CHAPTER

38 Conservation Biology

BIG IDEAS

The Loss of Biodiversity (38.1–38.6)

Biodiversity is declining rapidly worldwide as a result of human activities.

Conservation Biology and Restoration Ecology (38.7–38.13)

Biologists are applying their knowledge of ecology to slow the loss of biodiversity and help define a sustainable future.

How does a species become extinct? Here's one scenario. Imagine a species whose habitat constantly shrinks, squeezing populations into ever-smaller areas with ever-diminishing resources. As a population dwindles, the loss of even a single member to hunting, disease, or natural disaster brings the population closer to the brink. And then one day, that population is simply gone. Imagine a relentless succession of such occurrences—one population after another passing quietly out of existence, until none remains. This is the series of events unfolding as tigers slide toward extinction.

A hundred years ago, scientists estimate, about 100,000 tigers (*Panthera tigris*) could be found in the wild. Now that number has plummeted to around 3,200. Three of the world's nine tiger subspecies have disappeared entirely, and one has not been seen for the past 25 years. Tigers now occupy just 7% of their original range, and even that remaining sliver is decreasing. In Indonesia and Malaysia, tropical forests that are home to two tiger subspecies are being replaced by plantations for palm oil, paper, and rubber. In Russia, logging in temperate forests is destroying the habitat of the Siberian tiger. People moving into rural areas of South Asia are encroaching on the habitat of the Bengal tiger. And throughout their range, tigers are at risk from poachers eager to sell the big cats' bones and internal organs, considered potent ingredients in some traditional Asian medicines.

In this final chapter, you will learn about one of the major ecological challenges of our time—the rapid loss of biodiversity that is a result of our dominance over the environment. As you learn about the fight to save our biological heritage, you will see that conservation biology touches all levels of ecology, from a single tiger to the forest it roams.

The Loss of Biodiversity

38.1 Loss of biodiversity includes the loss of ecosystems, species, and genes

The decline of tiger populations is just one example of the worldwide loss of biodiversity. Why do we care about losing species, especially ones that are less charismatic than the magnificent tiger? One reason is what Harvard biologist E. O. Wilson calls biophilia, our sense of connection to nature and to other forms of life. And many people share a moral belief that other species have an inherent right to life. But as you learned in Module 37.23, our dependence on vital ecosystem services also gives us practical reasons for preserving biodiversity.

Biodiversity encompasses more than individual species—it includes ecosystem diversity, species diversity, and genetic diversity. Let's examine each level of diversity to see what we stand to lose if the decline is not stopped.

Ecosystem Diversity The world's natural ecosystems are rapidly disappearing. Nearly half of Earth's forests are gone, and thousands more square kilometers disappear every year. Grassland ecosystems in North America (see Figure 34.13), where millions of bison roamed as recently as the 19th century, have overwhelmingly been lost to agriculture and development.

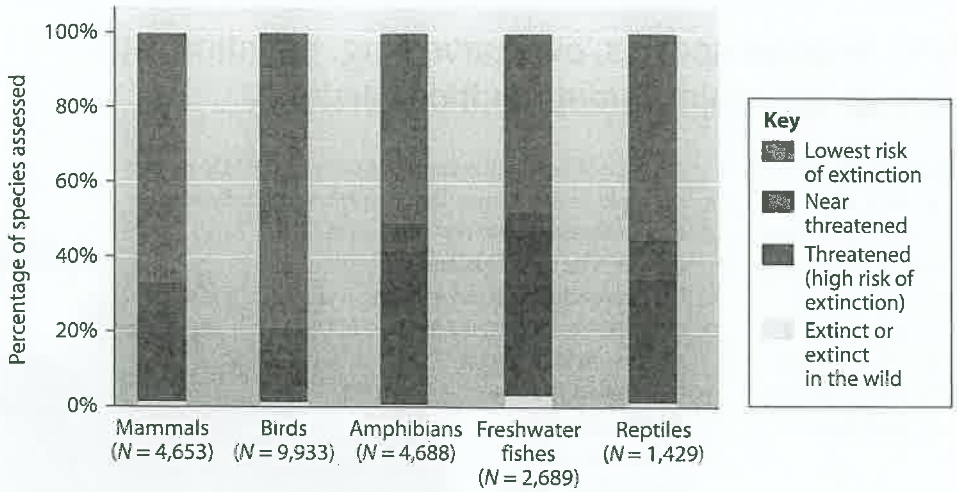
The temperate coniferous forest of the Klamath-Siskiyou Wilderness **(Figure 38.1A)** is located in a region spanning parts of California and Oregon that is extraordinarily rich in ecosystem diversity. In addition to the distinctive chaparral ecosystem (see Figure 34.12), forests of sequoia, redwood, and Douglas fir, coastal dunes, salt marshes, and a wide variety of other ecosystems are found in this rapidly vanishing treasure trove of biodiversity. Only about a quarter of the original area remains in its natural state.

Aquatic ecosystems are also threatened. For example, an estimated 20% of the world's coral reefs, ecosystems known for their species richness and productivity (see the opening photo in Chapter 16 and Figure 34.6B), have been destroyed by human activities, and 15% are in danger of collapse within the next two decades. The deteriorating state of freshwater ecosystems is particularly worrisome. Tens of thousands of species live in lakes and rivers, and these ecosystems supply food and water for many terrestrial species, as well—including us.

As natural ecosystems are lost, so are essential services. Water purification is one of the services provided free of charge by healthy ecosystems. As water moves slowly through forests, streams, and wetlands, pollutants and sediments are filtered out. Whether taken from surface waters such as lakes or subsurface sources (groundwater), the drinking water supplied by public water systems typically has passed through this natural filtration process. In some places, including New York City, no further filtration is required, although the water is chlorinated to kill microorganisms. As farm fields and housing developments replaced the naturally diverse ecosystems in New York City's watershed, the land's ability to purify water deteriorated. The additional pollution from agricultural runoff and sewage reduced water quality to the point where the city had to take action. Officials considered spending $8 billion to build a filtration plant, which would cost a further $1 million per day to operate. They decided to invest in lower cost ecosystem services instead. Actions included more tightly restricting land use in the watershed, purchasing land to preserve natural ecosystems, and helping landowners better manage their land to protect the watershed. As a result of these measures, the quality of naturally filtered water supplied to New York City remains high.

Species Diversity When ecosystems are lost, populations of the species that make up their biological communities are also lost. A species may disappear from a local ecosystem but remain in others; for example, a population of tigers may be lost from one region of India while other populations survive elsewhere. Ecologists refer to the loss of a single population of a species as **extirpation**. Although extirpation and declining population sizes are strong signals that a species is in trouble, it may still be possible to save it. **Extinction** means that all populations of a species have disappeared, an irreversible situation.

▼ **Figure 38.1A** The Klamath-Siskiyou Wilderness, home to a wide variety of ecosystems



▲ **Figure 38.1B** Results of the 2009 IUCN assessment of species at risk for extinction (*N* = the number of species assessed)

How rapidly are species being lost? Because biologists are uncertain of the total number of species that exist, it is difficult to determine the actual rate of species loss. Some scientists estimate that current extinction rates are around 100 times greater than the natural rate of extinction. The International Union for Conservation of Nature (IUCN) is a global environmental network that keeps track of the status of species worldwide. **Figure 38.1B** shows the 2009 IUCN assessment of five major groups of animals. Notice the large proportions of amphibians and freshwater fishes that are considered threatened, further indications of the declining health of freshwater ecosystems.

Because of the network of community interactions among populations of different species within an ecosystem, the loss of one species can have a negative impact on the overall species richness of the ecosystem. Keystone species illustrate this effect (see Module 37.11). Other species modify their habitat in ways that encourage species diversity. In prairie ecosystems, for instance, plant and arthropod diversity is greatest near prairie dog burrows, where the soil has been altered by the animal's digging **(Figure 38.1C)**. Abandoned burrows provide homes for cottontail rabbits, burrowing owls, and other animals. Thus, extirpation of prairie dogs results in lower species diversity in prairie communities.

In the United States, the Endangered Species Act protects species and the ecosystems on which they depend. Many other nations have also enacted laws to protect biodiversity, and an international agreement protects some 33,000 species of wild animals and plants from trade that would threaten their survival.

▼ **Figure 38.1C** A group of young black-tailed prairie dogs (*Cynomys ludovicianus*) near their burrow

Species loss also has practical consequences for human well-being. Many drugs have been developed from substances found in the natural world, including penicillin, aspirin, antimalarial agents, and anticancer drugs. Dozens more potentially useful chemicals from a variety of organisms are currently being investigated. For example, researchers are testing possible new antibiotics produced by microbial symbionts of marine sponges; painkillers extracted from a species of poison dart frog; and anti-HIV and anticancer drugs derived from compounds in from rain forest plants.

Genetic Diversity The genetic diversity within and between populations of a species is the raw material that makes microevolution and adaptation to the environment possible—a hedge against future environmental changes (see Module 13.11). If local populations are lost and the total number of individuals of a species declines, so, too, do the genetic resources for that species. Severe reduction in genetic variation threatens the survival of a species.

The enormous genetic diversity of all the organisms on Earth has great potential benefit for people, too. As you learned in Module 17.13, breeding programs have narrowed the genetic diversity of crop plants to a handful of varieties, leaving them vulnerable to pathogens. For example, researchers are currently scrambling to stop the spread of a deadly new strain of wheat stem rust, a fungal pathogen that has devastated harvests in Africa and central Asia. Resistance genes found in the wild relatives of wheat **(Figure 38.1D)** may hold the key to the world's future food supply. Many researchers and biotechnology leaders are enthusiastic about the possibilities that "bioprospecting" for potentially useful genes in other organisms holds for the development of new medicines, industrial chemicals, and other products.

Now that you have some insight into the nature and value of biodiversity, let's examine in more detail the causes for its decline.

▲ **Figure 38.1D** Einko[rn] wheat, a wild relative of m[od]ern cultivated varieties

? What are two reasons to be concerned about the impact of the biodiversity crisis on human welfare?

The environmental degradation threatening other species may also harm us. We are dependent on biodiversity, both directly through use of organisms and their products and indirectly through ecosystem services.

CONNECTION

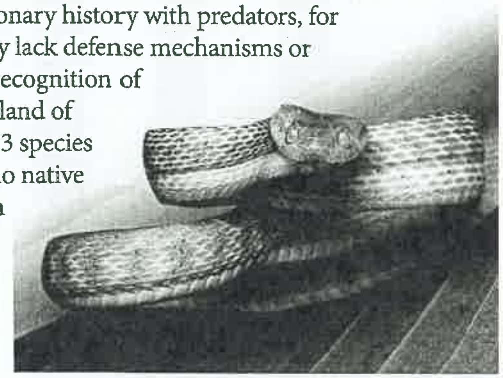
38.2 Habitat loss, invasive species, overharvesting, pollution, and climate change are major threats to biodiversity

The human population has been growing exponentially for more than 100 years. We have supported this growth by using increasingly effective technologies to capture or produce food, to extract resources from the environment, and to build cities. In industrialized countries, we consume far more resources than are required to meet our basic requirements for food and shelter. Thus, it should not surprise you to learn that human activities are largely responsible for the current decline of biodiversity. In this section, we examine the major factors that threaten biodiversity.

Habitat Loss Human alteration of habitats poses the single greatest threat to biodiversity throughout the biosphere. Agriculture, urban development, forestry, mining, and environmental pollution have brought about massive destruction and fragmentation of habitats. Deforestation continues at a blistering pace in tropical and coniferous forests **(Figure 38.2A)**.

The amount of human-altered land surface is approaching 50%, and we use over half of all accessible surface fresh water. The natural course of most of the world's major rivers has been changed. Worldwide, tens of thousands of dams constructed for flood control, hydroelectric power, drinking water, and irrigation have damaged river and wetland ecosystems. Some of the most productive aquatic habitats in estuaries and intertidal wetlands have been overrun by commercial and residential development. The loss of marine habitat is severe, especially in coastal areas and coral reefs.

Invasive Species Ranking second behind habitat loss as a threat to biodiversity are invasive species, which disrupt communities by competing with, preying on, or parasitizing native species. The lack of interspecific interactions that keep the newcomer populations in check is often a key factor in a non-native species becoming invasive (see Module 37.13). Meanwhile, a newly arrived species is an unfamiliar biotic factor in the environment of native species. Natives are especially vulnerable when a new species poses an unprecedented threat. In the absence of an evolutionary history with predators, for example, animals may lack defense mechanisms or even a fundamental recognition of danger. The Pacific island of Guam was home to 13 species of forest birds—but no native snakes—when brown tree snakes **(Figure 38.2B)** arrived as stowaways on a cargo plane. With no competitors, predators, or parasites to hinder them, the snakes proliferated rapidly on a diet of unwary birds. Four of the native species of birds were extirpated, although they survive on nearby islands. Three species of birds that lived nowhere else but Guam are now extinct. As the populations of two other species of birds became perilously low, officials took the remaining individuals into protective custody; they now exist only in zoos. The brown tree snake also eliminated species of seabirds and lizards.

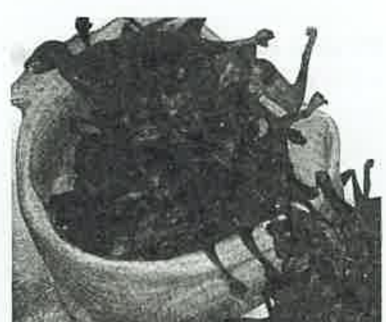


▲ **Figure 38.2B** A brown tree snake (*Boiga irregularis*)

▲ **Figure 38.2A** Clear-cut areas in Mount Baker-Snoqualmie National Forest, Washington

Overharvesting The third major threat to biodiversity is overexploitation of wildlife by harvesting at rates that exceed the ability of populations to rebound. Such overharvesting has threatened some rare trees that produce valuable wood, such as mahogany and rosewood. Animal species whose numbers have been drastically reduced by excessive commercial harvest, poaching, or sport hunting include tigers, whales, rhinoceroses, Galápagos tortoises, and numerous fishes. In parts of Africa, Asia, and South America, wild animals are heavily hunted for food, and the African term "bushmeat" is now used to refer generally to such meat. As once-impenetrable forests are opened to exploitation, the commercial bushmeat trade has become one of the greatest threats to primates, including gorillas, chimpanzees, and many species of monkeys, as well as other mammals and birds **(Figure 38.2C)**. No longer hunted only for local use, large quantities of bushmeat are sold at urban markets or exported worldwide, including to the United States.

Aquatic species are suffering overexploitation, too. Many edible marine fish and seafood species are in a precarious state (see Module 36.8). Worldwide, fishing fleets are working farther offshore and harvesting fish from greater depths in order to obtain hauls comparable to those of previous decades.



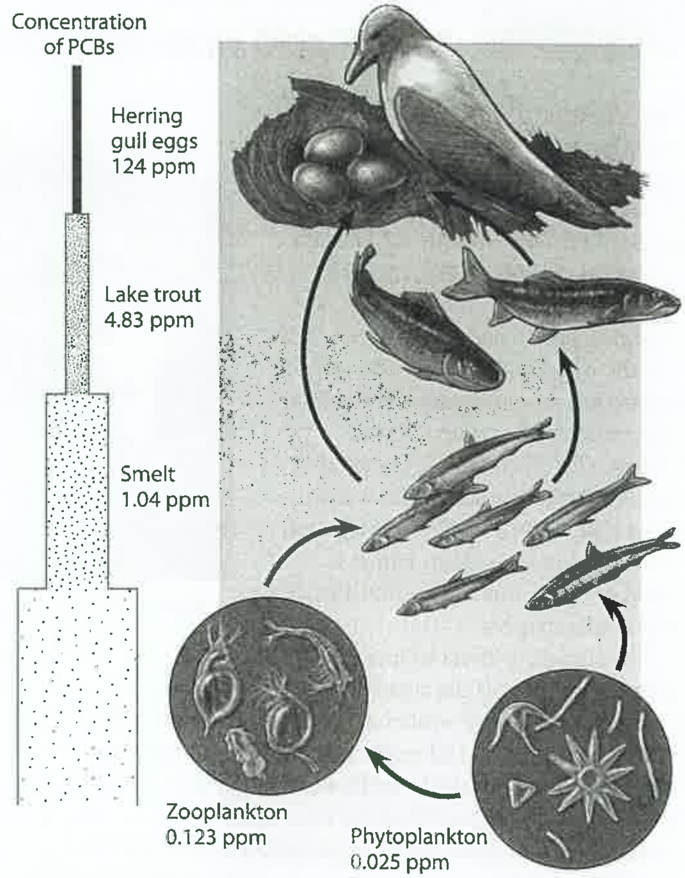
▲ **Figure 38.2C** Lemurs killed by poachers for sale in a bushmeat market

Pollution Pollutants released by human activities can have local, regional, and global effects. Some pollutants, such as oil spills, contaminate local areas (**Figure 38.2D**). Recall from Module 34.18 that the global water cycle can transport pollutants—for instance, pesticides used on land—from terrestrial to aquatic ecosystems hundreds of miles away. Pollutants that are emitted into the atmosphere, such as nitrogen oxides from the burning of fossil fuels, may be carried aloft for many of miles before falling to earth in the form of acid precipitation.

Ozone depletion in the upper atmosphere is another example of the global impact of pollution. As you learned in Module 7.14, the **ozone layer** protects Earth from the harmful ultraviolet rays in sunlight. Beginning in the mid-1970s, scientists realized that the ozone layer was gradually thinning. The consequences of ozone depletion for life on Earth could be quite severe, not only increasing skin cancers, but harming crops and natural communities, especially the phytoplankton that are responsible for a large proportion of Earth's primary production. International agreements to phase out the production of chemicals implicated in ozone destruction have been effective in slowing the rate of ozone depletion. Even so, complete ozone recovery is probably decades away.

In addition to being transported to areas far from where they originate, many toxins produced by industrial wastes or applied as pesticides become concentrated as they pass through the food chain. This concentration, or **biological magnification**, occurs because the biomass at any given trophic level is produced from a much larger toxin-containing biomass ingested from the level below (see Module 37.16). Thus, top-level predators are usually the organisms most severely damaged by toxic compounds in the environment. In the Great Lakes food chain shown in **Figure 38.2E**, the concentration of industrial chemicals called PCBs increased at each successive trophic level. The PCB concentration measured in the eggs of herring gulls, top-level consumers, was almost 5,000 times higher than that measured in phytoplankton. Many other synthetic chemicals that cannot be degraded by microorganisms also become concentrated through biological magnification, including DDT and mercury. Mercury, a by-product of plastic production and coal-fired power plants, enters the food chain after being converted to highly toxic methylmercury by benthic bacteria. Since people are top-level predators, too, eating fish from contaminated waters can be dangerous.

▲ **Figure 38.2D** A brown pelican on the Louisiana coast suffering the effects of the 2010 British Petroleum oil rig explosion



▲ **Figure 38.2E** Biological magnification of PCBs in a food web, measured in parts per million (ppm)

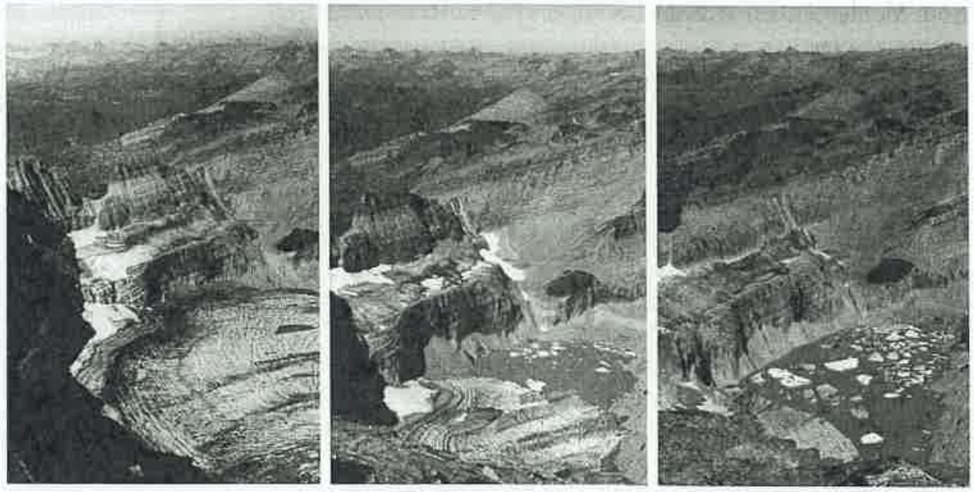
Recently, scientists have recognized a new type of aquatic pollutant: plastic particles that are small enough to be eaten by zooplankton. Many body washes and facial cleansers include plastic "microbeads" to boost scrubbing power. (To see if your shower products contain plastic, check the list of ingredients for polyethylene.) Too small to be captured by wastewater treatment plants, these microparticles enter the watershed and eventually wash out to sea. Larger particles called preproduction pellets or "nurdles," used in making plastic products, are also common marine pollutants. Nurdles may be broken down to microbead size in the ocean. Toxins such as PCBs and DDT adhere to these plastic spheres. Thus, toxins may be concentrated first on microparticles and then again by biological magnification.

Global Climate Change According to many scientists, the changes in global climate that are occurring as a result of global warming (see Module 7.13) are likely to become a leading cause of biodiversity loss. In the next four modules, you'll learn about some of the causes and consequences of global climate change.

? List four threats to biodiversity and give an example of each.

Habitat loss—deforestation; invasive species—brown tree snake; overharvesting—bushmeat; pollution—biological magnification of PCBs, DDT, and mercury. (Other examples could be used.)

CONNECTION **38.3** Rapid warming is changing the global climate



▲ **Figure 38.3B** Grinnell Glacier in Glacier National Park, 1938 (left), 1981 (center), and 2005 (right)

The scientific debate about global warming is over. The vast majority of scientists now agree that rising concentrations of greenhouse gases in the atmosphere (see Module 7.13), such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), are changing global climate patterns. This was the overarching conclusion of the assessment report released by the Intergovernmental Panel on Climate Change (IPCC) in 2007. Thousands of scientists and policymakers from more than 100 countries participated in producing the report, which is based on data published in hundreds of scientific papers.

The signature effect of increasing greenhouse gases is the steady increase in the average global temperature, which has risen 0.8°C (1.5°F) over the last 100 years, with 0.6°C of that increase occurring over the last three decades. Further increases of 2–4.5°C (3.6–8.1°F) are likely by the end of the 21st century, depending on the rate of future greenhouse gas emissions. Ocean temperatures are also rising, in deeper layers as well as at the surface. But the temperature increases are not distributed evenly around the globe. Warming is greater over land than sea, and the largest increases are in the northernmost regions of the Northern Hemisphere. In **Figure 38.3A**, red areas indicate the greatest temperature increases. In parts of Alaska and Canada, for example, the temperature has risen 1.4°C (2.5°F) just since 1961. Some of the consequences of the global warming trend are already clear from rising temperatures, unusual precipitation patterns, and melting ice.

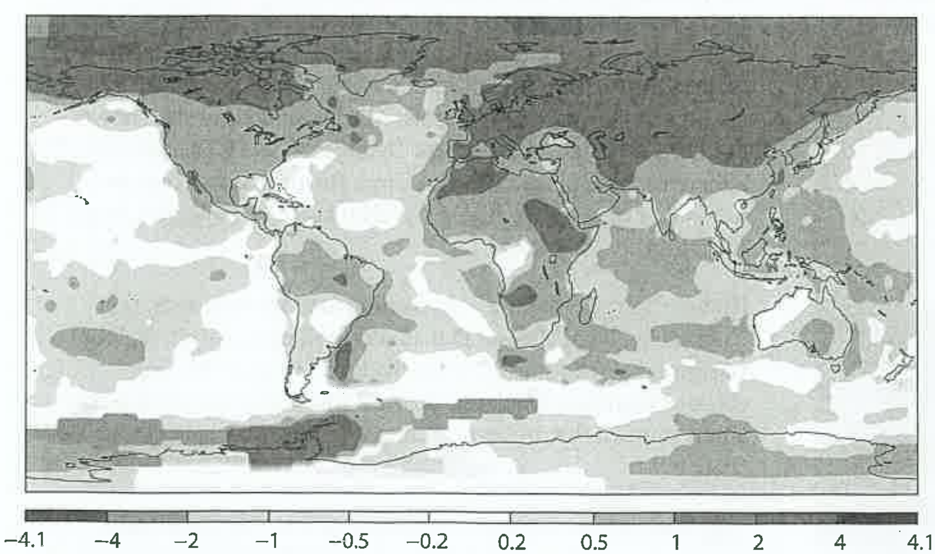
Many of the world's glaciers are receding rapidly, including mountain glaciers in the Himalayas, the Alps, the Andes, and the western United States. Glacier National Park in northwest Montana will need a new name by 2030, when its glaciers are projected to disappear entirely. For example, almost all of the Grinnell Glacier is now a meltwater lake **(Figure 38.3B)**. The permafrost that characterizes the tundra biome is also melting.

Permanent Arctic sea ice is shrinking; each summer brings increased melting and thinner ice. The massive ice sheets of Greenland and Antarctica are thinning and collapsing. If this melting trend accelerates, rising sea levels would cause catastrophic flooding of coastal areas worldwide.

Warm weather is beginning earlier each year. Cold days and nights and frosts have become less frequent; hot days and nights have become more frequent. Deadly heat waves are increasing in frequency and duration.

Precipitation patterns are changing, bringing longer and more intense drought to some areas. In other regions, a greater proportion of the total precipitation is falling in torrential downpours that cause flooding. Hurricane intensity is increasing, fueled by higher sea surface temperatures.

Many of these changes will have a profound impact on biodiversity, as we explore in Modules 38.5 and 38.6. In the next module, we examine the causes of rising greenhouse gas emissions.



▲ **Figure 38.3A** Differences in temperature during 2000–2009 relative to temperatures during 1951–1980 (in °C)

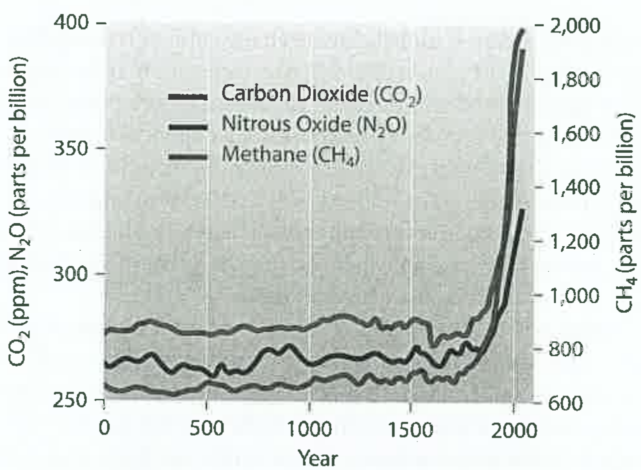
? From the map in Figure 38.3A, which biomes are likely to be most affected by global warming, and why?

The high-latitude biomes of the Northern Hemisphere, tundra and taiga, and the polar ice biomes will be most affected. Those biomes are experiencing the greatest temperature change. Also, the organisms that live there are adapted to cold weather and a short growing season, so their survival is on the line.

CONNECTION

38.4 Human activities are responsible for rising concentrations of greenhouse gases

Without its blanket of natural greenhouse gases such as CO_2 and water vapor to trap heat, Earth would be too cold to support most life. However, increasing the insulation that the blanket provides is making the planet uncomfortably warm, and that increase is occurring rapidly. For 650,000 years, the atmospheric concentration of CO_2 did not exceed 300 parts per million (ppm); the preindustrial concentration was 280 ppm. Today, atmospheric CO_2 is approximately 385 ppm. The levels of nitrous oxide (N_2O) and methane (CH_4), which also trap heat in the atmosphere, have increased dramatically, too **(Figure 38.4A)**. CO_2 and N_2O are released when fossil fuels—oil, coal, and natural gas—are burned. N_2O is also released when nitrogen fertilizers are used in agriculture. Livestock and landfills are among the factors responsible for increases of atmospheric CH_4. The consensus of scientists, as reported by the IPCC, is that rising concentrations of greenhouse gases—and thus, global warming—are the result of human activities.



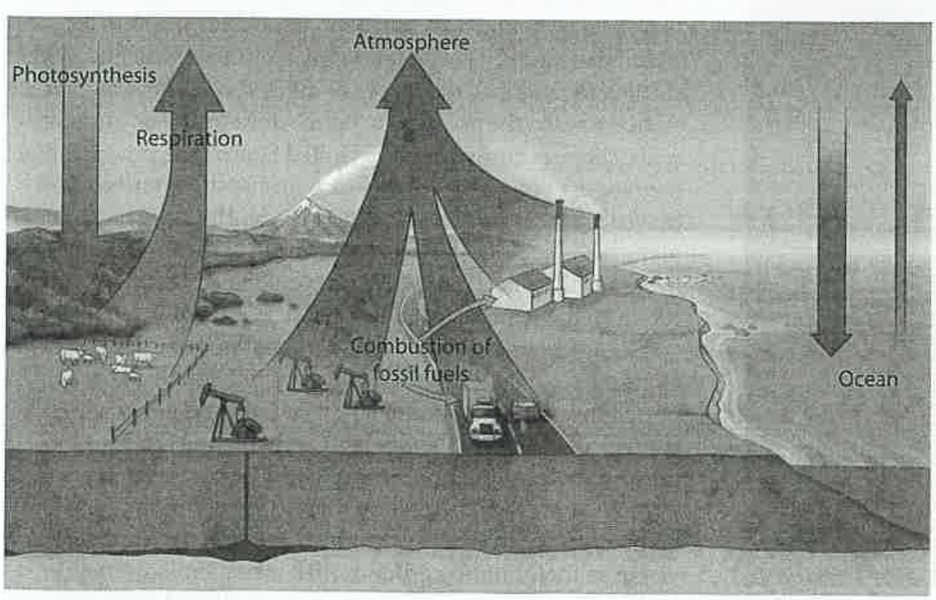
▲ **Figure 38.4A** Atmospheric concentrations of CO_2, N_2O (*y*-axis, left), and CH_4 (*y*-axis, right), as of 2009

Let's take a closer look at CO_2, the dominant greenhouse gas. Recall from Module 37.19 that atmospheric CO_2 is a major reservoir for carbon. (CH_4 is also part of that reservoir.) CO_2 is removed from the atmosphere by the process of photosynthesis and stored in organic molecules such as carbohydrates **(Figure 38.4B)**. Thus, biomass, the organic molecules in an ecosystem, is a biotic carbon reservoir. The carbon-containing molecules in living organisms may be used in the process of cellular respiration, which releases carbon in the form of CO_2. Nonliving biomass may be decomposed by microorganisms or fungi that also release CO_2. Overall, uptake of CO_2 by photosynthesis roughly equals the release of CO_2 by cellular respiration. CO_2 is also exchanged between the atmosphere and the surface waters of the oceans.

Fossil fuels consist of biomass that was buried under sediments without being completely decomposed (see Module 17.6). The burning of fossil fuels and wood, which is also an organic material, can be thought of as a rapid form of decomposition. While cellular respiration releases energy from organic molecules slowly and harnesses it to make ATP, combustion liberates the energy rapidly as heat and light. In both processes, the carbon atoms that make up the organic fuel are released in CO_2.

The CO_2 flooding into the atmosphere from combustion of fossil fuels may be absorbed by photosynthetic organisms and incorporated into biomass. But deforestation has significantly decreased the number of CO_2 molecules that can be accommodated by this pathway. CO_2 may also be absorbed into the ocean. For decades, the oceans have been absorbing considerably more CO_2 than they have released, and they will continue to do so, but the excess CO_2 is beginning to affect ocean chemistry. When CO_2 dissolves in water, it becomes carbonic acid. Recently, measurable decreases in ocean pH have raised concern among biologists. Organisms that construct shells or exoskeletons out of calcium carbonate ($CaCO_3$), including corals and many plankton, are most likely to be affected as decreasing pH reduces the concentration of the carbonate ions (see Module 2.15).

Greenhouse gas emissions are accelerating. From 2000 to 2005, global CO_2 emissions increased four times faster than in the preceding 10-year span. At this rate, further climate change is inevitable.



▲ **Figure 38.4B** Carbon cycling

? **The amount of CO_2 you are responsible for releasing every year is called your *carbon footprint*. Search for an online calculator that estimates your carbon footprint. What are the primary sources of the CO_2 you generate?**

Transportation and home energy use are the two major categories contributing to the footprint.

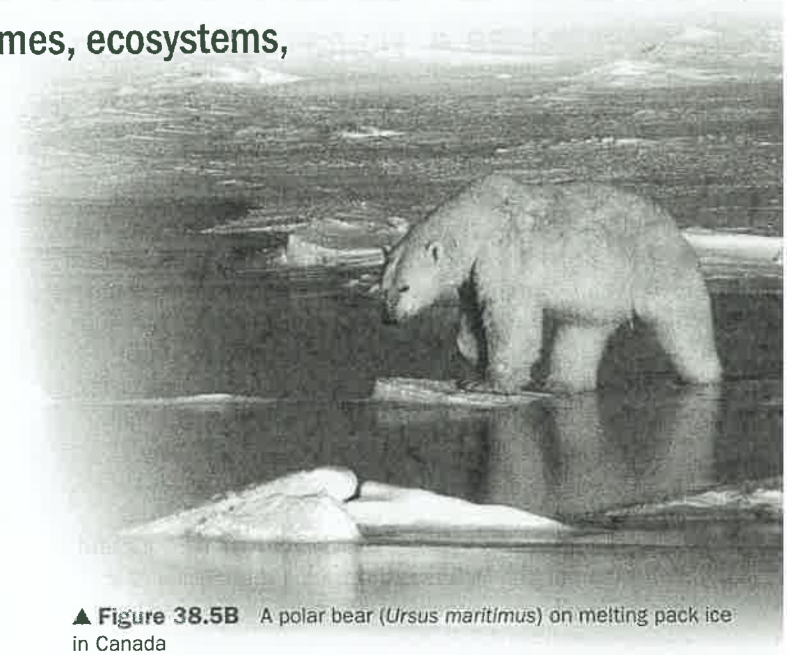
38.5 Global climate change affects biomes, ecosystems, communities, and populations

The distribution of terrestrial biomes, which is primarily determined by temperature and rainfall, is changing as a consequence of global warming. Melting permafrost is shifting the boundary of the tundra as shrubs and conifers are able to stretch their ranges into the previously frozen ground. Prolonged droughts will increasingly extend the boundaries of deserts. Great expanses of the Amazonian tropical rain forest will gradually become savanna as increased temperatures dry out the soil.

The combined effects of climate change on components of forest ecosystems in western North America have spawned catastrophic wildfire seasons **(Figure 38.5A)**. In these mountainous regions, spring snowmelt releases water into streams that sustain forest moisture levels over the summer dry season. With the earlier arrival of spring, snowmelt begins earlier and dwindles away before the dry season ends. As a result, the fire season has been getting longer since the 1980s. In addition, drought conditions have made trees more vulnerable to insect and pathogen attack; vast numbers of dead trees add fuel to the flames. Fires burn longer, and the number of acres burned has increased dramatically. As dry conditions persist and snowpacks diminish, the problem will worsen.

The earlier arrival of warm weather in the spring is disturbing ecological communities in other ways. In many animal and plant species, certain annual spring events are triggered by temperature increases. With temperatures rising earlier in the year, a variety of species, including some birds and frogs, have begun their breeding season earlier. Satellite images show earlier greening of the landscape, and flowering occurs sooner. For other species, day length is the environmental cue that spring has arrived. Because global climate change affects temperature but not day length, interactions between species may become out of sync. For example, plants may bloom before pollinators have emerged, or eggs may hatch before a dependable food source for the young is available. Because the magnitude of seasonal shifts increases from the tropics to the poles, migratory birds may also experience timing mismatches. For instance, birds arriving in the Arctic to breed may find that the period of peak food availability has already passed.

▲ **Figure 38.5A** A wildfire racing down a mountainside near Boulder, Colorado, in September 2010



▲ **Figure 38.5B** A polar bear (*Ursus maritimus*) on melting pack ice in Canada

Warming oceans threaten tropical coral reef communities. When stressed by high temperatures, corals expel their symbiotic algae in a phenomenon called bleaching. Corals can recover if temperatures return to normal, but they cannot survive prolonged temperature increases. When corals die, the community is overrun by large algae, and species diversity plummets.

The distributions of populations and species are also changing in response to climate change. Recall from Module 34.4 that the distribution of a species may be determined by its adaptations to the abiotic conditions in its environment. With rising temperatures, the ranges of many species have already shifted toward the poles or to higher elevations. For example, researchers in Europe and the United States have reported that the ranges of more than two dozen species of butterflies have moved north by as much as 150 miles. Shifts in the ranges of many bird species have also been reported; the Inuit peoples living north of the Arctic Circle have sighted birds such as robins in the region for the first time.

However, species that live on mountaintops or in polar regions have nowhere to go. Researchers in Costa Rica have reported the disappearance of 20 species of frogs and toads as warmer Pacific Ocean temperatures reduce the dry-season mists in their mountain habitats. In the Arctic, polar bears **(Figure 38.5B)**, which stalk their prey on ice and need to store up body fat for the warmer months, are showing signs of starvation as their hunting grounds melt away. Similarly, in the Antarctic, the disappearance of sea ice is blamed for recent decreases in populations of Emperor and Adélie penguins.

Global climate change has been a boon to some organisms, but so far the beneficiaries have been species that have a negative impact on humans. For example, in mountainous regions of Africa, Southeast Asia, and Central and South America, the ranges of mosquitoes that carry diseases such as malaria, yellow fever, and dengue are restricted to lower elevations by frost. With rising temperatures and fewer days of frost, these mosquitoes—and the diseases they carry—are appearing at higher elevations. In another example, longer summers in western North America have enabled bark beetles to complete their life cycle in one year instead of two, promoting beetle outbreaks that have destroyed millions of acres of conifers. Undesirable plants such as poison ivy and kudzu have also benefited from rising temperatures.

Environmental change has always been a part of life; in fact, it is a key ingredient of evolutionary change. In the next module, we consider the evidence of evolutionary adaptation to global warming.

? How might timing mismatches caused by climate change affect an individual's reproductive fitness?

Any factor that reduces the number of offspring an organism produces may affect fitness. Examples: flowers emerging too soon or too late for pollinators; birds that arrive too late in the season to find food for offspring

EVOLUTION CONNECTION

38.6 Climate change is an agent of natural selection

Global climate change is already affecting habitats thoughout the world. Why do some species appear to be adapting to these changes while others, like the polar bear, are endangered by them?

In the previous module, we described several ways in which organisms have responded to global climate change. For the most part, those examples can be attributed to **phenotypic plasticity**, the ability to change phenotype in response to local environmental conditions. Differences resulting from phenotypic plasticity are within the normal range of expression for an individual's genotype. Phenotypic plasticity allows organisms to cope with short-term environmental changes. On the other hand, phenotypic plasticity is itself a trait that has a genetic basis and can evolve. Researchers studying the effects of climate change on populations have detected microevolutionary changes in phenotypic plasticity.

▲ **Figure 38.6A** A great tit (*Parus major*)

A common bird in Europe, the great tit **(Figure 38.6A)** is the third link in a food chain that has been altered by climate change. As warm weather arrives earlier in the spring, tree leaves emerge earlier and caterpillars, which use the swelling buds and unfolding leaves as their food source, hatch sooner. The reproductive success of great tits depends on having an ample supply of these nutritious caterpillars to feed their offspring. Like many other birds, great tits have some phenotypic plasticity in the timing of their breeding, which helps them synchronize their reproduction with the availability of caterpillars. The range and degree of plasticity vary among great tits, and this variation has a genetic basis. Researchers have found evidence of directional selection (see Module 13.13) favoring individuals that have the greatest phenotypic plasticity and lay their eggs earlier, when the abundance of food gives their offspring a better chance of survival.

In another example, scientists studied reproduction in a population of red squirrels **(Figure 38.6B)** in the Yukon Territory of Canada, where spring temperatures have increased by approximately 2°C in the last three decades. These researchers also found earlier breeding times in the spring. Over a period of 10 years, the date on which female squirrels gave birth advanced by 18 days, a change of about 6 days per generation. Using statistical analysis, the scientists determined that phenotypic plasticity was responsible for most of the shift in breeding times. However, a small but significant portion of the change (roughly 15%) could be attributed to microevolution, directional selection for earlier breeding. The researchers hypothesize that red squirrels born earlier in the year are larger and more capable of gathering and storing food in the autumn and thus have a better chance of successful reproduction the following spring.

▶ **Figure 38.6B** A red squirrel (*Tamiasciurus hudsonicus*) eating the seeds from a spruce cone

From the scant evidence available at this time, it appears that some populations, especially those with high genetic variability and short life spans, may adapt quickly enough to avoid extinction. In addition to the studies on phenotypic plasticity in great tits and red squirrels, researchers have also documented microevolutionary changes in traits such as dispersal ability and timing of life cycle events in insect populations. However, evolutionary adaptation is unlikely to save long-lived species such as polar bears and penguins that are experiencing rapid habitat loss. The rate of climate change is incredibly fast compared with major climate shifts in evolutionary history, and if it continues on its present course, thousands of species—the IPCC estimates as many as 30% of plants and animals—will likely become extinct.

? How does a short generation time hasten the process of evolutionary adaptation?

Each generation has the potential for testing new phenotypes in the environment, allowing natural selection to proceed rapidly.

Conservation Biology and Restoration Ecology

38.7 Protecting endangered populations is one goal of conservation biology

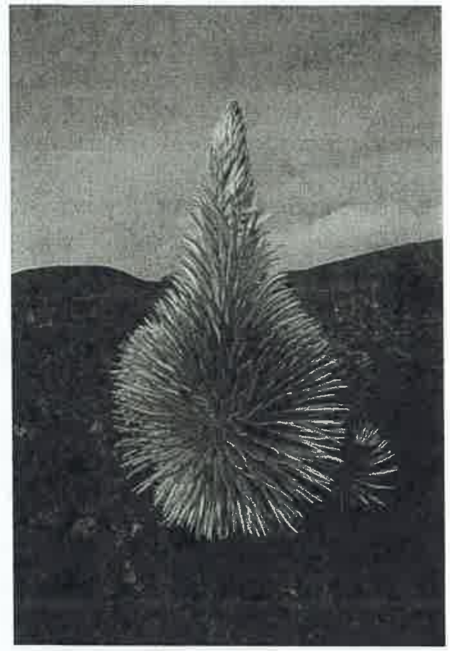
As we have seen in this unit, many of the environmental problems facing us today are consequences of human enterprises. But the science of ecology is not just useful for telling us how things have gone wrong. Ecological research is the foundation for finding solutions to these problems and for reversing the negative consequences of ecosystem alteration. Thus, we end the ecology unit with a section that highlights some of these applications of ecological research.

Conservation biology is a goal-oriented science that seeks to understand and counter the loss of biodiversity. Some conservation biologists focus on protecting populations of threatened species. This approach requires an understanding of the behavior and ecological niche of the target species, including its key habitat requirements and interactions with other members of its community. Threats posed by human activities are also assessed. With this knowledge, scientists can design a plan to expand or protect the resources needed. For example, the territory size required to support a tiger varies with the abundance of prey. Consequently, preserves set aside for Siberian tigers in Russia, where prey are scarce, must be 10 times as large as those provided for Bengal tigers in India.

The case of the black-footed ferret (**Figure 38.7A**) provides an example of the population approach to conservation. Little was known about this elusive nocturnal predator until the mid-20th century, and by then it was almost too late—population decline was already under way. Black-footed ferrets, one of three ferret species worldwide and the only one found in North America, feed almost exclusively on prairie dogs (see Figure 38.1C). Over the past century, prairie dogs have been extirpated from most of their former range by land-use changes and by poisoning or shooting. Epidemics of sylvatic plague, the animal version of bubonic plague, have devastated populations of black-footed ferrets as well as their prey. When an outbreak threatened to wipe out the last known population of black-footed ferrets, conservation biologists captured 18 remaining individuals and began breeding them in captivity to rebuild population numbers. Genetic variation, a prerequisite for adaptive evolutionary responses to environmental change, is a concern, given the bottleneck effect of near-extinction (see Module 13.11). Matings in the captive breeding facilities are carefully arranged to maintain as much genetic diversity as possible in the ferret populations.

▲ **Figure 38.7A** A black-footed ferret (*Mustela nigripes*)

In 1991, biologists began reintroducing captive-bred black-footed ferrets into the wild. Research carried out during these efforts has improved the success rate of reintroductions. For example, scientists found that the predatory behavior of ferrets has both innate and learned components, a discovery that led to more effective methods of preparing captive-bred animals to survive in the wild. Today, about 400 adult ferrets are living in the wild at sites scattered from Canada to Mexico. Despite the successes achieved thus far, however, the future of the black-footed ferret is far from secure. Biologists continue to monitor and manage the populations and their habitats.



▲ **Figure 38.7B** A Mauna Kea silversword (*Argyroxiphium sandwicense*)

Captive breeding programs are being used for numerous other species whose population numbers are perilously low. For example, you learned about efforts to save the whooping crane in Module 35.6. In Hawaii, biologists have planted thousands of greenhouse-grown silverswords (*Argyroxiphium sandwicense*; **Figure 38.7B**) on the cinder cone of the volcano Mauna Kea in hopes of reestablishing wild populations. Once so abundant that observers mistook their silvery color for snow on the distant peak, silverswords were grazed to near-extinction by goats and sheep that people had brought to the island.

By using a variety of methods, biologists have improved the conservation status of some endangered species, reintroduced many species to areas where they had been extirpated, and reversed declining population trends for others. However, we will not be able to save every threatened species. One way to select worthwhile targets is to identify and protect keystone species that may help preserve entire communities. And in many situations, conservation biologists must look beyond individual species to ecosystems.

? What do you think is the first priority for conservation biologists when they select a site for ferret reintroduction?

The presence of a sufficiently large population of prairie dogs

38.8 Sustaining ecosystems and landscapes is a conservation priority

One of the most harmful effects of habitat loss is population fragmentation, the splitting and consequent isolation of portions of populations. As you saw in Figure 38.2A, for example, logging carves once-continuous forest into a patchwork of disconnected fragments. For many species, the world instantly shrinks to a fraction of its former size. Populations are reduced, and so are resources such as food and shelter. To counteract the effects of fragmentation, conservation biology often aims to sustain the biodiversity of entire ecosystems and landscapes. Ecologically, a **landscape** is a regional assemblage of interacting ecosystems, such as a forest, adjacent fields, wetlands, streams, and streamside habitats. **Landscape ecology** is the application of ecological principles to the study of the structure and dynamics of a collection of ecosystems.

Edges, or boundaries between ecosystems, are prominent features of landscapes. The photograph in **Figure 38.8A** shows a landscape area in Yellowstone National Park that includes grassland and forest. Human activities, such as logging and road building, often create edges that are more abrupt than those delineating natural landscapes. Such edges have their own sets of physical conditions and thus their own communities of organisms. Some organisms thrive in edges because they require resources from the two adjacent areas. For instance, whitetail deer browse on woody shrubs found in edge areas between woods and fields, and their populations often expand when forests are logged or interrupted with housing developments.

▲ **Figure 38.8B** A male brown-headed cowbird (*Molothrus ater*)

Communities where human activities have generated many edges often have less diversity and are dominated by a few species that are adapted to edges. In one example, populations of the brown-headed cowbird **(Figure 38.8B)**, an edge-adapted species that lays its eggs in the nests of other birds, are currently expanding in many areas of North America. Cowbirds forage in open fields on insects disturbed by or attracted to cattle and other large herbivores; the cowbirds also need forests, where they can parasitize the nests of other birds. Increasing cowbird parasitism and loss of habitats are correlated with declining populations of several songbird species.

Where habitats have been severely fragmented, a **movement corridor**, a narrow strip or series of small clumps of high-quality habitat connecting otherwise isolated patches, can be a deciding factor in conserving biodiversity. In areas of heavy human use, artificial corridors are sometimes constructed. In many areas, bridges or tunnels have reduced the number of animals killed as they try to cross highways **(Figure 38.8C)**.

Corridors can also promote dispersal and reduce inbreeding in declining populations. Corridors are especially important to species that migrate between different habitats seasonally. In some European countries, amphibian tunnels have been constructed to help frogs, toads, and salamanders cross roads to access their breeding territories.

On the other hand, a corridor can be harmful—as, for example, in the spread of diseases, especially among small subpopulations in closely situated habitat patches. The effects of movement corridors between habitats in a landscape are not completely understood, and researchers continue to study them.

? **How can "living on the edge" be a good thing for some species, such as whitetail deer and cowbirds?**

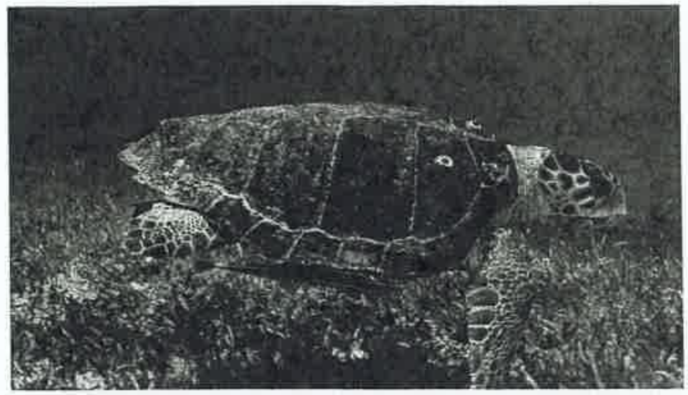
Such animals use a combination of resources from the two ecosystems on either side of the edge.

▲ **Figure 38.8A** A landscape in Yellowstone National Park with distinct edges

▲ **Figure 38.8C** A wildlife bridge in Banff National Park, Canada

38.9 Establishing protected areas slows the loss of biodiversity

Conservation biologists are applying their understanding of population, community, ecosystem, and landscape dynamics in establishing parks, wilderness areas, and other legally protected nature reserves. Choosing locations for protection often focuses on **biodiversity hot spots**. These relatively small areas have a large number of endangered and threatened species and an exceptional concentration of **endemic species**, those that are found nowhere else. Together, the "hottest" of Earth's biodiversity hot spots, shown in **Figure 38.9A**, total less than 1.5% of Earth's land but are home to a third of all species of plants and vertebrates. For example, all lemurs are endemic to Madagascar, which is home to more than 50 species. In fact, almost all of the mammals, reptiles, amphibians, and plants that inhabit Madagascar are endemic. There are also hot spots in aquatic ecosystems, such as certain river systems and coral reefs.



▲ **Figure 38.9B** An adult loggerhead turtle (*Caretta caretta*) swimming off the coast of Belize

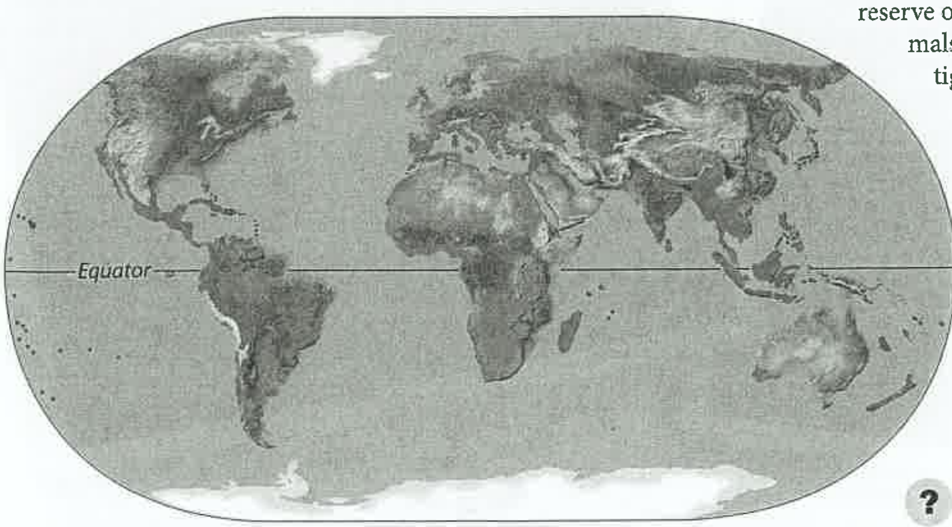
Because endemic species are limited to specific areas, they are highly sensitive to habitat degradation. Thus, biodiversity hot spots can also be hot spots of extinction. They rank high on the list of areas demanding strong global conservation efforts.

Concentrations of species provide an opportunity to protect many species in very limited areas. However, the "hot spot" designation tends to favor the most noticeable organisms, especially vertebrates and plants. Invertebrates and microorganisms are often overlooked. Furthermore, species endangerment is a truly global problem, and it is important that a focus on hot spots not detract from efforts to conserve habitats and species diversity in other areas.

Migratory species pose a special problem for conservationists. For example, monarch butterflies occupy much of the United States and Canada during the summer months, but migrate in the autumn to specific sites in Mexico and California, where they congregate in huge numbers. Overwintering populations are particularly susceptible to habitat disturbances because they are concentrated in small areas. Thus, habitat preservation must extend across all of the sites that monarchs inhabit in order to protect them. The situation is similar for many species of migratory songbirds, waterfowl, marine mammals, and sea turtles.

Sea turtles, such as the loggerhead turtle (**Figure 38.9B**), are threatened both in their ocean feeding grounds and on land. Loggerheads take about 20 years to reach sexual maturity, and great numbers of juveniles and adults are drowned at sea when caught in fishing nets. The adults mate at sea, and the females migrate to specific sites on sandy beaches to lay their eggs. Buried in shallow depressions, the eggs are susceptible to predators, especially raccoons. And many egg-laying sites have become housing developments and beachside resorts. An ongoing international effort to conserve sea turtles focuses on protecting egg-laying sites and minimizing the death rates of adults and juveniles at sea.

Currently, governments have set aside about 7% of the world's land in various forms of reserves. One major conservation question is whether it is better to create one large reserve or a group of smaller ones. Far-ranging animals with low-density populations, such as tigers, require extensive habitats. As conservation biologists learn more about the requirements for achieving minimum population sizes to sustain endangered species, it is becoming clear that most national parks and other reserves are far too small. Given political and economic realities, it is unlikely that many existing parks will be enlarged, and most new reserves will also be too small. In the next two modules, we look at two approaches to this problem.



▲ **Figure 38.9A** Earth's terrestrial biodiversity hot spots (pink)

? What is a biodiversity hot spot?

A relatively small area with a disproportionate number of endangered and threatened species, many of which are endemic

38.10 Zoned reserves are an attempt to reverse ecosystem disruption

Conservation of Earth's natural resources is not purely a scientific issue. The causes of declining biodiversity are rooted in complex social and economic issues, and the solutions must take these factors into account. Let's look at how the small Central American nation of Costa Rica is managing its biodiversity.

Despite its small size (about 51,000 km^2, the size of New Hampshire and Vermont combined), Costa Rica is a treasure trove of biodiversity. Its varied ecosystems, which extend over mountains and two coasts, are home to at least half a million species. As **Figure 38.10A** shows, the entire country is a biodiversity hot spot. Since the 1970s, the Costa Rican government and international agencies have worked together to preserve these unique assets. Approximately 25% of Costa Rica's territory is currently protected in some way.

One type of protection is called a **zoned reserve**, an extensive region of land that includes one or more areas undisturbed by humans. The lands surrounding these areas continue to be used to support the human population, but they are protected from extensive alteration. As a result, they serve as a buffer zone, or shield, against further intrusion into the undisturbed areas. A primary goal of the zoned reserve approach is to develop a social and economic climate in the buffer zone that is compatible with the long-term viability of the protected area.

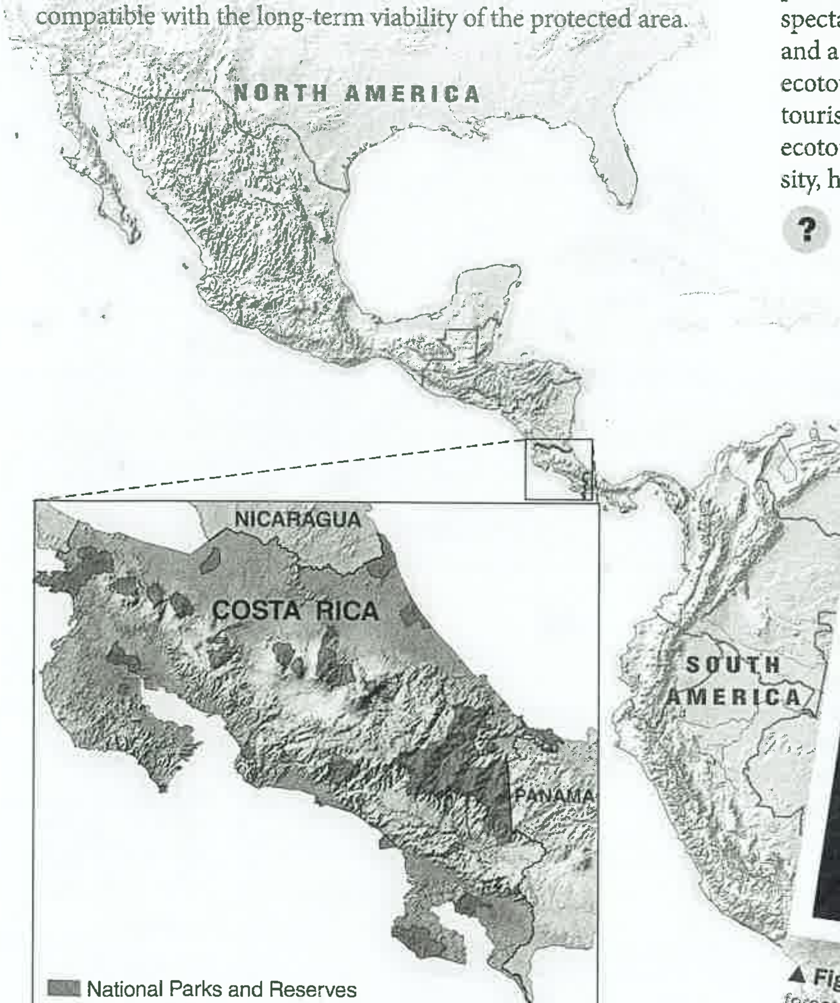
Costa Rica is making progress in managing its reserves so that the buffer zones provide a steady, lasting supply of forest products, water, and hydroelectric power and also support sustainable agriculture. An important goal is providing a stable economic base for people living there. Destructive practices that are not compatible with long-term ecosystem stability and from which there is often little local profit are gradually being discouraged. Such destructive practices include massive logging, large-scale single-crop agriculture, and extensive mining.

However, a recent analysis showed mixed results for Costa Rica's system of zoned reserves. The good news is that negligible deforestation has occurred within and just beyond protected parkland boundaries. However, some deforestation has occurred in the buffer zones, with plantations of cash crops such as banana and palm replacing the natural vegetation. Conservationists fear that continuing these practices will isolate protected areas, restricting gene flow and decreasing species and genetic diversity.

Costa Rica's commitment to conservation has resulted in a new source of income for the country—**ecotourism**, travel to natural areas for tourism and recreation **(Figure 38.10B)**. People from all over the world come to experience Costa Rica's spectacular range of biodiversity, generating thousands of jobs and a significant chunk of the country's revenue. Worldwide, ecotourism has grown into a multibillion-dollar industry as tourists flock to the world's remaining natural areas. Whether ecotourism dollars ultimately help conserve Earth's biodiversity, however, remains to be seen.

? Why is it important for zoned reserves to prevent large-scale alterations of habitat in the buffer zones? Why is it also important to support sustainable development for the people living there?

Large-scale disruptions could impact the nearby undisturbed areas. Preservation is a realistic goal only if it is compatible with an acceptable standard of living for the local people.



▲ **Figure 38.10A** Costa Rica

▲ **Figure 38.10B** Ecotourism: Seeing the tropical rain forest by boat in Costa Rica's Tortuguero National Park

CONNECTION

38.11 The Yellowstone to Yukon Conservation Initiative seeks to preserve biodiversity by connecting protected areas

If many existing reserves are too small to sustain a large number of threatened species, how can biologists include the land around reserves in conservation efforts? In North America, one ambitious biodiversity plan is creating innovative ways to give wild creatures more room. The plan builds on lessons from research on a howling predator that once roamed a vast stretch of the northern Rocky Mountains.

This predator was a single individual, a gray wolf dubbed Pluie that was captured by scientists in western Canada in 1991. The biologists fitted the 5-year-old female with a radio tracking collar and released her—routine work in studies of threatened animals. But the scientists were stunned by what they learned from Pluie. Over the next two years, this wolf roamed over an area of more than 100,000 km^2 (38,600 square miles), crossing between Canada and the United States and traveling between protected reserves and lands where she was fair game for killing. In 1995, her story came to a bloody end. While moving through lands outside the boundary of a nearby national park, Pluie, her mate, and one of her pups were shot (legally) by a hunter.

Biologists who had studied Pluie realized that the wolf's life captured all the promise—and all the pitfalls—of efforts to protect her. She had thrived for years within the sporadic shelter of parks and other protected territory. But such lands were never big enough to hold her. Like others of her species (*Canis lupus*), Pluie needed more room. Reserves could shield animals briefly, the scientists realized. True protection would have to include paths of safe passage between reserves.

This conclusion inspired the creation of the Yellowstone to Yukon Conservation Initiative (Y2Y), one of the world's most ambitious conservation biology efforts. The initiative aims to preserve the web of life that has long defined the Rocky Mountains of Canada and the northern United States. This area is dotted with famous parks—Canada's Banff National Park and Wyoming's Yellowstone National Park among them—but scientists behind Y2Y now say that those areas alone cannot protect native species from human threats.

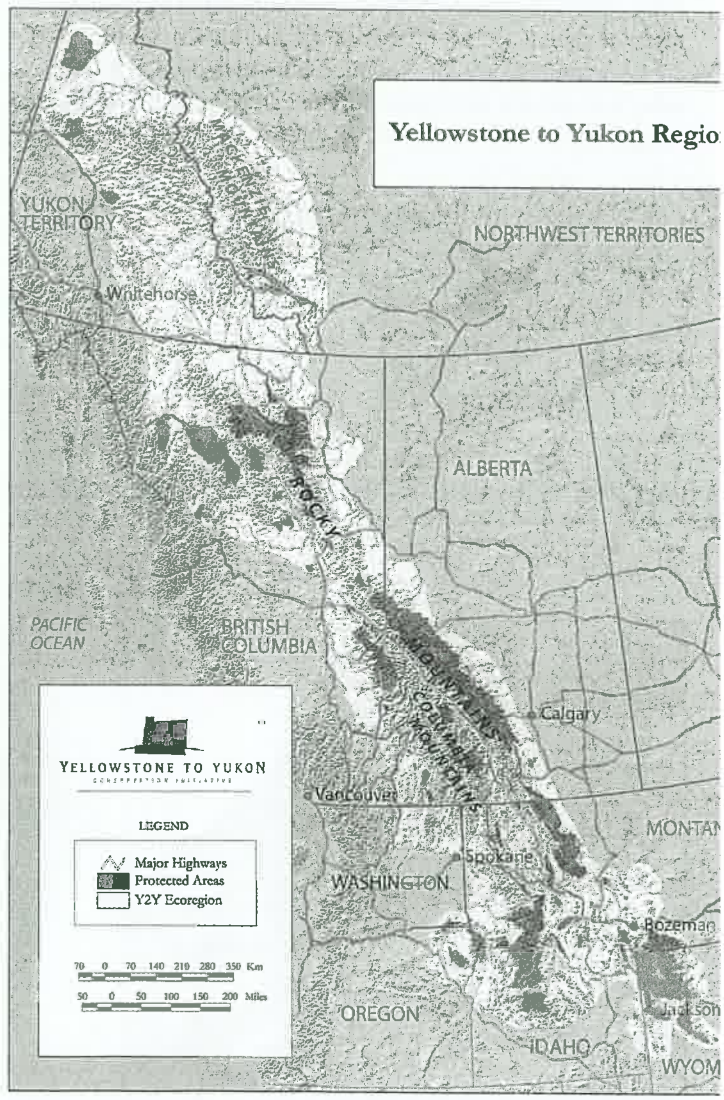
Y2Y seeks to knit together a string of parks and reserves, creating a vast 3,200-km wildlife corridor stretching down from Alaska across Canada to northern Wyoming **(Figure 38.11A)**. The idea is not to create one giant park, but rather to connect parks with protected corridors where wildlife can travel safely.

Many of the signature species that live in this vast region, such as grizzly bears **(Figure 38.11B)**, lynx, moose, and elk, don't confine themselves to human boundaries. But few have as great a range as the wolf. If Y2Y can provide safe passage for gray wolves, it will have also created secure zones for other animals in the Rockies.

Gray wolves **(Figure 38.11C)** once roamed all of North America. These carnivorous hunters live in packs that protect pups and search cooperatively for food. A pack may have a territory of about 130 km^2 or range much farther to find prey. The wolf's hunting prowess kept it the top predator of North American ecosystems as long as the human population was small. Things changed when large numbers of people migrated from Europe and pushed into the continent.

Deeming wolves a dangerous predator and competitor that threatened people and livestock, settlers in the United States launched widespread campaigns to wipe out wolves. By the early 20th century, gray wolves were nearly extinct in the lower 48 states, with only a few hundred surviving in northern Minnesota. More managed to stay alive in the wilds of less populated western Canada and Alaska.

Scientists gradually realized that widespread damage rippled through habitats after wolves had been removed. Without a predator to control their numbers, populations of elk and deer grew unchecked. As these increasing numbers of herbivores foraged for food, vegetation that sheltered smaller animals was damaged. Other animals, such as ravens and foxes, had once fed



▲ **Figure 38.11A** A map of the Yellowstone to Yukon Conservation Initiative region, with protected areas shown in green on the carcasses of wildlife killed by wolves and were now left without an important source of food. Gray wolves, biologists determined, were a keystone species—a species critical to the balance and maintenance of an ecosystem.

That understanding led to one of the most important and controversial conservation biology efforts in the Yellowstone to Yukon area. In 1991, the U.S. Fish and Wildlife Service launched a campaign to bring wolves back to Yellowstone National Park, a reserve that hadn't sheltered the animals in at least 50 years. After careful planning, which included compensation for ranchers who feared losing their cattle and sheep, about 60 wolves from Canada were released in the park in 1995 and 1996.

As wolf howls once again echoed through the Wyoming darkness, the wolf quickly became a hopeful symbol for Y2Y backers. Yellowstone's wolves formed new packs and raised pups. By 2004, scientists counted 12 wolf packs inside the park, totaling about 300 wolves. And the wolf's return has brought more than howling. Park officials noted significant environmental improvements as wolves once again roamed Yellowstone. As wolves killed elk, moose, and deer, streambeds and other lands near waterways started to shelter a greater variety of plants and animals. Fewer hoofed animals meant more grasses and taller trees. Those plants brought more birds, along with more water-dwelling beaver. In all, park biologists report that the wolf's return has affected at least 25 different species.

True to their nature, Yellowstone's wolves haven't followed human borders; six packs have been found just outside the park. Meanwhile, the migrations of Canadian wolves, along with smaller release programs, have brought the animals back to Idaho and Montana. In June 2004, a Yellowstone wolf was found hundreds of kilometers away in Colorado—a reminder that travels like Pluie's are common to wolves throughout the Y2Y region.

Such successes also bring risks—and reminders from scientists that wolves need safe corridors. The Colorado wolf was discovered dead by the side of a highway, most likely the victim of a car. Its appearance sparked angry protests from ranchers in the state, who said that any new wolves that appear should either be shot or shipped back to Yellowstone. Meanwhile, wildlife advocates maintain that wolves should be allowed to migrate naturally.

That argument reflects a broader debate about how to treat wolves as they return to their old ranges. As populations in the northern Rockies recovered, Federal officials removed gray wolves from the endangered species list in 2009. In August 2010, however, that decision was overturned when conservationists won a lawsuit charging that state management practices had failed to ensure sustainable population sizes.

The biologists involved in the Yellowstone to Yukon Conservation Initiative are studying wildlife population dynamics on a landscape scale to help support regional conservation planning. The initiative is backing a range of research projects to determine the requirements for maintaining terrestrial and aquatic ecosystems in the Y2Y region. Their efforts to connect habitats include wildlife bridges, such as the one in Banff National Park (see Figure 38.8C). This cross-border initiative is also providing broader lessons for global conservation. In Southeast Asia, for example, plans for a tiger reserve in Myanmar (Burma) include proposals to link the Myanmar reserve with others in neighboring countries.

In addition to creating reserves to protect species and their habitats from human disruptions, conservation efforts also attempt to restore ecosystems degraded by human activities. We look at the field of restoration ecology next.

? For what reasons are gray wolves considered a keystone species?

Wolves regulate the populations of their prey, preventing these herbivores from damaging vegetation and degrading habitat for other members of the community. Wolf kills also provide food for other animals.

▶ Figure 38.11C A gray wolf

▼ Figure 38.11B A grizzly bear with cubs in Yellowstone National Park

CONNECTION

38.12 The study of how to restore degraded habitats is a developing science

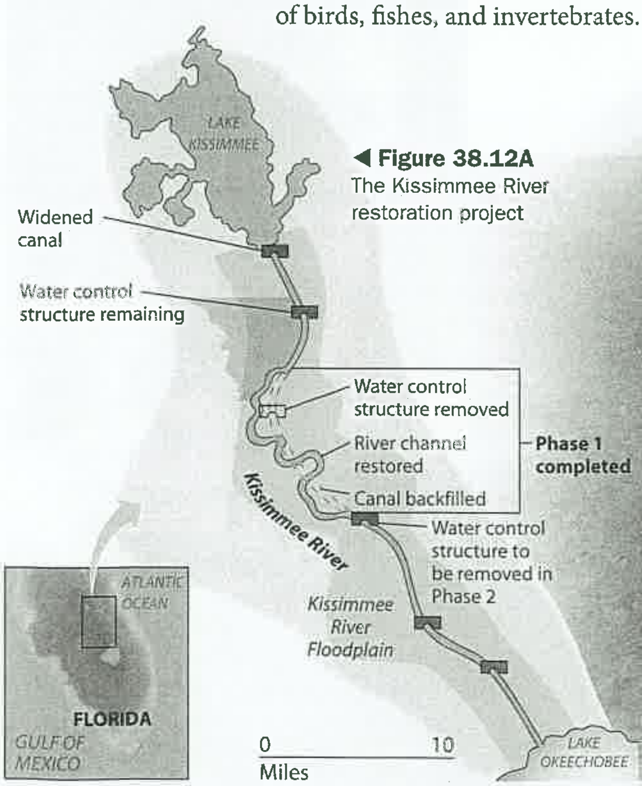
For centuries, humans have altered and degraded natural areas without considering the consequences. But as people have gradually come to realize the severity of some of the consequences of ecosystem alteration, they have sought ways to return degraded areas to their natural state. The expanding field of **restoration ecology** uses ecological principles to develop methods of achieving this goal.

One of the major strategies in restoration ecology is bioremediation, the use of living organisms to detoxify polluted ecosystems. For example, bacteria have been used to clean up oil spills and old mining sites. Bacteria are also employed to metabolize toxins in dump sites. As you read in the introduction to Chapter 32, plants have successfully extracted potentially toxic metals such as zinc, nickel, lead, and cadmium from contaminated soil. Researchers are using trees and lichens to clean up soil polluted with uranium.

Some restoration projects have the broader goal of returning ecosystems to their natural state, which may involve replanting vegetation, fencing out non-native animals, or removing dams that restrict water flow. Hundreds of restoration projects are currently under way in the United States. One of the most ambitious endeavors is the Kissimmee River project in south central Florida.

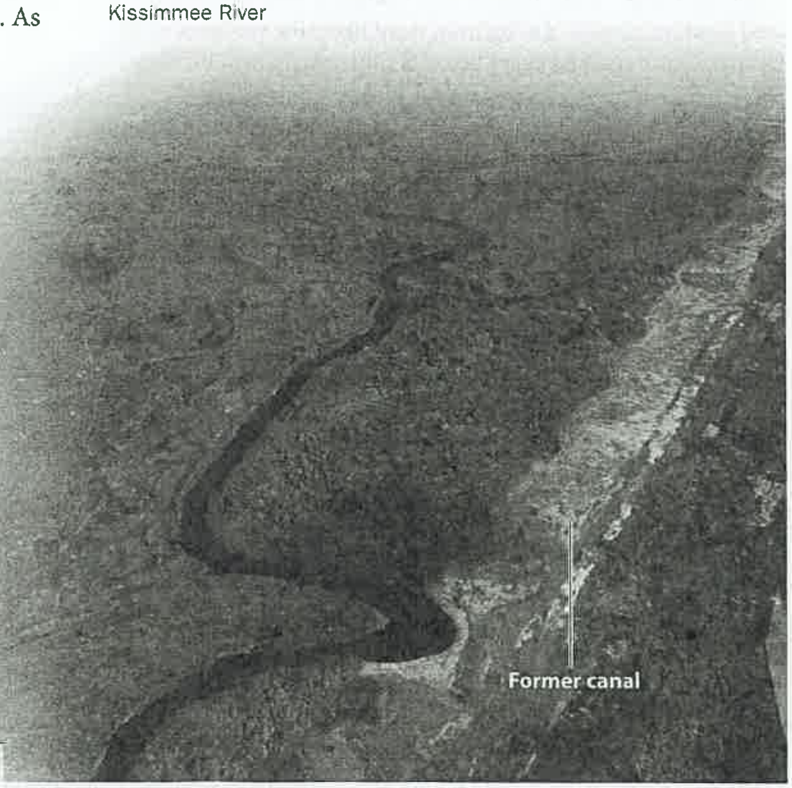
The Kissimmee River was once a meandering shallow river that wound its way through diverse wetlands from Lake Kissimmee southward into Lake Okeechobee **(Figure 38.12A)**. Periodic flooding of the river covered a wide floodplain during about half of the year, creating wetlands that provided critical habitat for vast numbers of birds, fishes, and invertebrates. As often happens, however, people saw the floodplain as wasted land that could be developed if the flooding were controlled. Between 1962 and 1971, the U.S. Army Corps of Engineers converted the 166-km wandering river into a straight canal 9 m deep, 100 m wide, and 90 km long. This project drained approximately 31,000 acres of wetlands, with significant negative impacts on fish and wetland bird populations. Spawning and foraging habitats for fishes were eliminated, and important sport fishes, such as largemouth bass, were replaced by nongame species more tolerant of the lower oxygen concentration in the deeper canal. The populations of waterfowl declined by 92%, and the number of bald eagle nesting territories decreased by 70%. Without the marshes to help filter and reduce agricultural runoff, phosphorus and other excess nutrients were transported through Lake Okeechobee into the Everglades ecosystem to the south.

As these negative ecological effects began to be recognized, public pressure to restore the river grew. In 1992, Congress authorized the Kissimmee River Restoration Project, one of the largest landscape restoration projects and ecological experiments in the world. As Figure 38.12A shows, the plan involves removing water control structures such as dams, reservoirs, and channel modifications and filling in about 35 km of the canal. The first phase of the project was completed in 2004, and the entire project is slated to be completed in 2015. In **Figure 38.12B**, the natural curves of the



◀ **Figure 38.12A** The Kissimmee River restoration project

▼ **Figure 38.12B** Restoring the natural water flow patterns of the Kissimmee River



river are a pleasing contrast to the artificial linearity of the backfilled canal. Birds and other wildlife have returned in unexpected numbers to the 11,000 acres of wetlands that have been restored. The marshes are filled with native vegetation, and game fishes again swim in the river channels. However, 2006 was the driest season on record in south central Florida. As the drought continued, the southward flow of the Kissimmee River stopped. Lake Okeechobee, which depends on the Kissimmee basin for more than half its water supply, hit record lows. The rapidly worsening water shortage in southern Florida has renewed attention to the urgent need to complete an even more ambitious project, the restoration of the Everglades.

? How will the Kissimmee River Restoration Project improve water quality in the Everglades ecosystem?

The wetlands filter agricultural runoff and prevent excess nutrients from entering the Everglades.

38.13 Sustainable development is an ultimate goal

The demand for the "provisioning" services of ecosystems, such as food, fibers, and water, is increasing as the world population grows and becomes more affluent. Although these demands are currently being met, they are satisfied at the expense of other critical ecosystem services, such as climate regulation and protection against natural disasters. Clearly, we have set ourselves and the rest of the biosphere on a precarious path into the future. How can we best manage Earth's resources to ensure that all generations inherit an adequate supply of natural and economic resources and a relatively stable environment?

Many nations, scientific societies, and private foundations have embraced the concept of sustainable development. The Ecological Society of America, the world's largest organization of ecologists, endorses a research agenda called the Sustainable Biosphere Initiative. The goal of this initiative is to acquire the basic ecological information necessary for the intelligent and responsible development, management, and conservation of Earth's resources. The research agenda includes devising ways to sustain the productivity of natural and artificial ecosystems and studying the relationship between biological diversity, global climate change, and ecological processes.

Sustainable development doesn't only depend on continued research and application of ecological knowledge. It also requires us to connect the life sciences with the social sciences, economics, and humanities. Conservation and restoration of biodiversity is only one side of sustainable development; the other key facet is improving the human condition. Public education and the political commitment and cooperation of nations, especially the United States, are essential to the success of this endeavor.

The image of the ring-tailed lemur on this book's cover and in **Figure 38.13** serves as a reminder of what we stand to lose if we fail to recognize and solve the ecological crises at hand. All of Madagascar's 37 species of lemurs are threatened with extinction, as are dozens of other species endemic to the island. Less than 20% of the original vegetation of Madagascar remains, and deforestation for agriculture, logging, and fuel wood continue. The country's steadily growing human population is beset by political and economic woes. Consequently, the future of Madagascar's splendid biodiversity may be bleak. On the other hand, national and international initiatives in sustainable agriculture, ecotourism, conservation, and ecosystem restoration could turn the tide and save this showcase of biodiversity.

▲ **Figure 38.13** The ring-tailed lemur (*Lemur catta*)

Biology is the scientific expression of the human desire to know nature. We are most likely to save what we appreciate, and we are most likely to appreciate what we understand. By learning about the processes and diversity of life, we also become more aware of our dependence on healthy ecosystems. An awareness of our unique ability to alter the biosphere and jeopardize the existence of other species, as well as our own, may help us choose a path toward a sustainable future.

The risk of a world without adequate natural resources for all its people is not a vision of the distant future. It is a prospect for your children's lifetime, or perhaps even your own. But although the current state of the biosphere is grim, the situation is far from hopeless. Now is the time to aggressively pursue more knowledge about life and to work toward long-term sustainability.

? Why is a concern for the well-being of future generations essential for progress toward sustainable development?

Sustainable development is a long-term goal—longer than a human lifetime. Preoccupation with the here and now is an obstacle to sustainable development because it discourages behavior that benefits future generations.

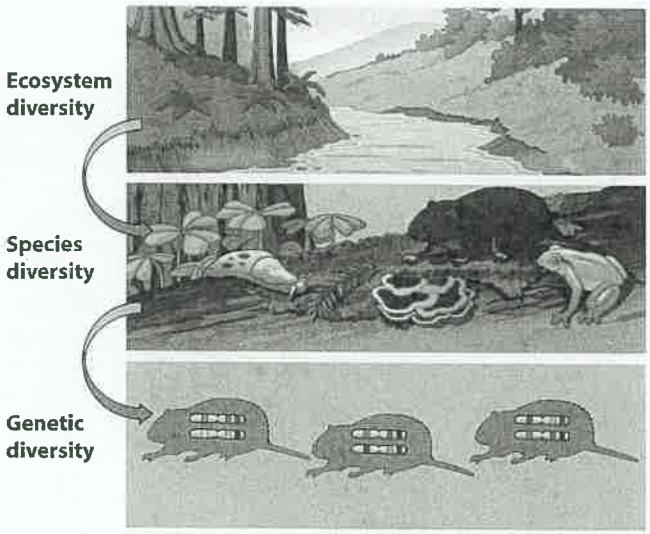
CHAPTER 38 REVIEW

For Practice Quizzes, BioFlix, MP3 Tutors, and Activities, go to www.masteringbiology.com.

Reviewing the Concepts

The Loss of Biodiversity (38.1–38.6)

38.1 Loss of biodiversity includes the loss of ecosystems, species, and genes. While valuable for its own sake, biodiversity also provides food, fibers, medicines, and ecosystem services.



38.2 Habitat loss, invasive species, overharvesting, pollution, and climate change are major threats to biodiversity. Human alteration of habitats is the single greatest threat to biodiversity. Invasive species disrupt communities by competing with, preying on, or parasitizing native species. Harvesting at rates that exceed a population's ability to rebound is a threat to many species. Human activities produce diverse pollutants that may affect ecosystems far from their source. Biomagnification concentrates synthetic toxins that cannot be degraded by organisms.

38.3 Rapid warming is changing the global climate. Increased global temperature caused by rising concentrations of greenhouse gases is changing climatic patterns, with grave consequences.

38.4 Human activities are responsible for rising concentrations of greenhouse gases. Much of the increase is the result of burning fossil fuels.

38.5 Global climate change affects biomes, ecosystems, communities, and populations. Organisms that live at high latitudes and high elevations are experiencing the greatest impact.

38.6 Climate change is an agent of natural selection. Phenotypic plasticity has minimized the impact on some species, and a few cases of microevolutionary change have been observed. However, the rapidity of the environmental changes makes it unlikely that evolutionary processes will save many species from extinction.

Conservation Biology and Restoration Ecology (38.7–38.13)

38.7 Protecting endangered populations is one goal of conservation biology. Conservation biology is a goal-driven science that seeks to understand and counter the rapid loss of biodiversity. Some conservation biologists direct their efforts at increasing endangered populations.

38.8 Sustaining ecosystems and landscapes is a conservation priority. Conservation efforts are increasingly aimed at sustaining ecosystems and landscapes. Edges between ecosystems have distinct sets of features and species. The increased frequency and abruptness of edges caused by human activities can increase species loss. Movement corridors connecting isolated habitats may be helpful to fragmented populations.

38.9 Establishing protected areas slows the loss of biodiversity. Biodiversity hot spots have high concentrations of endemic species.

38.10 Zoned reserves are an attempt to reverse ecosystem disruption. Zoned reserves are undisturbed wildlands surrounded by buffer zones of compatible economic development. Costa Rica has established many zoned reserves. Ecotourism has become an important source of revenue for conservation efforts.

38.11 The Yellowstone to Yukon Conservation Initiative seeks to preserve biodiversity by connecting protected areas. The success of this innovative international research and conservation effort hinged on the reintroduction of gray wolves.

38.12 The study of how to restore degraded habitats is a developing science. Restoration ecology uses ecological principles to return degraded areas to their natural state, a process that may include detoxifying polluted ecosystems, replanting native vegetation, and returning waterways to their natural course. Large-scale restoration projects attempt to restore damaged landscapes. The Kissimmee River Restoration Project is restoring river flow and wetlands, thus improving wildlife habitat.

38.13 Sustainable development is an ultimate goal. Sustainable development seeks to improve the human condition while conserving biodiversity. It depends on increasing and applying ecological knowledge as well as valuing our linkages to the biosphere.

Connecting the Concepts

1. Complete the following map, which organizes some of the key concepts of conservation biology.