57

Conservation Biology

Concept Outline

57.1 The new science of conservation biology is focused on conserving biodiversity.

Overview of the Biodiversity Crisis. In prehistoric times, humans decimated the faunas of many areas. Today, worldwide extinction rates are accelerating.

Species Endemism and Hotspots. Some geographic areas are particularly rich in species that occur nowhere else.

What's So Bad About Losing Biodiversity? Biodiversity has considerable direct economic value and provides key support to the biosphere.

57.2 The extinction crisis is a result of many factors.

Factors Responsible for Extinction. Most recorded extinctions can be attributed to a few causes. Sometimes more than one factor can affect a species at the same time.

Habitat Loss. Without a place to live, species cannot survive.

Overexploitation. Species cannot persist if too many individuals are removed by humans.

Detrimental Effects of Introduced Species. Introduced species can wreak havoc on native species and ecosystems.

Disruption of Ecosystems. Extinction of one species can have a cascading effect throughout the food web, making other species vulnerable as well.

The Perils of Small Population Size. Small populations are vulnerable to genetic and demographic problems.

57.3 Successful recovery efforts need to be multidimensional.

Approaches for Preserving Endangered Species. Species preservation efforts take many forms and must be tailored toward the particular threats that species face.

Conservation of Ecosystems. Maintaining large preserves and focusing on the health of the entire ecosystem may be the best means of preserving biodiversity.

FIGURE 57.1
Endangered. The Siberian tiger is in grave danger of extinction, being hunted for its pelt and having its natural habitat greatly reduced. A concerted effort to save it is using many of the approaches discussed in this chapter.

Among the greatest challenges facing the biosphere is the accelerating pace of species extinctions. Not since the Cretaceous period have so many species become extinct in so short a time span (figure 57.1). This challenge has led to the emergence in the last decade of the discipline of conservation biology. Conservation biology is an applied science that seeks to learn how to preserve species, communities, and ecosystems. It studies the causes of declines in species richness and attempts to develop methods for preventing such declines. In this chapter, we first examine the biodiversity crisis and its importance. Then, using case histories, we identify and study factors that have played key roles in many extinctions. We finish with a review of recovery efforts at the species and community levels.

57.1 The new science of conservation biology is focused on conserving biodiversity.

Overview of the Biodiversity Crisis

Extinction is a fact of life. Most species—probably all—become extinct eventually. More than 99% of species known to science (most from the fossil record) are now extinct. However, current rates are alarmingly high. Taking into account the rapid and accelerating loss of habitat that is occurring, especially in the tropics, it has been calculated that as much as 20% of the world's biodiversity may be lost by the middle of this century. In addition, many of these species may be lost before we are even aware of their existence. Scientists estimate that no more than 15% of the world's eukaryotic organisms have been discovered and given scientific names, and this proportion is probably much lower for tropical species.

These losses will not only affect poorly known groups. As many as 50,000 species of the world's total of 250,000 species of plants, 4000 of the world's 20,000 species of butterflies, and nearly 2000 of the world's 9000 species of birds could be lost during this time period. Considering that the human species has been in existence for only 600,000 years of the world's 4.5-billion-year history, and that our ancestors developed agriculture only about 10,000 years ago, this is an astonishing—and dubious—accomplishment.

FIGURE 57.2
North America before human inhabitants. Animals found in North America prior to the migration of humans included birds and large mammals, such as the ancient North American camel, saber-toothed cat, giant ground sloth, and teratorn vulture.

Extinctions Due to Prehistoric Humans

A great deal can be learned about current rates of extinction by studying the past, and in particular the impact of human-caused extinctions. In prehistoric times, members of *Homo sapiens* wreaked havoc whenever they entered a new area. For example, at the end of the last Ice Age, approximately 12,000 years ago, the fauna of North America was composed of a diversity of large mammals similar to those living in Africa today: mammoths and mastodons, horses, camels, giant ground sloths, saber-toothed cats, and lions, among others (figure 57.2). Shortly after humans arrived, 74 to 86% of the *megafauna* (that is, animals weighing more than 100 pounds) became extinct. These extinctions are thought to have been caused by hunting and, indirectly, by burning and clearing of forests. (Some scientists attribute these extinctions to climate change, but that hypothesis doesn't explain why the end of earlier ice ages was not associated with mass extinctions, nor does it explain why extinctions occurred primarily among larger animals, with smaller species relatively unaffected.)

Around the globe, similar results have followed the arrival of humans. Forty thousand years ago, Australia was occupied by a wide variety of large animals, including marsupials similar in size and ecology to hippos and leopards, a kangaroo nine feet tall, and a 20-foot-long monitor lizard. These all disappeared, at approximately the same time as humans arrived. Smaller islands have also been devastated. Madagascar has seen the extinction of at least 15 species of lemurs, including one the size of a gorilla; a pygmy hippopotamus; and the flightless elephant bird, *Aepyornis*, the largest bird to ever live (more than 3 meters tall and weighing 450 kilograms). On New Zealand, 30 species of birds went extinct, including all 13 species of moas, another group of large, flightless birds. Interestingly, one continent that seems to have been spared these megafaunal extinctions is Africa. Scientists speculate that this lack of extinction in prehistoric Africa may have resulted because much of human evolution occurred in Africa. Consequently, other African species had been coevolving with humans for several million years and thus had evolved counteradaptations to human predation.

Extinctions in Historical Time

Historical extinction rates are best known for birds and mammals because these species are conspicuous—that is, relatively large and well studied. Estimates of extinction rates for other species are much rougher. The data presented in table 57.1, based on the best available evidence, show recorded extinctions from 1600 to the present. These estimates indicate that about 85 species of mammals and 113 species of birds have become extinct since the year 1600. That is about 2.1% of known mammal species and 1.3% of known birds. The majority of extinctions have occurred in the last 150 years. The extinction rate for birds and mammals was about one species every decade from 1600 to 1700, but it rose to one species every year during the period from 1850 to 1950, and to four species per year between 1986 and 1990 (figure 57.3). This increase in the rate of extinction is the heart of the biodiversity crisis.

Table 57.1 Recorded Extinctions Since 1600 A.D.

Taxon	Recorded Extinctions: Mainland	Island	Ocean	Total	Approximate Number of Species	Percent of Taxon Extinct
Mammals	30	51	4	85	4,000	2.1
Birds	21	92	0	113	9,000	1.3
Reptiles	1	20	0	21	6,300	0.3
Amphibians*	2	0	0	2	4,200	0.05
Fish	22	1	0	23	19,100	0.1
Invertebrates	49	48	1	98	1,000,000+	0.01
Flowering plants	245	139	0	384	250,000	0.2

*An alarming decline in amphibian populations has occurred recently, and many species may be on the verge of extinction.

Unfortunately, the biodiversity crisis seems to be worsening. For example, the number of bird species recognized as "critically endangered" increased 8% from 1996 to 2000, and a 2002 report suggested that as many as half of the earth's plant species may be threatened with extinction. Some researchers predict that two-thirds of all vertebrate species could perish by the end of this century.

The majority of historic extinctions—though by no means all of them—have occurred on islands. For example, of the 90 species of mammals that have gone extinct in the last 500 years, 73% lived on islands (and another 19% in Australia). The particular vulnerability of island species probably results from a number of factors: Such species have often evolved in the absence of predators, and so have lost their ability to escape both humans and introduced predators such as rats and cats. In addition, humans have introduced competitors and diseases; avian malaria, for example has devastated the bird fauna of the Hawaiian Islands. Finally, island populations are often relatively small, and thus particularly vulnerable to extinction, as we shall see later in this chapter.

In recent years, the extinction crisis has moved from islands to continents. Most species now threatened with extinction occur on continents, and these areas will bear the brunt of the extinction crisis in this century.

Some people have argued that we should not be concerned, because extinctions are a natural event and mass extinctions (the extinction of large numbers of species within a geologically short period of time) have occurred in the past. Indeed, mass extinctions have taken place several times over the past half-billion years. However, the current mass extinction event is notable in several respects. First, it is the only such event triggered by a single species. Moreover, although species diversity usually recovers after a few million years, this is a long time to deny our descendants the benefits and joys of biodiversity. In addition, it is not clear that biodiversity will rebound this time. After previous mass extinctions, new species have evolved to utilize resources available due to extinctions of the species that previously used them. Today, however, such resources are unlikely to be available, because humans are destroying the habitats and taking the resources for their own use.

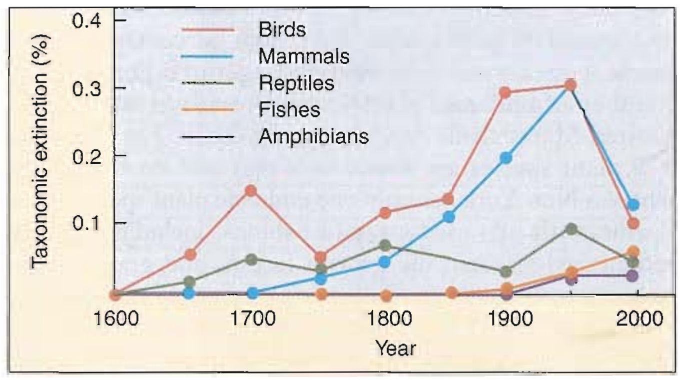


FIGURE 57.3
Trends in species loss. These graphs present data on recorded animal extinctions since 1600. The majority of extinctions have occurred on islands, with birds and mammals particularly affected (although this may reflect to some degree our more limited knowledge of other groups).
Why are extinction rates highest for birds and mammals?

Since prehistoric times, humans have had a devastating effect on biodiversity almost everywhere in the world. Most historical extinctions have occurred on islands, but most future extinctions will occur on continents.

Species Endemism and Hotspots

Table 57.2 Numbers of Endemic Species in Some Hotspot Areas

Region	Mammals	Reptiles	Amphibians	Plants
Atlantic coastal Brazil	160	60	253	6,000
South American Chocó	60	63	210	2,250
Philippines	115	159	65	5,832
Tropical Andes	68	218	604	20,000
Southwestern Australia	7	50	24	4,331
Madagascar	84	301	187	9,704
Cape region (South Africa)	9	19	19	5,682
California Floristic Province	30	16	17	2,125
New Caledonia	6	56	0	2,551
South-central China	75	16	51	3,500

A species found naturally in only one geographic area and no place else is said to be **endemic** to that area. The area over which an endemic species is found may be very large. For example, the black cherry tree (*Prunus serotina*) is endemic to all of temperate North America. More typically, however, endemic species occupy restricted ranges. The Komodo dragon (*Varanus komodoensis*) lives only on a few small islands in the Indonesian archipelago, while the Mauna Kea silversword (*Argyroxiphium sandwicense*) lives in a single volcano crater on the island of Hawaii.

Isolated geographic areas, such as oceanic islands, lakes, and mountain peaks, often have high percentages of endemic species, many in significant danger of extinction. The number of endemic plant species varies greatly in the United States from one state to another. For example, 379 plant species are found in Texas and nowhere else, whereas New York has only one endemic plant species. California, with its varied array of habitats, including deserts, mountains, seacoast, old-growth forests, and grasslands, is home to more endemic plant species than any other state.

Worldwide, notable concentrations of endemic species occur in particular regions. Conservationists have recently identified areas, termed **hotspots,** that have high endemism and are disappearing at a rapid rate. Such hotspots include Madagascar, a variety of tropical rain forests, the eastern Himalayas, areas with Mediterranean climates such as California, South Africa, and Australia, and in several other climatic areas (figure 57.4 and table 57.2). Overall, 25 such hotspots have been identified, which in total contain nearly half of all the terrestrial species in the world.

Why these areas contain so many endemic species is a topic of active scientific research. Some of these hotspots occur in areas of high species diversity, and the explanations for high species diversity in general (see chapter 55), such as high productivity, probably apply to these hotspots as well. In addition, some hotspots occur on isolated islands, such as New Zealand, New Caledonia, and Polynesia (including the Hawaiian Islands), where evolutionary diversification over long periods of time has resulted in rich biotas composed of plant and animal species found nowhere else in the world.

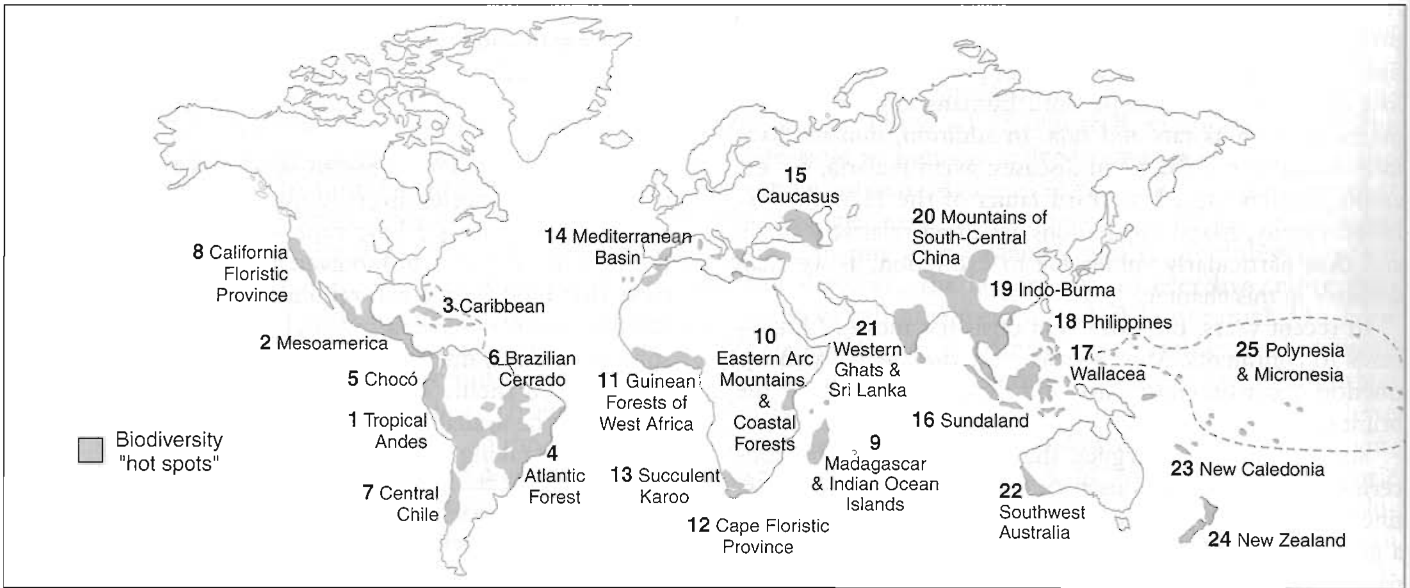


FIGURE 57.4
Hotspots of high endemism. These areas are rich in endemic species under threat of imminent extinction.

Population Growth in Hotspots

Because of the great number of endemic species that hotspots contain, conserving their biological diversity must be an important component of efforts to safeguard the world's biological heritage. Or, to look at it another way, by protecting just 1.4% of the world's land surface, 44% of the world's vascular plants and 35% of its terrestrial vertebrates can be preserved.

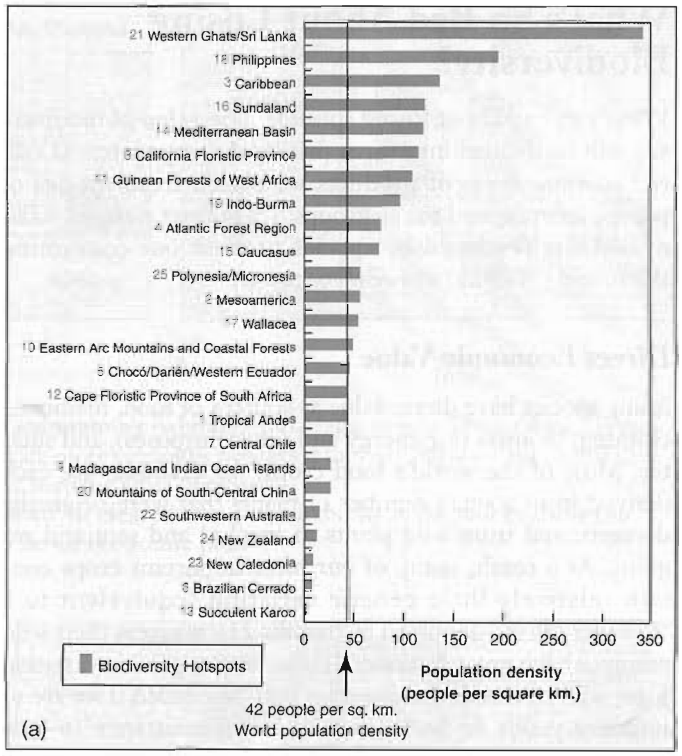
Unfortunately, hotspots contain not only many endemic species, but also growing human populations. In 1995, these areas contained 1.1 billion people—20% of the world's population—sometimes at high densities (figure 57.5*a*). More importantly, human populations were growing in all but one of these hotspots as the result of both high birth and immigration rates; overall, the rate of growth exceeded the global average in 19 hotspots (figure 57.5*b*). Indeed, in some hotspots, the rate of growth is nearly twice that of the rest of the world.

Not surprisingly, many of these areas are experiencing high rates of habitat destruction as land is cleared for agriculture, housing, and economic development. More than 70% of the original area of each hotspot has already disappeared, and in 14 hotspots, 15% or less of the original habitat remains. In Madagascar, it is estimated that 90% of the original forest has already been lost—this on an island where 85% of the species are found nowhere else in the world. In the forests of the Atlantic coast of Brazil, the extent of deforestation is even higher: 95% of the original forest is gone.

Of course, population pressure is not the only cause of habitat destruction in hotspots. Commercial exploitation to meet the demands of more affluent people in the developed world also plays an important role. For example, large-scale logging of tropical rain forests occurs in countries around the world to provide lumber, most of which ends up in the United States, western Europe, and Japan. Similarly, many forests in Central and South America are cleared to make way for cattle ranches that produce cheap meat for fast-food restaurants. Hotspots in more affluent countries are often at risk because they occur in areas where land has great value for real estate and commercial purposes.

Regardless of its cause, decimation of hotspots will take a great toll on the world's biological diversity. As we shall see shortly, such massive rates of habitat destruction result in extremely high rates of species extinction.

Some areas of the earth have particularly high levels of species endemism. Unfortunately, many of these areas are currently in great jeopardy due to human population growth and habitat destruction, with correspondingly high rates of species extinction.



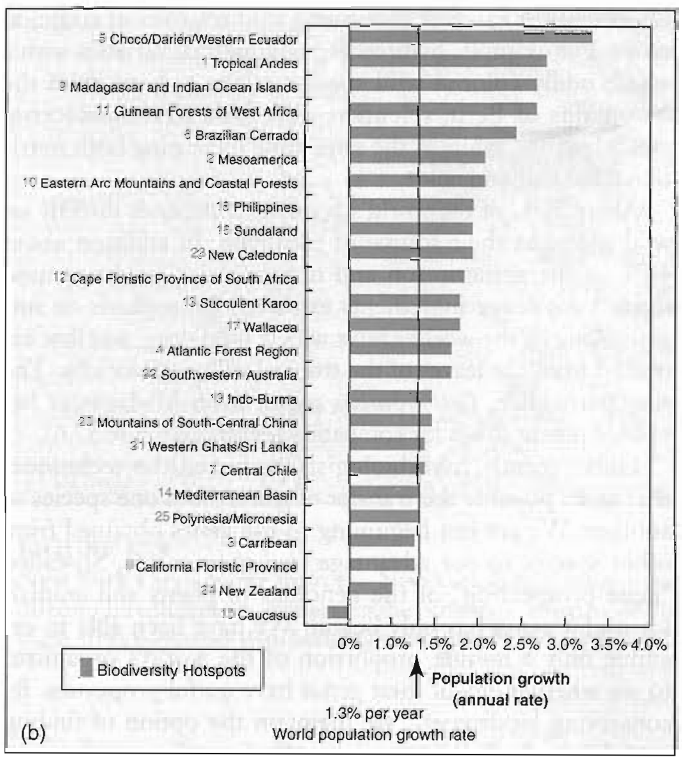


FIGURE 57.5

Human populations in hotspots. The rich biodiversity in many hotspots is under pressure from (*a*) dense and (*b*) rapidly growing human populations.

Why do population density and growth rates differ among hotspots?

What's So Bad About Losing Biodiversity?

What's so bad about losing species? The value of biodiversity can be divided into three principal components: (1) *direct economic value* of products we obtain from species of plants, animals, and other groups; (2) *indirect economic value* of benefits produced by species without our consuming them; and (3) *ethical and aesthetic values.*

Direct Economic Value

Many species have direct value as sources of food, medicine, clothing, biomass (for energy and other purposes), and shelter. Most of the world's food crops, for example, are each derived from a small number of plants that were originally domesticated from wild plants in tropical and semiarid regions. As a result, many of our most important crops contain relatively little genetic variation (equivalent to a "founder effect" discussed in chapter 21), whereas their wild relatives have great diversity. In the future, genetic variation from wild strains of these species may be needed if we are to improve yields or find a way to breed resistance to new pests. In fact, recent agricultural breeding experiments have illustrated the value of conserving wild relatives of common crops. For example, by breeding commercial varieties with a small, oddly colored wild species of the tomato from the mountains of Peru, scientists were able to increase crop yields by 50%, while at the same time increasing both nutritional content and color.

About 70% of the world's population depends directly on wild plants as their source of medicine. In addition about 40% of the prescription and nonprescription drugs used today have active ingredients extracted from plants or animals. Aspirin, the world's most widely used drug, was first extracted from the leaves of the tropical willow, *Salix alba.* The rosy periwinkle, *Catharanthus roseus,* from Madagascar has yielded potent drugs for combating leukemia (figure 57.6).

Only recently have biologists perfected the techniques that make possible the transfer of genes from one species to another. We are just beginning to use genes obtained from other species to our advantage (see chapter 16). So-called "gene prospecting" of the genomes of plants and animals for useful genes has only begun. We have been able to examine only a minute proportion of the world's organisms to see whether any of their genes have useful properties. By conserving biodiversity, we maintain the option of finding useful benefits in the future; unfortunately, many of the most promising species occur in habitats that are being destroyed at an alarming rate, such as tropical rain forests.

Indirect Economic Value

Diverse biological communities are of vital importance to healthy ecosystems. They help maintain the chemical quality of natural water, buffer ecosystems against floods and drought, preserve soils and prevent loss of minerals and nutrients, moderate local and regional climate, absorb pollution, and promote the breakdown of organic wastes and the cycling of minerals. By destroying biodiversity, we are creating conditions of instability and lessened productivity and promoting desertification, waterlogging, mineralization, and many other undesirable outcomes throughout the world.

FIGURE 57.6
The rosy periwinkle. Two drugs extracted from the Madagascar periwinkle *Catharanthus roseus,* vinblastine and vincristine, effectively treat common forms of childhood leukemia, increasing chances of survival from 20% to over 95%.

Economists have recently been able to compare the societal value, in monetary terms, of intact habitats compared with the value of destroying those habitats. Surprisingly, in most studies conducted so far, intact ecosystems are more valuable than the products derived by destroying them. For example, in Thailand, coastal mangrove habitats are commonly cleared so that shrimp farms can be established. Although the shrimp produced are valuable, their value is vastly outweighed by the benefits in timber, charcoal production, offshore fisheries, and storm protection provided by the mangroves (figure 57.7*a*). Similarly, intact tropical rain forest in Cameroon, West Africa, provides fruit and other forest materials. Clearing the forest for agriculture or palm plantations leads to stream-polluting erosion as well as increased flooding. Combining all the costs and benefits of the three options, maintaining intact forests has the highest economic value (figure 57.7*b*).

Probably the most famous example of the value of intact ecosystems is provided by the watersheds of New York City. Ninety percent of the water for the New York area's nine million residents comes from the Catskill Mountains and the nearby headwaters of the Delaware River (figure 57.8). Water that runs off from over 1600 square miles of rural, mountainous areas is collected into reservoirs and then transported by aqueduct more than 85 miles to New York City at a rate of 1.3 billion gallons per day.

In the 1990s, New York City faced a dilemma. New federal water regulations were requiring ever cleaner water, even as development and pollution in the source areas of the water were threatening to compromise water quality. The city had two choices: either work to protect the functioning ecosystem so that it could produce clean water, or construct filtration plants to clean it upon arrival. Economic analysis made the choice clear: Building the plants would cost $6 billion, with annual operating costs of $300 million, whereas spending a billion dollars over ten years could preserve the ecosystem and maintain water purity. The decision was easy.

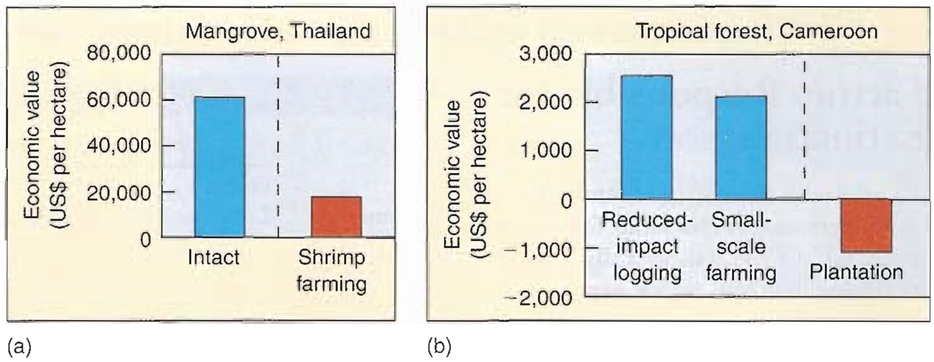


FIGURE 57.7
The economic value of maintaining habitats. (*a*) Mangroves in Thailand and (*b*) rain forests in Cameroon provide more economic benefits if they are left standing than if they are destroyed and the land used for other purposes.
If shrimp farms established on cleared mangrove habitats make money, how can clearing mangroves not be an economic plus?

These examples provide some idea of the value of the services that ecosystems provide. But maintaining ecosystems is not always more valuable than converting them to other uses. Certainly, when the United States was being settled and land was plentiful, ecosystem conversion was beneficial. Even today, habitat destruction may sometimes be economically desirable. Nonetheless, we still have only a rudimentary knowledge of the many ways intact ecosystems provide services. In many cases, it is not until they are lost that the value becomes clear, as unexpected negative effects, such as increased flooding and pollution or decreased rainfall, become apparent.

The same argument can be made for preserving particular species within ecosystems. Given how little we know about the biology of most species, particularly in the tropics, it is impossible to predict all the consequences of removing a species. Imagine taking a parts list for an airplane and randomly changing a digit in one of the part numbers: You might change a cushion to a roll of toilet paper—but you might just as easily change a key bolt holding up the wing to a pencil. By removing biodiversity, we are gambling with the future of the ecosystems upon which we depend and whose functioning we understand very little.

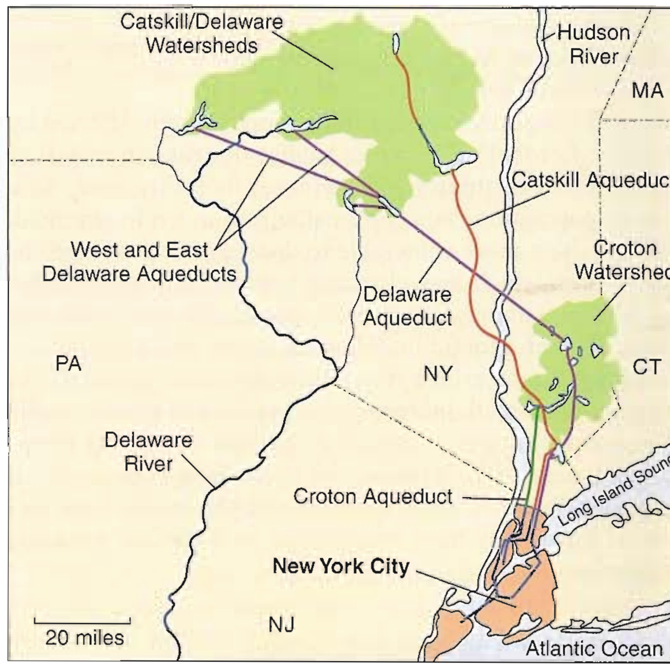


FIGURE 57.8
New York City's water source. New York gets its water from distant rain catchments. Preserving the ecological integrity of these areas is cheaper than building new water treatment plants.

Ethical and Aesthetic Values

Many people believe that preserving biodiversity is an ethical issue because every species is of value in its own right, even if humans are not able to exploit or benefit from it. These people feel that along with the power to exploit and destroy other species comes responsibility: As the only organisms capable of eliminating large numbers of species and entire ecosystems, and as the only organisms capable of reflecting upon what we are doing, humans should act as guardians or stewards for the diversity of life around us.

Almost no one would deny the aesthetic value of biodiversity—a beautiful flower or a noble elephant—but how do we place a value on beauty? Perhaps the best we can do is to appreciate the deep sense of loss we would feel if it no longer existed.

Biodiversity is of great value in its own right, as well as for the products it provides, its contributions to the health of the ecosystems we depend on, and the beauty it offers.

57.2 The extinction crisis is a result of many factors.

Factors Responsible for Extinction

A variety of causes, independently or in concert, are responsible for extinctions (table 57.3). Historically, overexploitation was the major cause of extinction; although overexploitation is still a factor, habitat loss is the major problem for most groups today, while introduced species rank second. Many other factors can contribute to species extinctions as well, including disruption of ecosystem interactions, pollution, loss of genetic variation, and catastrophic disturbances, either natural or man-made.

Table 57.3 Causes of Extinctions

	Percentage of Species Influenced by the Given Factor*				
Group	Habitat Loss	Overexploitation	Species Introduction	Other	Unknown
EXTINCTIONS					
Mammals	19	23	20	2	36
Birds	20	11	22	2	45
Reptiles	5	32	42	0	21
Fish	35	4	30	4	48
THREATENED EXTINCTIONS					
Mammals	68	54	6	20	—
Birds	58	30	28	2	—
Reptiles	53	63	17	9	—
Fish	78	12	28	2	—

*Some species may be influenced by more than one factor; thus, some rows may exceed 100%.

More than one of these factors may affect a species. In fact, a chain reaction is possible in which the action of one factor predisposes a species to be more severely affected by another factor. For example, habitat destruction may lead to decreased birthrates and increased mortality rates. As a result, populations become smaller and more fragmented, making them more vulnerable to disasters such as floods or forest fires, which may eliminate populations. As the habitat becomes more fragmented, populations become isolated, so that genetic interchange ceases and areas devastated by disasters are not recolonized. As populations become very small, inbreeding increases, and genetic variation is lost through genetic drift, further decreasing population fitness. Which factor causes the final coup de grace may be irrelevant; many factors, and the interactions between them, may have contributed to a species' eventual extinction.

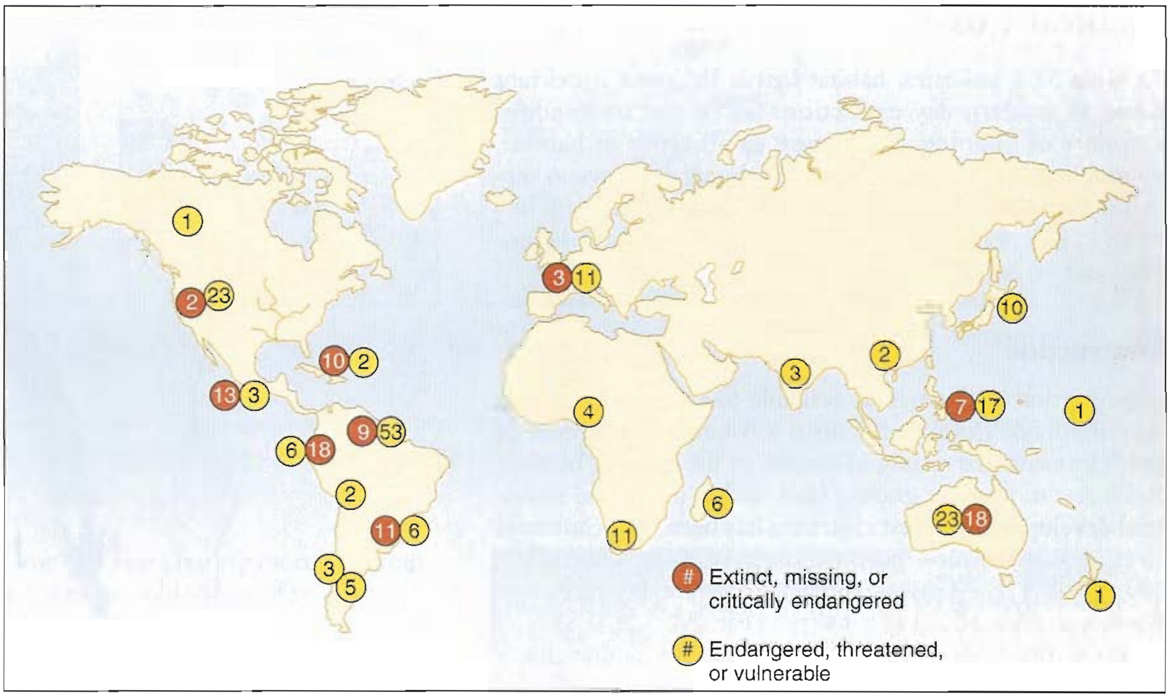
FIGURE 57.9
An extinct species. The golden toad was last seen in the wild in 1989.

Case Study: Amphibian Declines

In 1963, herpetologist Jay Savage was hiking through pristine cloud forest in Costa Rica. Reaching a wind-swept ridge, he couldn't believe his eyes. Before him was a huge aggregation of breeding toads. What was so amazing was the color of the toads: bright, eye-dazzling orange, unlike anything he had ever seen before (figure 57.9). The color of the toads was so amazing and unexpected that Savage briefly considered the possibility that colleagues had played a practical joke, getting to the clearing before him and somehow coloring normal toads orange. Realizing that this could not be, he went on to study the toads, eventually describing a species new to science, the golden toad, *Bufo periglenes*.

For the next 24 years, large numbers of toads were seen during the breeding season each spring. Their home was legally recognized as the Monteverde Cloud Forest Reserve, a well-protected, intact, and functioning ecosystem, seemingly a successful model of conservation. Then, in 1988, few toads were seen, and in 1989, only a single male was observed. Since then, despite exhaustive efforts, no more golden toads have been found. Despite living in a well-protected ecosystem, with no obvious threats from pollution, introduced species, overexploitation, or any other factor, the species appears to have gone extinct,

FIGURE 57.10 Amphibian extinction crisis. Circles indicate the number of extinct (*red*) and endangered (*yellow*) species around the world. These numbers are rapidly being revised upward as scientists focus their attention on little-known species, many of which turn out to be in grave danger.



right under the eyes of watchful scientists and conservationists. How could this happen?

Frogs in Trouble. At the first World Herpetological Congress in 1989 in Canterbury, England, frog experts from around the world met to discuss conservation issues relating to frogs and toads. At this meeting, it became clear that the golden toad story was not unique. Experts reported case after case of similar stories: Frog populations that had once been abundant were now decreasing or entirely gone.

Since then, scientists have devoted a great deal of time and effort to determining whether frogs and other amphibian species truly are in trouble and, if so, why. Unfortunately, the situation appears to be even worse than originally suspected. In 2002, experts associated with the University of California at Berkeley reported that at least 32 amphibian species have gone extinct in recent years; another 26 are "missing in action," not having been seen for many years and possibly extinct; and 91 species, in countries as different as Ecuador, Venezuela, Australia, and the United States, are critically endangered (figure 57.10). Moreover, these numbers are probably underestimates; little information exists from many areas of the world, such as Southeast Asia and central Africa. Indeed, in that same year, researchers suggested that as many as 100 species from the island nation of Sri Lanka have recently gone extinct, news that is perhaps not surprising given that 95% of the nation's rain forests have also disappeared in recent times.

Cause for Concern. Amphibian declines are worrisome for several reasons. First, many of the species—including the golden toad—have declined in pristine, well-protected habitats. If species are going extinct in such areas, it bodes ill for our ability to preserve global biological diversity. Second, many amphibian species are particularly sensitive to the state of the environment because of their moist skin, which allows chemicals from the environment to pass into the body, and their use of aquatic habitats for larval stages (such as the tadpoles of frogs), which requires unpolluted water. In other words, amphibians may be analogous to the canaries formerly used in coal mines to detect problems with air quality: If the canaries keeled over, the miners knew they had to get out.

Third, no single cause for amphibian declines is apparent. Although a single cause would be of concern, it would also suggest that a coordinated global effort could reverse the trend, as happened with chlorofluorocarbons and decreasing ozone levels (see chapter 56). However, different species are afflicted by different problems, including habitat destruction, global warming–induced environmental changes, pollution, decreased ozone levels, parasite epidemics, and introduced species. This is an area of active scientific research, and the implication is that the global environment is deteriorating in many different ways. Could amphibians be global "canaries," serving as indicators that the world's environment is in serious trouble?

Many factors are responsible for extinction. Many amphibian species are in trouble around the world. No single cause is responsible, which raises worry about the overall state of the global environment.

Habitat Loss

As table 57.3 indicates, habitat loss is the most important cause of modern-day extinction. Given the tremendous amounts of ongoing destruction of all types of habitat, from rain forest to ocean floor, this should come as no surprise. Natural habitats may be adversely affected by humans in four ways: (1) destruction, (2) pollution, (3) disruption, and (4) habitat fragmentation.

Destruction

A proportion of the habitat available to a particular species may simply be destroyed. This is a common occurrence in the "clear-cut" harvesting of timber, in the burning of tropical forest to produce grazing land, and in urban and industrial development. Forest clearance has been, and continues to be, by far the most pervasive form of habitat disruption (figure 57.11). Many tropical forests are being cut or burned at a rate of 1% or more per year.

To estimate the effect of reductions in habitat available to a species, biologists often use the well-established observation that larger areas support more species (see figure 55.20). Although this relationship varies according to geographic area, type of organism, and type of area (for example, oceanic islands or patches of habitat on the mainland), in general a tenfold increase in area leads to approximately a doubling in the number of species. This relationship suggests, conversely, that if the area of a habitat is reduced by 90%, so that only 10% remains, then half of all species will be lost. Evidence for this theory comes from a study of extinction rates of birds on habitat islands (that is, islands of a particular type of habitat surrounded by unsuitable habitat) in Finland where the extinction rate was found to be inversely proportional to island size (figure 57.12).

Pollution

Habitat may be degraded by pollution to the extent that some species can no longer survive there. Degradation occurs as a result of many forms of pollution, from acid rain to pesticides. Aquatic environments are particularly vulnerable; for example, many northern lakes in both Europe and North America have been essentially sterilized by acid rain.

Disruption

Human activities may disrupt a habitat enough to make it untenable for some species. For example, visitors to caves in Alabama and Tennessee caused significant population declines in bats over an eight-year period, some as great as 100%. When visits were fewer than one per month, less

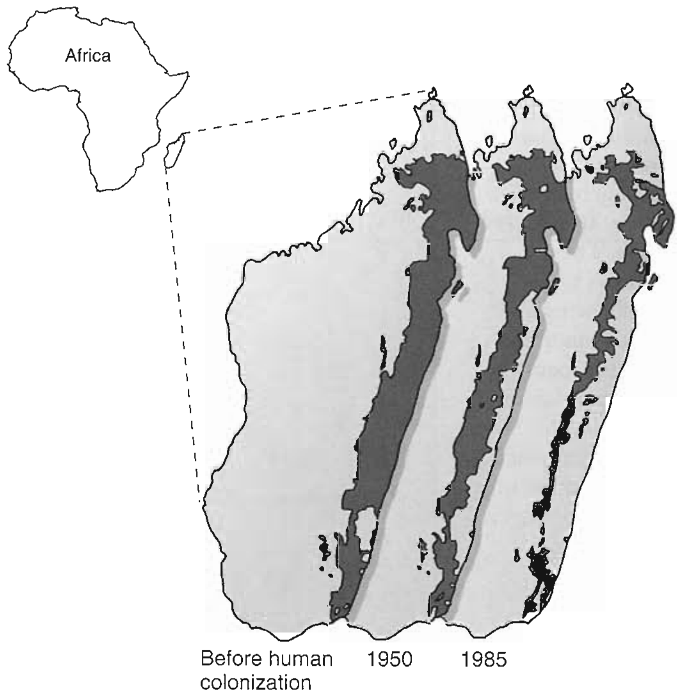


FIGURE 57.11
Extinction and habitat destruction. The rain forest covering the eastern coast of Madagascar, an island off the coast of East Africa, has been progressively destroyed as the island's human population has grown. Ninety percent of the original forest cover is now gone. Many species have become extinct, and many others are threatened, including 16 of Madagascar's 31 primate species.

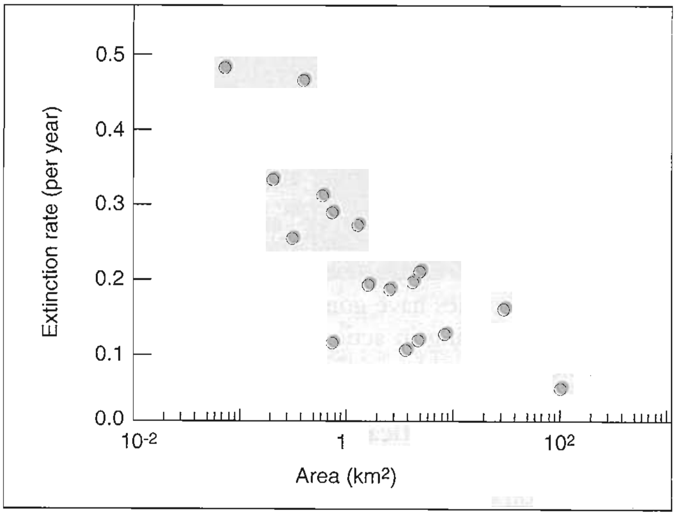


FIGURE 57.12
Extinction and the species-area relationship. The data present percent extinction rates as a function of habitat area for birds on a series of Finnish islands. Smaller islands experience far greater local extinction rates.
Why does extinction rate increase with decreasing island size?

FIGURE 57.13
Fragmentation of woodland habitat. From the time of settlement of Cadiz Township, Wisconsin, the forest has been progressively reduced from a nearly continuous cover to isolated woodlots covering less than 1% of the original area.

than 20% of bats were lost, but caves having more than four visits per month suffered population declines of 86–95%.

Habitat Fragmentation

Loss of habitat by a species frequently results not only in lowered population numbers, but also in fragmentation of the population into unconnected patches (figure 57.13).

A habitat may become fragmented in nonobvious ways, as when roads and habitation intrude into forest. The effect is to carve the populations living in the habitat into a series of smaller populations, often with disastrous consequences because of the relationship between range size and extinction rate. Although detailed data are not available, fragmentation of wildlife habitat in developed temperate areas is thought to be very substantial.

As habitats become fragmented and shrink in size, the relative proportion of the habitat that occurs on the boundary, or edge, increases. **Edge effects** can significantly degrade a population's chances of survival. Changes in microclimate (temperature, wind, humidity, etc.) near the edge may reduce appropriate habitat for many species more than the physical fragmentation suggests. In isolated fragments of rain forest, for example, trees on the edge are exposed to direct sunlight and, consequently, hotter and drier conditions than they are accustomed to in the cool, moist forest interior. As a result, in one study, the biomass of trees within 100 meters of the forest edge decreased by 36% in the first 17 years after fragment isolation.

Also, increasing habitat edges opens up opportunities for parasites and predators, which are both more effective at edges. As fragments decrease in size, the proportion of habitat that is distant from any edge decreases, and consequently, more and more of the habitat is within the range of these predators. Habitat fragmentation is blamed for local extinctions in a wide range of species.

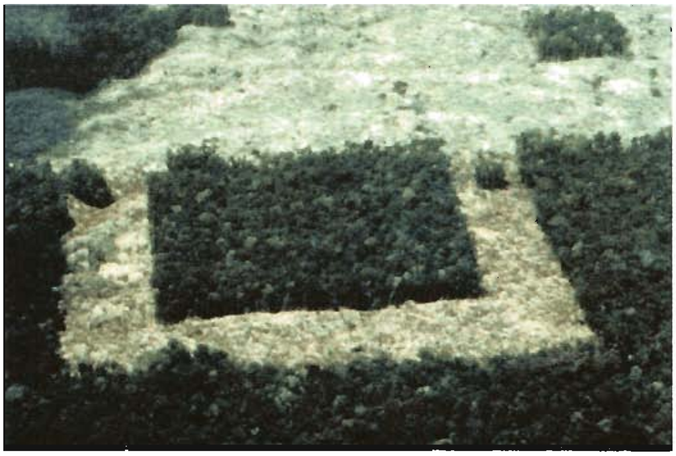


FIGURE 57.14
A study of habitat fragmentation. Biodiversity was monitored in the isolated patches of rain forest in Manaus, Brazil, before and after logging. Fragmentation led to significant species loss within patches.

The impact of habitat fragmentation can be seen clearly in a major study done in Manaus, Brazil, where the rain forest was commercially logged. Landowners agreed to preserve patches of rain forest of various sizes, and censuses of these patches were taken before the logging started, while they were still part of a continuous forest. After logging, species began to disappear from the now-isolated patches (figure 57.14). First to go were the monkeys, which have large home ranges. Birds that prey on ant colonies followed, disappearing from patches too small to maintain enough ant colonies to support them.

Because some species, such as monkeys, require large patches, large fragments are indispensable if we wish to preserve high levels of biodiversity. The take-home lesson is that preservation programs will need to provide suitably large habitat fragments to avoid this impact.

Case Study: Songbirds

Every year since 1966, the U.S. Fish and Wildlife Service has organized thousands of amateur ornithologists and bird-watchers in an annual bird count called the Breeding Bird Survey. In recent years, a shocking trend has emerged. While year-round residents that prosper around humans, such as robins, starlings, and blackbirds, have increased their numbers and distribution over the last 30 years, forest songbirds have declined severely. The decline has been greatest among long-distance migrants such as thrushes, orioles, tanagers, catbirds, vireos, buntings, and warblers. These birds nest in northern forests in the summer, but spend their winters in South or Central America or the Caribbean Islands.

In many areas of the eastern United States, more than three-quarters of the tropical migrant bird species have declined significantly. Rock Creek Park in Washington, D.C., for example, has lost 90% of its long-distance migrants in the past 20 years. Nationwide, American redstarts declined about 50% in the single decade of the 1970s. Studies of radar images from National Weather Service stations in Texas and Louisiana indicate that only about half as many birds fly over the Gulf of Mexico each spring compared to the numbers in the 1960s. This suggests a total loss of about half a billion birds.

The culprit responsible for this widespread decline appears to be habitat fragmentation and loss. Fragmentation of breeding habitat and nesting failures in the summer nesting grounds of the United States and Canada have had a major negative impact on the breeding of woodland songbirds. Many of the most threatened species are adapted to deep woods and need an area of 25 acres or more per pair to breed and raise their young. As woodlands are broken up by roads and developments, it is becoming increasingly difficult for them to find enough contiguous woods to nest successfully.

A second and perhaps even more important factor is the availability of critical winter habitat in Central and South America. Studies of the American redstart clearly indicate that birds with better winter habitat have a superior chance of successfully migrating back to their breeding grounds in the spring. Peter Marra and Richard Holmes of Dartmouth College and Keith Hobson of the Canadian Wildlife Service captured birds, took blood samples, and measured the levels of the stable carbon isotope ^{13}C. Plants growing in the best overwintering habitats in Jamaica and Honduras (mangroves and wetland forests) have low levels of ^{13}C, and so do the redstarts that feed on them. Of these wet-forest birds, 65% maintained or gained weight over the winter. By contrast, plants growing in substandard dry scrub have high levels of ^{13}C, and so do the redstarts that feed on them. Scrub-dwelling birds lost up to 11% of their body mass over the winter. Now here's the key: Birds that winter in the substandard scrub leave later in the spring on the long flight to northern breeding grounds, arrive later at their summer homes, and have fewer young (figure 57.15). The proportion of ^{13}C in birds arriving in New Hampshire breeding grounds increases as spring wears on and scrub-overwintering stragglers belatedly arrive. Thus, loss of mangrove habitat in the neotropics is having a real negative impact. As the best habitat disappears, overwintering birds fare poorly, and this leads to population declines. Unfortunately, the Caribbean lost about 10% of its mangroves in the 1980s, and continues to lose about 1% per year. This loss of key habitat appears to be a driving force in the looming extinction of songbirds.

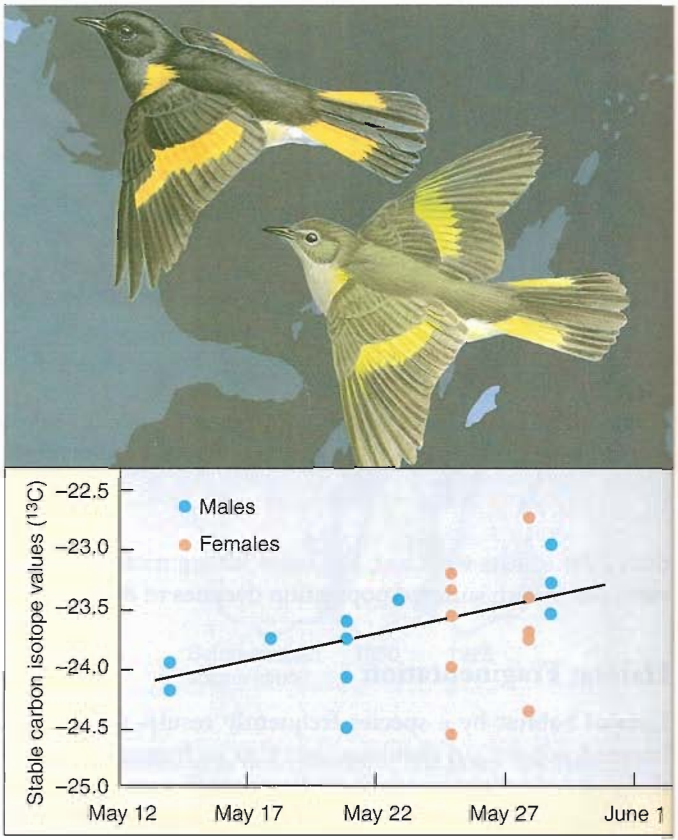


FIGURE 57.15
The American redstart, a migratory songbird. The numbers of this species are in serious decline. The graph presents data on the level of ^{13}C in redstarts arriving at summer breeding grounds. Early arrivals, with the best shot at reproductive success, have lower levels of ^{13}C, indicating they wintered in more favorable mangrove-wetland forest habitats.

As habitats are destroyed, remaining habitat becomes fragmented, increasing the threat to many species. Fragmentation of summer breeding grounds and loss of high-quality overwintering habitat seem to be contributing to a marked decline in migratory songbird species.

Overexploitation

Species that are hunted or harvested by humans have historically been at grave risk of extinction, even when the species is initially very abundant. A century ago, the skies of North America were darkened by huge flocks of passenger pigeons, but after being hunted as free and tasty food, they were driven to extinction. The bison that used to migrate in enormous herds across the central plains of North America only narrowly escaped the same fate.

The existence of a commercial market often leads to overexploitation of a species. The international trade in furs, for example, has severely reduced the numbers of chinchilla, vicuña, otter, and many cat species. The harvesting of commercially valuable trees provides another example: Almost all West Indies mahogany trees (*Swietenia mahogani*) have been logged, and the extensive cedar forests of Lebanon, once widespread at high elevations, now survive in only a few isolated groves.

A particularly telling example of overexploitation is the commercial harvesting of fish in the North Atlantic. During the 1980s, fishing fleets continued to harvest large amounts of cod off Newfoundland, even as the population numbers declined precipitously. By 1992, the cod population had dropped to less than 1% of its original numbers. The American and Canadian governments have closed the fishery, but no one can predict whether the fish populations will recover. The Atlantic bluefin tuna has experienced a 90% population decline in the past 10 years. The swordfish has declined even further. In both cases, the drop has led to even more intense fishing of the remaining populations.

Case Study: Whales

Whales, the largest living animals that ever evolved, are rare in the world's oceans today, their numbers driven down by commercial whaling. Before the advent of cheap, high-grade oils manufactured from petroleum in the early twentieth century, oil made from whale blubber was an important commercial product in the worldwide marketplace. In addition, the fine, latticelike structure termed "baleen" used by baleen whales to filter-feed plankton from seawater was used in undergarments. Because a whale is such a large animal, each individual captured is of significant commercial value.

Right whales were the first to bear the brunt of commercial whaling. They were called "right" whales because they were slow and easy to capture, and they provided up to 150 barrels of blubber oil and abundant baleen, making them the right whale for a commercial whaler to hunt.

As the right whale declined in the eighteenth century, whalers turned to the gray, humpback, and bowhead whales. As their numbers declined, whalers turned to the blue, the largest of all whales, and when those were decimated, to the fin, then the Sei, and then the sperm whales.

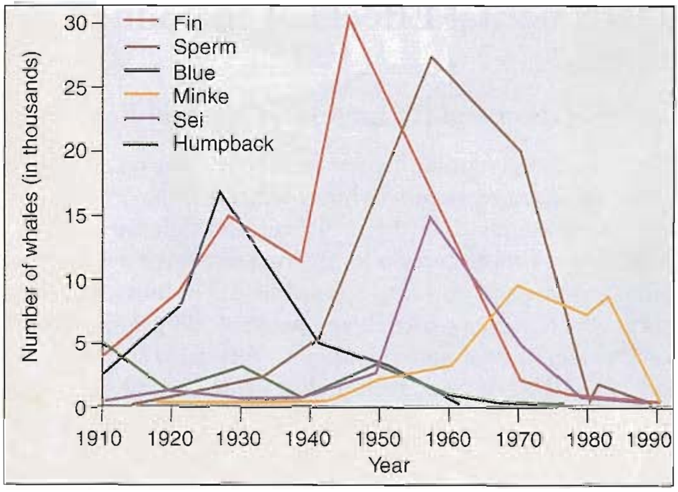


FIGURE 57.16
World catch of whales in the twentieth century. Each species is hunted in turn until its numbers fall so low that hunting it becomes commercially unprofitable.
Why might whale populations fail to recover once hunting is stopped?

As each species of whale became the focus of commercial whaling, its numbers began a steep decline (figure 57.16).

Hunting of right whales was made illegal in 1935. By then, they had been driven to the brink of extinction, their numbers less than 5% of what they had been. Although protected ever since, their numbers have not recovered in either the North Atlantic or the North Pacific. By 1946, several other whale species faced imminent extinction, and whaling nations formed the International Whaling Commission (IWC) to regulate commercial whale hunting. Like a fox guarding the henhouse, the IWC for decades did little to limit whale harvests, and whale numbers continued to decline steeply. Finally, in 1974, when the numbers of all but the small minke whales had been driven down, the IWC banned hunting of blue, gray, and humpback whales, and instituted partial bans on other species. The rule was violated so often, however, that the IWC in 1986 instituted a worldwide moratorium on all commercial killing of whales. While some commercial whaling continues, often under the guise of harvesting for scientific studies, annual whale harvests have dropped dramatically in the last 20 years.

Some species appear to be recovering, while others do not. Humpback numbers have more than doubled since the early 1960s, increasing nearly 10% annually, and Pacific gray whales have fully recovered to their previous numbers of about 20,000 animals after being hunted to less than 1000. Right, sperm, fin, and blue whales have not recovered, and no one knows whether they will.

Overharvesting has driven most large whale species to the brink of extinction. Stopping the harvest has allowed recovery of some, but not all, species.

Detrimental Effects of Introduced Species

Colonization and Extinction as Natural Processes

Colonization, a natural process by which a species expands it geographic range, occurs in many ways: A flock of birds gets blown off course, a bird eats a fruit and defecates its seed miles away, or lowered sea levels connect two previously isolated landmasses, allowing species to freely move back and forth. Such events—particularly those leading to successful establishment of a new population—probably occur rarely, but when they do, the resulting change to natural communities can be large. The reason is that colonization brings together species with no previous history of interaction. Consequently, ecological interactions may be particularly strong because the species have not evolved ways of adjusting to the presence of each other, such as adaptations to avoid predation or minimize competitive effects.

The paleontological record documents many cases in which geologic changes brought previously isolated species together, such as when the Isthmus of Panama emerged above the sea approximately three million years ago, connecting the previously isolated faunas and floras of North and South America. In some cases, the result has been an increase in species diversity, but in other cases, invading species have led to the extinction of natives.

Human Influence on the Process

Unfortunately, what was naturally a rare process has become all too common in recent years, thanks to the actions of humans. Species introductions due to human activities occur in many ways, sometimes intentionally, but usually not. Plants and animals can be transported in the ballast of large ocean vessels, in nursery plants, as stowaways in boats, cars, and planes, as beetle larvae within wood products—even as seeds in the mud stuck to the bottom of a shoe! Overall, some researchers estimate that as many as 50,000 species have been introduced into the United States. The results of such introductions are occasionally catastrophic.

The effects of introductions on humans have been enormous. In the United States alone, nonnative species cost the economy an estimated $140 billion per year. For example, dozens of foreign weeds in Colorado have covered more than a million acres. Just three of these species cost wheat farmers tens of millions of dollars. At the same time, leafy spurge, a plant from Europe, outcompetes native grasses, ruining rangeland for cattle at a price tag of $144 million per year. The zebra mussel, a mollusk native to the Black Sea, is a huge problem throughout much of the eastern and central United States, where it can attain densities as high as 700,000/m^2, clogging pipes, including those for water and power plants, and causing an estimated $3–5 billion damage a year.

Introduced species can have impacts on human health as well. For example, West Nile fever, the death rate of which is steadily mounting, was probably introduced from Africa or the Middle East in the late 1990s.

FIGURE 57.17
The akiapolaau, an endangered Hawaiian bird. More than two-thirds of Hawaii's native bird species are now extinct or have been greatly reduced in population size. Bird faunas on islands around the world have experienced similar declines after human arrival.

The effect of species introductions on native ecosystems is equally dramatic. Islands have been particularly affected. For example, a lighthouse keeper's cat singlehandedly (singlepawedly?) wiped out an entire species, the Stephens Island wren. Rats had a devastating effect throughout the South Pacific where bird species nested on the ground and had no defense against the voracious predators to which they were evolutionarily naive. More recently, the brown tree snake, introduced to the island of Guam, essentially eliminated all species of forest birds. In Hawaii, the problem has been slightly different: Introduced mosquitoes brought with them avian malaria, to which the native species had evolved no resistance. The result is that more than 100 species (more than 70% of the native fauna) either went extinct or are now restricted to higher and cooler elevations where the mosquitoes don't occur (figure 57.17).

The effects of introduced species are not always direct, but instead may reverberate throughout an ecosystem. For example, the Argentine ant has spread through much of the southern United States, eliminating most native ant species with which it comes in contact. The extinction of these ant species has had a dramatic negative effect on the coastal horned lizard, which specializes on the larger native species. In their absence, the lizards have shifted to less-preferred prey species. In addition, the native species consume seeds, and in the process, play an important role in seed dispersal. Argentine ants, by contrast, do not eat seeds. In South Africa, where the Argentine ant has also appeared, at least one plant species has experienced decreased reproductive success due to the loss of its dispersal agent.

The most dramatic effects of introduced species, however, occur when entire ecosystems are transformed. Some plant species can completely overrun a habitat, displacing all native species and turning the area into a monoculture (that is, an area occupied by a single species). In California, the yellow star thistle now covers 4 million hectares of what was once highly productive grassland. In Hawaii, a small tree native to the Canary Islands, *Myrica faya*, has spread widely. Because it is able to fix nitrogen at high rates, it has caused a 90-fold increase in the nitrogen content of the soil, thus allowing other, nitrogen-requiring species to invade. In South Africa, several introduced tree species have such high water uptake rates that nearby rivers are now dry.

Efforts to Combat Introduced Species

Once an introduced species becomes established, eradicating it is often extremely difficult, expensive, and time-consuming. Some efforts—such as the removal of goats and rabbits from certain small islands—have been successful, but many other efforts have failed. The best hope for stopping the ravages of introduced species is to prevent species from being introduced in the first place. Although easier said than done, government agencies are now working strenuously to put into place procedures that can intercept species in transit, before they have the opportunity to become established.

Case Study: Lake Victoria Cichlids

Lake Victoria, an immense, shallow, freshwater sea about the size of Switzerland in the heart of equatorial East Africa, had until 1954 been home to an incredibly diverse collection of over 300 species of cichlid fishes (see figure 23.14). These small, perchlike fish range from 2 to 10 inches in length, with males having endless varieties of color. Today, most of these cichlid species are threatened, endangered, or extinct.

What happened to bring about the abrupt loss of so many endemic cichlid species? In 1954, the Nile perch, *Lates niloticus*, a commercial fish with a voracious appetite, was introduced on the Ugandan shore of Lake Victoria. Nile perch, which grow to over 4 feet in length, were to form the basis of a new fishing industry (figure 57.18). For decades, these perch did not seem to have a significant impact; over 30 years later, in 1978, Nile perch still made up less than 2% of the fish harvested from the lake.

Then something happened to cause the Nile perch population to explode and to spread rapidly through the lake, eating their way through the cichlids. By 1986, Nile perch constituted nearly 80% of the total catch of fish from the lake and the endemic cichlid species were virtually gone. Over 70% of cichlid species disappeared, including all open-water species.

So what happened to kick-start the mass extinction of the cichlids? The trigger seems to have been eutrophication. Before 1978, Lake Victoria had high oxygen levels at all depths, down to the bottom layers more than 60 meters deep. However, by 1989 high inputs of nutrients from agricultural runoff and sewage from towns and villages had led to algal blooms that severely depleted oxygen levels in deeper parts of the lake. Cichlids feed on algae, and initially their population numbers are thought to have risen in response to this increase in their food supply, but unlike the conditions during similar algal blooms of the past, the Nile perch was present to take advantage of the situation. With a sudden increase in its food supply (cichlids), the numbers of Nile perch exploded, and they simply ate all available cichlids.

Since 1990, the situation has been compounded by the introduction into Lake Victoria of a floating water weed from South America, the water hyacinth *Eichornia crassipes*. Extremely fecund under eutrophic conditions, thick mats of water hyacinth soon covered entire bays and inlets, choking off the coastal habitats of non-open-water cichlids.

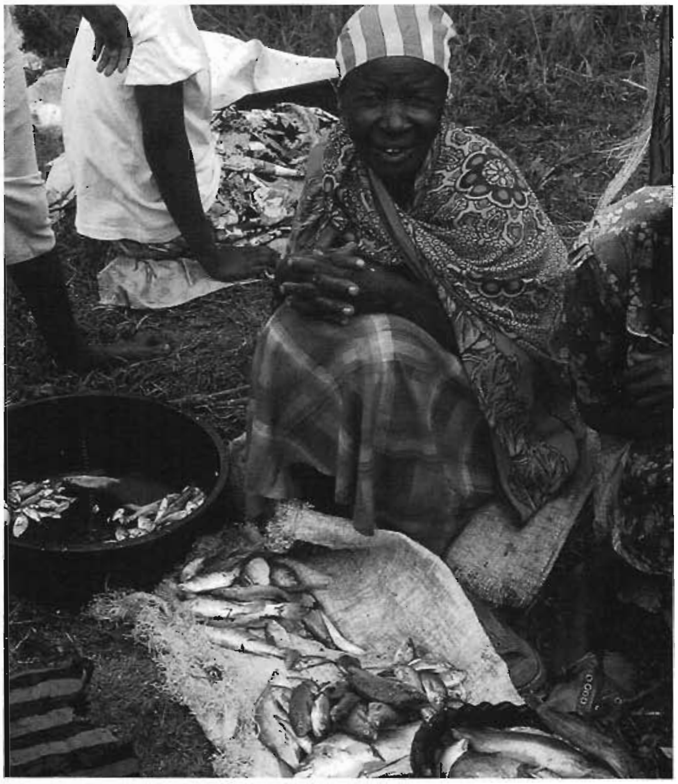


FIGURE 57.18
Victor and vanquished. The Nile perch (larger fishes in foreground), a commercial fish introduced into Lake Victoria as a potential food source, is responsible for the virtual extinction of hundreds of species of cichlid fishes (smaller fishes in tub).

Human activities are increasingly introducing many species all over the world. Such introductions often have catastrophic effects on the native fauna and flora, and can cause enormous economic damage.

Disruption of Ecosystems

Species often become vulnerable to extinction when their web of ecological interactions becomes seriously disrupted. Because of the many relationships linking species in an ecosystem (see chapter 55), human activities that affect one species can ramify throughout an ecosystem, ultimately affecting many other species.

A recent case in point are the sea otters that live in the cold waters off Alaska and the Aleutian Islands. Otter populations have declined sharply in recent years. In a 500-mile stretch of coastline, otter numbers have dropped from 53,000 in the 1970s to an estimated 6000, a plunge of nearly 90%. Investigating this catastrophic decline, marine ecologists uncovered a chain of interactions among the species of the ocean and kelp forest ecosystems, a falling-domino series of lethal effects that illustrates the concepts of both top-down and bottom-up trophic cascades discussed in chapter 55.

Case Study: Alaskan Near-Shore Habitat

The first in a series of events leading to the sea otter's decline seems to have been the heavy commercial harvesting of whales (see the case study earlier in this section, page 1239). Without whales to keep their numbers in check, ocean zooplankton thrived, leading in turn to proliferation of a species of fish called pollock that feeds on the abundant zooplankton. Given this ample food supply, the pollock proved to be very successful competitors of other northern Pacific fish, such as herring and ocean perch, so that levels of these other fish fell steeply in the 1970s.

Then the falling chain of dominoes began to accelerate. The decline in the nutritious forage fish led to an ensuing crash in Alaskan populations of Steller's sea lions and harbor seals, for which pollock did not provide sufficient nourishment. Numbers of these pinniped species have fallen precipitously since the 1970s.

Pinnipeds are the major food of orcas, also called killer whales. Faced with a food shortage, some orcas turned to the next best thing: sea otters. In one bay where the entrance from the sea was too narrow and shallow for orcas to enter, only 12% of the sea otters have disappeared, while in a similar bay that orcas could enter easily, two-thirds of the otters disappeared in a year's time.

Without otters to eat them, the population of sea urchins exploded, eating the kelp and thus "deforesting" the kelp forests and denuding the ecosystem (figure 57.19). As a result, fish species that live in the kelp forest, such as sculpins and greenlings (a cod relative), are declining.

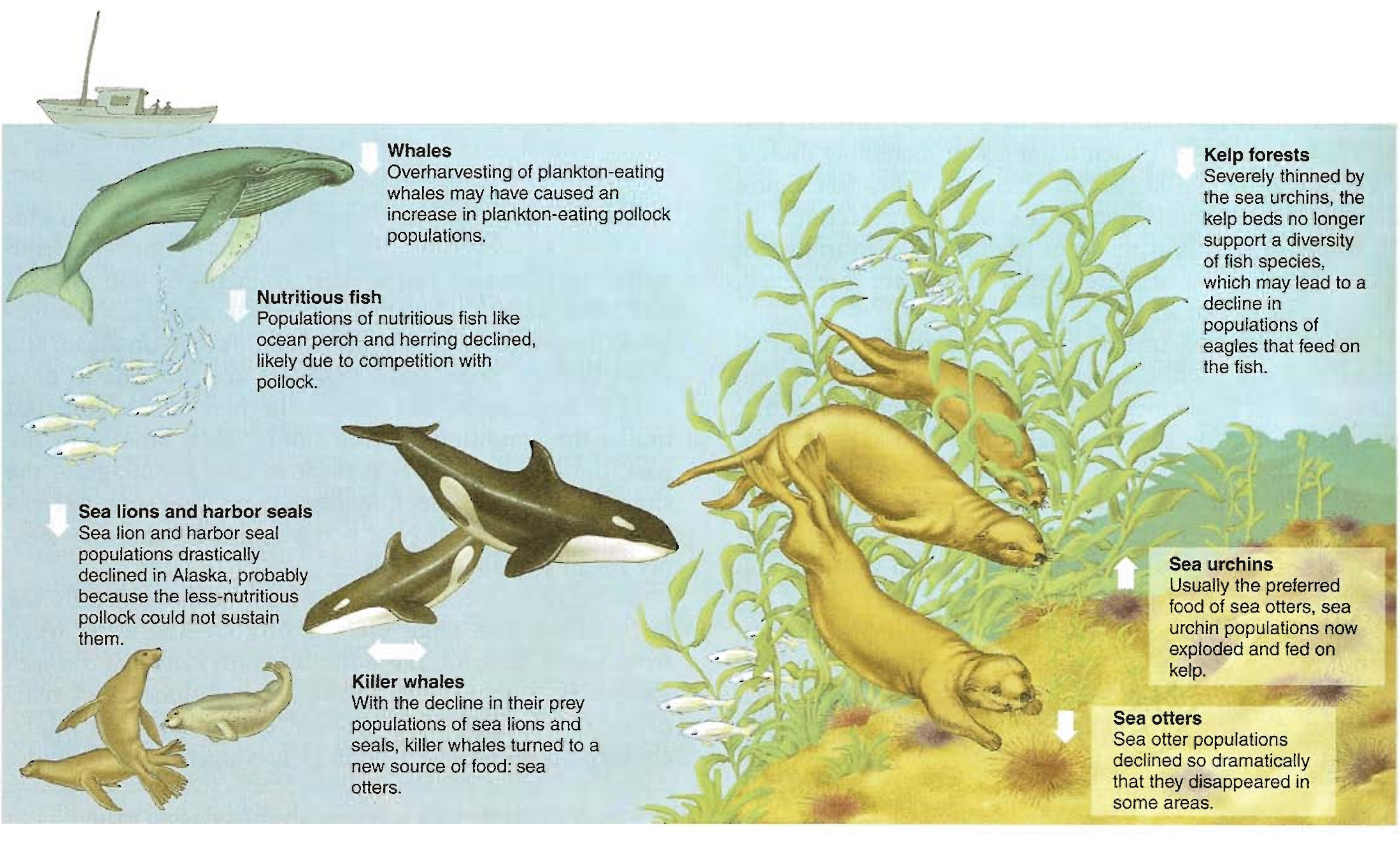


FIGURE 57.19
Disruption of the kelp forest ecosystem. Overharvesting by commercial whalers altered the balance of fish in the ocean ecosystem, inducing killer whales to feed on sea otters, a keystone species of the kelp forest ecosystem.

Preserving Keystone Species

As discussed in chapter 54, a keystone species is a species that exerts a particularly strong influence on the structure and functioning of a certain ecosystem. The sea otters of figure 57.19 are a keystone species of the kelp forest ecosystem, and their removal can have disastrous consequences. There is no hard-and-fast line that allows us to clearly identify keystone species. Rather, it is a qualitative concept, a statement that a species plays a particularly important role in its community. Keystone species are usually characterized by the strength of their impact on their community. *Community importance* measures the change in some quantitative aspect of the ecosystem (for example, species richness, productivity, or nutrient cycling) per unit of change in the abundance of a species.

FIGURE 57.20
Preserving keystone species. The flying fox is a keystone species on many Old World tropical islands. It pollinates many of the plants, and is a key disperser of seeds. Its elimination due to hunting and habitat loss is having a devastating effect on the ecosystems of many South Pacific Islands.

Case Study: Flying Foxes. The severe decline of many species of pteropodid bats, or "flying foxes," in the Old World tropics is an example of how the loss of a keystone species can dramatically affect the other species living within an ecosystem, sometimes even leading to a cascade of further extinctions (figure 57.20). These bats have very close relationships with important plant species on the islands of the Pacific and Indian Oceans. The family Pteropodidae contains nearly 200 species, approximately one-quarter of them in the genus *Pteropus*, and is widespread on the islands of the South Pacific, where they are the most important—and often the only—pollinators and seed dispersers. A study in Samoa found that 80 to 100% of the seeds landing on the ground during the dry season were deposited by flying foxes. Many species are entirely dependent on these bats for pollination. Some have evolved features such as night-blooming flowers that prevent any other potential pollinators from taking over the role of the fruit bats.

In Guam, where the two local species of flying fox have recently been driven extinct or nearly so, the impact on the ecosystem appears to be substantial. Botanists have found that some plant species are not fruiting or are doing so only marginally, producing fewer fruits than normal. Fruits are not being dispersed away from parent plants, so offspring shoots are being crowded out by the adults.

Flying foxes are being driven to extinction by human hunters who kill them for food and for sport, and by orchard farmers who consider them pests. Flying foxes are particularly vulnerable because they live in large, easily seen groups of up to a million individuals. Because they move in regular and predictable patterns and can be easily tracked to their home roost, hunters can easily bag thousands at a time.

Programs aimed at preserving particular species of flying foxes are only just beginning. One particularly successful example is the program to save the Rodrigues fruit bat, *Pteropus rodricensis*, which occurs only on Rodrigues Island in the Indian Ocean near Madagascar. The population dropped from about 1000 individuals in 1955 to fewer than 100 by 1974, largely due to the loss of the fruit bat's forest habitat to farming. Since 1974, the species has been legally protected, and the forest area of the island is being increased through a tree-planting program. Eleven captive-breeding colonies have been established, and the bat population is now increasing rapidly. The combination of legal protection, habitat restoration, and captive breeding has in this instance produced a very effective preservation program.

Because of the interrelationships among species within an ecosystem, activities that directly harm one species may indirectly have large impacts on many other species as well.

The Perils of Small Population Size

Because of the factors just discussed, populations of many species are fragmented and reduced in size. Such populations are particularly prone to extinction.

Demographic Factors

Small populations are vulnerable to a variety of demographic factors. By nature of their small size, they are ill-equipped to withstand a catastrophic event, such as a flood, forest fire, or disease epidemic. One example is the heath hen. Although the species was once common throughout the eastern United States, hunting pressure in the eighteenth and nineteenth centuries eventually eliminated all but one population, on the island of Martha's Vineyard near Cape Cod, Massachusetts. Protected in a nature preserve, the population was increasing in number until a fire destroyed most of the preserve's habitat. The small surviving population was then ravaged the next year by an unusual congregation of predatory birds, followed shortly thereafter by a disease epidemic.

When populations become extremely small, bad luck can spell the end. For example, the dusky seaside sparrow (figure 57.21), a now-extinct subspecies that was found on the east coast of Florida, dwindled to a population of five individuals, all of which happened to be males. In a large population, the probability that all individuals will be of one sex is infinitesimal. But in small populations, just by the luck of the draw, it is possible that five or ten or even 20 consecutive births will all be individuals of one sex, and that can be enough to send a species to extinction. In addition, when populations are small, individuals may have trouble finding each other (the Allee effect discussed in chapter 53), thus leading the population into a downward spiral toward extinction.

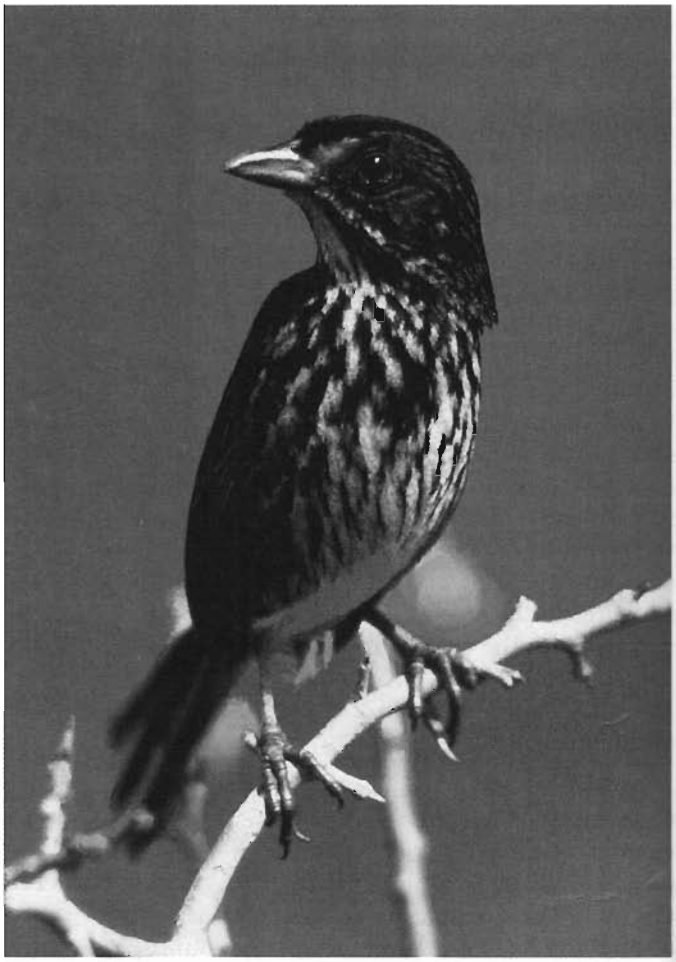


FIGURE 57.21
Alive no more. This male was one of the last dusky seaside sparrows, a subspecies that no longer exists.

Lack of Genetic Variability

Small populations face a second dilemma. Because of their low numbers, such populations are prone to the loss of genetic variation as a result of genetic drift (figure 57.22). Indeed, many small populations contain little or no genetic variability. The result of such genetic homogeneity can be catastrophic. Genetic variation is beneficial to a population both because of heterozygote advantage (see chapter 21) and because genetically variable individuals tend not to have two copies of deleteriously recessive alleles. As a result, populations lacking variation are often composed of sickly, unfit, or sterile individuals. Indeed, in the laboratory, groups of rodents and fruit flies that are maintained at small population sizes often perish after a few generations as each generation becomes less robust and fertile than the preceding one. Although it is difficult to demonstrate that a species has gone

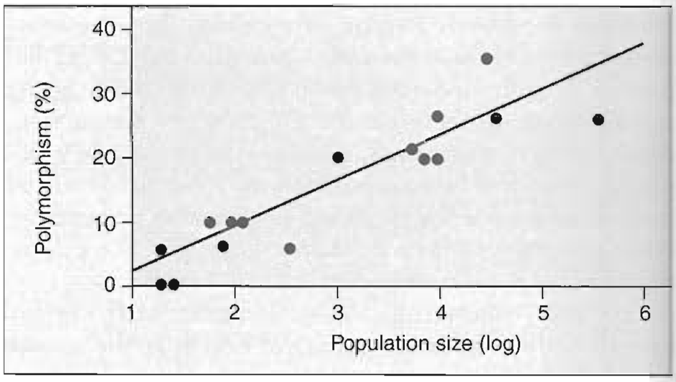


FIGURE 57.22
Loss of genetic variability in small populations. The percentage of polymorphic genes in isolated populations of the tree *Halocarpus bidwillii* in the mountains of New Zealand is a sensitive function of population size.
Why do small populations lose genetic variation?

extinct because of lack of genetic variation, studies of both zoo and natural populations clearly reveal that more genetically variable individuals have greater fitness. Furthermore, in the longer term, populations with limited genetic variation have diminished ability to adapt to changing environments.

Demographic and Genetic Factors Interact

As populations decrease in size, demographic and genetic factors feed on each other, causing what has been termed an "extinction vortex." That is, as a population gets smaller, it becomes more vulnerable to demographic catastrophes. In turn, genetic variation starts to be lost, causing reproductive rates to decline and population numbers to decline even further, and so on. Eventually, the population disappears entirely, but attributing its demise to one particular factor would be misleading.

FIGURE 57.23
A mating ritual. The male prairie chicken inflates bright orange air sacs, part of his esophagus, into balloons on each side of his head. As air is drawn into the sacs, it creates a three-syllable "boom-boom-boom" that can be heard for miles.

Case Study: Prairie Chickens

The greater prairie chicken (*Tympanuchus cupido pinnatus*) is a showy, two-pound wild bird renowned for its flamboyant mating rituals (figure 57.23). Abundant in many midwestern states, the prairie chickens in Illinois have in the past six decades undergone a population collapse. Once, enormous numbers of birds occurred throughout the state, but with the 1837 introduction of the steel plow, the first that could slice through the deep, dense root systems of prairie grasses, the Illinois prairie began to be replaced by farmland, and by the turn of the century, the prairie had vanished. By 1931, a related subspecies known as the heath hen (*Tympanuchus cupido cupido*) had become extinct in Illinois. The greater prairie chicken fared little better, its numbers falling to 25,000 statewide in 1933 and then to 2000 in 1962. In surrounding states with less intensive agriculture, it continued to prosper.

In 1962 and 1967, sanctuaries were established in Illinois to attempt to preserve the prairie chicken. But privately owned grasslands kept disappearing, along with their prairie chickens, and by the 1980s the birds were extinct in Illinois except for the two preserves. And even there, their numbers kept falling. By 1990, the egg hatching rate, which at one time had averaged between 91 and 100%, had dropped to an extremely low 38%. By the mid-1990s, the count of males had dropped to as low as six in each sanctuary.

What was wrong with the sanctuary populations? One suggestion was that because of very small population sizes and a mating ritual whereby one male may dominate a flock, the Illinois prairie chickens had lost so much genetic variability as to create serious inbreeding problems. To test this idea, biologists at the University of Illinois compared DNA from frozen tissue samples of birds that had died in Illinois between 1974 and 1993, and found that in recent years Illinois birds had indeed become genetically less diverse. After extracting DNA from tissue in the roots of feathers from stuffed birds collected in the 1930s from the same population, the researchers found that Illinois birds had lost fully one-third of the genetic diversity of birds living in the same place before the population collapse of the 1970s. By contrast, prairie chicken populations in other states still contained much of the genetic variation that had disappeared from Illinois populations.

Now the stage was set to halt the Illinois prairie chicken's race toward extinction. Wildlife managers began to transplant birds from genetically diverse populations of Minnesota, Kansas, and Nebraska to Illinois. Between 1992 and 1996, a total of 518 out-of-state prairie chickens were brought in to interbreed with the Illinois birds, and hatching rates were back up to 94% by 1998. It looks as though the Illinois prairie chickens have been saved from extinction.

The key lesson to be learned is the importance of not allowing things to go too far—not to drop down to a single isolated population. Without the outlying genetically different populations, the prairie chickens in Illinois could not have been saved. For example, when the last population of the dusky seaside sparrow lost its last female, there was no other source of females and the subspecies went extinct.

Small populations face a variety of perils: They have less ability to rebound from catastrophes and are vulnerable to loss of genetic variation. Worst of all, these problems build on each other, magnifying their impact.

57.3 Successful recovery efforts need to be multidimensional.

Approaches for Preserving Endangered Species

Once the cause of a species' endangerment is known, it becomes possible to design a recovery plan. If the cause is commercial overharvesting, regulations can be issued to lessen the impact and protect the threatened species. If the cause is habitat loss, plans can be instituted to restore the habitat. Loss of genetic variability in isolated subpopulations can be countered by transplanting individuals from genetically different populations. Populations in immediate danger of extinction can be captured, introduced into a captive-breeding program, and later reintroduced to other suitable habitat.

Of course, all of these solutions are extremely expensive. As Bruce Babbitt, Secretary of the Interior in the Clinton administration, noted, it is much more economical to prevent "environmental trainwrecks" from occurring than to clean them up afterwards. Preserving ecosystems and monitoring species before they are threatened is the most effective means of protecting the environment and preventing extinctions.

(a)

(b)

FIGURE 57.24
Habitat restoration. The University of Wisconsin–Madison Arboretum has pioneered restoration ecology. (*a*) The restoration of the prairie was at an early stage in November 1935. (*b*) The prairie as it looks today. This picture was taken at approximately the same location as the 1935 photograph.

Habitat Restoration

Conservation biology typically concerns itself with preserving populations and species in danger of decline or extinction. Conservation, however, requires that there be something left to preserve, while in many situations, conservation is no longer an option. Species, and in some cases whole communities, have disappeared or been irretrievably modified. The clear-cutting of the temperate forests of Washington State leaves little behind to conserve, as does converting a piece of land into a wheat field or an asphalt parking lot. Redeeming these situations requires restoration rather than conservation.

Three quite different sorts of habitat restoration programs might be undertaken, depending on the cause of the habitat loss.

Pristine Restoration. In ecosystems where all species have been effectively removed, conservationists might attempt to restore the plants and animals that are the natural inhabitants of the area, if these species can be identified. When abandoned farmland is to be restored to prairie, as in figure 57.24, how would you know what to plant? Although it is in principle possible to reestablish each of the original species in their original proportions, rebuilding a community requires knowing the identities of all the original inhabitants and the ecologies of each of the species. We rarely have this much information, so no restoration is ever truly pristine.

Removing Introduced Species. Sometimes the habitat of a species has been destroyed by a single introduced species. In such a case, habitat restoration involves removing the introduced species. Restoration of the once-diverse cichlid fishes to Lake Victoria will require more than breeding and restocking the endangered species. The introduced water hyacinth and Nile perch populations will have to be brought under control or removed, and eutrophication will have to be reversed.

It is important to act quickly if an introduced species is to be removed. When aggressive African bees (the so-called "killer bees") were inadvertently released in Brazil, they remained confined to the local area only one season. Now they occupy much of the western hemisphere.

Cleanup and Rehabilitation. Habitats seriously degraded by chemical pollution cannot be restored until the pollution is cleaned up. The successful restoration of the Nashua River in New England is one example of how a concerted effort can succeed in restoring a heavily polluted habitat to a relatively pristine condition.

Captive Breeding

Recovery programs, particularly those focused on one or a few species, must sometimes involve direct intervention in natural populations to avoid an immediate threat of extinction.

The Peregrine Falcon. American populations of birds of prey, such as the peregrine falcon (*Falco peregrinus*), began an abrupt decline shortly after World War II. Of the approximately 350 breeding pairs east of the Mississippi River in 1942, all had disappeared by 1960. The culprit proved to be the chemical pesticide DDT (dichlorodiphenyltrichloroethane) and related organochlorine pesticides. Birds of prey are particularly vulnerable to DDT because they feed at the top of the food chain, where DDT becomes concentrated. DDT interferes with the deposition of calcium in the bird's eggshells, causing most of the eggs to break before they are ready to hatch.

The use of DDT was banned by federal law in 1972, causing levels in the eastern United States to fall quickly. However, there were no peregrine falcons left in the eastern United States to reestablish a natural population. Falcons from other parts of the country were used to establish a captive-breeding program at Cornell University in 1970, with the intent of reestablishing the peregrine falcon in the eastern United States by releasing offspring of these birds. By the end of 1986, over 850 birds had been released in 13 eastern states, producing an astonishingly strong recovery (figure 57.25).

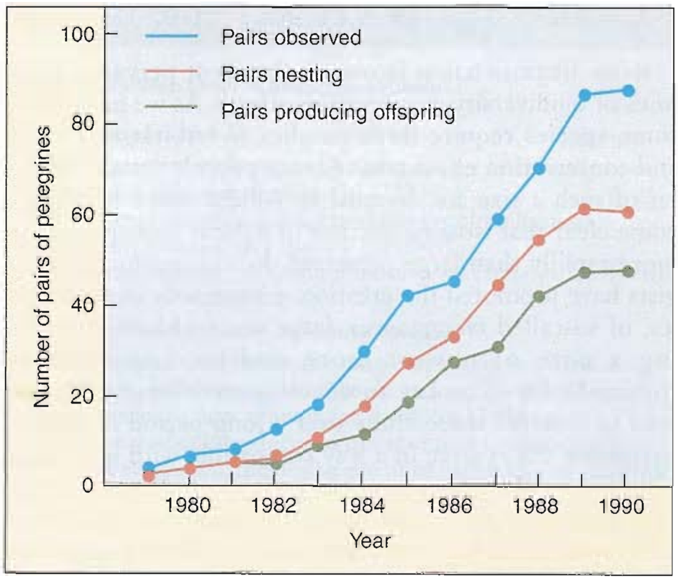


FIGURE 57.25
Captive breeding. The peregrine falcon has been reestablished in the eastern United States by releasing captive-bred birds over a period of 10 years.

The California Condor. Numbers of the California condor (*Gymnogyps californianus*), a large, vulturelike bird with a wingspan of nearly 3 meters, have been declining gradually for the past 200 years. By 1985, condor numbers had dropped so low that the bird was on the verge of extinction. Six of the remaining 15 wild birds disappeared that year alone. The entire breeding population of the species consisted of the birds remaining in the wild and an additional 21 birds in captivity. In a last-ditch attempt to save the condor from extinction, the remaining birds were captured and placed in a captive-breeding population. The breeding program was set up in zoos, with the goal of releasing offspring on a large, 5300-ha ranch in prime condor habitat. Birds were isolated from human contact as much as possible, and closely related individuals were prevented from breeding. By early 2002, the captive population of California condors had reached over 120 individuals. Thirty-two captive-reared condors have been released successfully in California at two sites in the mountains north of Los Angeles, after extensive prerelease training to avoid power poles and people. All of the released birds seem to be doing well, and another 21 birds released into the Grand Canyon have adapted successfully. Biologists are particularly excited by breeding activities that resulted in the first-ever offspring produced in the wild by captive-reared parents.

Yellowstone Wolves. The ultimate goal of captive-breeding programs is not simply to preserve interesting species, but rather to restore ecosystems to a balanced, functional state. Yellowstone Park has been an ecosystem out of balance, due in large part to the systematic extermination of the gray wolf (*Canis lupus*) in the park early in this century. Without these predators to keep their numbers in check, herds of elk and deer expanded rapidly, damaging vegetation so that the elk themselves starve in time of scarcity. In an attempt to restore the park's natural balance, two complete wolf packs from Canada were released into the park in 1995 and 1996. The wolves adapted well, breeding so successfully that by 2002 the park contained 16 free-ranging packs and more than 200 wolves.

While ranchers near the park have been unhappy about the return of the wolves, little damage to livestock has been noted, and the ecological equilibrium of Yellowstone Park seems well on the way to being regained. Elk are congregating in larger herds, and their populations are not growing as rapidly as in years past. Importantly, wolves are killing coyotes and their pups, driving them out of some areas. Coyotes, the top predators in the absence of wolves, are known to attack cattle on surrounding ranches, so reintroduction of wolves to the park may actually benefit the cattle ranchers who are opposed to it.

Efforts to preserve endangered species are as diverse as the causes of endangerment. Although captive breeding is not a solution in all, or even most, cases, it has helped restore several vertebrate species.

Conservation of Ecosystems

Habitat fragmentation is one of the most pervasive enemies of biodiversity conservation efforts. As we have seen, some species require large patches of habitat to thrive, and conservation efforts that cannot provide suitable habitat of such a size are doomed to failure. Since it has become clear that isolated patches of habitat lose species far more rapidly than large preserves do, conservation biologists have promoted the creation, particularly in the tropics, of so-called *megareserves,* large areas of land containing a core of one or more undisturbed habitats (figure 57.26). The key to devoting such large tracts of land to reserves successfully over a long period of time is to operate the reserve in a way compatible with local land use. Thus, while no economic activity is allowed in the core regions of the megareserve, the remainder of the reserve may be used for nondestructive harvesting of resources. Linking preserved areas to carefully managed land zones creates a much larger total "patch" of habitat than would otherwise be economically practical, and thus addresses the key problem created by habitat fragmentation. Pioneering these efforts, eight such megareserves have been created in Costa Rica (figure 57.27) to jointly manage biodiversity and economic activity.

In addition to this focus on maintaining large enough reserves, in recent years, conservation biologists also have recognized that the best way to preserve biodiversity is to focus on preserving intact ecosystems, rather than particular species. For this reason, attention in many cases is turning to identifying those ecosystems most in need of preservation and devising the means to protect not only the species within the ecosystem, but the functioning of the ecosystem itself.

Efforts are being undertaken worldwide to preserve biodiversity in megareserves designed to counter the influences of habitat fragmentation. Focusing on the health of entire ecosystems, rather than particular species, can often be a more effective means of preserving biodiversity.

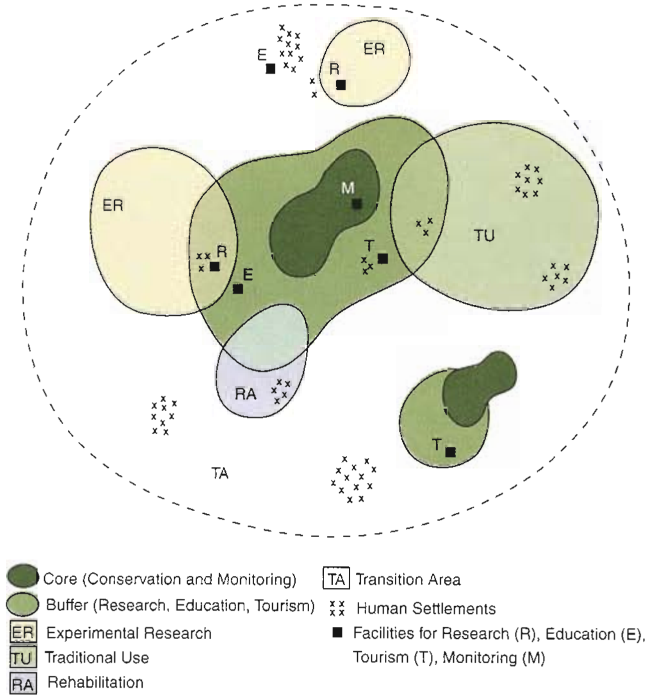


FIGURE 57.26
Design of a megareserve. A megareserve, or biosphere reserve, recognizes the need for people to have access to resources. Critical ecosystems are preserved in the core zone. Research and tourism are allowed in the buffer zone. Sustainable resource harvesting and permanent habitation are allowed in the multiple-use areas surrounding the buffer.

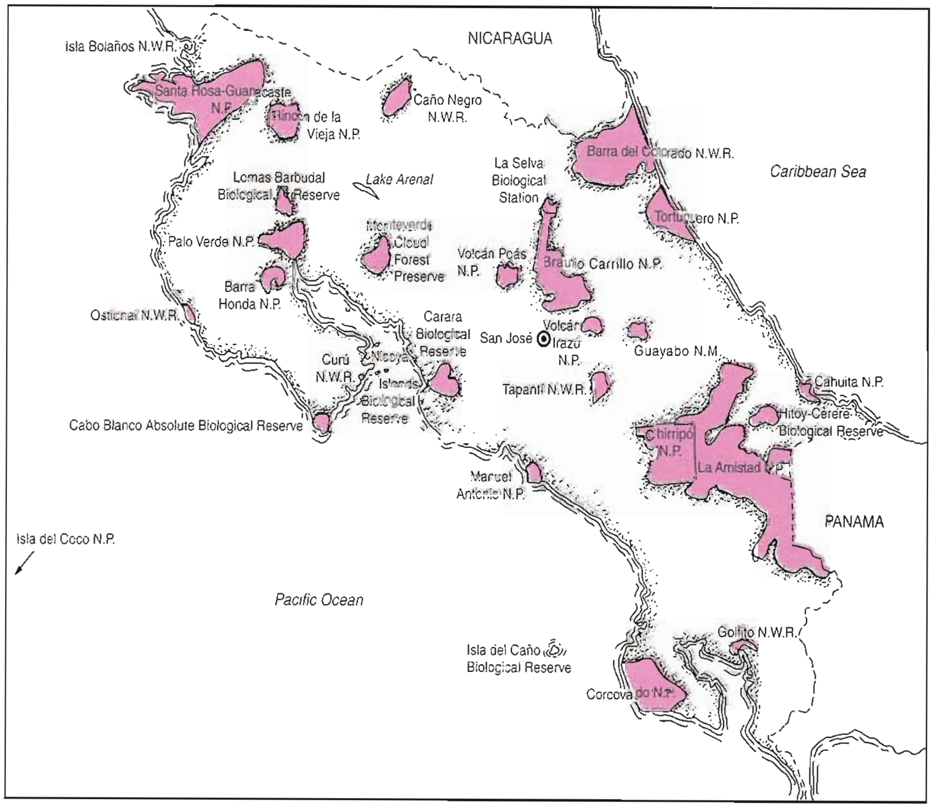


FIGURE 57.27
Biosphere reserves in Costa Rica. Costa Rica, a country the size of West Virginia, has placed about 12% of its land into national parks and eight megareserves.