31

Conservation Biology

Concept Outline

31.1 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. Worldwide extinction rates are accelerating.

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

What's So Bad about Losing Biodiversity? Biodiversity is of considerable direct economic value, and provides key support to the biosphere.

31.2 Vulnerable species are more likely to become extinct.

Predicting Which Species Are Vulnerable to Extinction. Biologists carry out population viability analyses to assess danger of extinction.

Dependence upon Other Species. Extinction of one species can have a cascading effect throughout the food web, making other species vulnerable as well.

Categories of Vulnerable Species. Declining population size, loss of genetic variation, and commercial value all tend to increase a species' vulnerability.

31.3 Causes of endangerment usually reflect human activities.

Factors Responsible for Extinction. Most recorded extinctions can be attributed to a few causes.

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

Case Study: Overexploitation

Case Study: Introduced Species

Case Study: Disruption of Ecological Relationships

Case Study: Loss of Genetic Variation

Case Study: Habitat Loss and Fragmentation

31.4 Successful recovery plans will need to be multidimensional.

Many Approaches Exist for Preserving Endangered Species. Species recovery requires restoring degraded habitats, breeding in captivity, maintaining population diversity, and maintaining keystone species.

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

FIGURE 31.1
Endangered. The Siberian tiger is in grave danger of extinction, hunted for its pelt and having its natural habitat greatly reduced. A concerted effort is being made to save it, 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 have so many species become extinct in so short a period of time (figure 31.1). This challenge has led to the emergence in the last decade of the new discipline of conservation biology. Conservation biology is an applied discipline that seeks to learn how to preserve species, communities, and ecosystems. It both studies the causes of declines in species richness and attempts to develop methods to prevent such declines. In this chapter we will first examine the biodiversity crisis and its importance. Then, we will assess the sorts of species which seem vulnerable to extinction. Using case histories, we go on to identify and study five factors that have played key roles in many extinctions. We finish with a review of recovery efforts at the species and community level.

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

Overview of the Biodiversity Crisis

Extinction is a fact of life, as normal and necessary as species formation is to a stable world ecosystem. Most species, probably all, go 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 at present, especially in the tropics, it has been calculated that as much as 20% of the world's biodiversity may be lost during the next 30 years. In addition, many of these species may be lost before we are even aware of their extinction. Scientists estimate that no more than 15% of the world's eukaryotic organisms have been discovered and given scientific names, and this proportion probably is much lower for tropical species.

These losses will not just 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 short period of time. Considering that our species has been in existence for only 500,000 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 31.2
North America before human inhabitants. Animals found in North America prior to the migration of humans included large mammals and birds such as the ancient North American camel, saber-toothed cat, giant ground-sloth, and the 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, *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 Africa today: mammoths and mastodons, horses, camels, giant ground-sloths, saber-toothed cats, and lions, among others (figure 31.2). 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 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).

Similar results have followed the arrival of humans around the globe. 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. On Madagscar, 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) all perished. 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—relatively large and well studied. Estimates of extinction rates for other species are much rougher. The data presented

Table 31.1 Recorded Extinctions since 1600 a.d.						
	Recorded Extinctions			Approximate Number of	Percent of Taxon	
Taxon	Mainland	Island	Ocean	Total	Species	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

Source: Reid and Miller, 1989; data from various sources.

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

in table 31.1, based on the best available evidence, shows 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 come 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 four species per year between 1986 and 1990 (figure 31.3). It is this increase in the rate of extinction that is the heart of the biodiversity crisis.

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% on 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 the chapter.

In recent years, however, the extinction crisis has moved from islands to continents. Most species now threatened with extinction occur on continents, and it is these areas which 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 have occurred in the past. Indeed, as we saw in chapter 21, mass extinctions have occurred 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 extinction events, new species have evolved to utilize resources available due to species extinctions. Today, however, such resources are unlikely to be available, because humans are destroying the habitats and taking the resources for their own use.

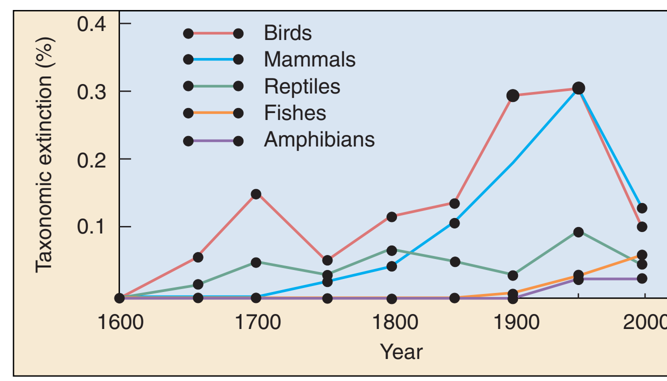


FIGURE 31.3
Trends in species loss. The graphs above present data on recorded animal extinctions since 1600. The majority of extinctions have occurred on islands, with birds and mammals particularly affected (although this may reflect to some degree our more limited knowledge of other groups).

Biologists estimate rates of extinction both by studying recorded extinction events and by analyzing trends in habitat loss and disruption. Since prehistoric times, humans have had a devastating effect on biodiversity almost everywhere in the world.

Species Endemism and Hot Spots

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. The black cherry tree (*Prunus serotina*), for example, 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 geographical areas, such as oceanic islands, lakes, and mountain peaks, often have high percentages of endemic species, often in significant danger of extinction. The number of endemic plant species varies greatly in the United States from one state to another. Thus, 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, grasslands, and many others, is home to more endemic species than any other state.

Worldwide, notable concentrations of endemic species occur in particular "hot spots" of high endemism. Such hot spots are found in Madagascar, in a variety of tropical rain forests, in the eastern Himalayas, in areas with Mediterranean climates like California, South Africa, and Australia, and in several other climatic areas (figure 31.4 and table 31.2). Unfortunately, many of these areas are experiencing high rates of habitat destruction with consequent species extinctions. In Madagascar, it is estimated that 90% of the original forest has already been lost, this in an island in which 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.

Table 31.2 Numbers of Endemic Vertebrate Species in Some "Hot Spot" Areas

Region	Mammals	Reptiles	Amphibians
Atlantic coastal Brazil	40	92	168
Colombian Chocó	8	137	111
Philippines	98	120	41
Northern Borneo	42	69	47
Southwestern Australia	10	25	22
Madagascar	86	234	142
Cae region (South Africa)	16	43	23
California Floristic Province	15	25	7
New Cledonia	2	21	0
Eastern Himalayas	—	20	25

Source: Data from Myers 1988; World Conservation and Monitoring Center 1992.

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

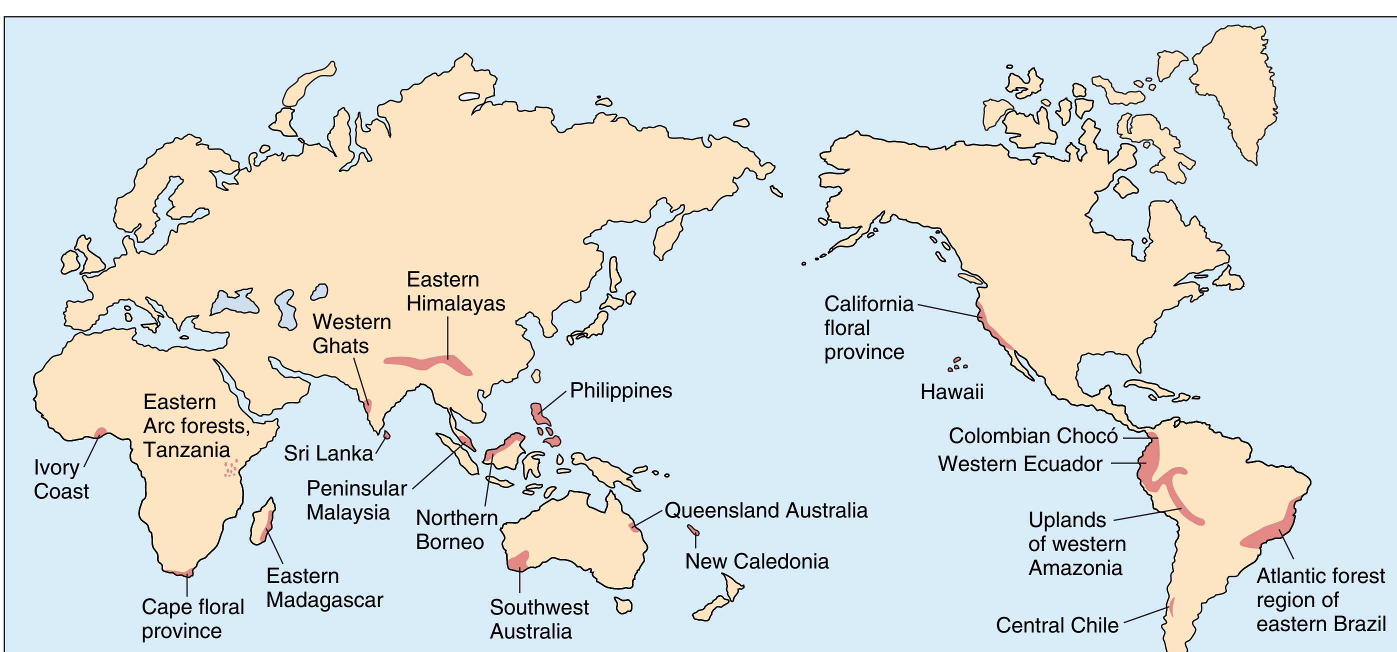


FIGURE 31.4
"Hot spots" of high endemism. These areas are rich in endemic species under significant threat of imminent extinction.

What's So Bad about Losing Biodiversity?

What's so bad about losing species? What is the value of biodiversity? Its value 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* value.

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, for example, is derived from a small number of plants that were originally domesticated from wild plants in tropical and semi-arid regions. In the future, wild strains of these species may be needed for their genetic diversity if we are to improve yields, or find a way to breed resistance to new pests.

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 31.5).

Only in the last few decades have biologists perfected the techniques that make possible the transfer of genes from one kind of organism to another. We are just beginning to be able to use genes obtained from other species to our advantage, as explored at length in chapter 19. 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 so far, to see whether any of their genes have useful properties. By conserving biodiversity we maintain the option of finding useful benefit in the future.

Indirect Economic Value

Diverse biological communities are of vital importance to healthy ecosystems, in maintaining the chemical quality of natural water, in buffering ecosystems against floods and drought, in preserving soils and preventing loss of minerals and nutrients, in moderating local and regional climate, in absorbing pollution, and in promoting 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.

Given the major role played by many species in maintaining healthy ecosystems, it is alarming how little we know about the details of how ecosystems and communities function. It is impossible to predict all the consequences of removing a species, or to be sure that some of them will not be catastrophic. Imagine taking a part list for an airliner, 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 as easily change a key bolt holding up the wing to a pencil. The point is, you shouldn't gamble if you cannot afford to lose, and in removing biodiversity we are gambling with the future of ecosystems upon which we depend, and upon whose functioning we only little understand.

FIGURE 31.5
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%.

Ethical and Aesthetic Value

Many people believe that preserving biodiversity is an ethical issue, feeling that every species is of value in its own right, even if humans are not able to exploit or benefit from it. It is clear that humans have the power to exploit and destroy other species, but it is not as ethically clear that they have the *right* to do so. Many people believe that along with power comes responsibility: as the only organisms capable of eliminating species and entire ecosystems, and as the only organisms capable of reflecting upon what we are doing, we should act as guardians or stewards for the diversity of life around us.

Almost no one would deny the aesthetic value of biodiversity, of a beautiful flower or noble elephant, but how do we place a value on beauty? Perhaps the best we can do is to appreciate the deep sense of lack we feel at its permanent loss.

Biodiversity is of great value, for the products with which it provides us, for its contributions to the health of the ecosystems upon which we all depend, and for the beauty it provides us, as well as being valuable in its own right.

31.2 Vulnerable species are more likely to become extinct.

Predicting Which Species Are Vulnerable to Extinction

How can a biologist assess whether a particular species is vulnerable to extinction? To get some handle on this, conservation biologists look for changes in population size and habitat availability. Species whose populations are shrinking rapidly, whose habitats are being destroyed (figure 31.6), or which are endemic to small areas can be considered to be endangered.

Population Viability Analysis

Quantifying the risk faced by a particular species is not a simple or precise enterprise. Increasingly, conservation biologists make a rough estimate of a population's risk of local extinction in terms of a **minimum viable population** (MVP), the estimated number or density of individuals necessary for the population to maintain or increase its numbers.

Some small populations are at high risk of extinction, while other populations equally small are at little or no risk. Conservation biologists carry out a **population viability analysis** (PVA) to assess how the size of a population influences its risk of becoming extinct over a specific time period, often 100 years. Many factors must be taken into account in a PVA. Two components of particular importance are *demographic stochasticity* (the amount of random variation in birth and death rates) and *genetic stochasticity* (fluctuations in a population's level of genetic variation). Demographic stochasticity refers to random events that affect a population. The smaller the population, the more likely it is that a random event, such as a disease epidemic or an environmental disturbance (such as a flood or a fire) could decimate a population and lead to extinction. Similarly, small populations are most likely to lose genetic variation due to genetic drift (see chapter 20) and thus be vulnerable to both the short- and long-term consequences of genetic uniformity. For these reasons, small populations are at particularly great risk of extinction.

Many species are distributed as metapopulations, collections of small populations each occupying a suitable patch of habitat in an otherwise unsuitable landscape (see chapter 24). Each individual subpopulation may be quite small and in real threat of extinction, but the metapopulation may be quite safe from extinction so long as individuals from other populations repopulate the habitat patches vacated by extinct populations. The extent of this rescue effect is an important component of the PVA of such species; if rates of population extinction increase, there may not be enough surviving populations to found new populations, and the species as a whole may slide toward extinction.

FIGURE 31.6
Habitat removal. In this clear-cut lumbering of National Forest land in Washington State, few if any trees have been left standing, removing as well the home of the deer, birds, and other animal inhabitants of temperate forest. Until a replacement habitat is provided by replanting, this is a truly "lost" habitat.

Small populations are particularly in danger of extinction. To assess the risk of local extinction of a particular species, conservation biologists carry out a population viability analysis that takes into account demographic and genetic variation.

Dependence upon Other Species

Species often become vulnerable to extinction when their web of ecological interactions becomes seriously disrupted. A recent case in point are the sea otters that live in the cold waters off Alaska and the Aleutian Islands. A keystone species in the kelp forest ecosystem, the otter populations have declined sharply in recent years. In a 500-mile stretch of coastline, otter numbers had dropped to an estimated 6000 from 53,000 in the 1970s, 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 chain of lethal effects.

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 history later in this chapter). Without whales to keep their numbers in check, ocean zooplankton thrived, leading in turn to proliferation of a species of fish called pollock that feed on the now-abundant zooplankton. Given this ample food supply, the pollock proved to be very successful competitors of other northern Pacific fish like herring and ocean perch, so that levels of these other fish fell steeply in the 1970s.

Now the falling chain of dominos begins 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 seem to have 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 which 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 in the ecosystem exploded, eating the kelp and so "deforesting" the kelp forests and denuding the ecosystem (figure 31.7). As a result, fish species that live in the kelp forest, like sculpins and greenlings (a cod relative), are declining. This chain reaction demonstrates why sea otters are considered to be a keystone species.

Commercial whaling appears to have initiated a series of changes that have led to orcas feeding on sea otters, with disastrous effects on their kelp forest ecosystem.

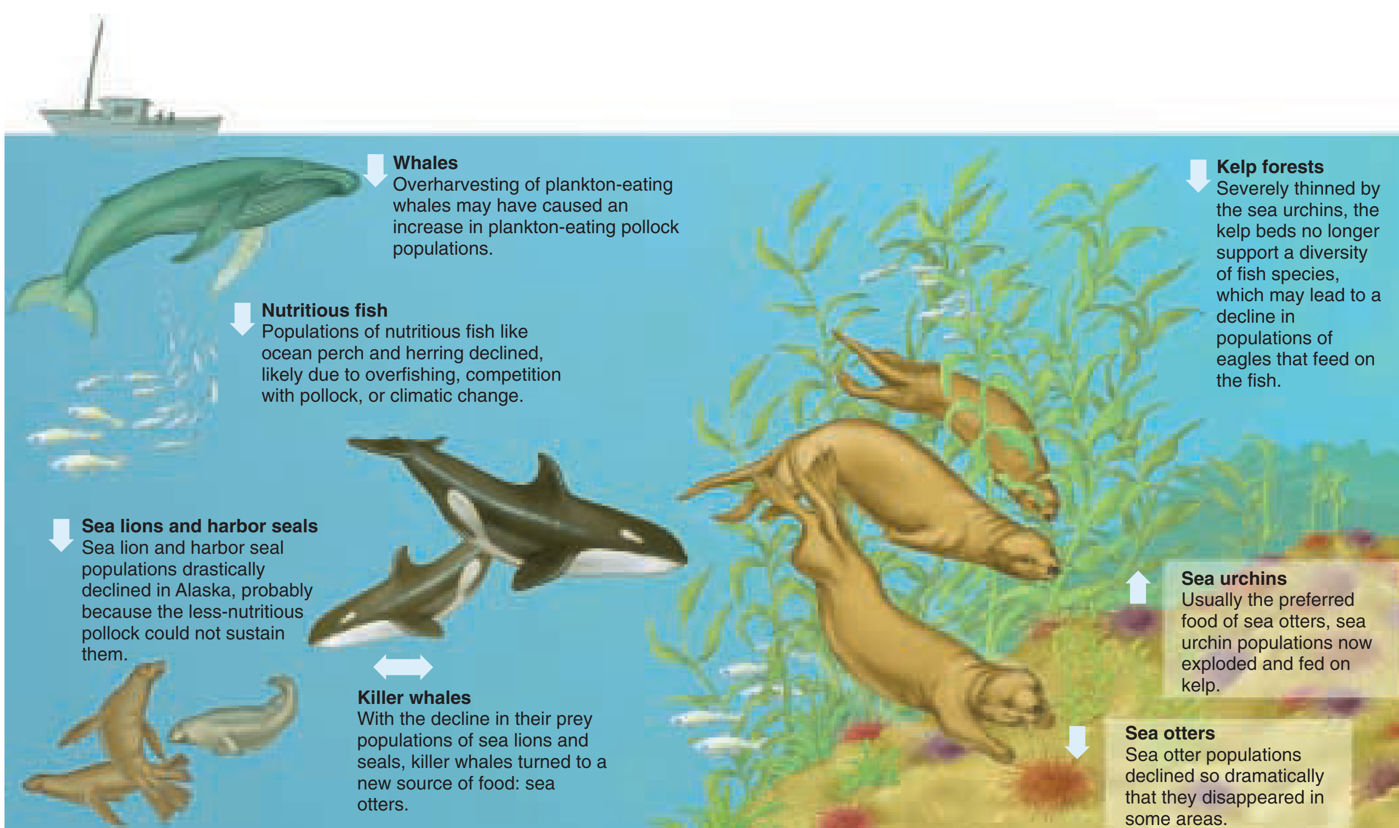


FIGURE 31.7
Disruption of the kelp forest ecosystem. Overharvesting by commercial whalers altered the balance of fish in the ocean ecosystem, inducing killer whales to feed on sea otters, a keystone species of the kelp forest ecosystem.

Categories of Vulnerable Species

Studying past extinctions of species and using population viability analyses of threatened ones, conservation biologists have observed that some categories of species are particularly vulnerable to extinction.

Local Endemic Distribution

Local endemic species typically occur at only one or a few sites in a restricted geographical range, which makes them particularly vulnerable to anything that harms the site, such as destruction of habitat by human activity. Bird species on oceanic islands have often become extinct as humans affect the island habitats. Many endemic fish species confined to a single lake undergo similar fates.

Local endemic species often have small population sizes, placing them at particular risk of extinction because of their greater vulnerability to demographic and genetic fluctuations. Indeed, population size by itself seems to be one of the best predictors of the extinction risk of populations.

Local endemic species often have quite specialized niche requirements. Once a habitat is altered, it may no longer be able to support a particular local endemic, while remaining satisfactory for species with less particular requirements. For example, wetlands plants that require very specific and regular changes in water level may be rapidly eliminated when human activity affects the hydrology of an area.

Declining Population Size

Species in which population size is declining are often at grave risk of extinction, particularly if the decline in numbers of individuals is severe. Although there is no hard rule, population trends in nature tend to continue, so a population showing significant signs of decline should be considered at risk of extinction unless the cause of the decline is identified and corrected. Darwin makes this point very clearly in *On the Origin of Species*:

"To admit that species generally become rare before they become extinct, to feel no surprise at the rarity of the species, and yet to marvel greatly when the species ceases to exist, is much the same as to admit that sickness in the individual is the forerunner of death—to feel no surprise at sickness, but when the sick man dies, to wonder and to suspect that he dies of some deed of violence."

Although long-term trends toward smaller population numbers suggest that a species may be at risk in future years, abrupt recent declines in population numbers, particularly when the population is small or locally endemic, fairly scream of risk of extinction. It is for this reason that PVA is best carried out with data on population sizes gathered over a period of time.

Lack of Genetic Variability

Species with little genetic variability are generally at significantly greater risk of extinction than more variable species, simply because they have a more limited arsenal with which to respond to the vagaries of environmental change. Species with extremely low genetic variability are particularly vulnerable when faced with a new disease, predator, or other environmental challenge. For example, the African cheetah (*Acinonyx jubatus*) has almost no genetic variability. This lack of genetic variability is considered to be a significant contributing factor to a lack of disease resistance in the cheetah—diseases that are of little consequence to other cat species can wipe out a colony of cheetahs (although environmental factors also seem to have played a key role in the cheetah's decline).

Hunted or Harvested by People

Species that are hunted or harvested by people have historically been at grave risk of extinction. Overharvesting of natural populations can rapidly reduce the population size of a species, even when that species is initially very abundant. A century ago the skies of North America were darkened by huge flocks of passenger pigeons; hunted as free and tasty food, they were driven to extinction. The buffalo that used to migrate in enormous herds across the central plains of North America only narrowly escaped the same fate, a few individuals preserved from this catastrophic exercise in overhunting founding today's modest herds.

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, vicuna, otter, and many wild cat species. The harvesting of commercially valuable trees provides another telling example: almost all West Indies mahogany (*Swietenia mahogani*) have been logged from the Caribbean islands, and the extensive cedar forests of Lebanon, once widespread at high elevations in the Middle East, now survive in only a few isolated groves.

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

A variety of factors can make a species particularly vulnerable to extinction.

31.3 Causes of endangerment usually reflect human activities.

Factors Responsible For Extinction

Because a species is rare does not necessarily mean that it is in danger of extinction. The habitat it utilizes may simply be in short supply, preventing population numbers from growing. In a similar way, shortage of some other resource may be limiting the size of populations. Secondary carnivores, for example, are usually rare because so little energy is available to support their populations. Nor are vulnerable species such as those categories discussed in the previous section always threatened with extinction. Many local endemics are quite stable and not at all threatened.

If it's not just size or vulnerability, what factors are responsible for extinction? Studying a wide array of recorded extinctions and many species currently threatened with extinction, conservation biologists have identified a few factors that seem to play a key role in many extinctions: overexploitation, introduced species, disruption of ecological relationships, loss of genetic variability, and habitat loss and fragmentation (figure 31.8 and table 31.3).

Most recorded extinctions can be attributed to one of five causes: overexploitation, introduced species, ecodisruption, loss of genetic variability, and habitat loss and fragmentation.

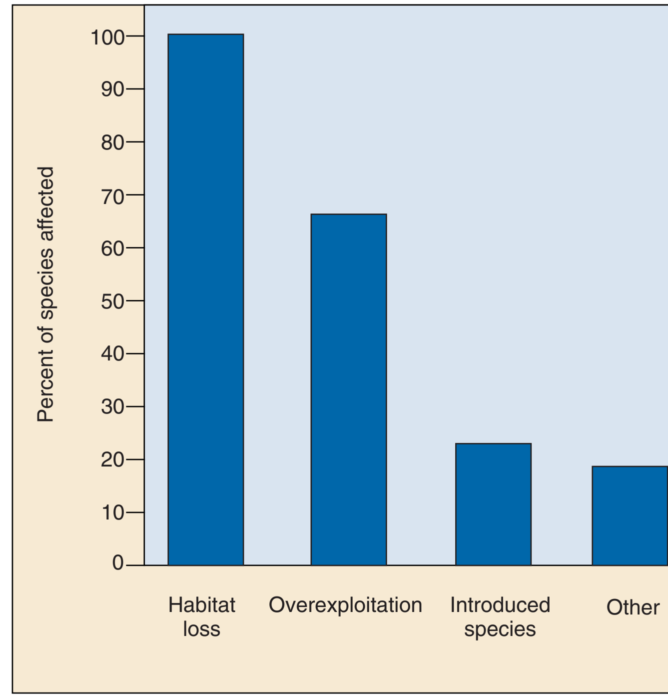


FIGURE 31.8
Factors responsible for animal extinction. These data represent known extinctions of mammals in Australasia and the Americas.

Table 31.3 Causes of Extinctions

Group	Habitat Loss	Overexploitation	Species Introduction	Predators	Other	Unknown
	Percentage of Species Influenced by the Given Factor*					
EXTINCTIONS						
Mammals	19	23	20	1	1	36
Birds	20	11	22	0	2	37
Reptiles	5	32	42	0	0	21
Fish	35	4	30	0	4	48
THREATENED EXTINCTIONS						
Mammals	68	54	6	8	12	—
Birds	58	30	28	1	1	—
Reptiles	53	63	17	3	6	—
Amphibians	77	29	14	—	3	—
Fish	78	12	28	—	2	—

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

Source: Reid and Miller, 1989.

Habitat Loss

As figure 31.8 and table 31.3 indicate, habitat loss is the single most important cause of 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 human influences in four ways: (1) destruction, (2) pollution, (3) human 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 is, by far the most pervasive form of habitat disruption (figure 31.9). Many tropical forests are being cut or burned at a rate of 1% or more per year.

Biologists often use the well-established observation that larger areas support more species (see figure 29.24) to estimate the effect of reductions in habitat available to a species. As we saw in chapter 30, a relationship usually exists between the size of an area and the number of species it contains. Although this relationship varies according to geographic area, type of organism, and type of area (for example, oceanic islands, patches of habitat on the mainland), a general result is that a tenfold increase in area usually leads to approximately a doubling in 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 31.10).

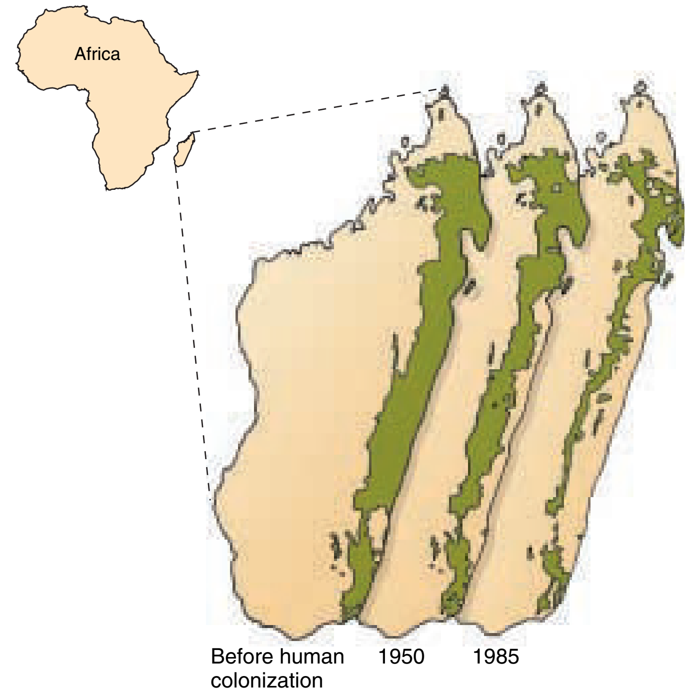


FIGURE 31.9
Extinction and habitat destruction. The rain forest covering the eastern coast of Madagascar, an island off the coast of East Africa, has been progressively destroyed as the island's human population has grown. Ninety percent of the original forest cover is now gone. Many species have become extinct, and many others are threatened, including 16 of Madagascar's 31 primate species.

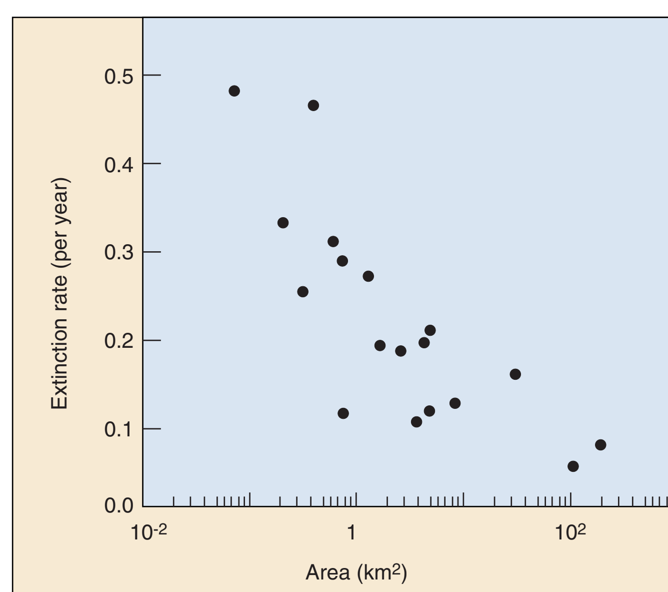


FIGURE 31.10
Extinction and the species-area relationship. The data present percent extinction rates as a function of habitat area for birds on a series of Finnish islands. Smaller islands experience far greater local extinction rates.

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; many northern lakes in both Europe and North America, for example, have been essentially sterilized by acid rain.

Human Disruption

Habitat may be so disturbed by human activities as to make it untenable for some species. For example, visitors to caves in Alabama and Tennessee produced significant population declines in bats over an eight-year period, some as great as 100%. When visits were fewer than one

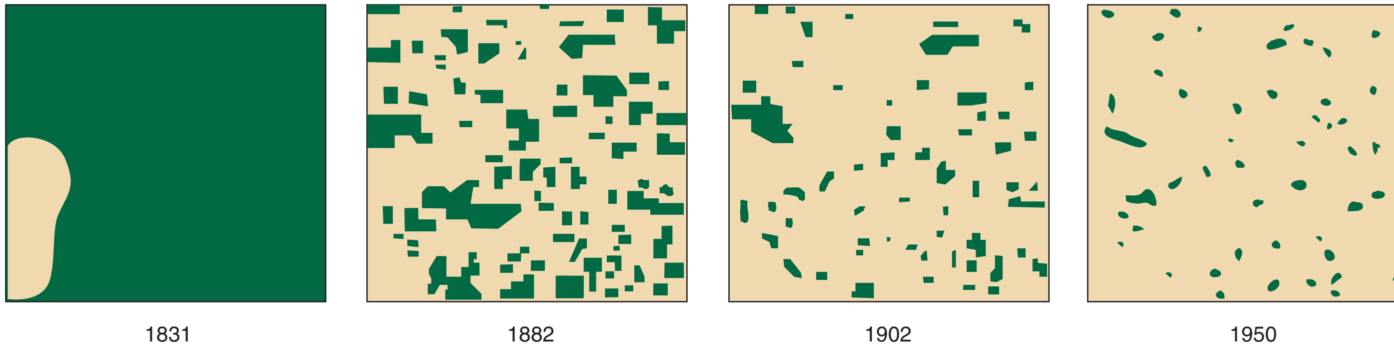


FIGURE 31.11
Fragmentation of woodland habitat. From the time of settlement of Cadiz Township, Wisconsin, the forest has been progressively reduced from a nearly continuous cover to isolated woodlots covering less than 1% of the original area.

per month, less than 20% of bats were lost, but caves with more than four visits per month suffered population declines of between 86 and 95%.

Habitat Fragmentation

Loss of habitat by a species frequently results not only in a lowering of population numbers, but also in fragmentation of the population into unconnected patches (figure 31.11).

A habitat may become fragmented in unobvious ways, such as when roads and habitation intrude into forest. The effect is to carve up the populations living in the habitat into a series of smaller populations, often with disastrous consequences. 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, within 100 meters of the forest edge, tree biomass decreased by 36% in the first 17 years after fragment isolation in one study.

Also, increasing habitat edges opens up opportunities for parasites and predators, 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 thought to have been responsible for local extinctions in a wide range of species.

The impact of habitat fragmentation can be seen clearly in a major study done in Manaus, Brazil, as 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 31.12). 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.

FIGURE 31.12
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.

Because some species like monkeys require large patches, this means that 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.

Habitat loss is probably the greatest cause of extinction. As habitats are destroyed, remaining habitat becomes fragmented, increasing the threat to many species.

Case Study: Overexploitation—Whales

Whales, the largest living animals, are rare in the world's oceans today, their numbers driven down by commercial whaling. Commercial whaling began in the sixteenth century, and reached its apex in the nineteenth and early twentieth centuries. 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 lattice-like structure used by baleen whales to filter-feed plankton from seawater (termed "baleen," but sometimes called "whalebone" even though it is actually made of keratin, like fingernails) 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, easy to capture, and provided up to 150 barrels of blubber oil and abundant whalebone, making them the "right" whale for a commercial whaler to hunt.

As the right whale declined in the eighteenth century, whalers turned to other species, the gray, humpback (figure 31.13), and bowhead. As their numbers declined, whalers turned to the blue, largest of all whales, and when they were decimated, to smaller whales: the fin, then the Sei, then the sperm whales. As each species of whale became the focus of commercial whaling, its numbers inevitably began a steep decline (figure 31.14).

Hunting of right whales was made illegal in 1935. By then, all three species had been driven to the brink of extinction, their numbers less than 5% of what they used to be. Protected since, their numbers have not recovered in either the North Atlantic or North Pacific. By 1946 several other species faced imminent extinction, and whaling nations formed the International Whaling Commission (IWC) to regulate commercial whale hunting. Like having the fox guard the hen house, the IWC for decades did little to limit whale harvests, and whale numbers continued a steep decline. Finally, in 1974, when 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 15 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.

FIGURE 31.13
A humpback whale. Only 5000 to 10,000 humpback whales remain, out of a world population estimated to have been 100,000.

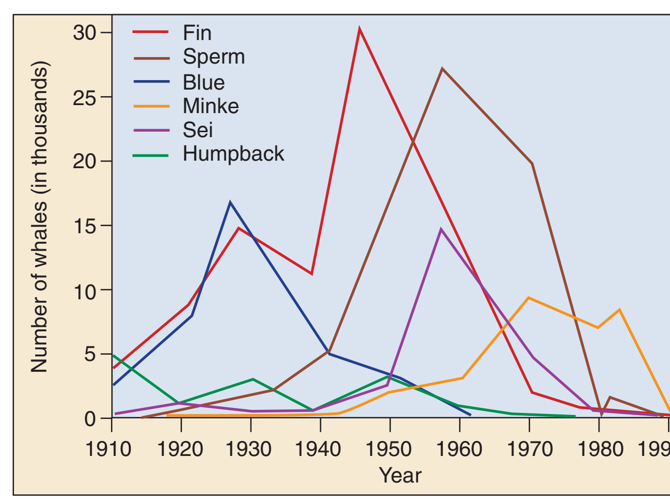


FIGURE 31.14
A history of commercial whaling. These data show the world catch of whales in the twentieth century. Each species in turn is hunted until its numbers fall so low that hunting it becomes commercially unprofitable.

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

Case Study: Introduced Species—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 (figure 31.15). These small, perchlike fishes range from 2 to 10 inches in length, with males coming in endless varieties of colors. Today, all 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 31.16). 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 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 exceeding 60 meters depth. 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 similar algal blooms of the past, the Nile perch was now present to take advantage of the situation. With a sudden increase in its food supply (cichlids), the numbers of Nile perch exploded, and the greater numbers of them simply ate all available cichlids.

Since 1990 the situation has been compounded by a second factor, 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.

Lake Victoria's diverse collection of cichlid species is being driven to extinction by an introduced species, the Nile perch. A normal increase in cichlid numbers due to algal blooms led to an explosive increase in perch, which then ate their way through the cichlids.

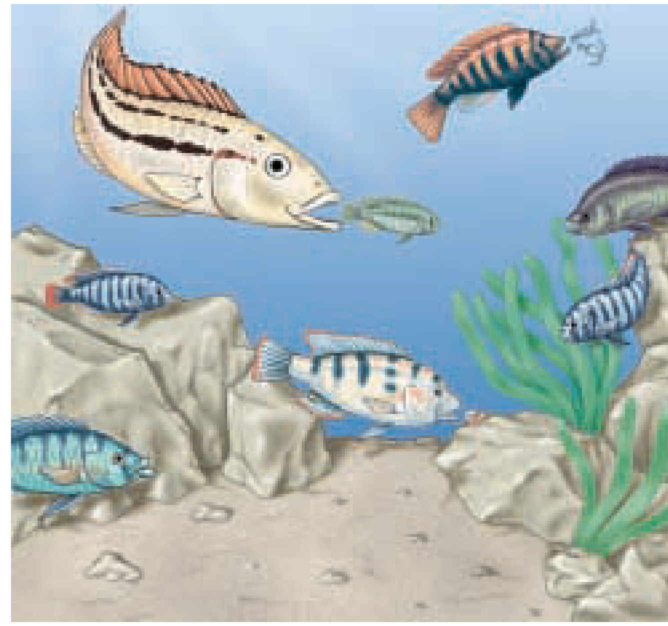


FIGURE 31.15
Lake Victoria cichlids. Cichlid fishes are extremely diverse and occupy different niches. Some species feed on arthropods, others on dense stands of plants; there are fish-eaters, and still other species feed on fish eggs and larvae.

FIGURE 31.16
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).

Case Study: Disruption of Ecological Relationships—Black-Footed Ferrets

The black-footed ferret (*Mustela nigripes*) is one of the most attractive weasels of North America. A highly specialized predator, black-footed ferrets prey on prairie dogs, which live in large underground colonies connected by a maze of tunnels. These ferrets have experienced a dramatic decline in their North American range during this century, as agricultural development has destroyed their prairie habitat, and particularly the prairie dogs on which they feed (figure 31.17). Prairie dogs once roamed freely over 100 million acres of the Great Plains states, but are now confined to under 700,000 acres (table 31.4). Their ecological niche devastated, populations of the black-footed ferret collapsed. Increasingly rare in the second half of the century, the black-footed ferret was thought to have gone extinct in the late 1970s, when the only known wild population—a small colony in South Dakota—died out.

In 1981, a colony of 128 animals was located in Meeteese, Wyoming. Left undisturbed for four years, the number of ferrets dropped by 50%, and the entire population seemed in immediate danger of extinction. A decision was made to capture some animals for a captive breeding program. The first six black-footed ferrets captured died of canine distemper, a disease present in the colony and probably responsible for its rapid decline.

At this point, drastic measures seemed called for. In the next year, a concerted effort was made to capture all the remaining ferrets in the Meeteese colony. A captive population of 18 individuals was established before the Meeteese colony died out. The breeding program proved a great success, the population jumping to 311 individuals by 1991.

In 1991, biologists began to attempt to reintroduce black-footed ferrets to the wild, releasing 49 animals in Wyoming. An additional 159 were released over the next two years. Six litters were born that year in the wild, and the reintroduction seemed a success. However, the released animals then underwent a drastic decline, and only ten individuals were still alive in the wild five years later in 1998. The reason for the decline is not completely understood, but predators such as coyotes appear to have played a large role. Current attempts at reintroduction involve killing the local coyotes. It is important that these attempts succeed, as numbers of offspring in the captive breeding colony are declining, probably as a result of the intensive inbreeding. The black-footed ferret still teeters at the brink of extinction.

Loss of its natural prey has eliminated black-footed ferrets from the wild; attempts to reintroduce them have not yet proven successful.

FIGURE 31.17
Teetering on the brink. The black-footed ferret is a predator of prairie dogs, and loss of prairie dog habitat as agriculture came to dominate the plains states in this century has led to a drastic decline in prairie dogs, and an even more drastic decline in the black-footed ferrets that feed on them. Attempts are now being made to reestablish natural populations of these ferrets, which have been extinct in the wild since 1986.

Table 31.4 Acres of Prairie Dog Habitat

State	1899-1990	1998
Arizona	unknown	extinct
Colorado	7,000,000	44,000
Kansas	2,500,000	36,000
Montana	6,000,000	65,000
Nebraska	6,000,000	60,000
New Mexico	12,000,000	15,000
North Dakota	2,000,000	20,400
Oklahoma	950,000	9,500*
South Dakota	1,757,000	244,500
Texas	56,833,000	22,650
Wyoming	16,000,000	70,000–180,000
U.S. Total	**111,000,000**	**700,000**

Source: National Wildlife Federation and U.S. Fish and Wildlife Report, 1998.
*1990.

Case Study: Loss of Genetic Variation—Prairie Chickens

The greater prairie chicken (*Tympanuchus cupido pinnatus*) is a showy 2-pound wild bird renowned for its flamboyant mating rituals (figure 31.18). Abundant in many midwestern states, the prairie chickens in Illinois have in the last six decades undergone a population collapse. Once, enormous numbers of birds covered the state, but with the introduction of the steel plow in 1837, 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, the subspecies known as the heath hen (*Tympanuchus cupido cupido*) became extinct in Illinois. The greater prairie chicken fared little better in Illinois, its numbers falling to 25,000 statewide in 1933, then to 2000 in 1962. In surrounding states with less intensive agriculture, it continued to prosper.

In 1962, a sanctuary was established in an attempt to preserve the prairie chicken, and another in 1967. But privately owned grasslands kept disappearing, with their prairie chickens, and by the 1980s the birds were extinct in Illinois except for the two preserves. And there they were not doing well. Their numbers kept falling. By 1990, the egg hatching rate, which had averaged between 91 and 100%, had dropped to an extremely low 38%. By the mid-1990s, the count of males dropped to as low as six in each sanctuary.

What was wrong with the sanctuary populations? One reasonable suggestion was that because of very small population sizes and a mating ritual where 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 died in Illinois between 1974 and 1993 and found that in recent years, Illinois birds had indeed become genetically less diverse. Extracting DNA from tissue in the roots of feathers from stuffed birds collected in the 1930s from the same population, the researchers found little genetic difference between the Illinois birds of the 1930s and present-day prairie chickens of other states. However, present-day 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.

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 like the Illinois prairie chickens have been saved from extinction.

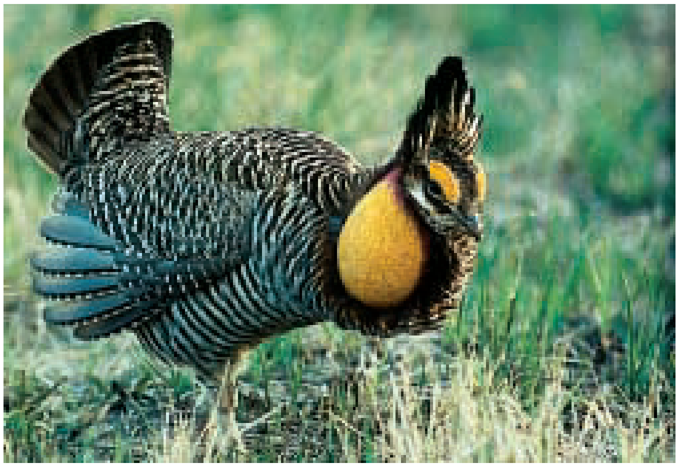


FIGURE 31.18
A male prairie chicken performing a mating ritual. He inflates bright orange air sacs, part of his esophagus, into balloons on each side of his head. As air is drawn into the sacs, it creates a three-syllable "boom-boom-boom" that can be heard for miles.

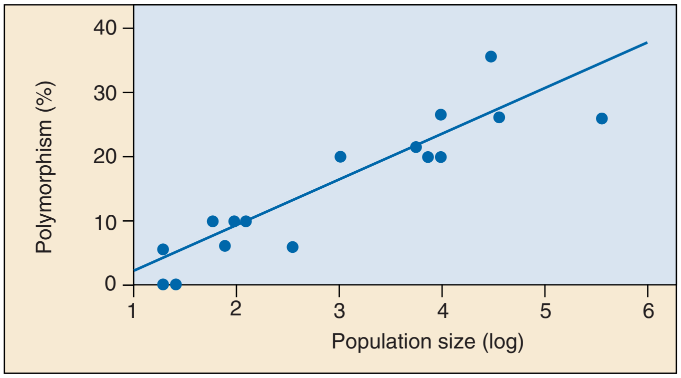


FIGURE 31.19
Small populations lose much of their genetic variability. The percentage of polymorphic genes in isolated populations of the tree *Halocarpus bidwilli* in the mountains of New Zealand is a sensitive function of population size.

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 (figure 31.19). Without the outlying genetically different populations, the prairie chickens in Illinois could not have been saved. The black-footed ferrets discussed on the previous page are particularly endangered because they exist as a single isolated population.

When their numbers fell, Illinois prairie chickens lost much of their genetic variability, resulting in reproductive failure and the threat of immediate extinction. Breeding with genetically more variable birds appears to have reversed the decline.

Case Study: Habitat Loss and Fragmentation—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, like 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 neotropical migrant bird species have declined significantly. Rock Creek Park in Washington, D.C., for example, has lost 90 percent of its long distance migrants in the last 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 numbers in the 1960s. This suggests a loss of about half a billion birds in total, a devastating loss.

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 to find enough contiguous woods to nest successfully.

A second and perhaps even more important factor seems to be the availability of critical winter habitat in Central and South America. Living in densely crowded limited areas, the availability of high-quality food is critical. 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. Sixty-five percent of the wet forest birds maintained or gained weight over the winter. Plants growing in substandard dry scrub, by contrast, 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 at their summer homes, and have fewer young. You can see this clearly in the redstart study (figure 31.20): the proportion of ^{13}C carbon 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% a year. This loss of key habitat appears to be a driving force in the looming extinction of songbirds.

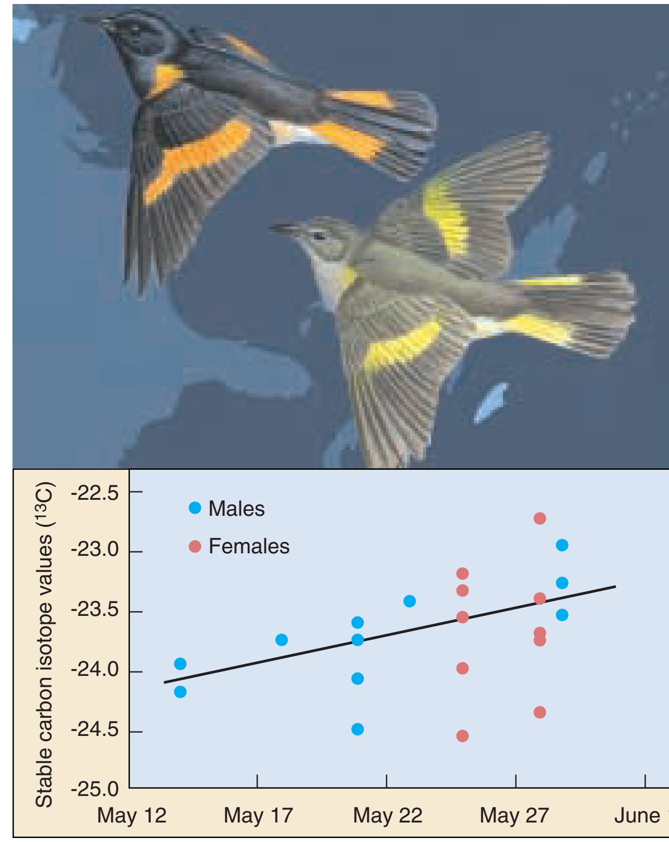


FIGURE 31.20
The American redstart, a migratory songbird whose numbers are in serious decline. The graph presents data on the level of ^{13}C in redstarts arriving at summer breeding grounds. Early arrivals, with the best shot at reproductive success, have lower levels of ^{13}C, indicating they wintered in more favorable mangrove-wetland forest habitats.

Fragmentation of summer breeding grounds and loss of high-quality overwintering habitat seem both to be contributing to a marked decline in migratory songbird species.

Many Approaches Exist for Preserving Endangered Species

Once you understand the reasons why a particular species is endangered, it becomes possible to think of designing a recovery plan. If the cause is commercial overharvesting, regulations can be designed to lessen the impact and protect the threatened species. If the cause is habitat loss, plans can be instituted to restore lost 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, Interior Secretary in the Clinton administration, noted, it is much more economical to prevent such "environmental trainwrecks" from occurring than it is 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 31.21
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 have been irretrievably modified. The clear-cutting of the temperate forests of Washington State leaves little behind to conserve; nor 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 very much on the cause of the habitat loss.

Pristine Restoration. In situations where all species have been effectively removed, one might attempt to restore the plants and animals that are believed to be the natural inhabitants of the area, when such information is available. When abandoned farmland is to be restored to prairie (figure 31.21), how do 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 that you know the identity of all of the original inhabitants, and the ecologies of each of the species. We rarely ever have this much information, so no restoration is 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 removal of the introduced species. Restoration of the once-diverse cichlid fishes to Lake Victoria will require more than breeding and restocking the endangered species. Eutrophication will have to be reversed, and the introduced water hyacinth and Nile perch populations brought under control or removed.

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 in 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, discussed in chapter 30, is one example of how a concerted effort can succeed in restoring a heavily polluted habitat to a relatively pristine condition.

Captive Propagation

Recovery programs, particularly those focused on one or a few species, often must involve direct intervention in natural populations to avoid an immediate threat of extinction. Earlier we learned how introducing wild-caught individuals into captive breeding programs is being used in an attempt to save ferret and prairie chicken populations in immediate danger of disappearing. Several other such captive propagation programs have had significant success.

Case History: 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 hatch.

The use of DDT was banned by federal law in 1972, causing levels in the eastern United States to fall quickly. There were no peregrine falcons left in the eastern United States to reestablish a natural population, however. 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 31.22).

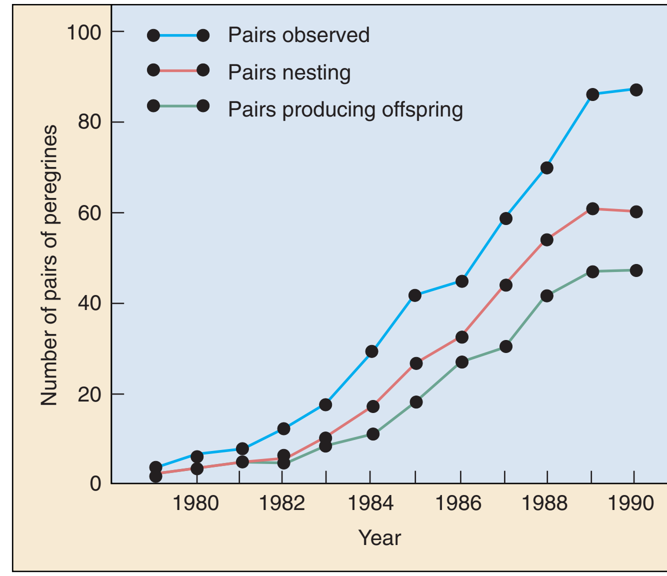


FIGURE 31.22
Captive propagation. The peregrine falcon has been reestablished in the eastern United States by releasing captive-bred birds over a period of 10 years.

Case History: 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 last 200 years. By 1985 condor numbers had dropped so low 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 6 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 the end of 1999 the captive population of California condors had reached over 110 individuals. Twenty-nine 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. Twenty additional birds released into the Grand Canyon have adapted well. Biologists are waiting to see if the released condors will breed in the wild and successfully raise a new generation of wild condors.

Case History: 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 times 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 1998 the park contained nine free-ranging packs, a total of 90 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 recovery. 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 that are opposed to it.

Sustaining Genetic Diversity

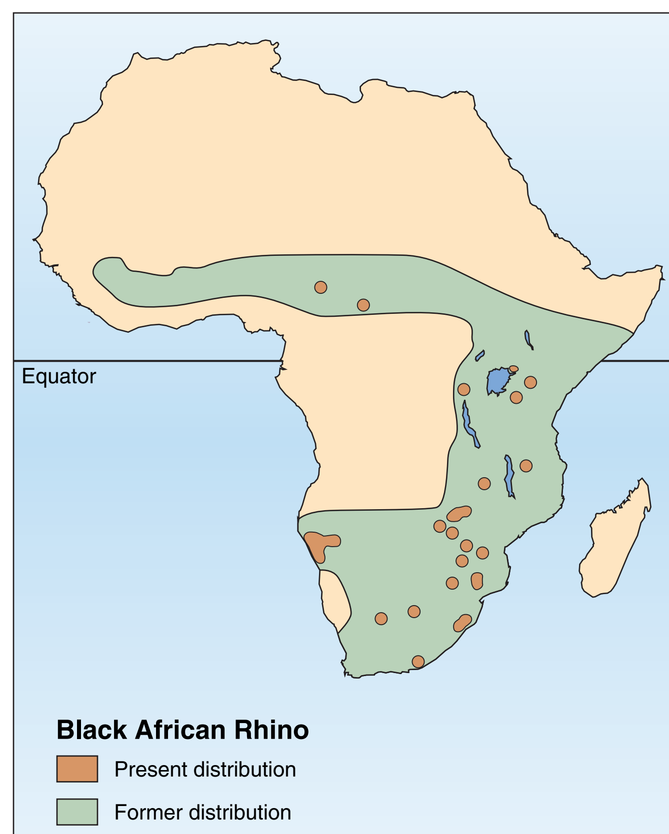
One of the chief obstacles to a successful species recovery program is that a species is generally in serious trouble by the time a recovery program is instituted. When populations become very small, much of their genetic diversity is lost (see figure 31.19), as we have seen clearly in our examination of the case histories of prairie chickens and black-footed ferrets. If a program is to have any chance of success, every effort must be made to sustain as much genetic diversity as possible.

Case History: The Black Rhino. All five species of rhinoceros are critically endangered. The three Asian species live in forest habitat that is rapidly being destroyed, while the two African species are illegally killed for their horns. Fewer than 11,000 individuals of all five species survive today. The problem is intensified by the fact that many of the remaining animals live in very small, isolated populations. The 2400 wild-living individuals of the black rhino, *Diceros bicornis*, live in approximately 75 small widely separated groups (figure 31.23) consisting of six subspecies adapted to local conditions throughout the species' range. All of these subspecies appear to have low genetic variability; in three of the subspecies, only a few dozen animals remain. Analysis of mitochondrial DNA suggests that in these populations most individuals are genetically very similar.

This lack of genetic variability represents the greatest challenge to the future of the species. Much of the range of the black rhino is still open and not yet subject to human encroachment. To have any significant chance of success, a species recovery program will have to find a way to sustain the genetic diversity that remains in this species. Heterozygosity could be best maintained by bringing all black rhinos together in a single breeding population, but this is not a practical possibility. A more feasible solution would be to move individuals between populations. Managing the black rhino populations for genetic diversity could fully restore the species to its original numbers and much of its range.

Placing black rhinos from a number of different locations together in a sanctuary to increase genetic diversity raises a potential problem: local subspecies may be adapted in different ways to their immediate habitats—what if these local adaptations are crucial to their survival? Homogenizing the black rhino populations by pooling their genes risks destroying such local adaptations, if they exist, perhaps at great cost to survival.

(a)



(b)

FIGURE 31.23
Sustaining genetic diversity. The black rhino (*a*) is highly endangered, living in 75 small, widely separated populations (*b*). Only about 2400 individuals survive in the wild.

Preserving Keystone Species

Keystone species are species that exert a particularly strong influence on the structure and functioning of a particular ecosystem. The sea otters of figure 31.7 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. It is rather a qualitative concept, a statement that a species plays a particularly important role in its community. Keystone species are usually characterized by measuring the strength of their impact on their community. **Community importance** measures the change in some quantitative aspect of the ecosystem (species richness, productivity, nutrient cycling) per unit of change in the abundance of a species.

FIGURE 31.24
Preserving keystone species. The flying fox is a keystone species in many Old World tropical islands. It pollinates many of the plants, and is a key disperser of seeds. Its elimination by hunting and habitat loss is having a devastating effect on the ecosystems of many South Pacific islands.

Case History: 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 have dramatic effects on the other species living within an ecosystem, sometimes even leading to a cascade of further extinctions (figure 31.24). 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 a 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 like 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 some plant species are not fruiting, or are doing so only marginally, with 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 hunting. They are hunted for food, 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.

Species preservation 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, the drop reflecting largely 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.

Recovery programs at the species level must deal with habitat loss and fragmentation, and often with a marked reduction in genetic diversity. Captive breeding programs that stabilize genetic diversity and pay careful attention to habitat preservation and restoration are typically involved in successful recoveries.

Conservation of Ecosystems

Habitat fragmentation is one of the most pervasive enemies of biodiversity conservation efforts. As we have seen, some species simply require large patches of habitat to thrive, and conservation efforts that cannot provide suitable habitat of such a size are doomed to failure. As 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 31.25). 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, a series of eight such megareserves have been created in Costa Rica (figure 31.26) 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 focusing on 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 of particular species, can often be a more effective means of preserving biodiversity.

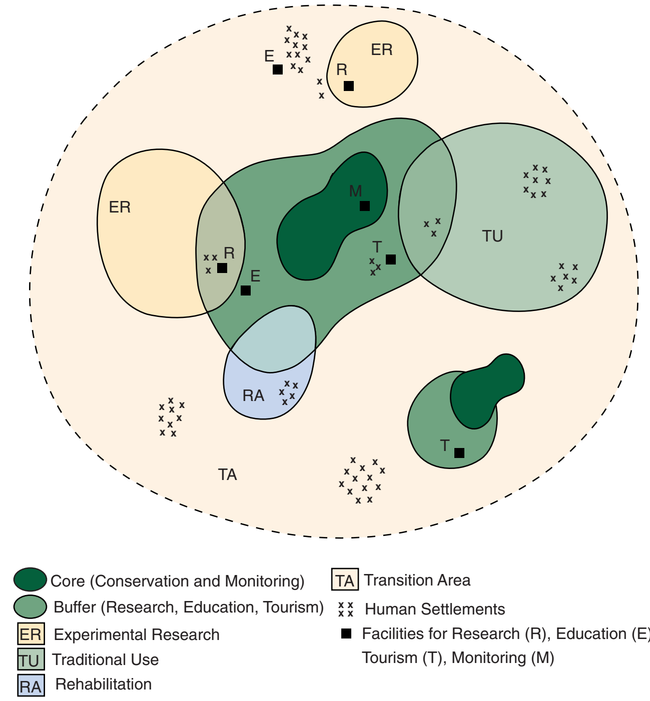


FIGURE 31.25
Design of a megareserve. A megareserve, or biosphere reserve, recognizes the need for people to have access to resources. Critical ecosystems are preserved in the core zone. Research and tourism is allowed in the buffer zone. Sustainable resource harvesting and permanent habitation is allowed in the multiple-use areas surrounding the buffer.

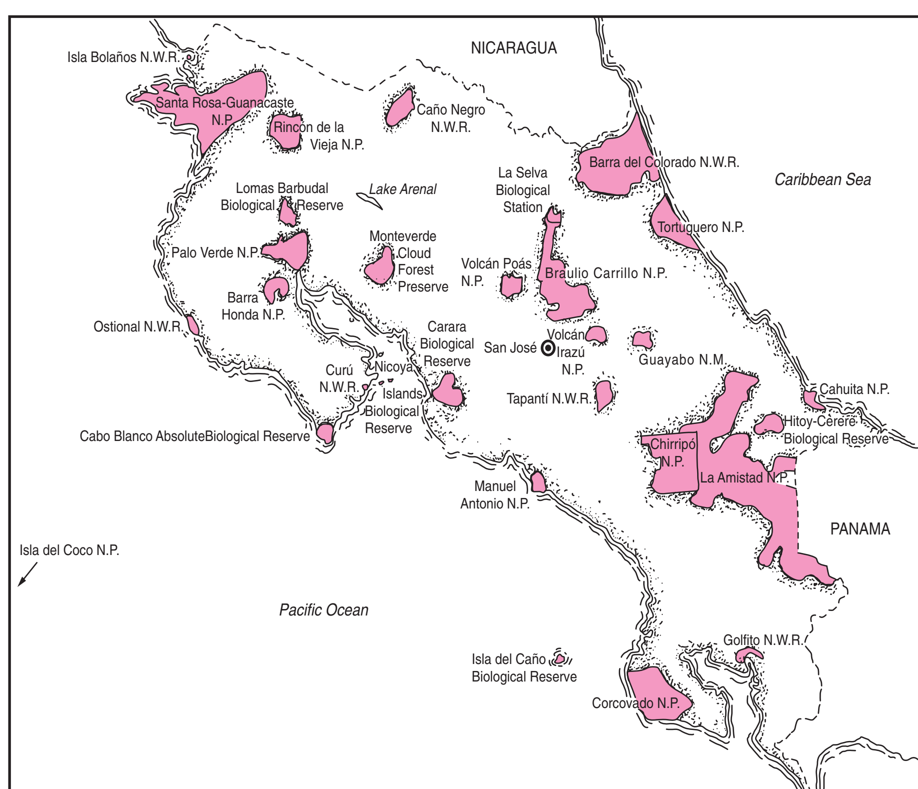


FIGURE 31.26
Biopreserves in Costa Rica. Costa Rica has placed about 12% of its land into national parks and eight megareserves.

Chapter 31

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Summary | Questions | Media Resources

31.1 The new science of conservation biology is focusing on conserving biodiversity.

- Early humans caused many extinctions when they appeared in new areas, but rates of extinction have increased in modern times.
- Some areas are particularly rich in species diversity and particularly merit conservation attention.

1. Are some areas particularly important for conserving biodiversity?

2. Describe some of the indirect economic values of biodiversity.

- Biodiversity
- Species
- Extinction
- Wetlands

31.2 Vulnerable species are more likely to become extinct.

- Interdependence among species in an ecosystem leads to the possibility of cascading extinctions if removal of one species has major effects throughout the food web.
- Species are particularly vulnerable when they have localized distributions, are declining in population size, lack genetic variability, or are harvested or hunted by humans.

3. What factors contribute to the extinction rate on a particular piece of land?

4. How does a low genetic variability contribute to a species' greater risk of extinction?

- Extinction

31.3 Causes of endangerment usually reflect human activities.

- Habitat loss is the single most important cause of species extinction.
- As suggested by the species-area relationship, a reduced habitat will support fewer numbers of species.
- This reduction in habitat can occur in four different ways: a habitat can be completely removed or destroyed, a habitat can become fragmented and disjunct, a habitat can be degraded or altered, or a habitat can become too frequently used by humans so as to disturb the species there.

5. How can problems resulting from lack of genetic diversity within a population be solved?

6. How can extinction of a keystone species be particularly disruptive to an ecosystem?

- Deoxygenation of Lakes

- On Science Article:What's Killing the Frogs?
- Book Review: *The End of the Game* by Beard
- Book Review: *West with the Night* by Markham

31.4 Successful recovery plans will need to be multidimensional.

- Pristine restoration of a habitat may be attempted, but removing introduced species, rehabilitating the habitat, and cleaning up the habitat may be more feasible.
- Captive propagation, sustaining genetic variability, and preserving keystone species have been effective in preserving biodiversity.
- Megareserves have been successfully designed in many parts of the world to contain core areas of undisturbed habitat surrounded by managed land.

7. Why is maintaining large preserves particularly important?

8. Is captive propagation always an answer to species vulnerability?

9. Why is it important to attempt to eradicate introduced species soon after they appear?

- Activity: Biomagnification

- On Science Article:Biodiversity Behind Bars

57 Conservation Biology

In 1998, botanists of the Massachusetts Natural Heritage and Endangered Species Program published a booklet called *A Guide to Invasive Plants in Massachusetts*. The purpose of the booklet was to warn citizens about certain non-native plants that were becoming established and interfering with the state's natural ecosystems. But many nursery owners were upset; some of these invasive exotic plants were big money-makers for the horticultural industry. Horticulturalists lobbied the state government and succeeded in getting the booklet withdrawn from publication.

Fortunately, many people in the horticultural world now recognize that even though most introduced plants do not become invasive, some plant species have become serious pests on several continents. Indeed, colonization of new areas by introduced plants, animals, and microorganisms that become abundant in their new ranges is second only to habitat loss as a threat to Earth's biodiversity.

Humans have caused extinctions for thousands of years. When people first crossed the Bering Land Bridge and arrived in North America about 20,000 years ago, they encountered a rich fauna of large mammals. Most of those species were exterminated—probably by overhunting—within a few thousand years. A similar extermination of large animals followed the human colonization of Australia, about 40,000 years ago. At that time, Australia had 13 genera of marsupials larger than 50 kg, a genus of gigantic lizards, and a genus of heavy, flightless birds. All the species in 13 of those 15 genera had become extinct by 18,000 years ago. When Polynesian people settled in Hawaii about 2,000 years ago, they exterminated, probably by overhunting, at least 39 species of endemic land birds. Among them were 7 species of geese, 2 species of flightless ibises, a sea eagle, a small hawk, 7 flightless rails, 3 species of owls, 2 large crows, a honeyeater, and at least 15 species of finches.

The pace of human-caused extinction of species is accelerating rapidly. Most of the human activities that are currently causing extinctions are not new—but today there are many more humans living on Earth, doing more things that endanger species. Current extinction rates have raised serious concerns about the future of biological diversity on Earth. These concerns led to the rapid development during the 1980s of the applied discipline of **conservation biology**: the scientific study of how to preserve the diversity of life. Conservation biologists study the factors that threaten species with extinction, and they develop methods to help preserve genes, species, communities, and ecosystems. The

A Successful Invasion Introduced into the northeastern United States from Europe during the 1800s, *Lythrum salicaria*—purple loosestrife—was sold as an ornamental plant and for medicinal uses. Loosestrife establishes itself readily in natural wetlands, such as this riverbank in Massachusetts, where it outcompetes native species and changes the habitat of waterfowl and other animals.

science of conservation biology draws heavily on concepts and knowledge from population genetics, evolution, ecology, biogeography, wildlife management, economics, and sociology. In turn, the needs of conservation are stimulating new research in those fields.

In this chapter, we will see how conservation biologists estimate rates of species extinction and determine the causes of extinctions. We will learn how science is used to reduce extinction rates and help populations recover. But why should we care about species extinctions?

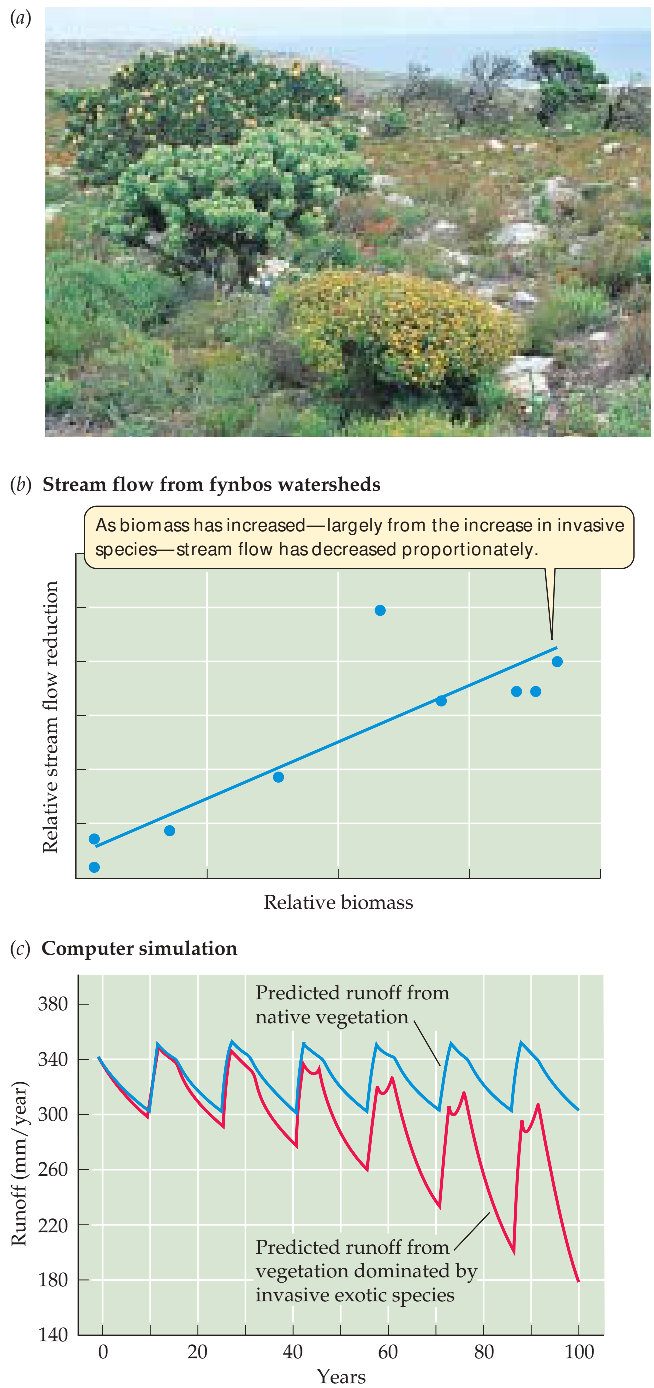
Why Care about Species Extinctions?

Extinction is forever. If we purposely or inadvertently exterminate a species, we have irreversibly destroyed a resource of unknown value. But people value biodiversity for many reasons:

- Humans depend on other species for food, fiber, and medicine. More than half the medical prescriptions written in the United States contain a natural plant or animal product.
- Humans derive enormous aesthetic pleasure from interacting with other organisms. Many people would consider a world with far fewer species to be a less desirable place in which to live.
- Living in ways that cause the extinction of other species raises serious ethical issues. These issues are receiving increased attention from philosophers, ethicists, and religious leaders.
- Extinctions deprive us of opportunities to study and understand ecological relationships among organisms. The more species are lost, the more difficult it will be to understand the structure and functioning of ecological communities and ecosystems.
- Species are necessary for the functioning of the ecosystems of which they are a part and the many benefits those ecosystems provide to humanity.

Among the benefits provided by ecosystems are generation and maintenance of fertile soils, prevention of soil erosion, detoxification and recycling of waste products, regulation of the hydrological cycle and the composition of the atmosphere, control of agricultural pests, and pollination of plants.

The benefits provided to humans by functioning ecosystems are very hard to calculate, but their value can be estimated. The benefits provided by the native vegetation of the Western Cape Province, South Africa, were estimated by a group of economists, ecologists, and land managers. The native vegetation of the highlands of this area is a species-rich community of shrubs, known as *fynbos* (pronounced "fain-bos"). These shrubs can survive regular summer droughts, nutrient-poor soils, and the fires that periodically sweep through the highlands (Figure 57.1*a*). The fynbos-clad highlands provide about two-thirds of the Western Cape's water requirements. In addition, some species of the endemic flora



57.1 Invasive Species Disrupt Ecosystem Function (*a*) The unique fynbos ecosystems of South Africa provide much of the area's water. (*b*) Stream flow from fynbos watersheds is inversely proportional to plant biomass. (*c*) A computer simulation of stream flows from watersheds that have and have not been invaded by exotic trees.

are harvested for cut and dried flowers and thatching grass. The combined value of these harvests in 1993 was about $19 million. Some of the income from tourism in the region comes from people who want to see the fynbos. About 400,000 people visit the Cape of Good Hope Nature Reserve each year, primarily to see the many endemic plants.

During recent decades, a number of plants introduced into South Africa from other continents have invaded the fynbos. Because they are taller and grow faster than the native plants, these exotics increase the intensity and severity of fires. By transpiring larger quantities of water, they decrease stream flows to less than half the amount flowing from mountains covered with native plants, reducing the water supply (Figure 57.1*b*). Removing the exotic plants by felling and digging out invasive trees and shrubs and managing fire is estimated to cost between $140 and $830 per hectare, depending on the densities of invasive plants. Annual follow-up operations cost about $8 per hectare.

When natural ecosystems are lost, the services they provided must be replaced, often at a much higher cost. A sewage purification plant that would deliver the same volume of water to the Western Cape Province as a well-managed watershed of 10,000 hectares would cost $135 million to build and $2.6 million per year to operate. Desalination of seawater would cost four times as much. Thus, the available alternatives would deliver water at a cost between 1.8 and 6.7 times more than the cost of maintaining natural vegetation in the watershed.

Modern industrial societies often favor technologically sophisticated methods of substituting for lost ecosystem services. The study of water resources in the Western Cape Province shows that simple but labor-intensive methods—cutting and burning—may, in some cases, be cheaper.

Estimating Current Rates of Extinction

We do not know how many species will become extinct during the next 100 years because we do not know how many species live on Earth, and because the number of extinctions will depend both on what we do and on unexpected events.

Nevertheless, several methods exist for estimating probable rates of extinction resulting from human actions. For example, conservation biologists often use the well-established relationship between the size of an area and the number of species present to estimate the number of species extinctions likely to result from habitat destruction. We saw in Chapter 56 that the number of species on an island increases with the size of the island. This **species–area relationship** can be applied to habitat patches on the mainland as well. Biologists have measured the rate at which species richness tends to decrease with decreasing patch size. Their findings suggest that, on average, a 90 percent loss of habitat will result in the loss of half of the species living in that habitat. The current rate of loss of tropical evergreen forests—Earth's richest biome—is about 2 percent of the remaining forest each year. If this rate of loss continues, about 1 million species that live in tropical evergreen forests will become extinct during the coming century.

To estimate the risk that a population will become extinct, conservation biologists develop models that incorporate information about a population's size, its genetic variation, and the morphology, physiology, and behavior of its members. Species in imminent danger of extinction over all or a significant part of their range are labeled *endangered species*. *Threatened species* are those that are likely to become endangered in the near future. Although rarity in and of itself is not always a cause for concern, species whose populations are shrinking rapidly usually are at risk. Species with only a few individuals confined to a small range are likely to be eliminated by local disturbances such as fires, unusual weather, disease, and predators.

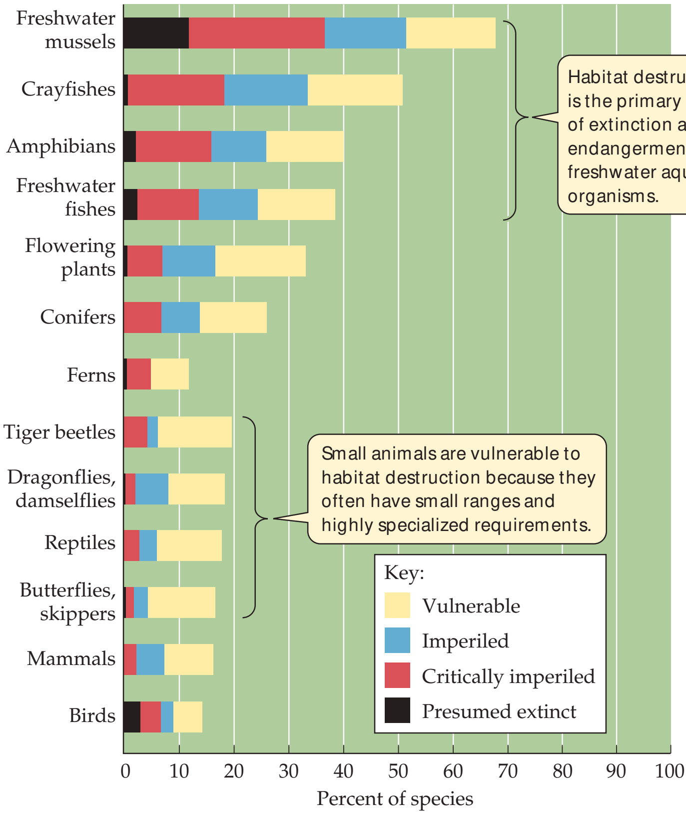
In an example of such a population study, an ecologist constructed a quantitative model of the dynamics of the grizzly bear population in Yellowstone National Park, using detailed data collected over a 12-year period. The model kept track of individual bears and incorporated the effects of chance events, such as fires. The output of the model suggested that for the grizzly bear population to have a 95 percent chance of persisting for a century, there must be enough habitat to support 70–90 bears. To achieve a higher probability of survival, or the same probability of survival for 200 years, more bear habitat would be needed.

Preserving Biodiversity

The human activities that threaten species include habitat destruction, the introduction of invasive species, overexploitation, disease, alteration of disturbance patterns, and climate change. Conservation biologists determine how these activities are affecting species and use that information to devise actions to preserve species that are endangered or threatened.

Habitat loss is studied by observation and experimentation

Habitat loss is the most important cause of endangerment of species in the United States, especially species that live in fresh waters (Figure 57.2). As habitats are progressively destroyed by human activities, the remaining habitat patches become smaller and more isolated. In other words, the habitat becomes **fragmented**. Small habitat patches are qualitatively different from larger patches of the same habitat in ways that affect the survival of species. Small patches cannot maintain populations of species that require large areas, and they can support only small populations of many of the species that can survive in them.



57.2 Proportions of U.S. Species Extinct or In Peril The groups of species that are most endangered—mussels, crayfishes, amphibians, and fishes—live in freshwater habitats, which have been extensively destroyed and polluted.

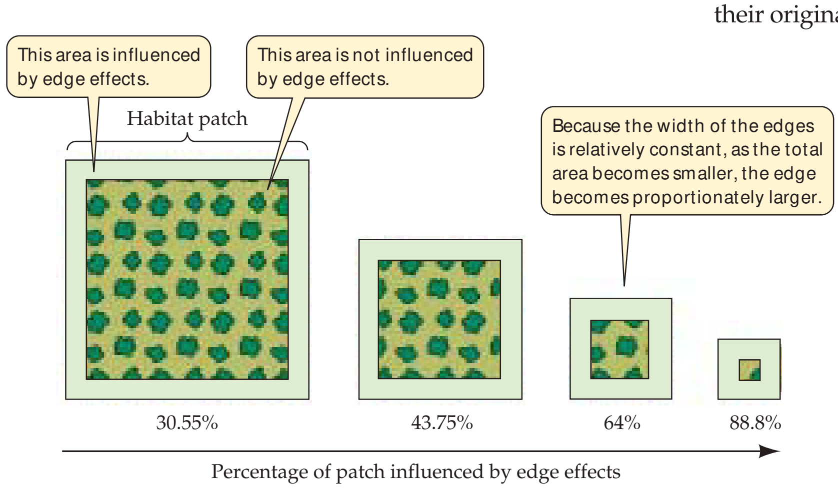
In addition, the fraction of a patch that is influenced by effects originating outside the habitat—**edge effects**—increases rapidly as patch size decreases (Figure 57.3). Close to the edges of forest patches, for example, winds are stronger, temperatures are higher, humidity is lower, and light levels are higher than they are farther inside the forest. Species from surrounding habitats often colonize the edges of patches to compete with or prey upon the species living there.

Usually we do not know which organisms lived in an area before its habitats became fragmented. To address this problem, a major research project in a tropical evergreen forest near Manaus, Brazil, was launched before logging took place. Landowners agreed to preserve forest patches of certain sizes and configurations (Figure 57.4). Biologists counted species in those patches while they were still part of the continuous forest. Soon after the surrounding forest was cut and converted to pasture, species began to disappear from isolated patches. The first species to be eliminated were monkeys that travel over large areas. Army ants and the birds that follow army ant swarms also disappeared.

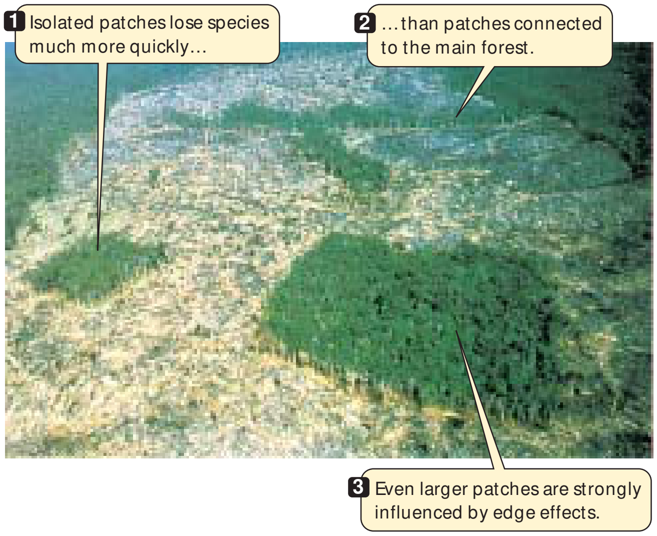
Species that become extinct in small habitat fragments are unlikely to become reestablished because the more isolated the patches are, the less likely dispersing individuals are to find them. However, as we saw in Chapter 54, a species may persist in a small patch if it is connected to other patches by corridors of habitat through which individuals can disperse. Some of the pastures that surrounded the experimental forest fragments in Brazil have been abandoned, and a young forest is growing on them. Within 7–9 years of abandonment, some ant-following birds recolonized forest fragments connected to larger forest patches by young forests. Other species of birds that forage in the forest canopy also reestablished themselves. The young forest is not a suitable permanent habitat for most of these species, but it is an environment through which individuals can disperse to find new places where they can live.

Introduced predators, competitors, and pathogens have eliminated many species

Some species that have been introduced to regions outside their original range have become *invasive*—that is, they have spread widely and become unduly abundant, at a cost to the native species of the region. Invasive species are a major component of human-caused environmental change. Deliberately or accidentally, people move many species of organisms from one continent to another. Hundreds of species of plants have been introduced to new areas as ornamentals, as we saw at the beginning of this chap-



57.3 Edge Effects The smaller a patch of habitat, the greater the proportion of that patch that is influenced by conditions in the surrounding environment.



57.4 Brazilian Forest Fragments Studied for Species Loss Isolated patches lost species much more quickly than patches connected to the main forest. Even the larger patches, such as the one in the foreground, were too small to maintain populations of some species.

ter. Weed seeds have been carried around the world accidentally in sacks of crop seeds. Europeans deliberately introduced rabbits and foxes to Australia for sport hunting. Nearly half of the small to medium-sized marsupials and rodents of Australia have been exterminated during the last 100 years by a combination of competition with introduced rabbits and predation by introduced domestic cats and foxes.

Some pathogens have proliferated quickly following their introduction to new continents. Exotic disease-causing organisms have decimated populations of several eastern North American forest trees. The chestnut blight, caused by a European fungus, virtually eliminated the American chestnut, formerly an abundant tree in Appalachian Mountain forests. Nearly all American elms over large areas of the East and Midwest have been killed by Dutch elm disease, caused by the fungus *Ceratocystis ulmi*, which reached North America in 1930. Ecologists suspect that intercontinental movement of disease organisms caused extinctions in the past, but evidence of such disease outbreaks is not usually preserved in the fossil record.

The best way to reduce the damage caused by invasive species is to prevent their establishment in the first place. For example, the shipping industry often spreads invasive species (bacteria, dinoflagellates, invertebrates, and fish) in ballast water, which is pumped into a ship at one port and discharged at another. (That is how zebra mussels were introduced into North America from Europe, as we saw in Chapter 54.) San Francisco Bay is now home to at least 234 exotic species, most of which arrived in ballast water, and some of them are displacing native species. Controlling invasive aquatic species costs millions of dollars per year, but transport of invasive species in ballast water could largely be eliminated by the simple procedure of deoxygenating ballast water before it is pumped out. This practice both kills most organisms in the water and extends the life of ballast tanks.

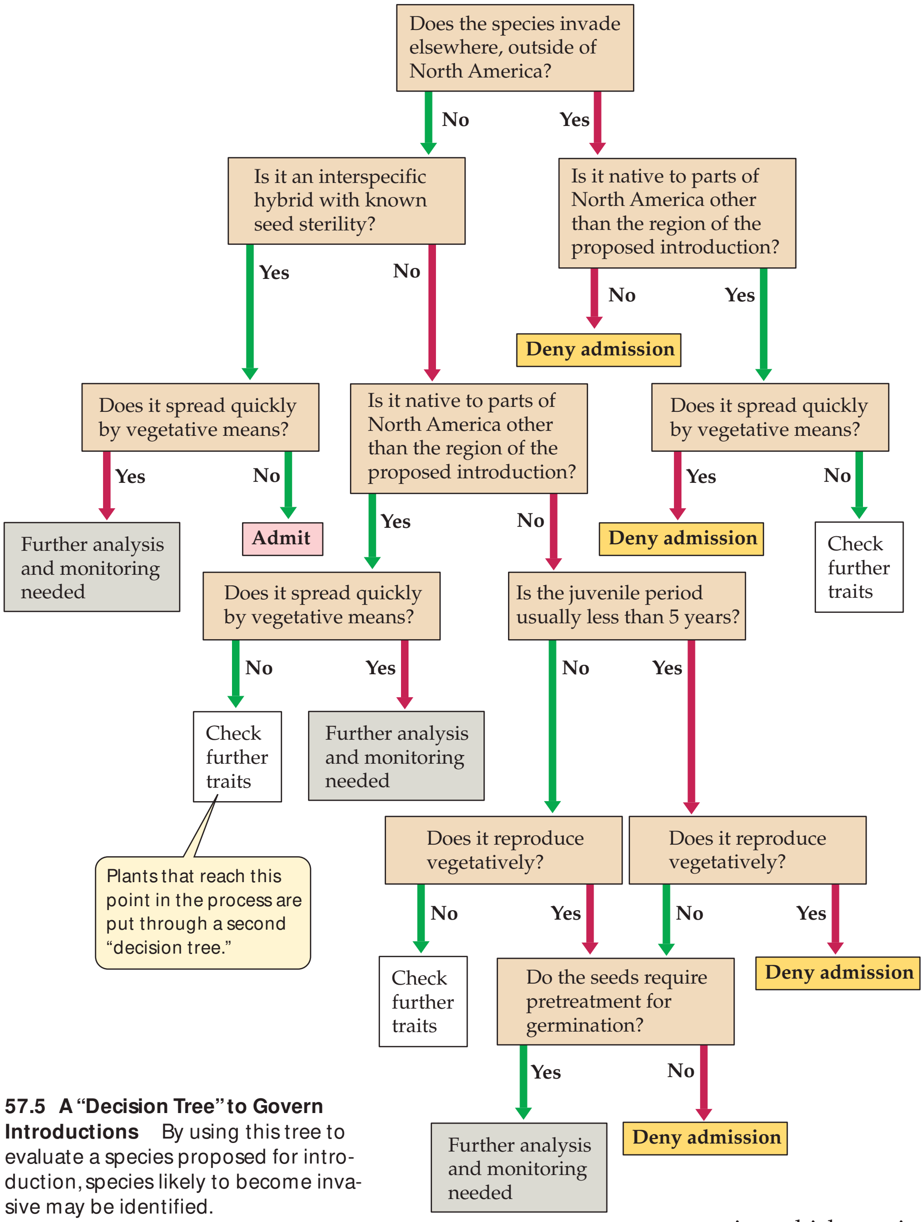
Strict rules already govern the deliberate introduction of animal species, but the introduction of ornamental plants is poorly regulated. In 1998, Australia and New Zealand began to require a weed risk assessment for the importation of plants not already in the country or not on a "clean list" of permitted species. Regulations do not yet exist in the United States, but in 2002 some members of the horticultural industry crafted a voluntary code of conduct for their profession. The code states that the invasive potential of a plant should be assessed prior to introducing and marketing it. Horticulturists work with conservation biologists to determine which species are currently invasive, or likely to become so, and to identify suitable alternative species. Stocks of invasive species will be phased out, and gardeners will be encouraged to use noninvasive plants.

But how can we assess the potential of a species to become invasive? One way is to compare the traits of species that have become invasive when introduced to a new area with those of other species that have not. Such comparisons show that a plant species is more likely to become invasive if it has a short generation time, small seeds, is dispersed by vertebrates, has a large range in its native continent, depends on nonspecific mutualists (root symbionts, pollinators, and seed dispersers), and is not evolutionarily closely related to plants in the area to which it is introduced. The best predictor, however, is whether the species is already known to be invasive elsewhere.

Using the traits that characterize most invasive species, conservation biologists have developed a decision tree to be used to determine whether an exotic species should be introduced into North America (Figure 57.5). Using such a decision tree cannot eliminate the introduction of all potentially invasive species, but if used conscientiously, its application can greatly reduce the risk.

Overexploitation has driven many species to extinction

Until recently, humans caused extinctions primarily by overhunting. Overexploitation of other species continues today. Elephants and rhinoceroses are threatened in Africa because poachers kill them for their tusks and horns, which are used for ornaments and knife handles, and because some men believe that powdered rhinoceros horn enhances their sexual potency. Massive international trade in pets, ornamental plants, and tropical forest hardwoods has decimated many species of orchids, tropical fishes, corals, parrots, and reptiles.



57.5 A "Decision Tree" to Govern Introductions By using this tree to evaluate a species proposed for introduction, species likely to become invasive may be identified.

Several programs have been initiated to help us continue to use species in ways that do not threaten their survival.

CERTIFICATION PROGRAMS. Many purchasers of wood products would like to buy only products that have been harvested in ways that protect biodiversity and ecosystem productivity. To enable them to exercise that choice, the Forest Stewardship Council (FSC) was established in 1993 by a consortium of environmental organizations and members of the forest product industry. FSC establishes criteria that a forest product company must meet for its products to be certified. Certification companies determine whether a forestry operation meets the criteria and ensure that there is a chain of custody that tracks certified products on their way to market. More than 400 companies in 18 countries have committed to purchasing certified wood products. By May 2003, more than 88 million acres of managed forests worldwide had been certified by FSC; 18.4 million of these acres were in North America.

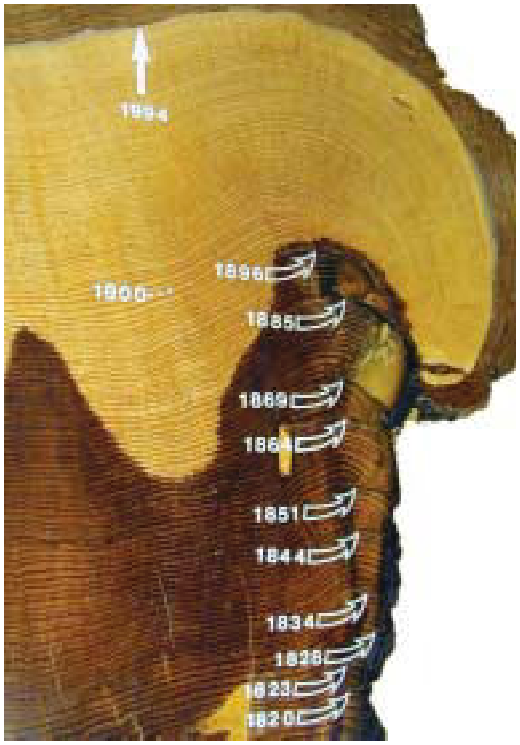
To serve the same function for marine products, the Marine Stewardship Council was formed through an alliance between the World Wildlife Fund and Unilever, one of the largest marketers of frozen seafood. The first marine certified product, Australian rock lobster, came to market in 2000. Alaskan salmon has also been certified; other major fisheries are in the process of becoming certified. This action, combined with the elimination of government subsidies and perverse incentives, can help reduce the current overexploitation of many marine fish stocks.

ENDING TRADE IN ENDANGERED SPECIES. Species that are truly endangered typically cannot withstand any rate of harvest. The mechanism for prohibiting exploitation of these species is the Convention on International Trade in Endangered Species (CITES). Most nations of the world are members of CITES. National representatives meet every two years to review the status of species currently under protection, to determine which species may no longer need protection, and to add new species to its lists. CITES rules currently prohibit international trade in items such as whale meat, rhinoceros horn, and many species of parrots and orchids.

Some species depend on particular disturbance patterns

In Chapter 56, we saw that local species richness is sometime greatest at intermediate levels of disturbance. Many species depend on particular patterns of disturbance to persist. Some plant species, for example, germinate only after a fire; others depend on flooding to open sites where they can become established. Humans often try to reduce the frequency and intensity of such disturbances for their own purposes. Conservation biologists work to assess whether reestablishment of historic disturbance patterns may help preserve biodiversity.

(*a*)



(*b*)

57.6 The Frequency and Intensity of Fires Affect Ecosystems (*a*) As revealed by scars (arrows) in tree growth rings, low-intensity ground fires were frequent in the pine forests of the southwestern United States prior to fire suppression. (*b*) Fire suppression results in the buildup of large quantities of fuel, so that subsequent fires are likely to spread to the canopy and kill most trees.

Many species require periodic fires for successful establishment and survival, but for many years the official policy in the United States, symbolized by Smokey Bear, was to suppress all forest fires. It is now generally regarded as appropriate to use controlled burning as a management tool, particularly in Western North America. But to determine how to do so, we need to know the historical pattern of fires in an area.

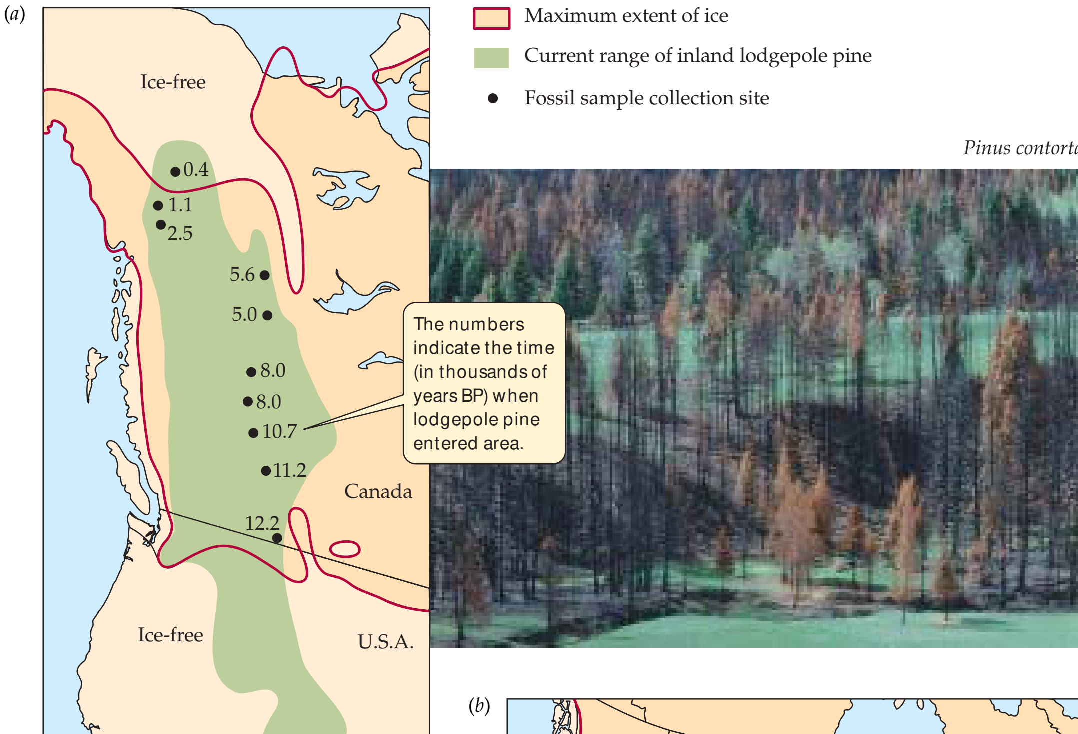
Scars in the annual growth rings of trees preserve evidence of past fires that did not kill them. Therefore, tree-ring researchers can determine when fires occurred, how severe they were, and when fire patterns changed. Annual growth rings on ponderosa pines show that low-intensity ground fires were common near Los Alamos, New Mexico, until about 1900 (Figure 57.6*a*). After that date, cattle and sheep grazing in pine forests and fire suppression greatly reduced the frequency of low-intensity fires. Without these fires, dead branches and needles accumulated in the forest. The buildup of these fuels meant that when fires inevitably did occur, they were much more likely to become intense, tree-consuming canopy fires (Figure 57.6*b*). Today, ground fires are deliberately started in many areas to keep fuel loads low and to mimic historic fire patterns, to which many native species are adapted.

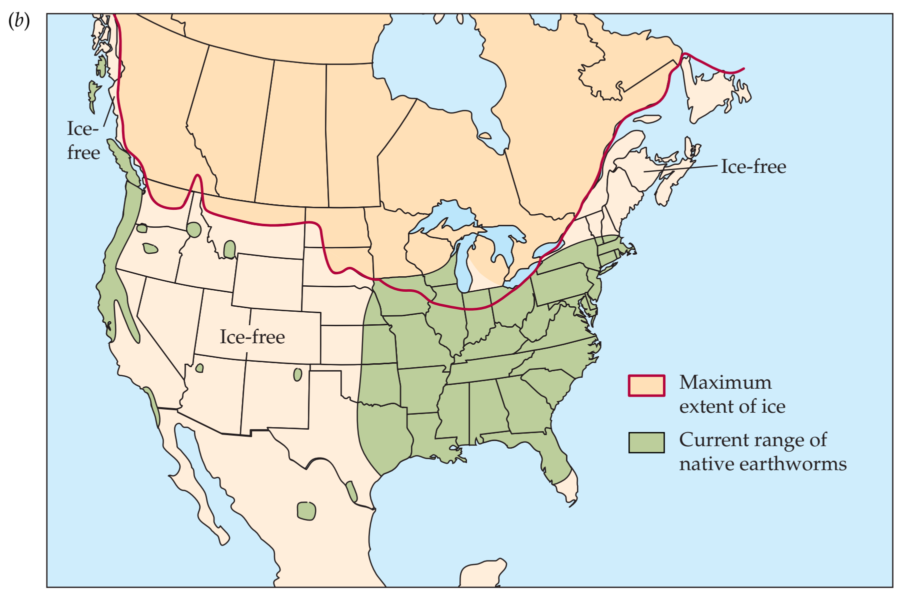
Rapid climate change may cause species extinctions

Scientists from many fields believe that Earth's climate is rapidly becoming warmer as a result of human-caused changes in Earth's atmosphere. We will examine the causes of this global warming in Chapter 58. Conservation biologists cannot alter rates of global warming, but their research can help us to predict how the resulting climate changes will affect organisms and find ways of mitigating those effects. Such research activities include analyses of past climatic events and studies of sites currently undergoing rapid climate change.

Atmospheric scientists predict that temperatures in North America will increase 2° to 5°C by the end of the twenty-first century. If the climate warms by only 1°C, the average temperature currently found at any particular location in North America will be found 150 km to the north. If the climate warmed 2°–5°C, species would need to shift their ranges as much as 500 to 800 km in a single century. Some habitats, such as alpine tundra, could be eliminated as forests expand up mountains.

Knowledge of how organisms responded to past climate changes can help us predict the effects of the current warming trend. Biologists are studying how rapidly species ranges

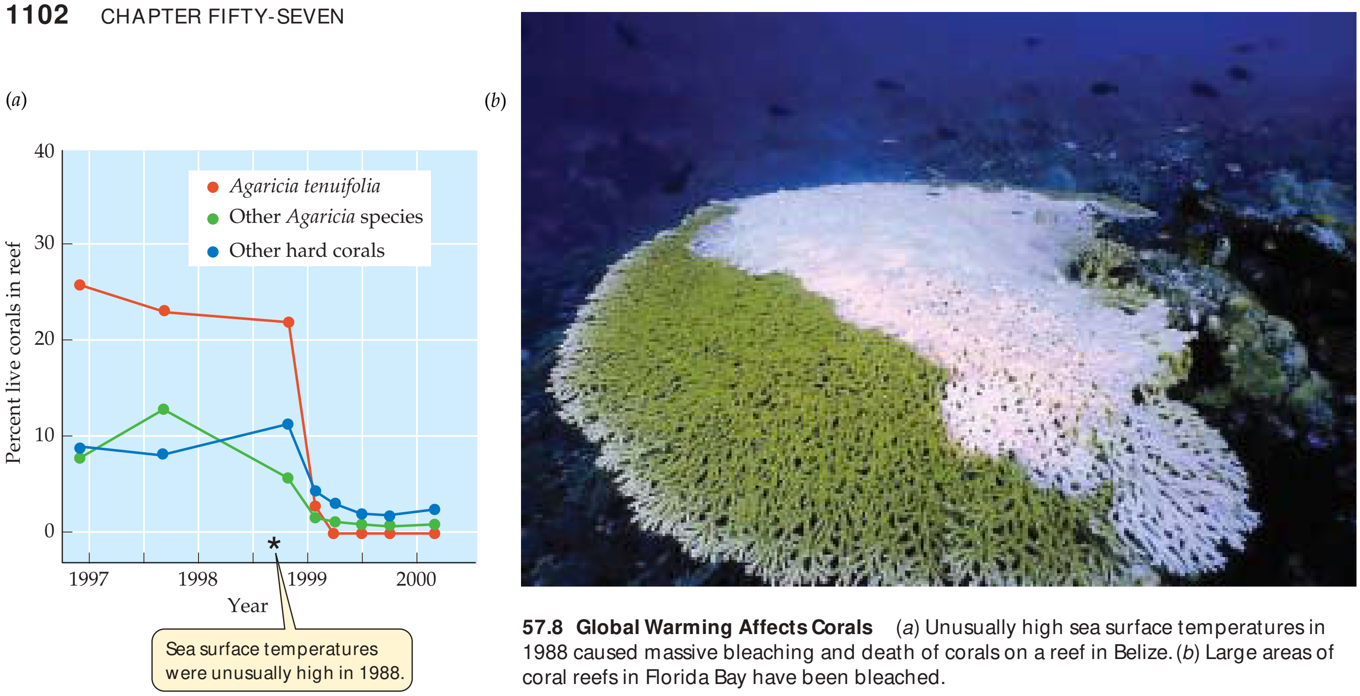




57.7 Some Species Shift Their Ranges in Response to Climate Change (*a*) The range of lodgepole pines in North America expanded north nearly as fast as glaciers retreated. (*b*) Some native earthworm species disperse so slowly they have hardly moved into glaciated regions.

shifted during the last 10,000 years of postglacial warming, which species were and were not able to keep pace with climate change by shifting their ranges, and how past ecological communities differed from those of today. Some organisms with good dispersal abilities, such as birds, can shift their ranges as rapidly as the climate changes, provided that appropriate habitat exists in new areas. However, the ranges of many species with sedentary adults are likely to shift slowly. As the glaciers retreated in North America, the ranges of some coniferous trees expanded northward, so that today they grow as far north as the current climate permits (Figure 57.7*a*). Some species of earthworms, on the other hand, spread very slowly into the areas that had been covered by ice (Figure 5.7*b*). Introduced European earthworms survive well in parts of Canada north of the ranges of native earthworms, indicating that slow dispersal, not lack of suitable habitat, is responsible for the range limitations of this group.

If Earth's surface warms as predicted, climatic zones will not simply shift northward. In addition to such shifts, entirely new climates will develop, and some existing climates will disappear. New climates are certain to develop at low elevations in the Tropics because a warming of even 2°C would result in climates near sea level that are warmer than those found anywhere in the humid Tropics today. Adaptation to those climates may prove difficult for many tropical organisms. Although there has been little recent climate warming in tropical regions, nights are now slightly warmer than they



57.8 Global Warming Affects Corals (*a*) Unusually high sea surface temperatures in 1988 caused massive bleaching and death of corals on a reef in Belize. (*b*) Large areas of coral reefs in Florida Bay have been bleached.

were only a few decades ago. Since the mid-1980s, the average minimum nightly temperature at the La Selva Biological Station, in the Caribbean lowlands of Costa Rica, has increased from about 20°C to 22°C. During the warmer nights, trees use more of their energy reserves. The result has been a reduction of about 20 percent in the average growth rates of trees of six different species.

In 1988, the highest sea surface temperatures ever recorded caused corals to lose their symbiotic dinoflagellates (a phenomenon called *bleaching*) and increased their mortality worldwide (Figure 57.8). If warming of the oceans continues as predicted, about 40 percent of coral reefs worldwide are likely to be killed by 2010. To identify possible ways to help preserve coral reefs, biologists are measuring conditions in places where corals have escaped bleaching. They have found that reefs adjacent to cool, upwelling waters and reefs with cloudy waters, both of which have relatively low temperatures, are generally healthy. These reefs are receiving special protection because corals are likely to continue to survive well there. Corals from those reefs could be sources of colonists for reestablishing reefs where the corals have died if cooler ocean temperatures return in the future.

Habitat Restoration and Species Recovery

If the cause of a species' endangerment is the loss or modification of its habitat , conservation biologists can attempt to find ways of restoring that habitat. A field called **restoration ecology** has developed to study methods of restoring natural habitats. Such methods are needed because many ecosystems will not recover, or will do so only very slowly, without assistance. Biologists can also attempt to maintain endangered species in captivity until suitable habitat is available for them in the wild.

Restoring ecosystem processes is difficult

Conservation biologists have only a limited ability to restore natural ecosystems. In the United States, the false belief that humans can create functioning ecosystems has resulted in policies that make it easy to get permits for developments that destroy habitats. Developers need only state that they will create habitats to substitute for the ones they are destroying. However, even the most experienced wetland ecologists have great difficulty creating new wetlands that support the species that live in those being destroyed.

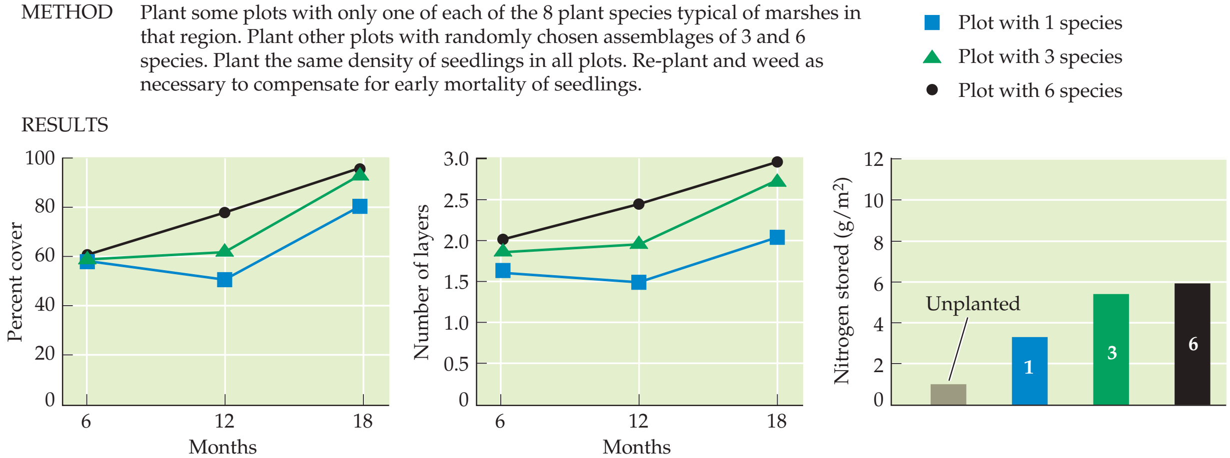
In southern California, where 90 percent of the coastal wetlands have been destroyed, wetland restoration is a high priority. Because species have been lost from degraded coastal wetlands, restoration requires species introductions, but which species should be introduced? In early attempts at restoration, only one or two common, easily grown wetland species were planted. Many wetland-associated species failed to recolonize these "rehabilitated" wetlands. To understand why, biologists established a large field experiment at the Tijuana Estuary to examine the effects of plant species richness on several factors that might affect the success of wetland restoration. They found that experimental plots planted with species-rich mixtures developed a complex vegetation structure, which is important to insects and birds. The species-rich plots also accumulated nitrogen faster than species-poor experimental communities (Figure 57.9).

EXPERIMENT

Hypothesis: Plots in wetlands planted with mixtures of species will develop vegetative cover more rapidly than single-species plots. Species-rich plots will also form more complex canopies and store more nitrogen below ground.

METHOD Plant some plots with only one of each of the 8 plant species typical of marshes in that region. Plant other plots with randomly chosen assemblages of 3 and 6 species. Plant the same density of seedlings in all plots. Re-plant and weed as necessary to compensate for early mortality of seedlings.

RESULTS



Conclusion: Recruitment, canopy complexity, and nitrogen accumulation are enhanced by species richness. In future wetland restoration attempts, a rich mixture of species should be planted.

57.9 Species Richness Enhances Wetland Restoration Both vegetation complexity and nitrogen accumulation are greater in species-rich than in species-poor experimental plots.

Captive propagation can prevent some species from becoming extinct

Sometimes an endangered species can be maintained in captivity while the external threats to its existence are reduced or removed. However, captive propagation is only a temporary measure that buys conservation biologists time to deal with those threats. Existing zoos, aquariums, and botanical gardens do not have enough space to maintain adequate populations of more than a small fraction of Earth's rare and endangered species. Nonetheless, captive propagation can play an important role by maintaining species during critical periods and by providing a source of individuals for reintroduction into the wild. Captive propagation projects in zoos also have raised public awareness of threatened and endangered species.

Captive propagation is helping to save the California condor, North America's largest bird (Figure 57.10). Two hundred years ago, condors ranged from southern British Columbia to northern Mexico, but by 1978, the wild population was plunging toward extinction—only 25 to 30 birds remained in southern California. Many birds were poisoned by ingesting carcasses containing lead shot.

To save the condor from certain extinction, biologists initiated a captive propagation program in 1983. The first chick conceived in captivity hatched in 1988. By 1993, nine captive pairs were producing chicks, and the captive population had increased to more than 60 birds. The captive population was large enough that six captive-bred birds could be released in the mountains north of Los Angeles in 1992. These birds are provided with lead-free food in remote areas, and they are using the same roosting sites, bathing pools, and mountain

Gymnogyps californianus

57.10 Soaring High Once More Captive propagation has enabled California condor populations to be reestablished. Captive-reared birds have successfully survived after being released into the wild in California and Arizona.

ridges as did their predecessors. Captive-reared birds also were released late in 1996 in northern Arizona. It is still too early to pronounce the program a success, but as of February 2003, there were 81 wild condors in California and Arizona. Lead poisoning is still a problem, but an effort to encourage hunters to use non-lead ammunition is under way. Without captive propagation, the California condor would probably be extinct today.

Healing Biotas: Conservation Medicine

On both land and sea, outbreaks of diseases among wild organisms are becoming more common threats to biodiversity. The Caribbean Basin is a disease hot spot. *Diadema antillarum*, a dominant sea urchin, and staghorn and elkhorn corals have been virtually eradicated, and disease among corals is increasing rapidly. Outbreaks of several diseases have affected large areas of corals in the Indo-Pacific region. Mortality rates of marine mammals are increasing in the North Atlantic.

The impressive endemic bird fauna of the Hawaiian Islands has been decimated by habitat destruction, overhunting, and introduced predators and diseases (Figure 57.11). For example, wild pigs introduced by the native Polynesians damage the ground cover and soils of Hawaiian forests. A side effect of this habitat destruction is that indentations left by the pigs' foraging fill with water and are breeding grounds for mosquitoes that carry avian malaria. Below 1,000 meters elevation, nearly all endemic Hawaiian bird species have been eliminated by this disease, which was introduced to the islands with exotic birds. The native birds, never having been exposed to malaria, were highly susceptible. Species that inhabit altitudes above the current range of mosquitoes have fared better, but the insects' range may be expanding upward as the climate warms.

Another disease of birds, the mosquito-borne West Nile virus, has exploded across the United States, where it has killed more than 250,000 birds. The virus primarily infects birds, but can be transmitted to humans. First detected in New York in autumn 1999, within 4 years the virus was found in 43 of the contiguous 48 states and 6 of Canada's 10 provinces. By November 2003, there had been a reported 11,516 human cases in the U.S., with 439 deaths. How West Nile virus spread so rapidly is not understood. To find out, biologists are studying where its mosquito vectors feed, how long they survive, and where they hibernate.

A new field of **conservation medicine** is developing to help identify the causes of such increases in wildlife diseases and to devise effective solutions. Molecular techniques are being used to identify species, strains, and life cycle stages of microbial pathogens. Life histories of disease vectors are being studied to discover the vulnerable stages where interventions are most likely to prevent transmission of the pathogen and limit its effects.

57.11 Extinct Hawaiian Honeycreepers Shown here are just six of the many Hawaiian bird species that have disappeared over the past 150 years. The O'o was among the birds native Polynesians hunted for their feathers, hundreds of thousands of which were used in ceremonial capes for the chiefs. Since 1900, many honeycreeper species have become extinct largely due to avian malaria, an introduced disease to which most endemic birds have no resistance.

Setting Limits: The Legacy of Samuel Plimsoll

During the nineteenth century, many British merchant ships sailed Earth's oceans. At that time, there were no undersea telegraph cables or shipboard radios. Once a ship left a harbor, it was out of contact with the rest of the world; in the case of a shipwreck, rescue was impossible. Owners could maximize their profits by overloading their ships, even though this caused some of them to be unseaworthy and sink. Samuel Plimsoll, a member of England's Parliament, became concerned about the rate of loss of British ocean-going vessels and sailors. He convinced Parliament to require that a "load line" be painted on the hull of every large vessel. The position of the line was calculated using factors such as the structural strength of the vessel and the shape of its hull. If the load line was under water, the ship was not permitted to leave the harbor. The "Plimsoll line," as it has come to be known, dramatically reduced the rate of loss of British ships and sailors at sea.

The increasing loss of Earth's species suggests that the load of human activities has pushed the hull of Noah's Ark below the Plimsoll line. But where and how should society draw that line? The decision should be based on scientific information, but just as in Samuel Plimsoll's time, science cannot determine an "acceptable rate of loss." Moreover, we must be concerned not only with species extinctions and ecosystem functioning, but with the overall functioning of the biosphere as well. To help you think more about how society should decide where to draw its Plimsoll line, we turn in the next and final chapter of this book to the functioning of the entire Earth system and how human activities are changing its processes at a global scale.

Chapter Summary

▶ Humans have caused extinctions of species for thousands of years, but the rate of human-caused extinctions is rising rapidly today.

Why Care about Species Extinctions?

▶ Species provide the food, fiber, medicines, and aesthetic opportunities upon which the quality of human life depends.

▶ The extinction of species as a result of human activities raises serious ethical issues.

▶ Extinctions deprive us of opportunities to understand ecological relationships among organisms.

▶ Ecosystems provide valuable services that can be replaced only by expensive and continuing human effort. **Review Figure 57.1**

Estimating Current Rates of Extinction

▶ Estimates of current rates of extinction are based primarily on species–area relationships and population models.

Preserving Biodiversity

▶ Habitat destruction is the most important cause of species extinction today. **Review Figure 57.2**

▶ A greater proportion of small than large habitat patches is affected by external influences. **Review Figures 57.3, 57.4**

▶ Invasive species are major causes of extinction. Biologists use information on species that have become invasive to identify species likely to become invasive if introduced. **Review Figure 57.5**

▶ Certification programs enable consumers to purchase materials produced in ways that do not harm biodiversity.

▶ Overexploitation, which historically resulted in most human-caused extinctions, is still an important cause of extinctions today.

▶ Information on how species are affected by disturbances helps conservation biologists decide where to reestablish historic disturbance patterns.

▶ Species have responded at different rates to past climate changes. **Review Figure 57.7**

Habitat Restoration and Species Recovery

▶ Restoration of habitats is often necessary to preserve species. Restoration of some ecosystem types, especially wetlands, is difficult. **Review Figure 57.9**

▶ Captive propagation plays a useful but limited role in conservation.

Healing Biotas: Conservation Medicine

▶ Disease outbreaks among wild species are increasing. Some of these diseases can be transmitted to humans. The new field of conservation medicine is helping to identify the causes of increases in diseases and to devise effective solutions.

Setting Limits: The Legacy of Samuel Plimsoll

▶ Like an overloaded merchant ship, the "Noah's Ark" of Earth's biodiversity may be in danger of sinking from an overload of stresses and extinctions attributable to human activities.

See Web/CD Activity 57.1 for a concept review of this chapter.

Self-Quiz

1. Which of the following is *not* currently a major cause of species extinctions?
   a. Habitat destruction
   b. Rising sea levels
   c. Overexploitation
   d. Introduction of predators
   e. Introduction of diseases
2. The most important cause of endangerment of species in the United States currently is
   a. pollution.
   b. exotic species.
   c. overexploitation.
   d. habitat loss.
   e. loss of mutualists.
3. People care about species extinctions because
   a. more than half of the medical prescriptions written in the United States contain a natural plant or animal product.
   b. people derive aesthetic pleasure from interacting with other organisms.
   c. causing species extinctions raises serious ethical issues.
   d. biodiversity helps maintain ecosystem services.
   e. All of the above
4. As a habitat patch gets smaller, it
   a. cannot support populations of species that require large areas.
   b. supports only small populations of many species.
   c. is influenced to an increasing degree by edge effects.
   d. is invaded by species from surrounding habitats.
   e. All of the above
5. A plant species is most likely to become invasive when introduced to a new area if it
   a. grows tall.
   b. has become invasive in other places where it has been introduced.
   c. is closely related to species living in the area into which it is introduced.
   d. has specialized dispersers of its seeds.
   e. has a long life span.

6. Conservation biologists are concerned about global warming because
   a. the rate of change in climate is projected to be faster than the rate at which many species can shift their ranges.
   b. it is already too hot in the Tropics.
   c. climates have been so stable for thousands of years that many species lack the ability to tolerate variable temperatures.
   d. climate change will be especially harmful to rare species.
   e. None of the above
7. Scientists can determine the historical frequency of fires in an area by
   a. examining charcoal in sites of ancient villages.
   b. measuring carbon in soils.
   c. radioactively dating fallen tree trunks.
   d. examining fire scars in growth rings of living trees.
   e. determining the age structure of forests.
8. Captive propagation is a useful conservation tool, provided that
   a. there is space in zoos, aquariums, and botanical gardens for breeding a few individuals.
   b. the genetic pedigree of all individuals is known.
   c. the threats that endangered the species are being alleviated so that captive-reared individuals can later be released back into the wild.
   d. there are sufficient caretakers.
   e. Captive propagation should not be used because it directs attention away from the need to protect the species in their natural habitats.
9. Restoration ecology is an important field because
   a. many areas have been highly degraded.
   b. many areas are vulnerable to global climate change.
   c. many species suffer from demographic stochasticity.
   d. many species are genetically impoverished.
   e. fire is a threat to many areas.
10. The new discipline of conservation medicine has developed because
   a. the frequency of diseases has increased among marine organisms.
   b. the frequency of diseases has increased among terrestrial organisms.
   c. the frequency of diseases has increased among both marine and terrestrial organisms.
   d. scientists can better control diseases today than they previously could.
   e. diseases can be readily diagnosed today.

For Discussion

1. Most species driven to extinction by humans in the past were large vertebrates. Do you expect this pattern to persist into the future? If not, why not?
2. Conservation biologists have debated extensively which is better: many small nature reserves or a few large ones. What ecological processes should be evaluated in making judgments about the size and location of reserves? To what extent should we be concerned with preserving the largest number of species rather than those species judged to be of unusual importance for scientific, aesthetic, or commercial reasons?
3. During World War I, French doctors adopted a "triage" system for dealing with wounded soldiers. The wounded were divided into three categories: those almost certain to die no matter what was done to help them, those likely to recover even if not assisted, and those whose probability of survival was greatly increased if they were given immediate medical attention. Limited medical resources were directed primarily at the third category. What are some implications of adopting a similar attitude toward species preservation?
4. Utilitarian arguments dominate discussions about the importance of preserving the biological richness of the planet. In your opinion, what role should ethical and moral arguments play?
5. The desert bighorn sheep of the southwestern United States is endangered. Its major predator, the puma, is also threatened in the region. Under what conditions, if any, would it be appropriate to suppress the population of one rare species to assist another rare species?