300,000 individuals **(Figure 53.15),** but commercial hunting reduced their numbers to about 3000 individuals by the start of the twentieth century. Sea otters are keystone predators (see Section 50.4), and the destruction of sea otter populations had profound effects on the communities in which they lived. As the numbers of sea otters plummeted, populations of sea urchins, one of their favored prey, exploded; burgeoning sea urchin populations decimated local kelp

a. Sea otter

b. Geographical range of sea otters

Figure 53.15
Sea otters. After being hunted nearly to extinction, **(a)** sea otters *(Enhydra lutris)* have been reintroduced in many parts of their historical range **(b).**

beds, disrupting the communities of animals that live among these giant algae.

International treaties ended nearly all hunting of sea otters in 1911, and the populations subsequently recovered to about one-third of their original levels. Conservation biologists facilitated the recovery by reintroducing otters into southeastern Alaska, British Columbia, Washington, and California. Before deciding where otters should be reintroduced, scientists had to assess the resources available at different sites and determine how far individual otters would move, how rapidly they would reproduce, and how quickly their populations would spread. The reintroduction effort was successful at first. However, populations in California have experienced high mortality since the mid-1990s, and nearly half of those dying have been adults in their reproductive prime. Researchers have identified parasitic infections and heart disease as leading causes of death, suggesting that some coastal environments are so badly degraded that they may no longer support populations of this species.

Given the complexities of the ecological relationships in natural communities and ecosystems, conservation biologists have developed two sophisticated types of population analysis, *population viability analysis* and *metapopulation dynamics,* to design effective conservation plans.

Population Viability Analysis. Using complex mathematical models, conservation biologists can conduct a **population viability analysis** (PVA) to determine how large a population must be to ensure its long-term survival. PVAs evaluate phenomena that may influence the longevity of the population or species: habitat suitability, the likelihood of catastrophic events, and other factors that may cause fluctuations in demographics, population size, or genetic variability. When conducting a PVA, researchers must decide what level of risk is acceptable for a given survival time. For example, should a conservation plan attempt to ensure a 95% probability that the species will survive for 100 years, or should it specify a 99% survival probability? An increase in either the survival probability or the survival time requires an increase in the size of the population that must be conserved. The **minimum viable population size** identifies the smallest population that fits the desired specifications of the conservation plan. *Focus on Research* describes how biologists used PVA in the conservation of an Australian marsupial, the yellow-bellied glider.

Metapopulation Dynamics. In many species, individuals move frequently from one local population to another. To describe the dynamics of such movements, ecologists define a **metapopulation** as a group of neighboring populations that exchange individuals. Local populations within a metapopulation are not all equal: they often differ in size, population growth rates, the suitability of their habitats, their exposure to predators, and other factors. Moreover, some may decline steadily in size, while others may increase.

Under favorable circumstances, a population may produce numerous offspring, some of which emigrate and join nearby populations, where they breed, providing a genetic connection between local populations (see the discussion of gene flow in Section 20.3). Thus, dispersal and gene flow between local populations maintain the metapopulation.

Populations that are either stable or increasing in size are described as **source populations** because they are a possible source of immigrants to other populations. Those that decline in size are called **sink**

Focus on Research

Applied Research: Preserving the Yellow-Bellied Glider

Predicting the future is never easy, especially the future of a threatened species. But population viability analysis (PVA) allows conservation biologists to predict how a species will fare under a range of possible scenarios. An effective PVA for an animal species requires detailed information about its diet, predators, mating habits, habitat preferences, space requirements, demography, geographical distribution, responses to climatic fluctuations and human disturbances, and a host of other aspects of its biology.

The Australian yellow-bellied gliding marsupial, *Petaurus australis,* better known as the yellow-bellied glider, provides an example of how PVA is essential for a conservation effort. This mammal, about the size of a squirrel, lives in small family groups in undisturbed *Eucalyptus* forests along Australia's eastern coast. Each glider family maintains a home range (the area it uses for feeding and other activities) of 25 to 85 hectares; the home ranges of neighboring families do not overlap. As a result, the population density of gliders has never been high. But glider populations have declined precipitously as forests have been cleared, and the species is now considered threatened.

Using data from nearly 20 published papers, two Australian conservation biologists, Russ Goldingay of the University of Wollongong and Hugh Possingham of the University of Adelaide, conducted a PVA for this species. They estimated age distributions in glider populations as well as survival probabilities, litter sizes, sex ratios, lifespan, and home range sizes. They analyzed these data using a mathematical model that predicts the viability for populations of various sizes. In most PVAs, a population is considered viable if it has a 95% probability of surviving for 100 years. Goldingay and Possingham introduced additional complexity to their analysis by assessing the effects of unpredictable environmental events, such as drought, on breeding success. They also conducted sensitivity analyses to examine how changing the values of specific parameters—such as litter size, mortality rates of the different age classes, or the frequency and severity of droughts—might influence the general predictions of the viability model.

Once Goldingay and Possingham had completed many thousands of these calculations, they concluded that a viable population of gliders would require at least 150 family groups. They also suggested that a population of that size would need approximately 18,000 hectares (roughly 70 square miles). Currently, only 1 of the 15 existing conservation reserves is that large.

Goldingay and Possingham did not factor some common environmental disturbances—fire, disease, or predation by introduced species—into their analyses. Such disturbances could decimate a small glider population in short order. Thus, the outlook for gliders may be bleaker than the researchers suggest, because their estimates of minimum viable population size and minimum necessary habitat size are almost certainly too low. Given only this information, we might predict that the glider will inevitably become extinct.

However, there is some hope for the yellow-bellied glider. Goldingay and Possingham assumed that gliders don't move between populations, a behavior that promotes gene flow. They ignored this aspect of metapopulation dynamics because they had no data on gene flow in this species. The movement of individuals between populations could reduce the required minimum viable population size by decreasing the likelihood of genetic drift and the extinction of local populations. Biologists may even be able to transplant gliders from one population to another, effectively creating source and sink populations. This procedure might increase population size and genetic diversity in the most endangered populations. If successful, such an approach could stave off extinction.

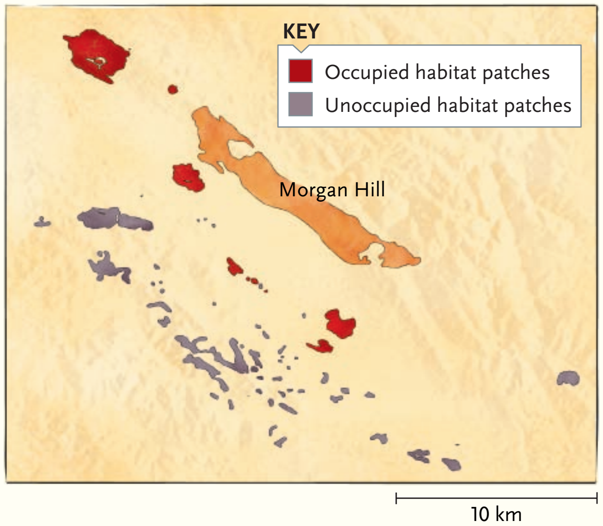
As a result of this PVA, conservation biologists can determine which of the remaining forest tracts are large enough to sustain a yellow-bellied glider population. Thus, they now know where to concentrate their limited resources to secure the future survival of this species. Although predicting the future is difficult, PVAs allow conservation biologists to make accurate and reliable recommendations for selective transplants that will contribute to the conservation of threatened species.

Jean-Paul Ferrero/Anscape/ardea.com

Figure 53.16 Observational Research

Metapopulation Structure of the Bay Checkerspot Butterfly

Map of serpentine habitat patches near Morgan Hill



HYPOTHESIS: Populations of the bay checkerspot butterfly *(Euphydryas editha bayensis)* living on small patches of suitable habitat are "sink" populations that frequently become extinct. Populations in large habitat patches can serve as a "source" of individuals to recolonize small habitat patches nearby.

PREDICTION: Because the bay checkerspot butterfly is a weak flyer, small patches of suitable habitat that are close to a large source population will be recolonized frequently. Patches of suitable habitat that are far from a large source population will be recolonized only rarely.

METHOD: Susan Harrison, Dennis D. Murphy, and Paul R. Ehrlich of Stanford University surveyed 59 small patches of serpentine grassland near San Jose, California, in 1986 and 1987. They estimated each patch's "quality" based on the presence or absence of food plants on which bay checkerspots depend and on aspects of the physical environment that are important to these butterflies. They also measured each patch's distance from Morgan Hill, a very large patch of suitable habitat that had sustained a bay checkerspot population for years. In patches where they found butterflies, they estimated bay checkerspot population sizes.

RESULTS: A complex statistical analysis revealed that both distance from the Morgan Hill population and habitat patch quality were important factors in determining whether bay checkerspots would be present or absent in a small habitat patch. The authors noted that only the nine high-quality habitat patches near Morgan Hill (red on the map) were occupied by bay checkerspots. Of 50 unoccupied habitat patches, 6 were near Morgan Hill but of low quality; 18 were of high quality but far from Morgan Hill; and 26 were too far from Morgan Hill and of too low quality to support a population of bay checkerspots.

CONCLUSION: Populations of bay checkerspot butterflies that occupy large patches of suitable habitat serve as source populations for individuals that recolonize small patches of suitable habitat where butterfly populations frequently become extinct. However, because the bay checkerspot is a weak flyer, it recolonizes small patches of suitable habitat only if they are close to a source population.

populations because they represent a drain on the supply of available immigrants. Individuals usually move from source populations to sink populations, and sink populations persist because they receive immigrants from source populations in the metapopulation.

The bay checkerspot butterfly, *Euphydryas editha bayensis* **(Figure 53.16),** provides an example of metapopulation dynamics. This species is restricted to serpentine grassland in the San Francisco Bay area (see Figure 50.18) because its larvae eat plants that grow only in that community. Human disturbance has fragmented much of the butterfly's natural habitat into patches of varying size, each of which may support a local butterfly population. The life cycle of these butterflies is always a race against time, because the larvae must feed and mature before dry summer weather kills their food plants. Populations in small patches often become extinct, but those occupying larger patches, where food plants stay alive longer, generally survive the seasonal drought. Butterfly populations in larger habitat patches therefore serve as source populations for emigrants that repopulate small habitat patches the following year. But the bay checkerspot is a poor flyer, and it cannot disperse long distances. Thus, small patches of suitable habitat harbor bay checkerspots only if they are close to a larger patch that serves as a source. A conservation plan for this butterfly would therefore aim to preserve habitat patches of sufficient size to serve as sources for nearby smaller patches.

Community and Landscape Ecology Help Large-Scale Preservation Projects

Many conservation efforts focus on the preservation of entire communities or ecosystems. These projects often depend on the work of community and landscape ecologists.

Species/Area Relationships. As you know from Chapter 50, community composition is dynamic: some species become extinct and others join the community

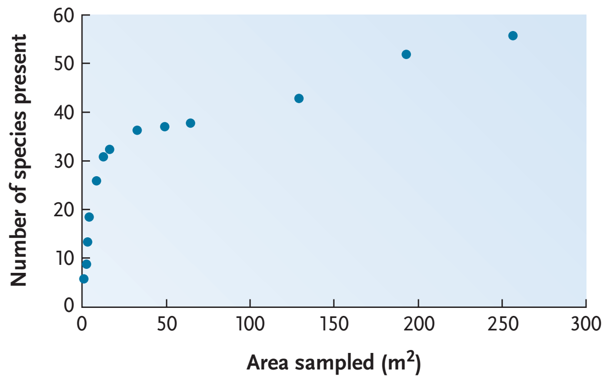


Figure 53.17 **The species/area relationship.** Data on plant distributions in Quarry Meadow in Austin, Texas, illustrate the relationship between habitat area and number of species present.

through immigration. If we view fragmented patches of intact habitat as islands in a sea of unsuitable terrain, we can apply the predictions of the theory of island biogeography (see Section 50.7) to the design of protected areas. For example, we might expect that the number of species a patch will support depends on its size and proximity to larger patches.

Indeed, ecologists recognized long ago that large habitat patches sustain more species than small patches do **(Figure 53.17).** When plotted on an arithmetic scale, the relationship between species richness and habitat area increases sharply at first and then flattens. In other words, for relatively small habitat patches, even minor increases in area allow a large increase in the number of resident species; but as habitat patches get larger, the number of species present eventually levels off. You encountered an example of this relationship in our discussion of bird species richness on islands of different sizes (see Figure 50.30b).

As habitats become increasingly fragmented, edge effects exaggerate the species/area relationship in mainland habitat patches **(Figure 53.18).** Consider two hypothetical patches of habitat: one is 100 m on a side, with a total area of 10,000 m^2; the other is 200 m on a side, with a total area of 40,000 m^2. Now, imagine that edge-effect disturbances penetrate 20 m into each patch from all directions. The small patch contains only 3600 m^2 of intact habitat, but the large patch contains 25,600 m^2 of intact habitat. Although the large patch is only four times larger than the small patch, the large patch contains more than seven times as much *intact* habitat.

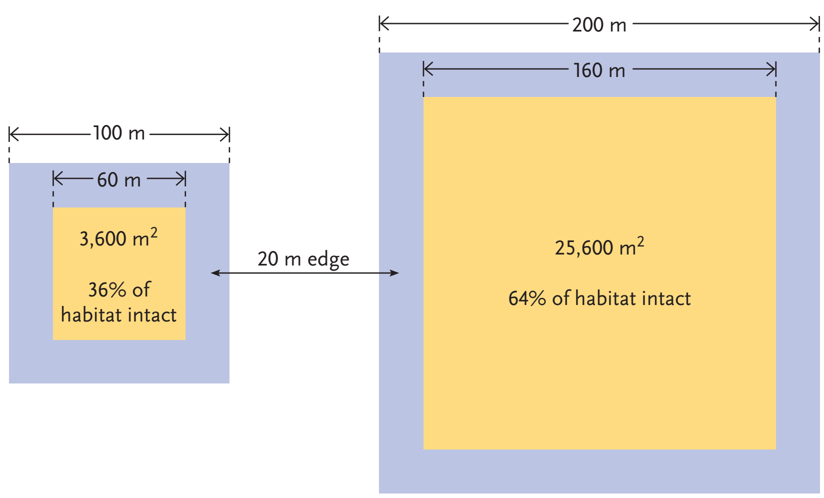


Figure 53.18 **Edge effects and patch size.** This hypothetical example illustrates how a 20 m wide edge disrupts a larger fraction of a small habitat patch than a large habitat patch.

Landscape Ecology. Researchers in the field of **landscape ecology** determine how large-scale ecological factors—such as the distribution of plants, topography, and human activity—influence local populations and communities. Knowing that larger protected areas will preserve more species, conservation biologists have debated whether nature preserves should comprise one large habitat patch or several smaller patches. Ecologists identify this debate with the acronym **SLOSS** (*S*ingle *L*arge *O*r *S*everal *S*mall). Jared Diamond of the University of California, Los Angeles, initiated the SLOSS debate in 1975. Applying the lessons of island biogeography, Diamond concluded that a single large preserve was preferable to several smaller ones, even if they encompassed an equivalent area.

Conservation biologists have since concluded that no single design is best for all organisms. For large animals, such as predatory cats, one large preserve may be best, because individuals must patrol large areas to search for food. For smaller animals, such as insects, several small preserves, each providing a slightly different environment that supports one population, is preferable; if a population in one preserve becomes extinct, individuals from elsewhere in the metapopulation can recolonize the area.

Diamond also suggested that small preserves would function better if corridors of intact habitat connected them. Individuals could move between preserves, reviving any local populations that experienced a decline. These landscape corridors might effectively join the smaller constituent populations into one larger population, which would avoid some of the genetic difficulties encountered by small populations.

However, some conservation biologists argued that landscape corridors connecting small preserves may actually threaten biodiversity. Corridors are usually narrow and thus subject to strong edge effects. In some environments, they are drier and more susceptible to fires that could spread into the preserves they connect. Corridors might also provide entry points for exotic species and disease-causing organisms. Finally, species that don't enter habitat edges would be unlikely to use the corridors at all.

Ellen I. Damschen of North Carolina State University and several colleagues conducted an ambitious long-term field experiment on the effect of landscape corridors on plant species richness **(Figure 53.19).** Their results, published in late 2006, suggest that habitat patches connected by corridors retain more native plant species than isolated patches and that corridors did not promote the entry of exotic species. Thus, based on limited experimental evidence, corridors appear to be a useful feature in the design of nature preserves.

Landscape corridors may also allow large animals to move freely between patches of suitable habitat. For example, the Florida panther *(Puma concolor coryi)*, shown on page 1229, is critically endangered: only 70 to 100 individuals of this subspecies remain from a population that once ranged throughout the southeastern United States; other panther subspecies still inhabit the western states. Panthers are large predators, and each female requires nearly 20,000 hectares (more than 75 square miles) for hunting and breeding; males each require more than twice as much space.

Although the state and federal governments have set aside several panther conservation areas in Florida, 52% of the habitat panthers occupy is privately owned, and most of it is highly fragmented. Panthers frequently cross roads, and most panther deaths in Florida are caused by accidents with motor vehicles. Protected landscape corridors might enable panthers to move more safely between conservation areas. A preliminary study found that panthers already use such corridors, typically along wooded riverbanks, when they are available. The Florida Fish and Wildlife Service has proposed the creation of an ambitious 6100-hectare network of such corridors alongside the Caloosahatchee River to link several significant habitat fragments in neighboring counties.

Study Break

1. How does a population bottleneck change the likelihood that a species will become extinct?
2. How does a population viability analysis assist in the development of a conservation plan for a species?
3. Would a single large nature preserve or several small preserves experience greater edge effects?

53.5 Conservation Biology: Practical Strategies and Economic Tools

Conservation biology seeks to protect native species, communities, and ecosystems from the effects of human activity. Meeting that goal and reversing some of the existing damage requires the integration of biological research with economic and social realities.

Conservation Efforts Aim to Preserve, Conserve, and Restore Habitats

Conservation groups often highlight efforts to preserve individual animal species, such as the giant panda *(Ailuropoda melanoleuca)* or California condor *(Gymnogyps californianus)*. The preservation of "charismatic megavertebrates," as these large animals are sometimes described, attracts substantial public support. Nonetheless, there is little point in trying to preserve natural populations of individual species if their habitats are in jeopardy. An alternative to species-based conservation focuses on the preservation of intact habitats; individual species are conserved as a consequence of preserving the habitats on which they depend. Conservation biologists approach this goal with a continuum of approaches, which fall into three general categories: *preservation, mixed-use conservation,* and *restoration*.

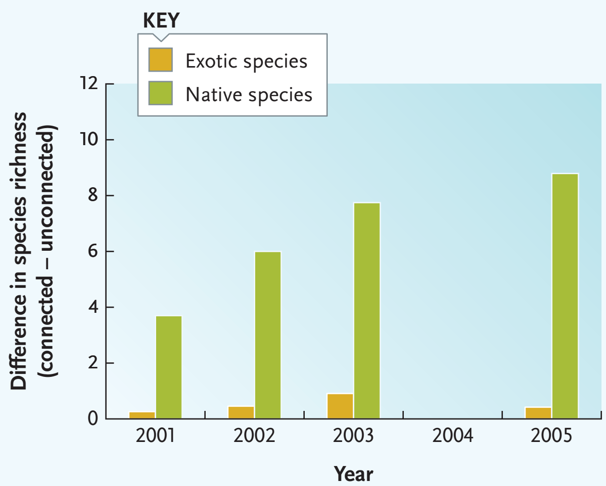
Figure 53.19 Experimental Research

Effect of Landscape Corridors on Plant Species Richness in Habitat Fragments

QUESTION: Do landscape corridors connecting habitat patches influence the species richness of native and exotic plants within the habitat patches?

EXPERIMENT: Damschen and her colleagues studied changes in the community composition and species richness of the plants in open habitat patches within a longleaf pine *(Pinus palustris)* forest in South Carolina. Their experimental design included both isolated patches and patches that were connected to one another by a landscape corridor. All patches included the same land area, and their large size (1.375 ha each, including the landscape corridors) allowed the researchers to make a realistic assessment of the effects of landscape corridors. After creating the patches of open habitat within the forest in 2000, the researchers catalogued all plant species occurring in the patches through 2005, although they were unable to collect data in 2004.

RESULTS: Over the course of the study, habitat patches that were connected by landscape corridors harbored increasingly more plant species than did isolated habitat patches. The researchers also noted that the difference in species richness between the two experimental treatments was caused by a difference in the number of native plant species present. The number of exotic species in connected and isolated habitat patches was similar.



CONCLUSION: Landscape corridors between patches of open habitat in longleaf pine forests increase the species richness of native species in open habitat patches, but they do not foster the entry of exotic species.

a. Albany Pine Bush

Darlene Bordwell

b. Karner Blue butterfly

Ruth Cole/Animals, Animals—Earth Scenes

Figure 53.20
The Albany Pine Bush habitat. **(a)** The Pine Bush lies entirely within the city limits of Albany, New York. It is home to about 50 threatened or endangered plant and animal species, including **(b)** the Karner Blue butterfly *(Lycaeides melissa samuelis)*.

Conservation through Preservation. In many countries, habitats are preserved when an individual or organization purchases them and enforces strict standards of land use. In sensitive habitats, people may be excluded altogether; in other cases, access is restricted and the exploitation of resources is controlled. This approach works well in countries with efficient law enforcement and a tradition of private land ownership. In the United States, for example, the Nature Conservancy has purchased large tracts of land to preserve native species.

The preservation approach has been successful in preserving portions of the Pine Bush habitat near Albany, New York **(Figure 53.20).** This unique ecosystem arose approximately 11,000 years ago at the end of the last glacial period, when a massive deposit of sand was left near the western margin of Albany's current city limits. This sandy region formed an inland pine-barrens habitat in which pitch pine *(Pinus rigida)*, scrub oak *(Quercus ilicifolia)*, and dwarf chestnut oak *(Quercus prinoides)* are now the dominant vegetation. The Pine Bush is home to more than 50 plant and animal species that the state and federal government list as threatened or endangered. The habitat itself was once vulnerable because it lies within Albany's city limits; however, since 1988, the Pine Bush has been jointly owned and protected by New York state, local municipalities, and the Nature Conservancy.

Figure 53.21
Mixed-use conservation. The Maasai use the Ngorongoro Conservation Area to graze cattle and goats.

Brian K. Miller/Animals, Animals—Earth Scenes

Mixed-Use Conservation. The preservation approach does not work under all circumstances. Where outright preservation is impractical, conservation biologists advocate mixed-use conservation, which combines the protection of some land parcels with the controlled development of others.

The Ngorongoro Conservation Area (NCA) in Tanzania provides an example of mixed-use conservation. The NCA covers 829,000 hectares of grassland and borders the Serengeti National Park. Because it houses a high concentration of wildlife, the NCA is one of the most heavily visited tourist destinations in eastern Africa. For the past several hundred years, the Maasai people have herded cattle, goats, and sheep in the Serengeti and Ngorongoro **(Figure 53.21).** The Maasai are nomadic pastoralists who frequently move their relatively small herds to new grazing areas in the region. As a result, their activities do not degrade the land or exclude native wildlife. In 1959 the Maasai agreed to vacate the Serengeti, which was converted into a national park, in return for retaining the rights to live and herd livestock within the NCA. The government of Tanzania helped create the necessary infrastructure within the NCA, including a constant water supply as well as social services. Under this agreement, 40,000 indigenous residents, most of them Maasai, live in this large and valuable conservation area.

Conservation through Restoration. Conservation biologists sometimes create restoration plans to reestablish the vitality of a previously disrupted community or ecosystem. This effort requires the removal of contaminants, impediments to the natural flow of water, and barriers to animal movement as well as the restoration of natural processes, such as periodic fires or floods. Most restoration projects also require replanting key plant communities and long-term management once restoration is complete.

Not all degraded habitats can be restored, and not all potential restoration projects are equally feasible. When making project decisions, restoration ecologists consider a number of factors: Will the restored habitat be suitable for rare or endangered species, and will its creation increase endemic biodiversity? Would the restoration reunite previously fragmented land parcels? Will the restored habitat experience the periodic disturbances, such as fires or floods, that are essential for its continued existence? What are the costs of implementing the plan and maintaining the area? Finally, would the restored land be valued by local residents, and will they support and maintain it?

A successful restoration project is currently underway in the Brazilian Atlantic Forest, sponsored by the Instituto de Pesquisas Ecológicas (IPÊ), a Brazilian nongovernmental organization. In western São Paulo state, near the Morro do Diabo state park, IPÊ is trying to recreate the natural Brazilian Atlantic Forest ecosystem by planting native trees in habitat corridors between remaining forest fragments. These corridors of native tree species should facilitate the preservation of species in those forest patches and supply valuable botanical resources for endemic wildlife and local residents.

Successful Conservation Plans Must Incorporate Economic Factors

Biologists can almost always develop a plan to conserve a species, community, or ecosystem. But to be successful, a plan must be economically feasible, and it must provide direct benefits to local residents whose lives it will affect.

Local Involvement. Early conservation efforts simply set aside protected areas in which most human activities were banned. Local people were denied access to resources within the preserve—resources that were sometimes essential for their survival. Not surprisingly, these plans generated antipathy towards conservationists and the organisms they were trying to preserve.

For example, the northern spotted owl *(Strix occidentalis caurina)* lives only in old growth coniferous forests of the Pacific Northwest, where many local residents worked in forestry or supporting industries. The suggestion that the owl be listed as an endangered species triggered a bitter political battle between conservationists and local residents because the conservation plan for the owls required closing large tracts of forest to logging. Washington State listed the owl as an endangered species in 1988, but local residents, who lost jobs when logging was reduced, remain hostile to these conservation efforts.

Conservation plans are more successful if they provide local residents with benefits that depend on the existence of a preserve. Royal Chitwan National Park provides an excellent example. For more than 100 years, this area, located in south central Nepal near the northern border of India, was a privately owned "preserve" used for big game hunting by royalty. These activities decimated local populations of large mammals, especially the Bengal tiger *(Panthera tigris)* and one-horned or Indian rhinoceros *(Rhinoceros unicornis)*. Populations of both species dwindled to approximately 100 individuals by the mid-1960s. The area was subsequently opened for settlement, and, as immigrants swarmed into the fragile grassland, its human population exploded.

The area was converted into Royal Chitwan National Park in 1973. Today, humans are excluded from the park for most of the year. But each January, after the monsoon rains end and the grasses have dried, local residents are welcomed into the park for their annual harvest festival. They cut the grass and carry it away to thatch roofs, make mats, and feed domestic animals **(Figure 53.22).** The local people value Chitwan and argue for its preservation. Today, more than 600 one-horned rhinos survive in Nepal, most of them in Royal Chitwan National Park. And the Bengal tiger population of Chitwan has increased to approximately 250 individuals.

Ecotourism. In some preserves, governments enlist local residents in park development and operations, providing them with a viable livelihood. The most successful approach has been the development of **ecotourism,** in which visitors, often from wealthier countries, pay a fee to visit a nature preserve. Local people work as guides, cooks, and logistical and support staff.

Not everyone agrees that ecotourism is helpful. Critics note that increased human traffic may degrade habitats, and unregulated ecotourism can eventually lead to overdevelopment. For example, several million people visit national parks in the western United States annually. Traffic jams, automobile accidents, and long lines routinely plague visitors at the most popular sites. Cranky ecotourists call for the construction of more roads and parking lots, which are inconsistent with the purpose of a national park because cars increase local air pollution and occasionally kill wildlife. In 2006, the government began charging a $20 fee for each automobile entering Yosemite Na-

Ed Degginger/Color-Pic

Figure 53.22 Conservation and the local economy. Local residents support conservation efforts at the Royal Chitwan National Park, Nepal, because officials open the park for a grass harvest each year.

tional Park in California, hoping to limit the number of visitors arriving in private vehicles and to increase reliance on public transportation.

Countrywide Economic Approaches. In the mid-1990s, conservation biologists and economists developed the concept of **ecosystem valuation,** in which ecosystem services—such as carbon dioxide processing or water retention and purification, which are best provided by intact ecosystems—are assigned an economic value. These estimated values are used to negotiate contracts in which a private company or conservation organization pays a community, state, or country to maintain intact ecosystems. By one 1997 estimate, the gross global ecosystem valuation is roughly 18 trillion U.S. dollars per year. If less obvious benefits provided by nature are tallied—soil formation, crop pollination, and nutrient cycling—the total value of ecosystem services rises to 33 trillion U.S. dollars—almost twice the value of all goods produced by all humans on the planet!

The implementation of ecosystem valuation exchanges is determined on a case-by-case basis, depending on what ecosystem services the paying organization wants to preserve. Costa Rica is leading the way in this effort by creating valuation contracts with several corporations. For example, in 1998, the Monteverde Conservation League signed a contract with a local electrical company to ensure the continued flow of water from the Bosque Eternal de los Niños, a forest preserve. The company had plans to build a hydroelectric dam on the Rio Esperanza, and feared that deforestation upstream would disrupt water flow through the dam. The contract specifies that the electrical company will pay the people who live upstream to preserve their forests rather than cutting them.

Unanswered Questions

Are there general patterns in networks of interacting species? What causes those patterns, and what are their consequences for biodiversity conservation?

Biodiversity is a buzzword referring to the diversity of life at its different levels of organization—from molecules and genes to organisms and ecosystems. The term describes not only the component parts but also the way the parts are assembled and how they function. In any ecosystem, organisms interact with each other through a variety of beneficial and detrimental interactions. Ecologists usually describe and summarize these complex interactions as *networks,* in which species are represented as nodes and interspecific interactions as links. Ecologists have long sought to uncover the emergent properties of interaction networks, their causes, and their consequences.

Some early theoretical models of food webs (networks depicting who eats whom in an ecosystem) suggested that species-rich, highly connected networks would be less stable than smaller, simpler networks. This finding astounded many ecologists because it contradicted a widely accepted hypothesis that larger, more complex food webs were more stable and thus more resistant to disturbance, such as invasions by exotic species. Supporters of the "complex food webs are more stable" hypothesis noted that many large, complex food webs—such as those in tropical forests—exist in nature, and their persistence over time had to be explained.

Later theoretical research suggested that the solution to the contradiction might lie in the strength of species interactions (that is, the impact that one species has on others). Food webs with a few very strong interactions and many weaker ones tend to be more stable than food webs with many interactions of medium strength. In other words, food webs that include one or two keystone species tend to be more stable than those without keystone species. Further research has revealed that many real food webs include a few strong interactions and many weaker ones, but ecologists still do not know what factors determine interaction strength and why we often observe only a few strong interactions and many weak ones.

For many years, research on ecological interaction networks has focused almost exclusively on food webs—that is, on predator–prey interactions. More recently, however, other types of interactions (including those between plants and their mutualistic pollinators and seed dispersers, or between hosts and their parasites) have started to receive more attention. This new research has uncovered some intriguing general patterns. For example, mutualistic networks include asymmetric interactions of two general types: (1) species that have few links to other species ("specialists") tend to interact with species that have many links to other species ("generalists"); and (2) species that exhibit weak interactions tend to be associated with species that affect them strongly. These two types of asymmetry in mutualistic networks seem to result from the fact that only a few species have many links and only a few interactions are strong. As was the case for the analysis of food webs, the unresolved issue is *why* only a few species have many links or have strong interactions.

Answering these questions is important not only because they improve our understanding of the complexity of ecological systems, but also because they may have important implications for biodiversity conservation. For example, the widespread existence of asymmetric interactions makes interaction networks highly resistant to perturbations (such as habitat modification and species invasions) that could result in the local extinction of some species. The removal of highly linked species with strong interactions will affect many other species in the community, but because most species have few links and weak interactions, most extinctions will have only minor effects on the overall structure and functioning of the network.

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Thus, both the forests and water flow are preserved, maintaining the forest ecosystem and generating badly needed electricity.

Biodiversity is a precious resource that is disappearing rapidly throughout the world. It can still be conserved through a monumental effort to catalog the diversity of living organisms and develop an understanding of their ecological relationships. Perhaps the major challenge for conservation biologists is the education of the human population about the value of biodiversity and the development of conservation plans that will enlist the support of people who live among the threatened species.

Study Break

1. Is the Pine Bush habitat in New York State an example of preservation, mixed-use conservation, or restoration?
2. How has the establishment of the Royal Chitwan National Park in Nepal been a successful conservation effort? How do conservation biologists measure its success?
3. How can the concept of ecosystem services be used to foster conservation of threatened habitats and species?

Review

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53.1 The Benefits of Biodiversity

- Biodiversity provides direct benefits to humans because natural populations of organisms can be sources of useful natural products as well as genetic resources that can improve domesticated crops and animals (Figures 53.2 and 53.3).
- Biodiversity provides indirect benefits to humans by maintaining normal ecosystem processes, some of which help to counteract the harmful effects of human activities.
- Ethicists and environmentalists argue that biodiversity should be preserved simply because of its intrinsic worth.

53.2 The Biodiversity Crisis

- Human disruption of a habitat usually begins with the construction of a road that provides access to resources; the disruption spreads rapidly. Habitat fragmentation reduces the size of intact habitat patches, and edge effects diminish the quality of remaining habitat (Figure 53.4). Only small populations, which are subject to genetic drift and an increased likelihood of extinction, can inhabit small habitat patches.
- Deforestation is occurring at an alarming rate, especially in tropical regions (Figure 53.5). Excessive deforestation may lead to desertification and the loss of entire ecosystems (Figure 53.6). Deforestation, desertification, and global warming reinforce each other in a positive feedback cycle.
- Although pollution is released locally, it often spreads to regional and global scales, especially in bodies of water and the atmosphere (Figure 53.7). Pollution can take many forms (Figure 53.8).
- Exotic species often contribute to the extinction of native species through competition, predation, or parasitism (Figures 53.9–53.11). Humans frequently introduce exotics into communities either intentionally or inadvertently.
- Overexploitation of natural populations reduces their sizes and may induce evolutionary responses in the exploited populations (Figure 53.12).
- Although extinction has been common in the history of life, human activities have recently initiated what may be the greatest mass extinction of all time. Some biologists estimate that extinction rates today may be 1000 times the background extinction rate.

Animation: Five major extinctions

Animation: Effects of deforestation

Animation: Effect of air pollution in forests

53.3 Biodiversity Hotspots

- Biodiversity hotspots harbor large numbers of endemic species and are threatened by human activities (Figure 53.13). Although hotspots encompass only 1.4% of the land, a much larger proportion of biodiversity inhabits these areas.
- More than half the identified hotspots are in the tropics, and nearly all tropical islands are included within the hotspot designation.
- Preserving the hotspots will conserve a substantial part of Earth's biodiversity.

Animation: Global crises by region and habitat

Animation: Three types of reefs

53.4 Conservation Biology: Principles and Theory

- Conservation biology draws its theoretical foundation from systematics, population genetics, population ecology, behavior, community ecology, and landscape ecology.
- Systematists provide taxonomic inventories of biodiversity that are helpful for establishing conservation priorities.
- Conservation biologists design breeding programs to maintain or increase the genetic variability of species being preserved (Figure 53.14).
- Besides studying the population ecology and behavior of targeted species (Figure 53.15), conservation biologists use population viability analyses to determine the minimum viable population size necessary to conserve threatened species. Analyses of metapopulation dynamics can help conservation biologists understand the interactions among small populations of threatened species (Figure 53.16).
- Studies in community ecology have established the generality of the species/area effect: large habitat patches harbor more species than small habitat patches do (Figure 53.17).
- From the perspective of landscape ecology, biologists have debated the advantages and disadvantages of establishing one large reserve versus several smaller ones that are connected by habitat corridors (Figures 53.18 and 53.19).

53.5 Conservation Biology: Practical Strategies and Economic Tools

- Efforts to conserve communities or ecosystems follow one of three general strategies. *Preservation* requires the restriction or prohibition of human access to the area (Figure 53.20). *Mixed-use conservation,* an approach that balances the conflicting demands of habitat preservation and development, allows local residents to use the protected area in limited ways (Figure

53.21). *Restoration* attempts to recreate natural communities and ecosystems in places that have already been degraded by human activities.

- Conservation plans must also incorporate economic and social factors to win local support. Most conservation plans now include the involvement of local residents to generate revenue for their communities (Figure 53.22). Ecosystem valuation also encourages the preservation of ecosystems by assigning them a significant economic value.

Animation: Sustainable resource management

Questions

Self-Test Questions

1. The greatest extinction in the history of life on Earth:
   a. occurred at the end of the Permian period.
   b. occurred at the end of the Cretaceous period.
   c. occurred at the end of the Ordovician period.
   d. occurred at the end of the Cambrian era.
   e. may be occurring now.
2. Which of the following is usually the first step in the disruption of a natural habitat by humans?
   a. establishment of small villages
   b. planting of crops
   c. building of a road
   d. invasion by exotic species
   e. overexploitation of resources
3. Habitat fragmentation has damaged populations of breeding birds in North America because:
   a. the remaining habitat patches rarely contain enough food for birds to rear their offspring.
   b. the nests of birds in small habitat patches are frequently attacked by predators.
   c. pairs of breeding birds cannot easily move from one habitat patch to another.
   d. female birds cannot locate potential mates in small habitat patches.
   e. small habitat patches do not have enough edges to provide adequate hiding places.
4. Deforestation:
   a. is a problem only in the tropics.
   b. may speed desertification.
   c. is slowed by grazing and farming.
   d. permanently enriches the soil.
   e. leads to the formation of lush grasslands.
5. Chemical pollutants:
   a. can spread rapidly from the places they are released.
   b. do not appear to influence global climate change.
   c. have contributed to global mass extinctions.
   d. rarely affect natural bodies of water.
   e. rarely influence animals feeding at higher trophic levels.
6. Which of the following is most likely to be a biodiversity hotspot?
   a. a patch of forest in the middle of North America that is 500 km from the nearest big city
   b. a series of uninhabitable sand dunes in the Sahara Desert
   c. a botanical garden that houses representatives of 25,000 plant species
   d. a tropical island with many endemic species and a growing human population
   e. a suburban neighborhood where fields have been converted to backyards and playgrounds
7. Population viability analyses allow conservation biologists to:
   a. identify the source population from which an individual dispersed to a sink population.
   b. determine how large an area must be preserved for the protection of a threatened species.
   c. identify whether individuals of a threatened species are reproductively mature.
   d. predict the minimum population size of a threatened species that is likely to survive.
   e. predict whether a threatened species will use habitat corridors.
8. Metapopulations are defined as:
   a. neighboring populations that exchange individuals.
   b. populations that steadily decrease in size.
   c. populations that steadily increase in size.
   d. populations that produce numerous fertile offspring.
   e. populations that never receive immigrants.
9. For which of the following species has the use of habitat corridors been proposed as an important conservation tool?
   a. sea otters
   b. bay checkerspot butterflies
   c. Florida panthers
   d. whooping cranes
   e. Eastern hemlocks
10. The main goal of restoration ecology is the reestablishment of:
    a. natural patterns of water flow.
    b. the vitality of a degraded ecosystem.
    c. the historical corridors linking forest fragments.
    d. the natural barriers to animal movement.
    e. ecotourism.

Questions for Discussion

1. National parks are often established in ecologically sensitive areas. In many places they have become so popular that visitors endanger the ecosystems the parks were originally designed to preserve. How can the goals of conservationists, who work to maintain intact ecosystems, be balanced with those of citizens who wish to visit intact ecosystems? In other words, how would you regulate domestic ecotourism?
2. How do the principles of population genetics and the principles of metapopulation dynamics apply to the SLOSS debate? Do they suggest different ideal designs for nature preserves?
3. Imagine that you are a conservation biologist who has been asked to develop a conservation plan for a species of lizard that lives in the deserts of the American Southwest. What sorts of data would you collect before developing a final plan?

Experimental Analysis

Devise a field study to determine whether the species/area relationship applies to aquatic ecosystems, such as ponds and lakes, as it does to terrestrial habitats.

Evolution Link

Overexploitation of marine fish stocks has depleted natural populations and caused a reduction in the age and size at which many fish species become reproductively mature. What sort of government regulations of fishing might reverse the current trend toward smaller adult size? Explain your answer in terms of the selection pressures that fishing places on targeted species.

How Would You Vote?

Material goods can be manufactured in ways that protect biodiversity but often are more expensive than comparable goods produced without regard for the environment. As a consumer, are you willing to pay extra for the first kind? Go to www.thomsonedu.com/login to investigate both sides of the issue and then vote.