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 Horticulturalists lobbied the state government and succeeded in getting the booklet withdrawn from publication.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?

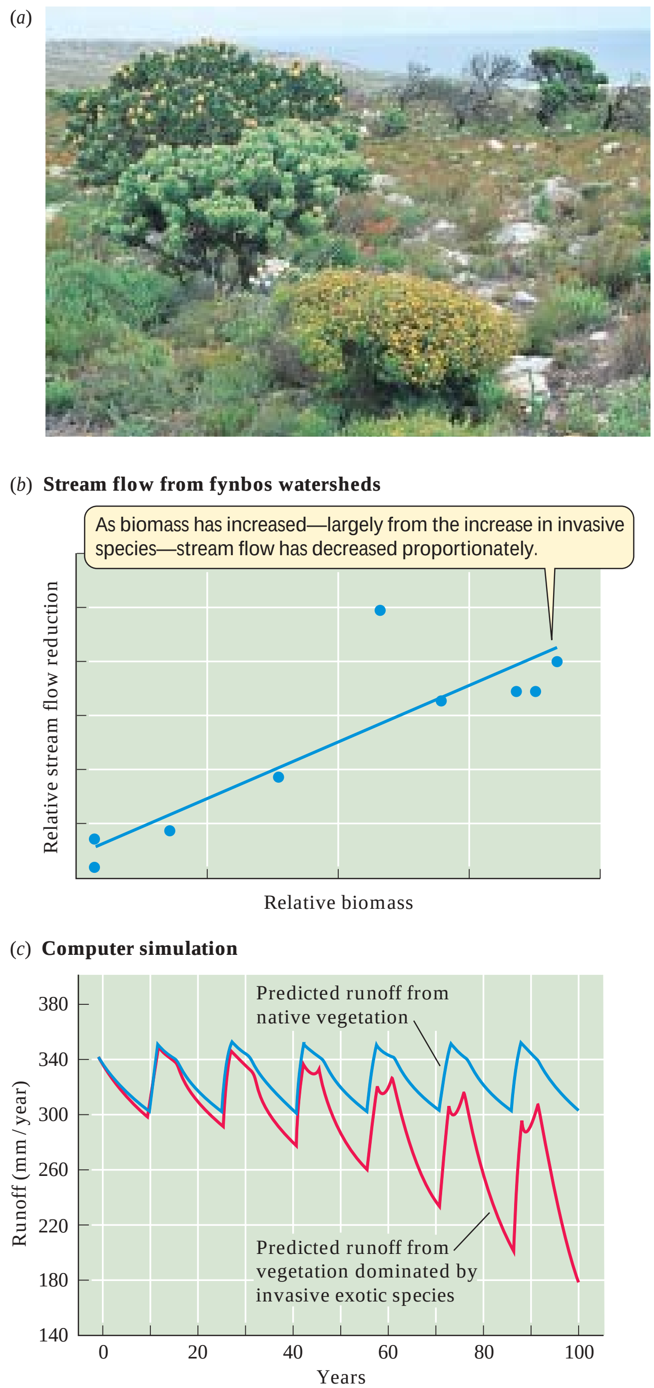
Why Care about Species Extinctions?

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.

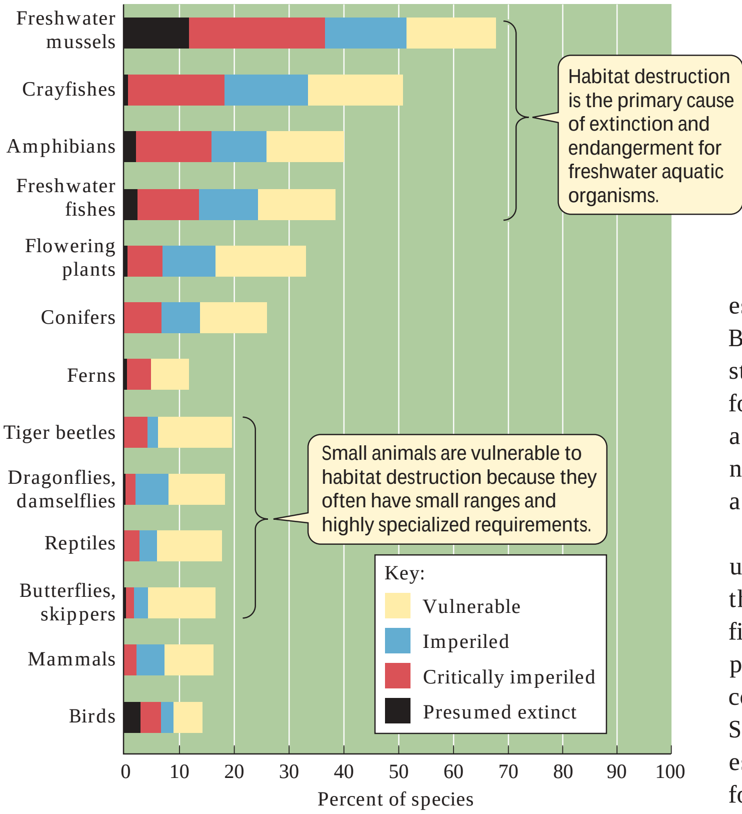
In an example of such a population study, an ecologist constructed a quantitative model of the dynamics of the grizzly bear population in Yellowstone National Park, using detailed data collected over a 12-year period. The model kept track of individual bears and incorporated the effects of chance events, 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.

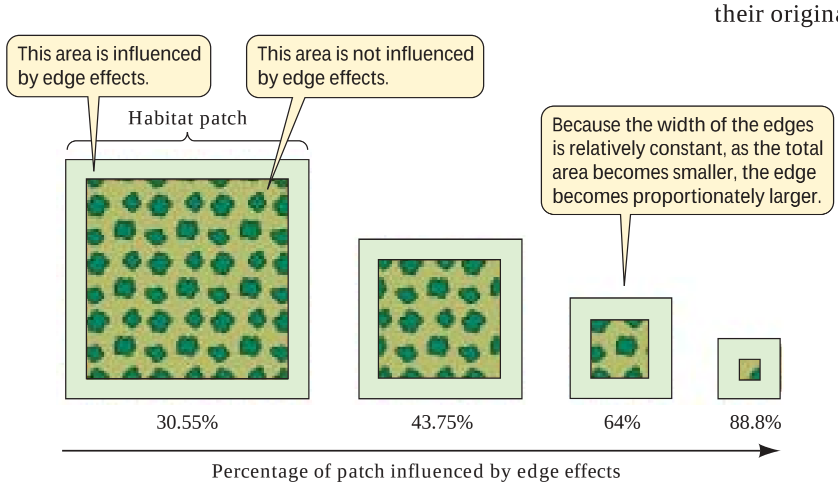
In addition, the fraction of a patch that is influenced by effects originating outside the habitat—**edge effects**—increases rapidly as patch size decreases (Figure 57.3). Close to the edges of forest patches, for example, winds are stronger, temperatures are higher, humidity is lower, and light levels 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.

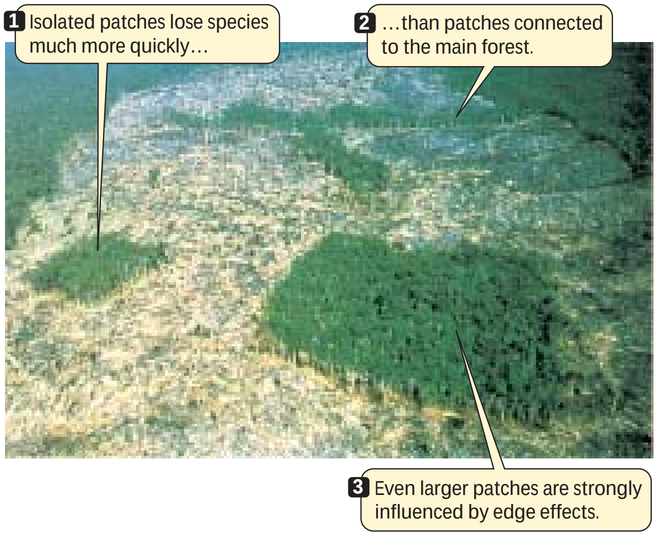
Species that become extinct in small habitat fragments are unlikely to become reestablished because the more isolated the patches are, the less likely dispersing individuals are to find them. However, as we saw in Chapter 54, a species may persist in a small patch if it is connected to other patches 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.

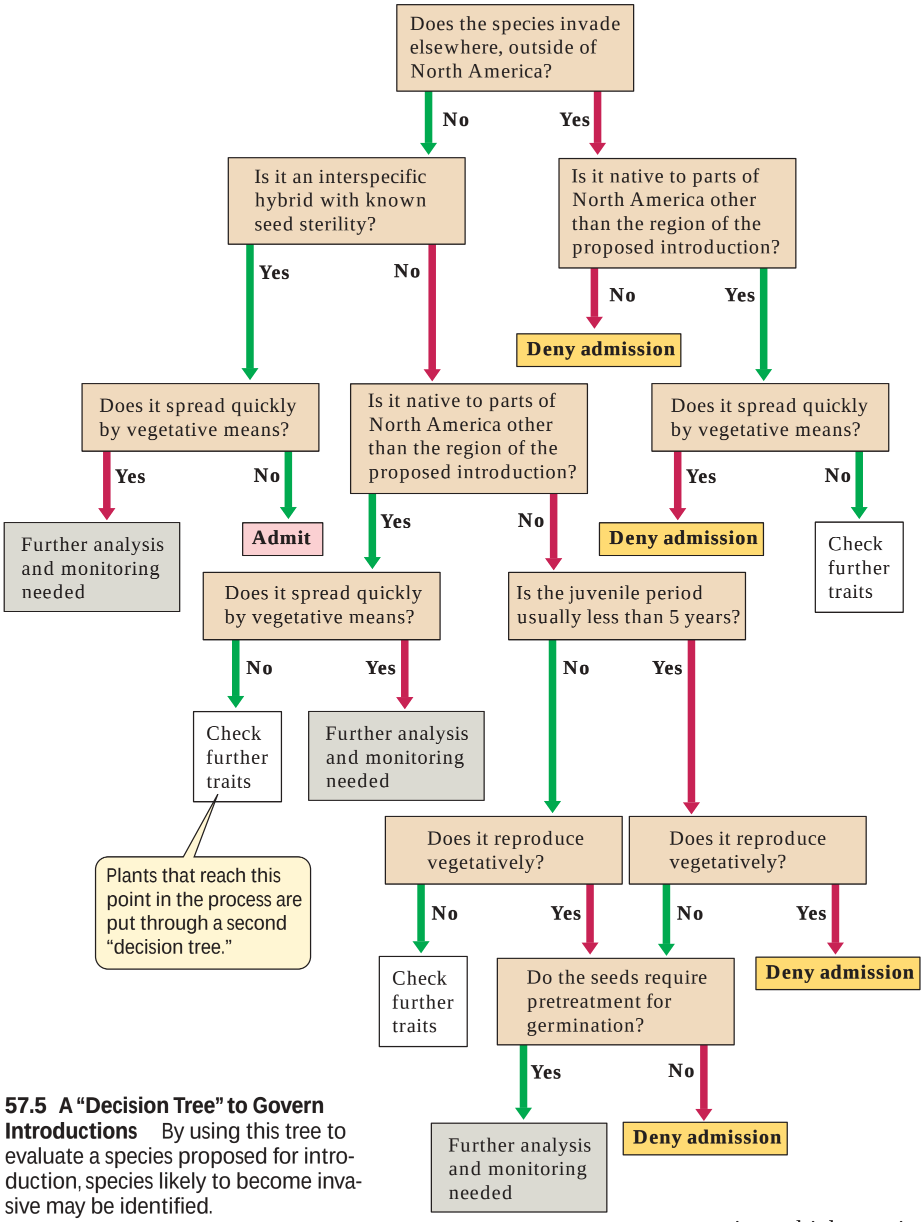
Strict rules already govern the deliberate introduction of animal species, but the introduction of ornamental plants is poorly regulated. In 1998, Australia and New Zealand began to require a weed risk assessment for the importation of plants not already in the country or not on a "clean list" of permitted 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.

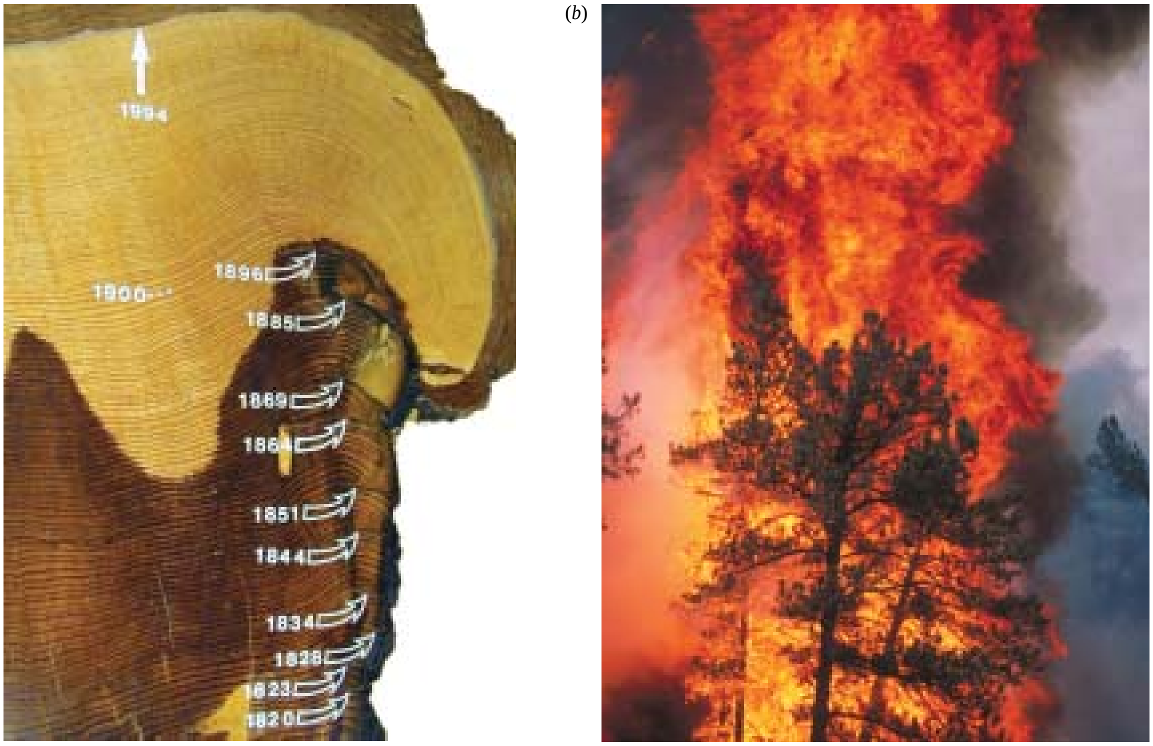
To serve the same function for marine products, the Marine Stewardship Council was formed through an alliance between the World Wildlife Fund and Unilever, one of the largest marketers of frozen seafood. The first marine certified product, Australian rock lobster, came to market in 2000. Alaskan salmon 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.

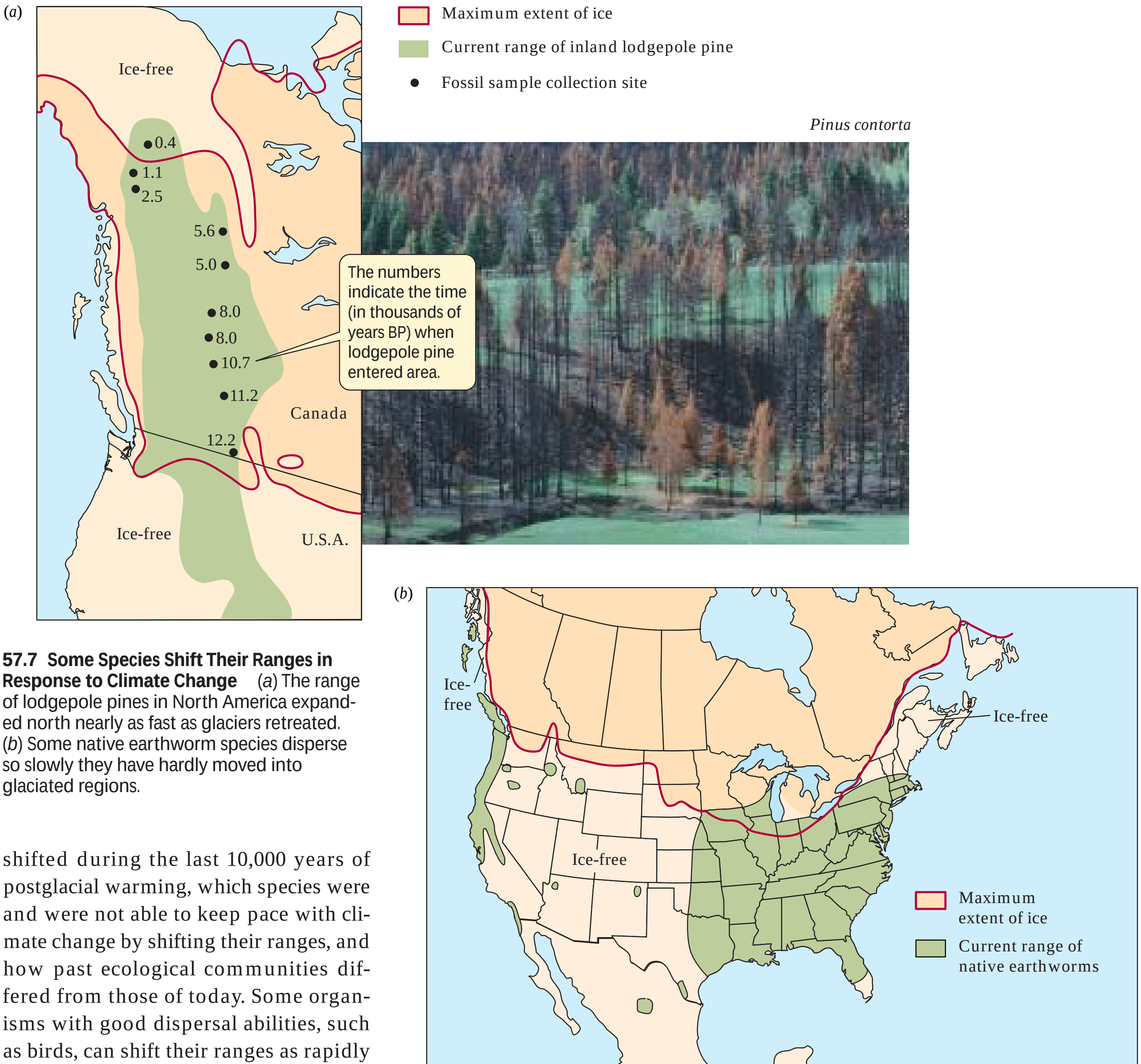
Scars in the annual growth rings of trees preserve evidence of past fires that did not kill them. Therefore, tree-ring researchers can determine when fires occurred, how severe they were, and when fire patterns changed. Annual growth rings on ponderosa pines show that low-intensity ground fires were 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.

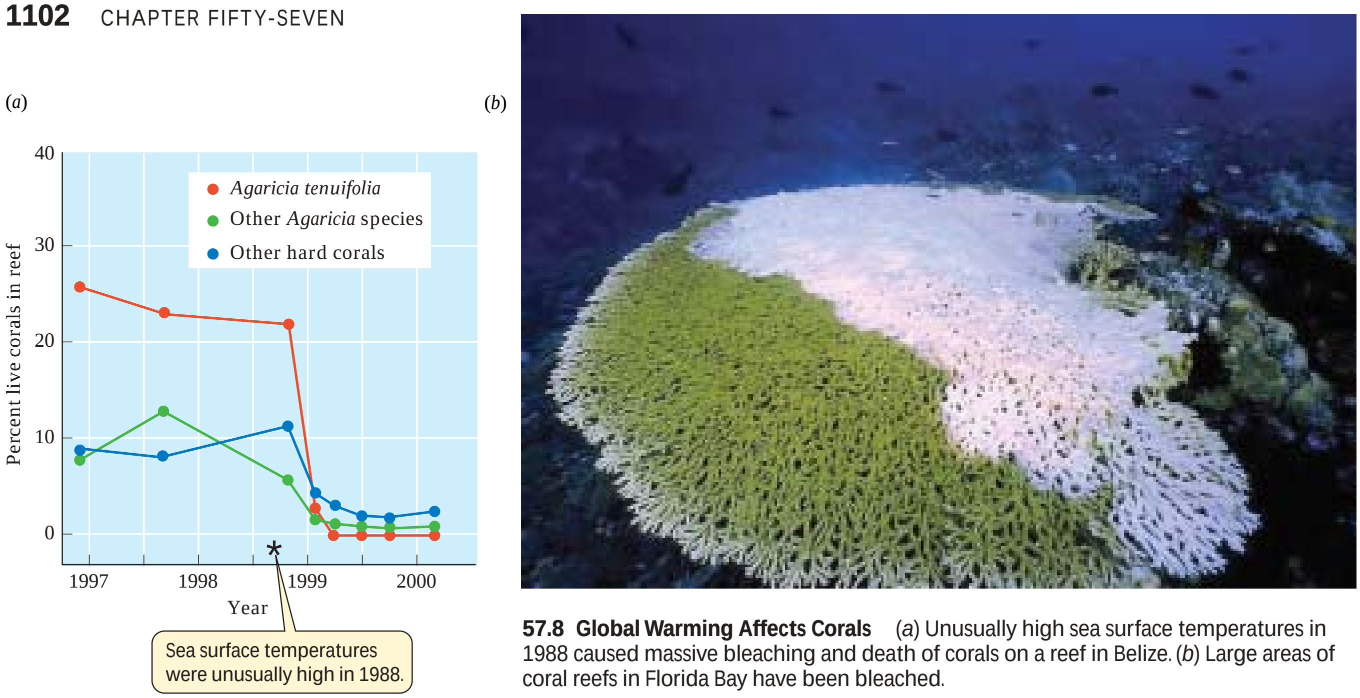
Knowledge of how organisms responded to past climate changes can help us predict the effects of the current warming trend. Biologists are studying how rapidly species ranges



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.

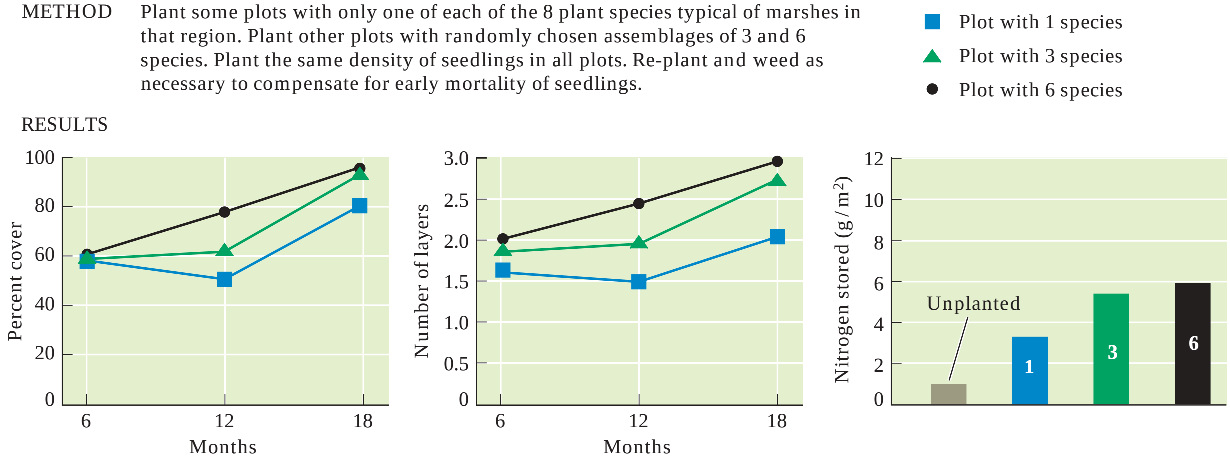
In southern California, where 90 percent of the coastal wetlands have been destroyed, wetland restoration is a high priority. Because species have been lost from degraded coastal wetlands, restoration requires species introductions, but which species should be introduced? In early attempts at restoration, 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 Oʻo 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?