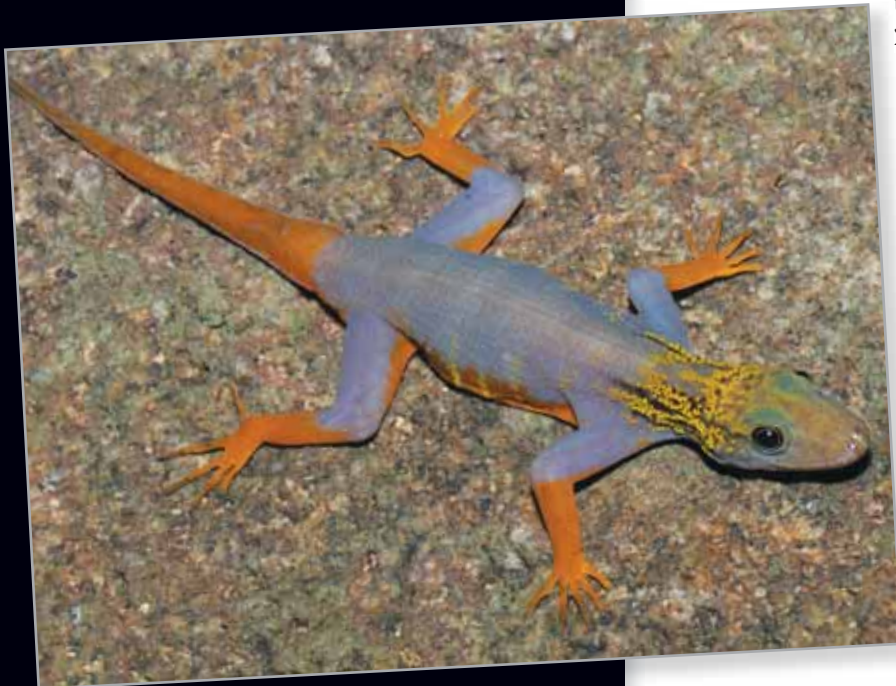


43 Global Ecology and Conservation Biology

▼ **Figure 43.1** What will be the fate of this newly described lizard species?



KEY CONCEPTS

- 43.1** Human activities threaten Earth's biodiversity
- 43.2** Population conservation focuses on population size, genetic diversity, and critical habitat
- 43.3** Landscape and regional conservation help sustain biodiversity
- 43.4** Earth is changing rapidly as a result of human actions
- 43.5** The human population is no longer growing exponentially but is still increasing rapidly
- 43.6** Sustainable development can improve human lives while conserving biodiversity

OVERVIEW

Psychedelic Treasure

Scurrying across a rocky outcrop, a lizard stops abruptly in a patch of sunlight. A conservation biologist senses the motion and turns to find a gecko splashed with rainbow colors, its bright orange legs and tail blending into a striking blue body, its head splotched with yellow and green. The psychedelic rock gecko (*Cnemaspis psychedelica*) was discovered in 2010 during an expedition to the Greater Mekong region of southeast Asia (**Figure 43.1**). Its known habitat is restricted to Hon Khoai, an island occupying just 8 km² (3 square miles) in southern Vietnam. Other new species found during the same series of expeditions include the Elvis monkey, which sports a hairdo like

that of a certain legendary musician. Between 2000 and 2010, biologists identified more than a thousand new species in the Greater Mekong region alone.

To date, scientists have described and named about 1.8 million species of organisms. Some biologists think that about 10 million more species currently exist; others estimate the number to be as high as 100 million. The greatest concentrations of species are found in the tropics. Unfortunately, tropical forests are being cleared at an alarming rate to support a burgeoning human population. In Vietnam, rates of deforestation are among the very highest in the world (**Figure 43.2**). What will become of the psychedelic rock gecko and other newly discovered species if such activities continue unchecked?

Throughout the biosphere, human activities are altering trophic structures, energy flow, chemical cycling, and natural disturbance—ecosystem processes on which we and all other species depend (see Chapter 42). We have physically altered nearly half of Earth's land surface, and we use over half of all accessible

surface fresh water. In the oceans, stocks of most major fisheries are shrinking because of overharvesting. By some estimates, we may be pushing more species toward extinction than the large asteroid that triggered the mass extinctions at the close of the Cretaceous period 65.5 million years ago (see Figure 23.10).

In this chapter, we apply a global perspective to the changes happening across Earth, focusing on a discipline that seeks to preserve life: **Conservation biology** integrates ecology, evolutionary biology, molecular biology, genetics,



▲ **Figure 43.2 Tropical deforestation in Vietnam.**

and physiology to conserve biological diversity at all levels. Efforts to sustain ecosystem processes and stem the loss of biodiversity also connect the life sciences with the social sciences, economics, and humanities.

We'll begin by taking a closer look at the biodiversity crisis and examining some of the conservation strategies being adopted to slow the rate of species loss. We'll also examine how human activities are altering the environment through climate change and other global processes, and we'll investigate the link between these alterations and the growing human population. Finally, we'll consider how decisions about long-term conservation priorities could affect life on Earth.

CONCEPT 43.1

Human activities threaten Earth's biodiversity

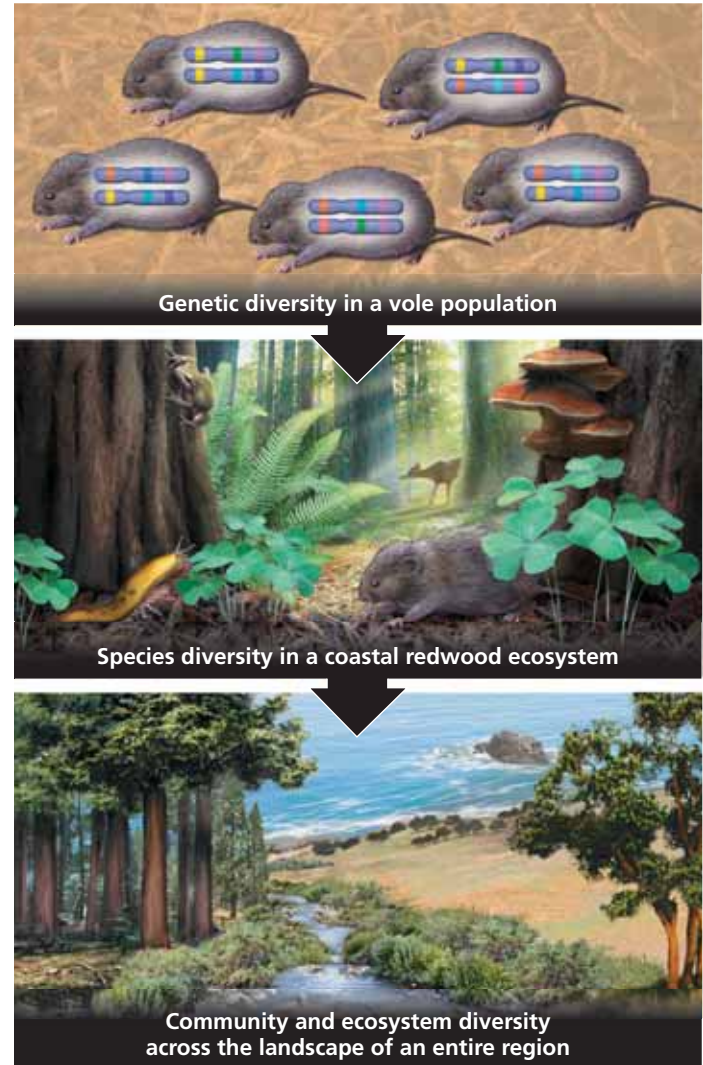
Extinction is a natural phenomenon that has been occurring since life first evolved; it is the high *rate* of extinction that is responsible for today's biodiversity crisis (see Chapter 23). Because we can only estimate the number of species currently existing, we cannot determine the exact rate of species loss. However, we do know that human activities threaten Earth's biodiversity at all levels.

Three Levels of Biodiversity

Biodiversity—short for biological diversity—can be considered at three main levels: genetic diversity, species diversity, and ecosystem diversity (**Figure 43.3**).

Genetic Diversity

Genetic diversity comprises not only the individual genetic variation *within* a population, but also the genetic variation *between* populations that is often associated with adaptations to local conditions (see Chapter 21). If one population becomes extinct, then a species may have lost some of the



▲ **Figure 43.3 Three levels of biodiversity.** The oversized chromosomes in the top diagram symbolize the genetic variation within the population.

genetic diversity that makes microevolution possible. This erosion of genetic diversity in turn reduces the adaptive potential of the species.

Species Diversity

Public awareness of the biodiversity crisis centers on species diversity—the variety of species in an ecosystem or across the biosphere (see Chapter 41). As more species are lost to extinction, species diversity decreases. The U.S. Endangered Species Act defines an **endangered species** as one that is “in danger of extinction throughout all or a significant portion of its range.”

Threatened species are those considered likely to become endangered in the near future. The following are just a few statistics that illustrate the problem of species loss:

- According to the International Union for Conservation of Nature and Natural Resources (IUCN), 12% of the 10,000 known species of birds and 21% of the 5,500 known species of mammals are threatened.

Philippine eagle



Yangtze River dolphin



▲ **Figure 43.4** A hundred heartbeats from extinction. These are two members of what E. O. Wilson calls the Hundred Heartbeat Club, species with fewer than 100 individuals remaining on Earth. The Yangtze River dolphin was even thought to be extinct, but a few individuals were reportedly sighted in 2007.

? To document that a species has actually become extinct, what factors would you need to consider?

- A survey by the Center for Plant Conservation showed that of the nearly 20,000 known plant species in the United States, 200 have become extinct since such records have been kept, and 730 are endangered or threatened.
- In North America, at least 123 freshwater animal species have become extinct since 1900, and hundreds more species are threatened. The extinction rate for North American freshwater fauna is about five times as high as that for terrestrial animals.

Extinction of species may also be local; for example, a species may be lost in one river system but survive in an adjacent one. Global extinction of a species means that it is lost from *all* the ecosystems in which it lived, leaving them permanently impoverished (**Figure 43.4**).

Ecosystem Diversity

The variety of the biosphere's ecosystems is a third level of biological diversity. Because of the many interactions between populations of different species in an ecosystem, the local extinction of one species can have a negative impact on other species in the ecosystem (see Figure 41.15). For instance, bats called "flying foxes" are important pollinators and seed dispersers in the Pacific Islands, where they are increasingly hunted as a luxury food (**Figure 43.5**). Conservation biologists fear that the extinction of flying foxes would also harm the native plants of the Samoan Islands, where four-fifths of the tree species depend on flying foxes for pollination or seed dispersal.



▲ **Figure 43.5** The endangered Marianas "flying fox" bat (*Pteropus mariannus*), an important pollinator.

Some ecosystems have already been heavily affected by humans, and others are being altered at a rapid pace. Since European colonization, more than half of the wetlands in the contiguous United States have been drained and converted to agricultural and other uses. In California, Arizona, and New Mexico, roughly 90% of native riparian (streamside) communities have been affected by overgrazing, flood control, water diversions, lowering of water tables, and invasion by non-native plants.

Biodiversity and Human Welfare

Why should we care about the loss of biodiversity? One reason is what Harvard biologist E. O. Wilson calls *biophilia*, our sense of connection to nature and all life. The belief that other species are entitled to life is a pervasive theme of many religions and the basis of a moral argument that we should protect biodiversity. There is also a concern for future human generations. Paraphrasing an old proverb, G. H. Brundtland, a former prime minister of Norway, said: "We must consider our planet to be on loan from our children, rather than being a gift from our ancestors." In addition to such philosophical and moral justifications, species and genetic diversity bring us many practical benefits.

Benefits of Species and Genetic Diversity

Many species that are threatened could potentially provide medicines, food, and fibers for human use, making biodiversity a crucial natural resource. Products from aspirin to antibiotics were originally derived from natural sources. In food production, if we lose wild populations of plants closely related to agricultural species, we lose genetic resources that could be used to improve crop qualities, such as disease resistance. For instance, plant breeders responded to devastating outbreaks of the grassy stunt virus in rice (*Oryza sativa*) by screening 7,000 populations of this species and its close relatives for

resistance to the virus. One population of a single relative, Indian rice (*Oryza nivara*), was found to be resistant to the virus, and scientists succeeded in breeding the resistance trait into commercial rice varieties. Today, the original disease-resistant population has apparently become extinct in the wild.

In the United States, about 25% of the prescriptions dispensed from pharmacies contain substances originally derived from plants. In the 1970s, researchers discovered that the rosy periwinkle (*Catharanthus roseus*), which grows on the island of Madagascar, off the coast of Africa, contains alkaloids that inhibit



Rosy periwinkle

cancer cell growth. This discovery led to treatments for two deadly forms of cancer, Hodgkin's lymphoma and childhood leukemia, resulting in remission in most cases.

Each loss of a species means the loss of unique genes, some of which may code for enormously useful proteins. The enzyme Taq polymerase was first extracted from a bacterium, *Thermus aquaticus*, found in hot springs at Yellowstone National Park. This enzyme is essential for the polymerase chain reaction (PCR) because it is stable at the high temperatures required for automated PCR (see Figure 13.25). However, because millions of species may become extinct before we discover them, we stand to lose the valuable genetic potential held in their unique libraries of genes.

Ecosystem Services

The benefits that individual species provide to humans are substantial, but saving individual species is only part of the reason for preserving ecosystems. We humans evolved in Earth's ecosystems, and we rely on these systems and their inhabitants for our survival. **Ecosystem services** encompass all the processes through which natural ecosystems help sustain human life. Ecosystems purify our air and water. They detoxify and decompose our wastes and reduce the impacts of extreme weather and flooding. The organisms in ecosystems pollinate our crops, control pests, and create and preserve our soils. Moreover, these diverse services are provided for free.

Perhaps because we don't attach a monetary value to the services of natural ecosystems, we generally undervalue them. In 1997, ecologist Robert Costanza and his colleagues estimated the value of Earth's ecosystem services at \$33 trillion per year, nearly twice the gross national product of all the countries on Earth at the time (\$18 trillion). It may be more realistic to do the accounting on a smaller scale. In 1996, New York City invested more than \$1 billion to buy land and restore habitat in the Catskill Mountains, the source of much of the city's fresh water. This investment was spurred by increasing pollution of the water by sewage, pesticides, and fertilizers. By harnessing

ecosystem services to purify its water naturally, the city saved \$8 billion it would have otherwise spent to build a new water treatment plant and \$300 million a year to run the plant.

There is growing evidence that the functioning of ecosystems, and hence their capacity to perform services, is linked to biodiversity. As human activities reduce biodiversity, we are reducing the capacity of the planet's ecosystems to perform processes critical to our own survival.

Threats to Biodiversity

Many different human activities threaten biodiversity on local, regional, and global scales. The threats posed by these activities are of four major types: habitat loss, introduced species, overharvesting, and global change.

Habitat Loss

Human alteration of habitat is the single greatest threat to biodiversity throughout the biosphere. Habitat loss has been brought about by agriculture, urban development, forestry, mining, and pollution. As discussed later in this chapter, global climate change is already altering habitats today and will have an even larger effect later this century. When no alternative habitat is available or a species is unable to move, habitat loss may mean extinction. The IUCN implicates destruction of physical habitat for 73% of the species that have become extinct, endangered, vulnerable, or rare in the last few hundred years.

Habitat loss and fragmentation may occur over large regions. Approximately 98% of the tropical dry forests of Central America and Mexico have been cut down. The clearing of tropical rain forest in the state of Veracruz, Mexico, mostly for cattle ranching, has resulted in the loss of more than 90% of the original forest, leaving relatively small, isolated patches of forest. Other natural habitats have also been fragmented by human activities (**Figure 43.6**).



▲ Figure 43.6 Habitat fragmentation in the foothills of Los Angeles. Development in the valleys may confine the organisms that inhabit the narrow strips of hillside.

In almost all cases, habitat fragmentation leads to species loss because the smaller populations in habitat fragments have a higher probability of local extinction. Prairie covered about 800,000 hectares (ha) of southern Wisconsin when Europeans first arrived in North America but occupies less than 800 ha today; most of the original prairie in this area is now used to grow crops. Plant diversity surveys of 54 Wisconsin prairie remnants conducted in 1948–1954 and repeated in 1987–1988 showed that the remnants lost between 8% and 60% of their plant species in the time between the two surveys.

Habitat loss is also a major threat to aquatic biodiversity. About 70% of coral reefs, among Earth's most species-rich aquatic communities, have been damaged by human activities. At the current rate of destruction, 40–50% of the reefs, home to one-third of marine fish species, could disappear in the next 30 to 40 years. Freshwater habitats are also being lost, often as a result of the dams, reservoirs, channel modification, and flow regulation now affecting most of the world's rivers. For example, the more than 30 dams and locks built along the Mobile River basin in the southeastern United States changed river depth and flow. While providing the benefits of hydroelectric power and increased ship traffic, these dams and locks also helped drive more than 40 species of mussels and snails to extinction.

Introduced Species

Introduced species, also called exotic species, are those that humans move intentionally or accidentally from the species' native locations to new geographic regions. Human travel by ship and airplane has accelerated the transplant of species. Free from the predators, parasites, and pathogens that limit their populations in their native habitats, such transplanted species may spread rapidly through a new region.

Some introduced species disrupt their new community, often by preying on native organisms or outcompeting them for resources. The brown tree snake was accidentally introduced to the island of Guam from other parts of the South Pacific after World War II: It was a "stowaway" in military cargo. Since then, 12 species of birds and 6 species of lizards that the snakes ate have become extinct on Guam, which had no native snakes. The devastating zebra mussel, a filter-feeding mollusc, was introduced into the Great Lakes of North America in 1988, most likely in the ballast water of ships arriving from Europe. Zebra mussels form dense colonies and have disrupted freshwater ecosystems, threatening native aquatic species. They have also clogged water intake structures, causing billions of dollars in damage to domestic and industrial water supplies.

Humans have deliberately introduced many species with good intentions but disastrous effects. An Asian plant called kudzu, which the U.S. Department of Agriculture once introduced in the southern United States to help control erosion, has taken over large areas of the landscape there (**Figure 43.7**).



▲ **Figure 43.7** Kudzu, an introduced species, thriving in South Carolina.

Introduced species are a worldwide problem, contributing to approximately 40% of the extinctions recorded since 1750 and costing billions of dollars each year in damage and control efforts. There are more than 50,000 introduced species in the United States alone.

Overharvesting

The term *overharvesting* refers generally to the harvesting of wild organisms at rates exceeding the ability of their populations to rebound. Species with restricted habitats, such as small islands, are particularly vulnerable to overharvesting. One such species was the great auk, a large, flightless seabird found on islands in the North Atlantic Ocean. By the 1840s, the great auk had been hunted to extinction to satisfy the human demand for its feathers, eggs, and meat.

Also susceptible to overharvesting are large organisms with low reproductive rates, such as elephants, whales, and rhinoceroses. The decline of Earth's largest terrestrial animals, the African elephants, is a classic example of the impact of overhunting. Largely because of the trade in ivory, elephant populations have been declining in most of Africa for the last 50 years. An international ban on the sale of new ivory resulted in increased poaching (illegal hunting), so the ban had little effect in much of central and eastern Africa. Only in South Africa, where once-decimated herds have been well protected for nearly a century, have elephant populations been stable or increasing (see Figure 40.18).

Conservation biologists increasingly use the tools of molecular genetics to track the origins of tissues harvested from endangered species. Researchers at the University of Washington have constructed a DNA reference map for the African elephant using DNA isolated from elephant dung. By comparing this reference map with DNA isolated from samples of ivory harvested either legally or by poachers, they can determine to within a few hundred kilometers where the elephants were killed (**Figure 43.8**). Such work in Zambia suggested that poaching rates were 30 times higher than previously estimated,



▲ **Figure 43.8 Ecological forensics and elephant poaching.** These severed tusks were part of an illegal shipment of ivory intercepted on its way from Africa to Singapore in 2002. DNA-based evidence showed that the thousands of elephants killed for the tusks came from a relatively narrow east-west band centered in Zambia rather than from across Africa.

leading to improved antipoaching efforts by the Zambian government. Similarly, biologists using phylogenetic analyses of mitochondrial DNA (mtDNA) showed that some whale meat sold in Japanese fish markets came from illegally harvested endangered species (see Figure 20.6).

Many commercially important fish populations, once thought to be inexhaustible, have been decimated by overfishing. Demands for protein-rich food from an increasing human population, coupled with new harvesting technologies, such as long-line fishing and modern trawlers, have reduced these fish populations to levels that cannot sustain further exploitation. Until the past few decades, the North Atlantic bluefin tuna had little commercial value—just a few cents per pound for use in cat food. In the 1980s, however, wholesalers began airfreighting fresh, iced bluefin to Japan for sushi and sashimi. In that market, the fish now brings up to \$100 per pound (**Figure 43.9**). With increased harvesting spurred by such high prices, it took just ten years to reduce the western North Atlantic bluefin population to less than 20% of its 1980 size.



▲ **Figure 43.9 Overharvesting.** North Atlantic bluefin tuna are auctioned in a Japanese fish market.

Global Change

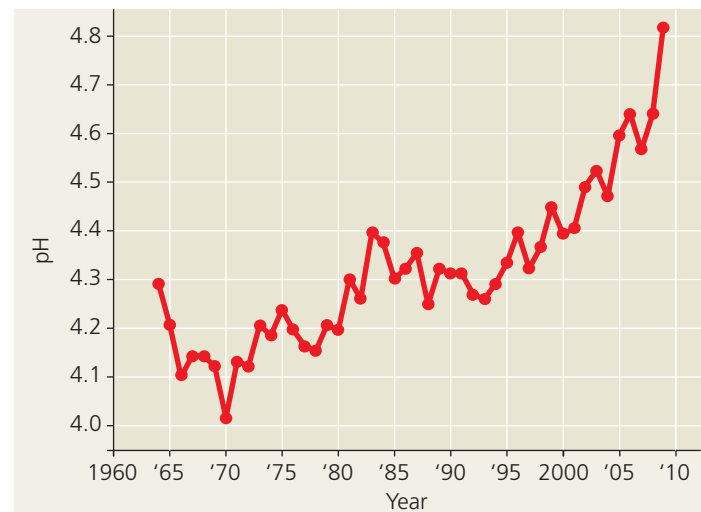
The fourth threat to biodiversity, global change, alters the fabric of Earth's ecosystems at regional to global scales. Global change includes alterations in climate, atmospheric chemistry, and broad ecological systems that reduce the capacity of Earth to sustain life.

One of the first types of global change to cause concern was *acid precipitation*, which is rain, snow, sleet, or fog with a pH less than 5.2. The burning of wood and fossil fuels releases oxides of sulfur and nitrogen that react with water in air, forming sulfuric and nitric acids. The acids eventually fall to Earth's surface, harming some aquatic and terrestrial organisms.

In the 1960s, ecologists determined that lake-dwelling organisms in eastern Canada were dying because of air pollution from factories in the midwestern United States. Newly hatched lake trout, for instance, die when the pH drops below 5.4. Lakes and streams in southern Norway and Sweden were losing fish because of pollution generated in Great Britain and central Europe. By 1980, the pH of precipitation in large areas of North America and Europe averaged 4.0–4.5 and sometimes dropped as low as 3.0. (To review pH, see Concept 2.5.)

Environmental regulations and new technologies have enabled many countries to reduce sulfur dioxide emissions in recent decades. In the United States, sulfur dioxide emissions decreased more than 40% between 1993 and 2009, gradually reducing the acidity of precipitation (**Figure 43.10**). However, ecologists estimate that it will take decades for aquatic ecosystems to recover. Meanwhile, emissions of nitrogen oxides are increasing in the United States, and emissions of sulfur dioxide and acid precipitation continue to damage forests in Europe.

We will explore the importance of global change for Earth's biodiversity in more detail in Concept 43.4, where we examine such factors as climate change.



© 2001 Pearson Education, Inc.

▲ **Figure 43.10 Changes in the pH of precipitation at Hubbard Brook, New Hampshire.** Although still acidic, the precipitation in this northeastern U.S. forest has been increasing in pH for more than three decades.

CONCEPT CHECK 43.1

1. Explain why it is too narrow to define the biodiversity crisis as simply a loss of species.
2. Identify the four main threats to biodiversity and explain how each damages diversity.
3. **WHAT IF?** Imagine two populations of a fish species, one in the Mediterranean Sea and one in the Caribbean Sea. Now imagine two scenarios: (1) The populations breed separately, and (2) adults of both populations migrate yearly to the North Atlantic to interbreed. Which scenario would result in a greater loss of genetic diversity if the Mediterranean population were harvested to extinction? Explain your answer.

For suggested answers, see Appendix A.

CONCEPT 43.2

Population conservation focuses on population size, genetic diversity, and critical habitat

Biologists who work on conservation at the population and species levels use two main approaches. One approach focuses on populations that are small and hence often vulnerable. The other emphasizes populations that are declining rapidly, even if they are not yet small.

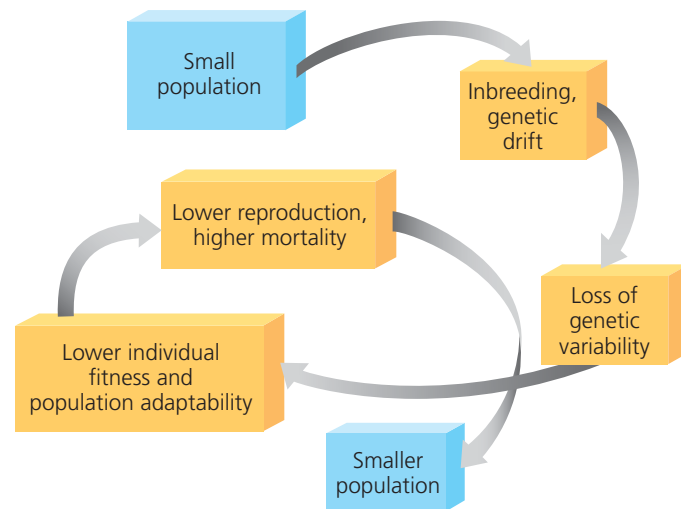
Small-Population Approach

Small populations are particularly vulnerable to overharvesting, habitat loss, and the other threats to biodiversity that you read about in Concept 43.1. After such factors have reduced a population's size, the small size itself can push the population to extinction. Conservation biologists who adopt the small-population approach study the processes that cause extinctions once population sizes have been reduced.

The Extinction Vortex: Evolutionary Implications of Small Population Size

EVOLUTION A small population is vulnerable to inbreeding and genetic drift, which draw the population down an **extinction vortex** toward smaller and smaller population size until no individuals survive (**Figure 43.11**). A key factor driving the extinction vortex is the loss of the genetic variation that enables evolutionary responses to environmental change, such as the appearance of new strains of pathogens. Both inbreeding and genetic drift can cause a loss of genetic variation (see Chapter 21), and their effects become more harmful as a population shrinks. Inbreeding often reduces fitness because offspring are more likely to be homozygous for harmful recessive traits.

Not all small populations are doomed by low genetic diversity, and low genetic variability does not automatically lead to permanently small populations. For instance, overhunting of northern elephant seals in the 1890s reduced the species to only 20 individuals—clearly a bottleneck with reduced genetic



▲ **Figure 43.11** Processes driving an extinction vortex.

variation. Since that time, however, the northern elephant seal populations have rebounded to about 150,000 individuals today, though their genetic variation remains relatively low. Thus, low genetic diversity does not always impede population growth.

Case Study: The Greater Prairie Chicken and the Extinction Vortex

When Europeans arrived in North America, the greater prairie chicken (*Tympanuchus cupido*) was common from New England to Virginia and across the western prairies of the continent. Land cultivation for agriculture fragmented the populations of this species, and its abundance decreased rapidly (see Chapter 21). Illinois had millions of greater prairie chickens in the 19th century but fewer than 50 by 1993. Researchers found that the decline in the Illinois population was associated with a decrease in fertility. As a test of the extinction vortex hypothesis, scientists increased the genetic variation of the Illinois population by importing 271 birds from larger populations elsewhere (**Figure 43.12**). The Illinois population rebounded, confirming that it had been on its way to extinction until rescued by the transfusion of genetic variation.

Minimum Viable Population Size

How small does a population have to be before it starts down an extinction vortex? The answer depends on the type of organism and other factors. Large predators that feed high on the food chain usually require extensive individual ranges, resulting in low population densities. Therefore, not all rare species concern conservation biologists. All populations, however, require some minimum size to remain viable.

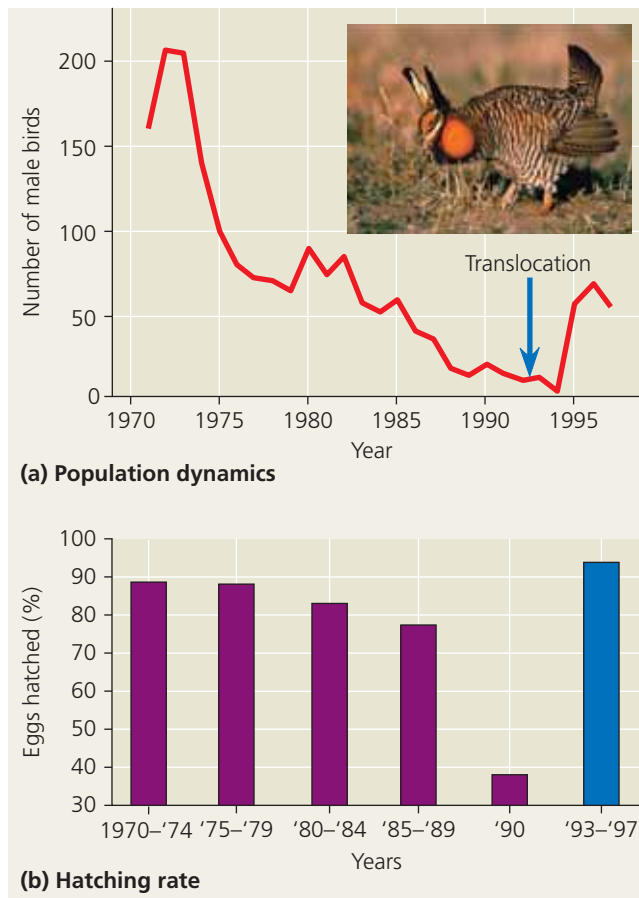
The minimal population size at which a species is able to sustain its numbers is known as the **minimum viable population (MVP)**. MVP is usually estimated for a given species using computer models that integrate many factors. The calculation may include, for instance, an estimate of how many individuals in a small population are likely to be killed by a natural

▼ Figure 43.12 Inquiry

What caused the drastic decline of the Illinois greater prairie chicken population?

Experiment Researchers had observed that the population collapse of the greater prairie chicken was mirrored in a reduction in fertility, as measured by the hatching rate of eggs. Comparison of DNA samples from the Jasper County, Illinois, population with DNA from feathers in museum specimens showed that genetic variation had declined in the study population (see Figure 21.11). In 1992, Ronald Westemeier, Jeffrey Brawn, and colleagues began translocating prairie chickens from Minnesota, Kansas, and Nebraska in an attempt to increase genetic variation.

Results After translocation (blue arrow), the viability of eggs rapidly increased, and the population rebounded.



© 1998 AAAS

Conclusion Reduced genetic variation had started the Jasper County population of prairie chickens down the extinction vortex.

Source R. L. Westemeier et al., Tracking the long-term decline and recovery of an isolated population, *Science* 282:1695–1698 (1998).

Inquiry in Action Read and analyze the original paper in *Inquiry in Action: Interpreting Scientific Papers*.

WHAT IF? Given the success of using transplanted birds as a tool for increasing the percentage of hatched eggs in Illinois, why wouldn't you transplant additional birds immediately to Illinois?

catastrophe such as a storm. Once in the extinction vortex, two or three consecutive years of bad weather could finish off a population that is already below its MVP.

Effective Population Size

Genetic variation is the key issue in the small-population approach. The *total* size of a population may be misleading because only certain members of the population breed successfully and pass their alleles on to offspring. Therefore, a meaningful estimate of MVP requires the researcher to determine the **effective population size**, which is based on the breeding potential of the population.

The following formula incorporates the sex ratio of breeding individuals into the estimate of effective population size, abbreviated N_e :

$$N_e = \frac{4N_fN_m}{N_f + N_m}$$

where N_f and N_m are, respectively, the number of females and the number of males that successfully breed. If we apply this formula to an idealized population whose total size is 1,000 individuals, N_e will also be 1,000 if every individual breeds and the sex ratio is 500 females to 500 males. In this case, $N_e = (4 \times 500 \times 500) / (500 + 500) = 1,000$. Any deviation from these conditions (not all individuals breed or there is not a 1:1 sex ratio) reduces N_e . For instance, if the total population size is 1,000 but only 400 females and 400 males breed, then $N_e = (4 \times 400 \times 400) / (400 + 400) = 800$, or 80% of the total population. Numerous life history traits can influence N_e , and alternative formulas for estimating N_e take into account factors such as family size, age at maturation, genetic relatedness among population members, the effects of gene flow between geographically separated populations, and population fluctuations.

In actual study populations, N_e is always some fraction of the total population. Thus, simply determining the total number of individuals in a small population does not provide a good measure of whether the population is large enough to avoid extinction. Whenever possible, conservation programs attempt to sustain total population sizes that include at least the minimum viable number of *reproductively active* individuals. The conservation goal of sustaining effective population size (N_e) above MVP stems from the concern that populations retain enough genetic diversity to adapt as their environment changes.

Case Study: Analysis of Grizzly Bear Populations

One of the first population viability analyses was conducted in 1978 by Mark Shaffer, of Duke University, as part of a long-term study of grizzly bears in Yellowstone National Park and its surrounding areas (Figure 43.13). A threatened species in the United States, the grizzly bear (*Ursus arctos horribilis*) is currently found in only 4 of the 48 contiguous states. Its populations in those states have been drastically reduced and fragmented. In 1800, an estimated 100,000 grizzlies ranged over about 500 million ha of habitat, while today only about 1,000 individuals in six relatively isolated populations range over less than 5 million ha.



▲ Figure 43.13 Long-term monitoring of a grizzly bear population. The ecologist is fitting this tranquilized bear with a radio collar so that the bear's movements can be compared with those of other grizzlies in the Yellowstone National Park population.

Shaffer attempted to determine viable sizes for the Yellowstone grizzly population. Using life history data obtained for individual Yellowstone bears over a 12-year period, he simulated the effects of environmental factors on survival and reproduction. His models predicted that, given a suitable habitat, a Yellowstone grizzly bear population of 70–90 individuals would have about a 95% chance of surviving for 100 years. A slightly larger population of only 100 bears would have a 95% chance of surviving for twice as long, about 200 years.

How does the actual size of the Yellowstone grizzly population compare with Shaffer's predicted MVP? A current estimate puts the total grizzly bear population in the greater Yellowstone ecosystem at about 500 individuals. The relationship of this estimate to the effective population size, N_e , depends on several factors. Usually, only a few dominant males breed, and it may be difficult for them to locate females, since individuals inhabit such large areas. Moreover, females may reproduce only when there is abundant food. As a result, N_e is only about 25% of the total population size, or about 125 bears.

Because small populations tend to lose genetic variation over time, researchers have analyzed proteins, mtDNA, and short tandem repeats (see Chapter 18) to assess genetic variability in the Yellowstone grizzly bear population. All results to date indicate that the Yellowstone population has less genetic variability than other grizzly bear populations in North America.

How might conservation biologists increase the effective size and genetic variation of the Yellowstone grizzly bear population? Migration between isolated populations of grizzlies could increase both effective and total population sizes. Computer models predict that introducing only two unrelated bears each decade into a population of 100 individuals would reduce the loss of genetic variation by about half. For the grizzly bear, and probably for many other species with small populations, finding ways to promote dispersal among populations may be one of the most urgent conservation needs.

This case study and that of the greater prairie chicken bridge small-population models and practical applications in conservation. Next, we look at an alternative approach to understanding the biology of extinction.

Declining-Population Approach

The declining-population approach focuses on threatened and endangered populations that show a downward trend, even if the population is far above its minimum viable population. The distinction between a declining population, which may not be small, and a small population, which may not be declining, is less important than the different priorities of the two approaches. The small-population approach emphasizes smallness itself as an ultimate cause of a population's extinction, especially through the loss of genetic diversity. In contrast, the declining-population approach emphasizes the environmental factors that caused a population decline in the first place. If, for instance, an area is deforested, then species that depend on trees will decline in abundance and become locally extinct, whether or not they retain genetic variation. The following case study is one example of how the declining-population approach has been applied to the conservation of an endangered species.

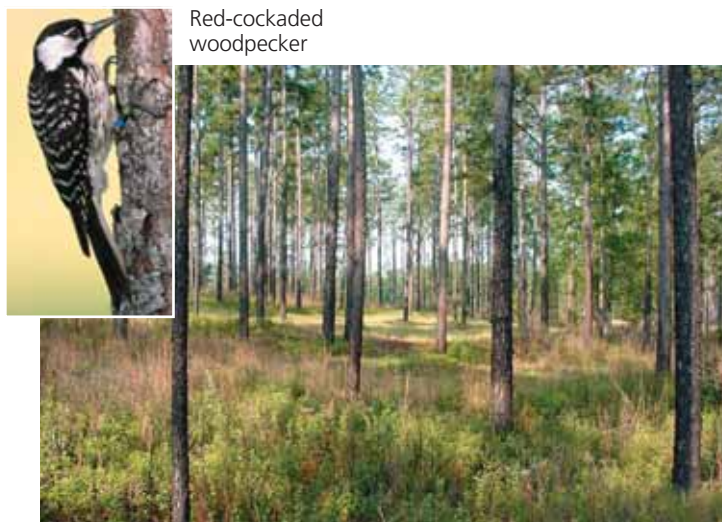
Case Study: Decline of the Red-Cockaded Woodpecker

The red-cockaded woodpecker (*Picoides borealis*) is found only in the southeastern United States. It requires mature pine forests, preferably ones dominated by the longleaf pine, for its habitat. Most woodpeckers nest in dead trees, but the red-cockaded woodpecker drills its nest holes in mature, living pine trees. It also drills small holes around the entrance to its nest cavity, which causes resin from the tree to ooze down the trunk. The resin seems to repel predators, such as corn snakes, that eat bird eggs and nestlings.

Another critical habitat factor for the red-cockaded woodpecker is that the undergrowth of plants around the pine trunks must be low (Figure 43.14a). Breeding birds tend to abandon nests when vegetation among the pines is thick and higher than about 4.5 m (Figure 43.14b). Apparently, the birds need a clear flight path between their home trees and the neighboring feeding grounds. Periodic fires have historically swept through longleaf pine forests, keeping the undergrowth low.

One factor leading to the woodpecker's decline has been the destruction or fragmentation of suitable habitats by logging and agriculture. By recognizing key habitat factors, protecting some longleaf pine forests, and using controlled fires to reduce forest undergrowth, conservation managers have helped restore habitat that can support viable populations.

Sometimes conservation managers also help species colonize restored habitats. Because red-cockaded woodpeckers take months to excavate nesting cavities, researchers performed an experiment to see whether providing cavities for the birds would make them more likely to use a site. The



(a) Forests that can sustain red-cockaded woodpeckers have low undergrowth.



(b) Forests that cannot sustain red-cockaded woodpeckers have high, dense undergrowth that interferes with the woodpeckers' access to feeding grounds.

▲ Figure 43.14 A habitat requirement of the red-cockaded woodpecker.

? *How is habitat disturbance necessary for the long-term survival of the woodpecker?*

researchers constructed cavities in pine trees at 20 restored sites and compared nesting rates there with rates in sites without constructed cavities. The results were dramatic. Cavities in 18 of the 20 sites with constructed cavities were colonized by red-cockaded woodpeckers, and new breeding groups formed only in those sites. Based on this experiment, conservationists initiated a habitat maintenance program that included controlled burning and excavation of new nesting cavities, enabling this endangered species to begin to recover.

Weighing Conflicting Demands

Determining population numbers and habitat needs is only part of a strategy to save species. Scientists also need to weigh a species' needs against other conflicting demands.

Conservation biology often highlights the relationship between science, technology, and society. For example, an ongoing, sometimes bitter debate in the western United States pits habitat preservation for wolf, grizzly bear, and bull trout populations against job opportunities in the grazing and resource extraction industries. Programs that restocked wolves in Yellowstone National Park remain controversial for people concerned about human safety and for many ranchers concerned with potential loss of livestock outside the park.

Large, high-profile vertebrates are not always the focal point in such conflicts, but habitat use is almost always the issue. Should work proceed on a new highway bridge if it destroys the only remaining habitat of a species of freshwater mussel? If you owned a coffee plantation growing varieties that thrive in bright sunlight, would you be willing to change to shade-tolerant varieties that produce less coffee per hectare but can grow beneath trees that support large numbers of songbirds?

Another important consideration is the ecological role of a species. Because we cannot save every endangered species, we must determine which species are most important for conserving biodiversity as a whole. Identifying keystone species and finding ways to sustain their populations can be central to maintaining communities and ecosystems. In most situations, we must look beyond a species and consider the whole community and ecosystem as an important unit of biodiversity.

CONCEPT CHECK 43.2

1. How does the reduced genetic diversity of small populations make them more vulnerable to extinction?
2. If there was a total of 50 individuals in the two Illinois populations of greater prairie chickens in 1993, what was the effective population size if 15 females and 5 males bred?
3. **WHAT IF?** In 2011, at least ten grizzly bears in the greater Yellowstone ecosystem were killed through contact with people. Three things caused many of these deaths: collisions with automobiles, hunters (of other animals) shooting when charged by a female grizzly bear with cubs nearby, and conservation managers killing bears that attacked livestock repeatedly. If you were a conservation manager, what steps might you take to minimize such encounters in Yellowstone?

For suggested answers, see Appendix A.

CONCEPT 43.3

Landscape and regional conservation help sustain biodiversity

Although conservation efforts historically focused on saving individual species, efforts today often seek to sustain the biodiversity of entire communities, ecosystems, and landscapes. Such a broad view requires applying not just the principles of community, ecosystem, and landscape ecology but aspects of

human population dynamics and economics as well. The goals of landscape ecology (see Chapter 40) include projecting future patterns of landscape use and making biodiversity conservation part of land-use planning.

Landscape Structure and Biodiversity

The biodiversity of a given landscape is in large part a function of the structure of the landscape. Understanding landscape structure is critically important in conservation because many species use more than one kind of ecosystem, and many live on the borders between ecosystems.

Fragmentation and Edges

The boundaries, or *edges*, between ecosystems—such as between a lake and the surrounding forest or between cropland and suburban housing tracts—are defining features of landscapes (Figure 43.15). An edge has its own set of physical conditions, which differ from those on either side of it. The soil surface of an edge between a forest patch and a burned area receives more sunlight and is usually hotter and drier than the forest interior, but it is cooler and wetter than the soil surface in the burned area.

Some organisms thrive in edge communities because they gain resources from both adjacent areas. The ruffed grouse (*Bonasa umbellus*) is a bird that needs forest habitat for nesting, winter food, and shelter, but it also needs forest openings with dense shrubs and herbs for summer food.

Ecosystems in which edges arise from human alterations often have reduced biodiversity and a preponderance of edge-adapted species. For example, white-tailed deer thrive in edge habitats, where they can browse on woody shrubs; deer populations often expand when forests are logged and more edges are generated. The brown-headed cowbird (*Molothrus ater*) is

an edge-adapted species that lays its eggs in the nests of other birds, often migratory songbirds. Cowbirds need forests, where they can parasitize the nests of other birds, and open fields, where they forage on seeds and insects. Consequently, their populations are growing where forests are being cut and fragmented, creating more edge habitat and open land. Increasing cowbird parasitism and habitat loss are correlated with declining populations of several of the cowbird's host species.

The influence of fragmentation on the structure of communities has been explored since 1979 in the long-term Biological Dynamics of Forest Fragments Project. Located in the heart of the Amazon River basin, the study area consists of isolated fragments of tropical rain forest separated from surrounding continuous forest by distances of 80–1,000 m (Figure 43.16). Numerous researchers working on this project have clearly documented the effects of this fragmentation on organisms ranging from bryophytes to beetles to birds. They have consistently found that species adapted to forest interiors show the greatest declines when patches are the smallest, suggesting that landscapes dominated by small fragments will support fewer species.

Corridors That Connect Habitat Fragments

In fragmented habitats, the presence of a **movement corridor**, a narrow strip or series of small clumps of habitat connecting otherwise isolated patches, can be extremely important for conserving biodiversity. Riparian habitats often serve as corridors, and in some nations, government policy prohibits altering these habitats. In areas of heavy human use, artificial corridors are sometimes constructed. Bridges or tunnels, for instance, can reduce the number of animals killed trying to cross highways (Figure 43.17).

Movement corridors can also promote dispersal and reduce inbreeding in declining populations. Corridors have been



▲ **Figure 43.15 Edges between ecosystems.** Grasslands give way to forest ecosystems in Yellowstone National Park.



▲ **Figure 43.16 Amazon rain forest fragments created as part of the Biological Dynamics of Forest Fragments Project.**



▲ **Figure 43.17** An artificial corridor. This bridge in Banff National Park, Canada, helps animals cross a human-created barrier.

shown to increase the exchange of individuals among populations of many organisms, including butterflies, voles, and aquatic plants. Corridors are especially important to species that migrate between different habitats seasonally. However, a corridor can also be harmful—for example, by allowing the spread of disease. In a 2003 study, a scientist at the University of Zaragoza, Spain, showed that habitat corridors facilitate the movement of disease-carrying ticks among forest patches in northern Spain. All the effects of corridors are not yet understood, and their impact is an area of active research in conservation biology.

Establishing Protected Areas

Conservation biologists are applying their understanding of landscape dynamics in establishing protected areas to slow biodiversity loss. Currently, governments have set aside about 7% of the world's land in various forms of reserves. Choosing where to place nature reserves and how to design them poses many challenges. Should the reserve be managed to minimize the risks of fire and predation to a threatened species? Or should the reserve be left as natural as possible, with such processes as fires ignited by lightning allowed to play out on their own? This is just one of the debates that arise among people who share an interest in the health of national parks and other protected areas.

Preserving Biodiversity Hot Spots

In deciding which areas are of highest conservation priority, biologists often focus on hot spots of biodiversity. A **biodiversity hot spot** is a relatively small area with numerous endemic species (species found nowhere else in the world) and a large number of endangered and threatened species (**Figure 43.18**). Nearly 30% of all bird species can be found in hot spots that make up only about 2% of Earth's land area. Together,

the “hottest” of the terrestrial biodiversity hot spots total less than 1.5% of Earth's land but are home to more than a third of all species of plants, amphibians, reptiles (including birds), and mammals. Aquatic ecosystems also have hot spots, such as coral reefs and certain river systems.

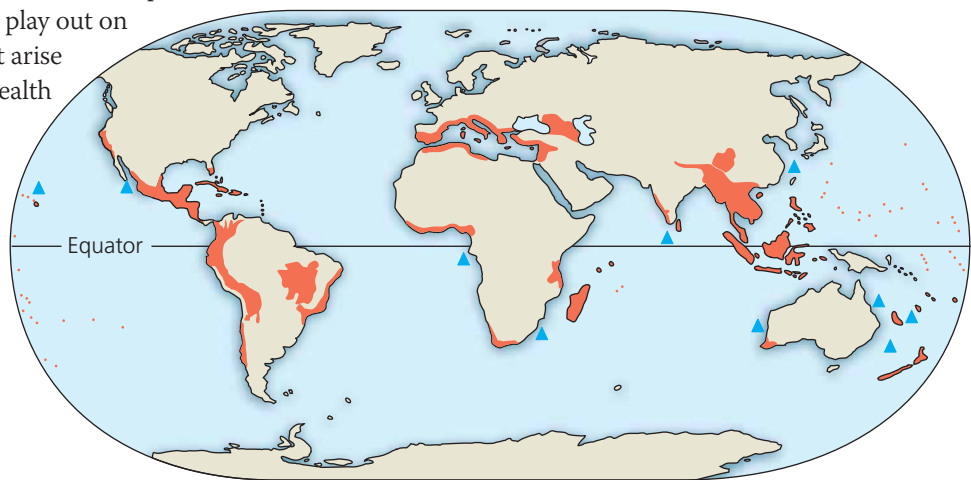
Biodiversity hot spots are good choices for nature reserves, but identifying them is not always simple. One problem is that a hot spot for one taxonomic group, such as butterflies, may not be a hot spot for some other taxonomic group, such as birds. Designating an area as a biodiversity hot spot is often biased toward saving vertebrates and plants, with less attention paid to invertebrates and microorganisms. Some biologists are also concerned that the hot-spot strategy places too much emphasis on such a small fraction of Earth's surface.

Global change makes the task of preserving hot spots even more challenging because the conditions that favor a particular community may not be found in the same location in the future. The biodiversity hot spot in the southwest corner of Australia (see **Figure 43.18**) holds thousands of species of endemic plants and numerous endemic vertebrates. Researchers recently concluded that between 5% and 25% of the plant species they examined may become extinct by 2080 because the plants will be unable to tolerate the increased dryness predicted for this region.

Philosophy of Nature Reserves

Nature reserves are biodiversity islands in a sea of habitat degraded by human activity. Protected “islands” are not isolated from their surroundings, however, and the nonequilibrium model (see Chapter 41) applies to nature reserves as well as to the larger landscapes around them.

An earlier policy—that protected areas should be set aside to remain unchanged forever—was based on the concept that ecosystems are balanced, self-regulating units. However, disturbance is common in all ecosystems (see Chapter 41), and management policies that ignore natural disturbances or attempt to prevent them have generally failed. For instance, setting aside an area of a fire-dependent community, such as a



© 2000 Macmillan Publishers Ltd.

▲ **Figure 43.18** Earth's terrestrial (■) and marine (▲) biodiversity hot spots.

portion of a tallgrass prairie, chaparral, or dry pine forest, with the intention of saving it is unrealistic if periodic burning is excluded. Without the dominant disturbance, the fire-adapted species are usually outcompeted and biodiversity is reduced.

An important conservation question is whether to create numerous small reserves or fewer large reserves. Small, unconnected reserves may slow the spread of disease between populations. One argument for large reserves is that large, far-ranging animals with low-density populations, such as the grizzly bear, require extensive habitats. Large reserves also have proportionately smaller perimeters than small reserves and are therefore less affected by edges.

As conservation biologists have learned more about the requirements for achieving minimum viable populations for endangered species, they have realized that most national parks and other reserves are far too small. The area needed for the long-term survival of the Yellowstone grizzly bear population, for instance, is more than ten times the combined area of Yellowstone and Grand Teton National Parks (Figure 43.19). Areas of private and public land surrounding reserves will likely have to contribute to biodiversity conservation.

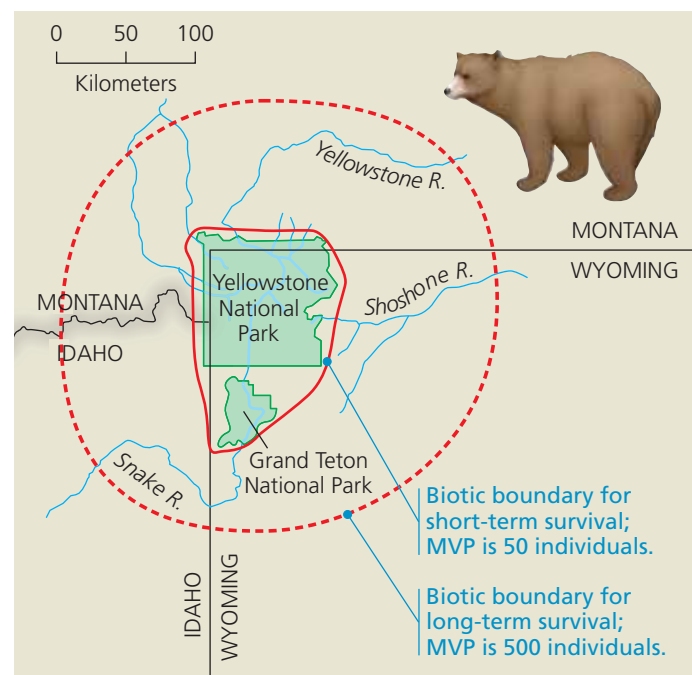
Zoned Reserves

Several nations have adopted a zoned reserve approach to landscape management. A **zoned reserve** is an extensive region that includes relatively undisturbed areas surrounded by areas that have been changed by human activity and are used for economic gain. The key challenge of the zoned reserve

approach is to develop a social and economic climate in the surrounding lands that is compatible with the long-term viability of the protected core. These surrounding areas continue to support human activities, but regulations prevent the types of extensive alterations likely to harm the protected area. As a result, the surrounding habitats serve as buffer zones against further intrusion into the undisturbed area.

The small Central American nation of Costa Rica has become a world leader in establishing zoned reserves (Figure 43.20). An agreement initiated in 1987 reduced Costa Rica's international debt in return for land preservation there. The agreement resulted in eight zoned reserves, called "conservation areas," that contain designated national park land. Costa Rica is making progress toward managing its zoned reserves, and the buffer zones provide a steady, lasting supply of forest products, water, and hydroelectric power while also supporting sustainable agriculture and tourism, both of which employ local people.

Although marine ecosystems have also been heavily affected by human exploitation, reserves in the ocean are far less common than reserves on land. Many fish populations around the world have collapsed as increasingly sophisticated equipment puts nearly all potential fishing grounds within human reach. In response, scientists at the University of York, England, have proposed establishing marine reserves around the world that would be off limits to fishing. They present strong evidence that a patchwork of marine reserves can serve as a means of both increasing fish populations within the reserves and improving fishing success in nearby areas. Their proposed system is a modern application of a centuries-old practice in the Fiji Islands in which some areas have historically remained closed to fishing—a traditional example of the zoned reserve concept.



▲ Figure 43.19 Biotic boundaries for grizzly bears in Yellowstone and Grand Teton National Parks. The biotic boundaries (solid and dashed red lines) surround the areas needed to support minimum viable populations of 50 and 500 bears. Even the smaller of these areas is larger than the two parks.



▲ Figure 43.20 Zoned reserves in Costa Rica. Boundaries of the zoned reserves are indicated by black outlines.



▲ **Figure 43.21** A diver measuring coral in the Florida Keys National Marine Sanctuary.

The United States adopted such a system in creating a set of 13 national marine sanctuaries, including the Florida Keys National Marine Sanctuary, which was established in 1990 (**Figure 43.21**). Populations of marine organisms, including fishes and lobsters, recovered quickly after harvests were banned in the 9,500-km² reserve. Larger and more abundant fish now produce larvae that help repopulate reefs and improve fishing outside the sanctuary. The increased marine life within the sanctuary also makes it a favorite for recreational divers, increasing the economic value of this zoned reserve.

CONCEPT CHECK 43.3

1. What is a biodiversity hot spot?
2. How do zoned reserves provide economic incentives for long-term conservation of protected areas?
3. **WHAT IF?** Suppose a developer proposes to clear-cut a forest that serves as a corridor between two parks. To compensate, the developer also proposes to add the same area of forest to one of the parks. As a professional ecologist, how might you argue for retaining the corridor?

For suggested answers, see Appendix A.

CONCEPT 43.4

Earth is changing rapidly as a result of human actions

As we've discussed, landscape and regional conservation help protect habitats and preserve species. However, environmental changes that result from human activities are creating new challenges. As a consequence of human-caused climate change, for example, the place where a vulnerable species is found today may not be the same as the one needed for preservation in the future. What would happen if *many* habitats on

Earth changed so quickly that the locations of preserves today were unsuitable for their species in 10, 50, or 100 years? Such a scenario is increasingly likely.

The rest of this section describes three types of environmental change that threaten biodiversity: nutrient enrichment, toxin accumulation, and climate change. The impacts of these and other changes are evident not just in human-dominated ecosystems, such as cities and farms, but also in the most remote ecosystems on Earth.

Nutrient Enrichment

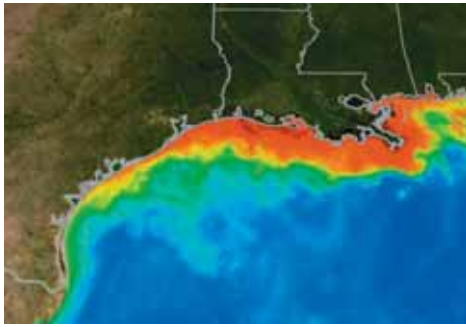
Human activity often removes nutrients from one part of the biosphere and adds them to another. Someone eating strawberries in Washington, DC, consumes nutrients that only days before were in the soil in California; a short time later, some of these nutrients will be in the Potomac River, having passed through the person's digestive system and a local sewage treatment facility.

Farming is an example of how human activities are altering the environment through the enrichment of nutrients. After vegetation is cleared from an area, the existing reserve of nutrients in the soil is sufficient to grow crops for only a brief period because a substantial fraction of these nutrients is exported from the area in crop biomass. For this reason, farmers typically add fertilizers to increase crop yields.

Nitrogen is the main nutrient element lost through agriculture (see Figure 42.13). Plowing mixes the soil and speeds up decomposition of organic matter, releasing nitrogen that is then removed when crops are harvested. Applied fertilizers make up for the loss of usable nitrogen from agricultural ecosystems. However, without plants to take up nitrates from the soil, the nitrates are likely to be leached from the ecosystem (see Figure 42.14). Recent studies indicate that human activities have more than doubled Earth's supply of fixed nitrogen available to primary producers.

A problem arises when the nutrient level in an ecosystem exceeds the **critical load**, the amount of added nutrient, usually nitrogen or phosphorus, that can be absorbed by plants without damaging ecosystem integrity. For example, nitrogenous minerals in the soil that exceed the critical load eventually leach into groundwater or run off into freshwater and marine ecosystems, sometimes contaminating water supplies and killing fish. Nitrate concentrations in groundwater are increasing in most agricultural regions, sometimes reaching levels that are unsafe for drinking.

Many rivers contaminated with nitrates and ammonium from agricultural runoff and sewage drain into the Atlantic Ocean, with the highest inputs coming from northern Europe and the central United States. The Mississippi River carries nitrogen pollution to the Gulf of Mexico, fueling a phytoplankton bloom each summer. When the phytoplankton die, their decomposition by oxygen-using organisms creates an extensive "dead zone" of low oxygen concentrations along the Gulf coast



▲ **Figure 43.22** A phytoplankton bloom arising from nitrogen pollution in the Mississippi basin that leads to a dead zone. In this satellite image from 2004, red and orange represent high concentrations of phytoplankton in the Gulf of Mexico.

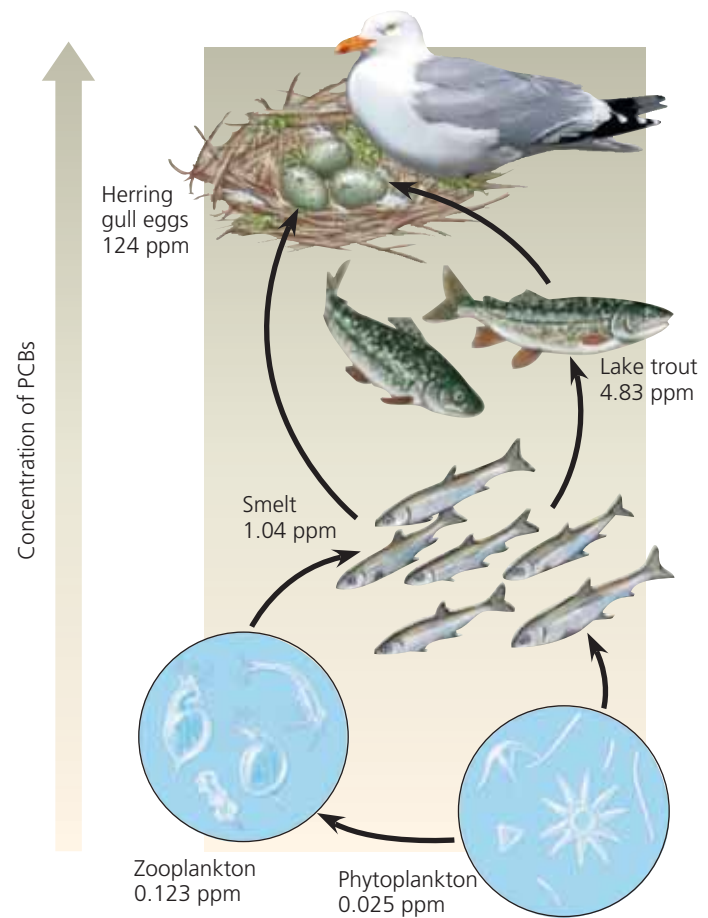
(Figure 43.22). Fish and other marine animals disappear from some of the most economically important waters in the United States. To reduce the size of the dead zone, farmers have begun using fertilizers more efficiently, and managers are restoring wetlands in the Mississippi watershed, two changes stimulated by the results of ecosystem experiments.

Nutrient runoff can also lead to the eutrophication of lakes (see Concept 42.2). The bloom and subsequent die-off of algae and cyanobacteria and the ensuing depletion of oxygen are similar to what occurs in a marine dead zone. Such conditions threaten the survival of organisms. For example, eutrophication of Lake Erie coupled with overfishing wiped out commercially important fishes such as blue pike, whitefish, and lake trout by the 1960s. Since then, tighter regulations on the dumping of sewage and other wastes into the lake have enabled some fish populations to rebound, but many native species of fish and invertebrates have not recovered.

Toxins in the Environment

Human activities release an immense variety of toxic chemicals, including thousands of synthetic compounds previously unknown in nature, with little regard for the ecological consequences. Organisms acquire toxic substances from the environment along with nutrients and water. Some of the poisons are metabolized or excreted, but others accumulate in specific tissues, often fat. One of the reasons accumulated toxins are particularly harmful is that they become more concentrated in successive trophic levels of a food web. This phenomenon, called **biological magnification**, occurs because the biomass at any given trophic level is produced from a much larger biomass ingested from the level below (see Concept 42.3). Thus, top-level carnivores tend to be most severely affected by toxic compounds in the environment.

One class of industrially synthesized compounds that have demonstrated biological magnification are the chlorinated hydrocarbons, which include the industrial chemicals called PCBs (polychlorinated biphenyls) and many pesticides, such as DDT. Current research implicates many of these compounds in endocrine system disruption in a large number of animal



▲ **Figure 43.23** Biological magnification of PCBs in a Great Lakes food web.

species, including humans. Biological magnification of PCBs has been found in the food web of the Great Lakes, where the concentration of PCBs in herring gull eggs, at the top of the food web, is nearly 5,000 times that in phytoplankton, at the base of the food web (Figure 43.23).

An infamous case of biological magnification that harmed top-level carnivores involved DDT, a chemical used to control insects such as mosquitoes and agricultural pests. In the decade after World War II, the use of DDT grew rapidly; its ecological consequences were not yet fully understood. By the 1950s, scientists were learning that DDT persists in the environment and is transported by water to areas far from where it is applied. One of the first signs that DDT was a serious environmental problem was a decline in the populations of pelicans, ospreys, and eagles, birds that feed at the top of food webs. The accumulation of DDT (and DDE, a product of its breakdown) in the tissues of these birds interfered with the deposition of calcium in their eggshells. When the birds tried to incubate their eggs, the weight of the parents broke the shells of affected eggs, resulting in catastrophic declines in the birds' reproduction rates. Rachel Carson's book *Silent Spring* helped bring the problem to public attention in the 1960s (Figure 43.24), and DDT was banned in the United States in 1971. A dramatic recovery in populations of the affected bird species followed.

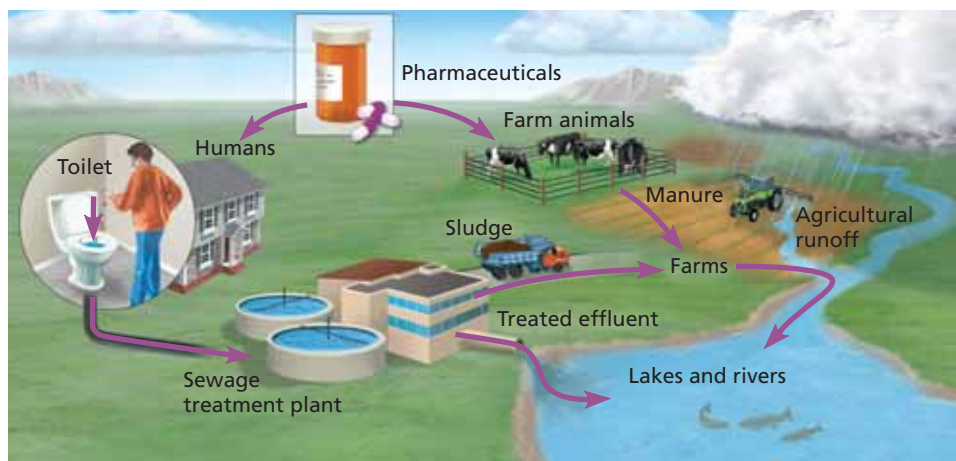
► **Figure 43.24**
Rachel Carson.

Through her writing and her testimony before the U.S. Congress, biologist and author Rachel Carson helped promote a new environmental ethic. Her efforts led to a ban on DDT use in the United States and stronger controls on the use of other chemicals.



In countries throughout much of the tropics, DDT is still used to control the mosquitoes that spread malaria and other diseases. Societies there face a trade-off between saving human lives and protecting other species. The best approach seems to be to apply DDT sparingly and to couple its use with mosquito netting and other low-technology solutions. The complicated history of DDT illustrates the importance of understanding the ecological connections between diseases and communities (see Concept 41.5).

Pharmaceuticals make up another group of toxins in the environment, one that is a growing concern among ecologists. The use of over-the-counter and prescription drugs has risen in recent years, particularly in industrialized nations. People who consume such products excrete residual chemicals in their waste and may also dispose of unused drugs improperly, such as in their toilets or sinks. Drugs that are not broken down in sewage treatment plants may then enter rivers and lakes with the material discharged from these plants. Growth-promoting drugs given to farm animals can also enter rivers and lakes with agricultural runoff. As a consequence, many pharmaceuticals are spreading in low concentrations across the world's freshwater ecosystems (**Figure 43.25**).



▲ **Figure 43.25** Sources and movements of pharmaceuticals in the environment.

Among the pharmaceuticals that ecologists are studying are the sex steroids, including forms of estrogen used for birth control. Some fish species are so sensitive to certain estrogens that concentrations of a few parts per trillion in their water can alter sexual differentiation and shift the female-to-male sex ratio toward females. Researchers in Ontario, Canada, conducted a seven-year experiment in which they applied the synthetic estrogen used in contraceptives to a lake in very low concentrations (5–6 ng/L). They found that chronic exposure of the fathead minnow (*Pimephales promelas*) to the estrogen led to feminization of males and a near extinction of the species from the lake.

Many toxins cannot be degraded by microorganisms and persist in the environment for years or even decades. In other cases, chemicals released into the environment may be relatively harmless but are converted to more toxic products by reaction with other substances, by exposure to light, or by the metabolism of microorganisms. Mercury, a by-product of plastic production and coal-fired power generation, has been routinely expelled into rivers and the sea in an insoluble form. Bacteria in the bottom mud convert the waste to methylmercury (CH_3Hg^+), an extremely toxic water-soluble compound that accumulates in the tissues of organisms, including humans who consume fish from the contaminated waters.

Greenhouse Gases and Climate Change

Human activities release a variety of gaseous waste products. People once thought that the vast atmosphere could absorb these materials indefinitely, but we now know that such additions can cause fundamental changes to the atmosphere and to its interactions with the rest of the biosphere. In this section, we'll examine how increasing concentrations of carbon dioxide and other greenhouse gases may affect species and ecosystems.

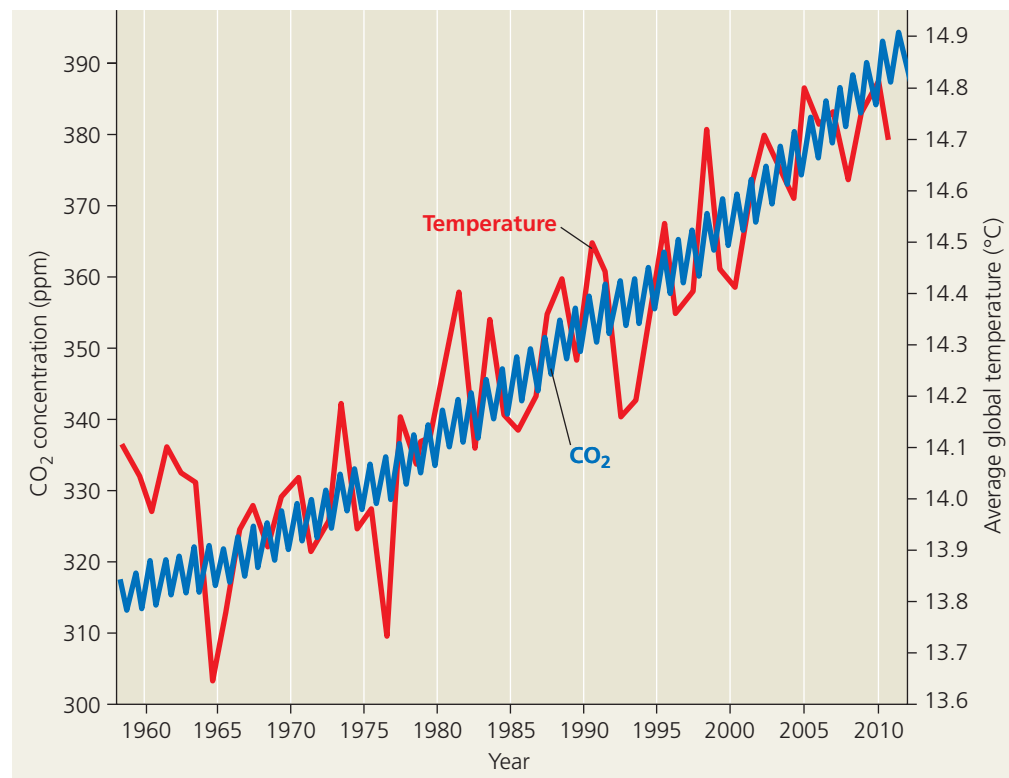
Since the Industrial Revolution, the concentration of CO_2 in the atmosphere has been increasing as a result of the burning of fossil fuels and deforestation. Scientists estimate that the average CO_2 concentration in the atmosphere before 1850 was

about 274 ppm. In 1958, a monitoring station began taking very accurate measurements on Hawaii's Mauna Loa peak, a location far from cities and high enough for the atmosphere to be well mixed. At that time, the CO_2 concentration was 316 ppm (**Figure 43.26**). Today, it exceeds 390 ppm, an increase of more than 40% since the mid-19th century. In the **Scientific Skills Exercise**, you can graph and interpret changes in CO_2 concentration that occur during the course of a year and over longer periods.

The marked increase in the concentration of atmospheric CO_2 over the last 150 years concerns scientists because

► **Figure 43.26 Increase in atmospheric carbon dioxide concentration at Mauna Loa, Hawaii, and average global temperatures.**

Aside from normal seasonal fluctuations, the CO₂ concentration (blue curve) has increased steadily from 1958 to 2011. Though average global temperatures (red curve) fluctuated a great deal over the same period, there is a clear warming trend.



Scientific Skills Exercise

Graphing Cyclic Data

How Does the Atmospheric CO₂ Concentration Change

During a Year and from Decade to Decade? The blue curve in Figure 43.26 shows how the concentration of CO₂ in Earth's atmosphere has changed over a span of more than 50 years. For each year in that span, two data points are plotted, one in May and one in November. A more detailed picture of the change in CO₂ concentration can be obtained by looking at measurements made at more frequent intervals. In this exercise, you'll graph monthly CO₂ concentrations for three years over three decades.


Data from the Study The data in the table below are average CO₂ concentrations (in parts per million) at the Mauna Loa monitoring station for each month in 1990, 2000, and 2010.

Month	1990	2000	2010
January	353.79	369.25	388.45
February	354.88	369.50	389.82
March	355.65	370.56	391.08
April	356.27	371.82	392.46
May	359.29	371.51	392.95
June	356.32	371.71	392.06
July	354.88	369.85	390.13
August	352.89	368.20	388.15
September	351.28	366.91	386.80
October	351.59	366.91	387.18
November	353.05	366.99	388.59
December	354.27	369.67	389.68

Interpret the Data

1. Plot the data for all three years on one graph. Select a type of graph that is appropriate for these data, and choose a vertical-axis scale that allows you to clearly see the patterns of CO₂ concentration changes, both during each year and from decade to decade. (For additional information about graphs, see the Scientific Skills Review in Appendix F and in the Study Area in MasteringBiology.)
2. Within each year, what is the pattern of change in CO₂ concentration? Why does this pattern occur?
3. The measurements taken at Mauna Loa represent average atmospheric CO₂ concentrations for the Northern Hemisphere. Suppose you could measure CO₂ concentrations under similar conditions in the Southern Hemisphere. What pattern would you expect to see in those measurements over the course of a year? Explain.
4. In addition to the changes within each year, what changes in CO₂ concentration occurred between 1990 and 2010? Calculate the average CO₂ concentration for the 12 months of each year. By what percentage did this average change from 1990 to 2000 and from 1990 to 2010?

Data from National Oceanic & Atmospheric Administration, Earth System Research Laboratory, Global Monitoring Division

 A version of this Scientific Skills Exercise can be assigned in MasteringBiology.

of its link to increased global temperature. Much of the solar radiation that strikes the planet is reflected back into space. Although CO₂, methane, water vapor, and other gases in the atmosphere are transparent to visible light, they intercept and absorb much of the infrared radiation Earth emits, re-reflecting some of it back toward Earth. This process retains some of the solar heat. If it were not for this **greenhouse effect**, the average air temperature at Earth's surface would be a frigid −18°C (−0.4°F), and most life as we know it could not exist.

For more than a century, scientists have studied how greenhouse gases warm Earth and how fossil fuel burning could contribute to the warming. Most scientists are convinced that such warming is already occurring and will increase rapidly this century (see Figure 43.26). Global models predict that by the end of the 21st century, the atmospheric CO₂ concentration will have more than doubled, increasing average global temperature by about 3°C (5°F).

Supporting these models is a correlation between CO₂ levels and temperatures in prehistoric times. One way climatologists estimate past CO₂ concentrations is to measure CO₂ levels in bubbles trapped in glacial ice, some of which are 700,000 years old. Prehistoric temperatures are inferred by several methods, including analysis of past vegetation based on fossils and the chemical isotopes in sediments and corals. An increase of only 1.3°C would make the world warmer than at any time in the past 100,000 years. A warming trend would also alter the geographic distribution of precipitation, likely making agricultural areas of the central United States much drier, for example.

The ecosystems where the largest warming has *already* occurred are those in the far north, particularly northern coniferous forests and tundra. As snow and ice melt and uncover darker, more absorptive surfaces, these systems reflect less radiation back to the atmosphere and warm further. Arctic sea ice in the summer of 2007 covered the smallest area on record. Climate models suggest that there may be no summer ice there within a few decades, decreasing habitat for polar bears, seals, and seabirds. Higher temperatures also increase the likelihood of fires. In boreal forests of western North America and Russia, fires have burned twice the usual area in recent decades.

Range Shifts and Climate Change

Many organisms, especially plants that cannot disperse rapidly over long distances, may not be able to survive the rapid climate change projected to result from global warming. Furthermore, many habitats today are more fragmented than ever (see Concept 43.3), further limiting the ability of many organisms to migrate.

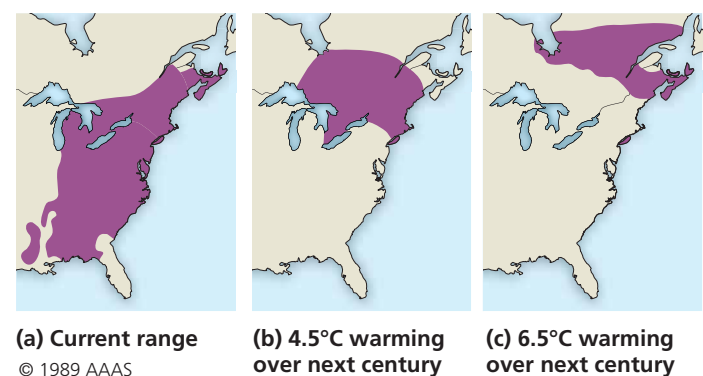
One way to predict the possible effects of future climate change on geographic ranges is to look back at the changes that have occurred in temperate regions since the last ice age ended. Until about 16,000 years ago, continental glaciers covered much of North America and Eurasia. As the climate

warmed and the glaciers retreated, tree distributions expanded northward. A detailed record of these changes is captured in fossil pollen deposited in lakes and ponds. (Recall from Chapter 26 that wind and animals sometimes disperse pollen and seeds over great distances.) If researchers can determine the climatic limits of current distributions of organisms, they can make predictions about how those distributions may change with continued climatic warming.

A fundamental question when applying this approach to plants is whether seeds can disperse quickly enough to sustain the range shift of each species as climate changes. Fossil pollen shows that species with winged seeds that disperse relatively far from a parent tree, such as the sugar maple (*Acer saccharum*), expanded rapidly into the northeastern United States and Canada after the last ice age ended. In contrast, the northward range expansion of the eastern hemlock (*Tsuga canadensis*), whose seeds lack wings, was delayed nearly 2,500 years compared with the shift in suitable habitat.

Will plants and other species be able to keep up with the much more rapid warming projected for this century? Ecologists have attempted to answer this question for the American beech (*Fagus grandifolia*). Their models predict that the northern limit of the beech's range may move 700–900 km northward in the next century, and its southern range limit will shift even more. The current and predicted geographic ranges of this species under two different climate-change scenarios are illustrated in **Figure 43.27**. If these predictions are even approximately correct, the beech's range must shift 7–9 km northward per year to keep pace with the warming climate. However, since the end of the last ice age, the beech has moved at a rate of only 0.2 km per year. Without human help in moving to new habitats, species such as the American beech may have much smaller ranges or even become extinct.

Changes in the distributions of species are already evident in many well-studied groups of terrestrial, marine, and freshwater organisms, consistent with the signature of a warmer world. In Europe, for instance, the northern range limits of



▲ Figure 43.27 Current range and predicted range for the American beech under two climate-change scenarios.

? The predicted range in each scenario is based on climate factors alone. What other factors might alter the distribution of this species?

22 of 35 butterfly species studied had shifted farther north by 35–240 km over the time periods for which records exist, in some cases beginning in 1900. Other research shows that a Pacific diatom, *Neodenticula seminae*, recently has colonized the Atlantic Ocean for the first time in 800,000 years. As Arctic sea ice has receded in the past decade, the increased flow of water from the Pacific has swept these diatoms around Canada and into the Atlantic, where they quickly became established.

Climate Change Solutions

We will need a variety of approaches to slow global warming and climate change in general. Quick progress can be made by using energy more efficiently and by replacing fossil fuels with renewable solar and wind power and, more controversially, with nuclear power. Today, coal, gasoline, wood, and other organic fuels remain central to industrialized societies and cannot be burned without releasing CO₂. Stabilizing CO₂ emissions will require concerted international effort and changes in both personal lifestyles and industrial processes.

Another important approach to slowing global warming is to reduce deforestation around the world, particularly in the tropics. Deforestation currently accounts for about 12% of greenhouse gas emissions. Recent research shows that paying countries *not* to cut forests could decrease the rate of deforestation by half within 10 to 20 years. Reduced deforestation would not only slow the buildup of greenhouse gases in our atmosphere but sustain native forests and preserve biodiversity, a positive outcome for all.

CONCEPT CHECK 43.4

1. How can the addition of excess mineral nutrients to a lake threaten its fish population?
2. **MAKE CONNECTIONS** There are vast stores of organic matter in the soils of northern coniferous forests and tundra around the world. Suggest an explanation for why scientists who study global warming are closely monitoring these stores (see Figure 42.12).

For suggested answers, see Appendix A.

CONCEPT 43.5

The human population is no longer growing exponentially but is still increasing rapidly

Global environmental problems, such as climate change, arise from the intersection of two factors. One is the growing amount of goods and resources that each of us consumes. The other is the increasing size of the human population, which has grown at an unprecedented rate in the last few centuries. No population can grow indefinitely, however. In this section,

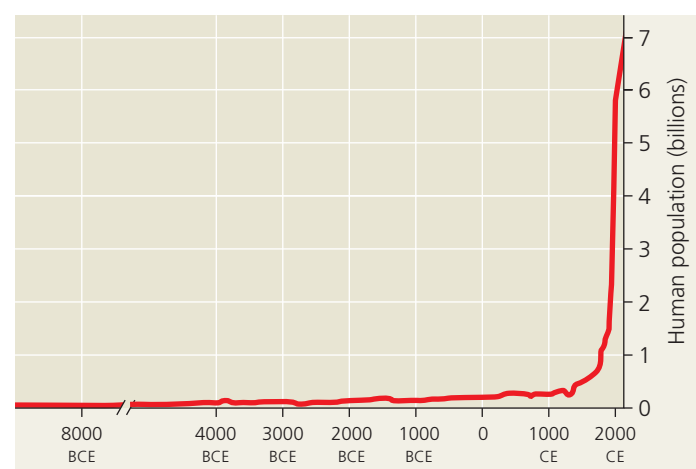
we'll apply ecological concepts to the specific case of the human population.

The Global Human Population

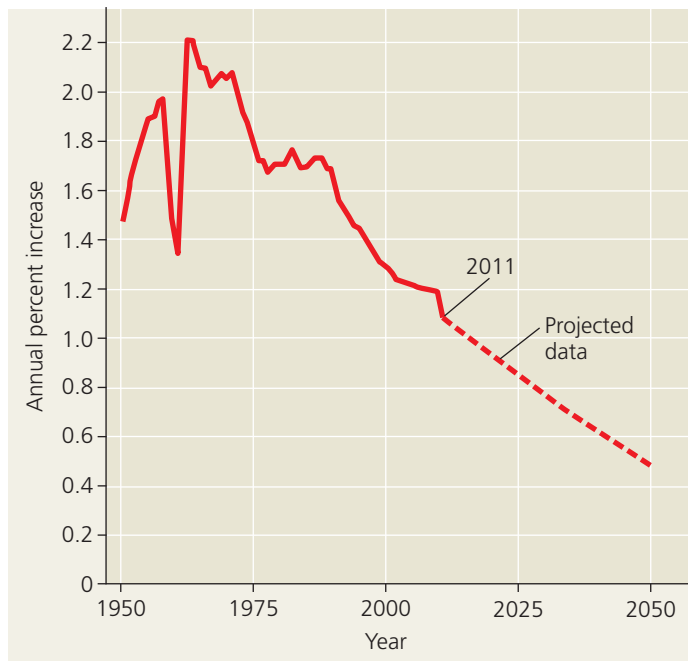
The exponential growth model (see Figure 40.19) approximates the human population explosion over the last four centuries (**Figure 43.28**). Ours is a singular case; no other population of large animals has likely ever sustained so much growth for so long. The human population increased relatively slowly until about 1650, at which time approximately 500 million people inhabited Earth. Our population doubled to 1 billion within the next two centuries, doubled again to 2 billion by 1930, and doubled still again by 1975 to more than 4 billion. The global population is now more than 7 billion and is increasing by about 78 million each year. At this rate, it takes only about four years to add the equivalent of another United States to the world population. Ecologists predict a population of 8.1–10.6 billion people on Earth by the year 2050.

Though the global population is still growing, the *rate* of growth did begin to slow during the 1960s (**Figure 43.29**). The annual rate of increase in the global population peaked at 2.2% in 1962 but had declined to 1.1% by 2011. Current models project a continued decline in the annual growth rate to roughly 0.5% by 2050, a rate that would still add 45 million more people per year if the population climbs to a projected 9 billion. The reduction in growth rate over the past four decades shows that the human population has departed from true exponential growth, which assumes a constant rate. This departure is the result of fundamental changes in population dynamics due to diseases, including AIDS, and to voluntary population control.

The growth rates of individual nations vary with their degree of industrialization. In industrialized nations, populations are



▲ Figure 43.28 Human population growth (data as of 2011). The global human population has grown almost continuously throughout history, but it skyrocketed after the Industrial Revolution. The rate of population growth has slowed in recent decades, mainly as a result of decreased birth rates throughout the world.



▲ **Figure 43.29 Annual percent increase in the global human population (data as of 2011).** The sharp dip in the 1960s is due mainly to a famine in China in which about 60 million people died.

near equilibrium, with growth rates of about 0.1% per year and reproductive rates near the replacement level (total fertility rate = 2.1 children per female). In countries such as Canada, Germany, Japan, and the United Kingdom, total reproductive rates are in fact *below* replacement. These populations will eventually decline if there is no immigration and if the birth rate does not change. In fact, the population is already declining in many eastern and central European countries.

In contrast, most of the current global population growth of 1.1% per year is concentrated in less industrialized nations, where about 80% of the world's people now live. Countries such as Afghanistan, Uganda, and Jordan had populations that grew by more than 3% *per year* between 2005 and 2010. Although death rates have declined rapidly since 1950 in many less industrialized countries, birth rates have declined substantially in only some of them. The fall in birth rate has been most dramatic in China. Largely because of the Chinese government's strict one-child policy, the expected total fertility rate (children per woman per lifetime) decreased from 5.9 in 1970 to 1.6 in 2011. The transition to lower birth rates has also been rapid in some African countries, though birth rates remain high in most of sub-Saharan Africa. In India, birth rates have fallen more slowly.

A unique feature of human population growth is our ability to control family sizes using family planning and voluntary contraception. Social change and the rising educational and career aspirations of women in many cultures encourage women to delay marriage and postpone reproduction. Delayed reproduction helps to decrease population growth rates and to

move a society toward zero population growth under conditions of low birth rates and low death rates. However, there is a great deal of disagreement as to how much support should be provided for global family planning efforts.

Global Carrying Capacity

No ecological question is more important than the future size of the human population. The projected worldwide population size depends on assumptions about future changes in birth and death rates. As we noted earlier, population ecologists project a global population of approximately 8.1–10.6 billion people in 2050. In other words, without some catastrophe, an estimated 1–4 billion people will be added to the population in the next four decades because of the momentum of population growth. But just how many humans can the biosphere support? Will the world be overpopulated in 2050? Is it *already* overpopulated?

Estimates of Carrying Capacity

Estimates of the human carrying capacity of Earth have varied from less than 1 billion to more than 1,000 billion (1 trillion), with an average of 10–15 billion. Carrying capacity is difficult to estimate, and scientists use different methods to produce their estimates. Some current researchers use curves like that produced by the logistic equation (see Figure 40.19) to predict the future maximum of the human population. Others generalize from existing “maximum” population density and multiply this number by the area of habitable land. Still others base their estimates on a single limiting factor, such as food, and consider variables such as the amount of available farmland, the average yield of crops, the prevalent diet—vegetarian or meat based—and the number of calories needed per person per day.

Limits on Human Population Size

A more comprehensive approach to estimating the carrying capacity of Earth is to recognize that humans have multiple constraints: We need food, water, fuel, building materials, and other resources, such as clothing and transportation. The **ecological footprint** concept summarizes the aggregate land and water area required by each person, city, or nation to produce all the resources it consumes and to absorb all the waste it generates. One way to estimate the ecological footprint of the entire human population is to add up all the ecologically productive land on the planet and divide by the population. This calculation yields approximately 2 ha per person (1 ha = 2.47 acres). Reserving some land for parks and conservation means reducing this allotment to 1.7 ha per person—the benchmark for comparing actual ecological footprints. Anyone who consumes resources that require more than 1.7 ha to produce is said to be using an unsustainable share of Earth's resources. A typical ecological footprint for a person in the United States is about 10 ha.

Ecologists sometimes calculate ecological footprints using other currencies besides land area, such as energy use. Average energy use differs greatly in developed and developing nations (**Figure 43.30**). A typical person in the United States, Canada, or Norway consumes roughly 30 times the energy that a person in central Africa does. Moreover, fossil fuels, such as oil, coal, and natural gas, are the source of 80% or more of the energy used in most developed nations. This unsustainable reliance on fossil fuels is changing Earth's climate and increasing the amount of waste that each of us produces. Ultimately, the combination of resource use per person and population density determines our global ecological footprint.

How many people our planet can sustain depends on the quality of life each of us enjoys and the distribution of wealth across people and nations, topics of great concern and political debate. Unlike other organisms, we can decide whether zero population growth will be attained through social changes based on human choices or, instead, through increased mortality due to resource limitation, plagues, war, and environmental degradation.

CONCEPT CHECK 43.5

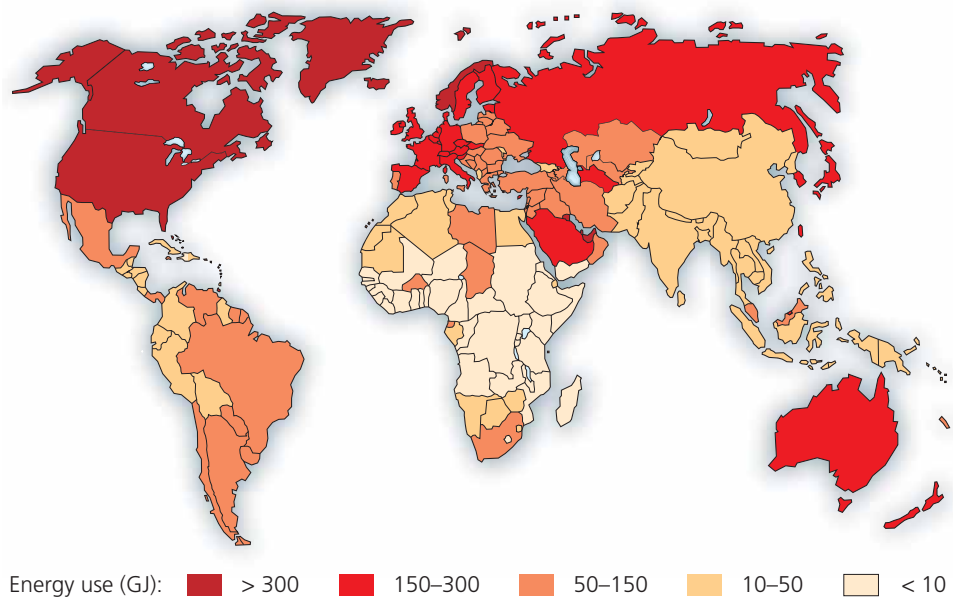
1. How has the growth of Earth's human population changed in recent decades? Answer in terms of growth rate and the number of people added each year.
2. **WHAT IF?** What choices can you make to influence your own ecological footprint?

For suggested answers, see Appendix A.

CONCEPT 43.6

Sustainable development can improve human lives while conserving biodiversity

With the loss and fragmentation of habitats, changes in Earth's physical environment and climate, and increasing human population, we face difficult trade-offs in managing the world's resources. Preserving all habitat patches isn't feasible, so biologists must help societies set conservation priorities by identifying which habitat patches are most crucial. Ideally, implementing these priorities should also improve the quality of life for local people. Ecologists use the concept of *sustainability* as a tool to establish long-term conservation priorities.



▲ Figure 43.30 Annual per capita energy use around the world. A gigajoule (GJ) equals 10^9 J. For comparison, leaving a 100-watt light bulb on continuously for one year would use 3.15 GJ.

Sustainable Development

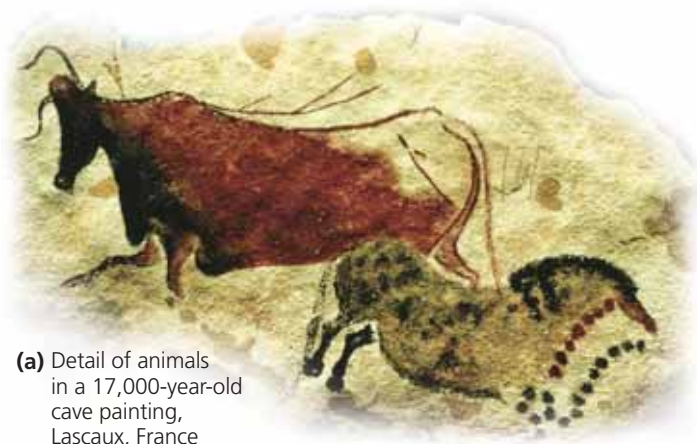
We need to understand the interconnections of the biosphere if we are to protect species from extinction and improve the quality of human life. To this end, many nations, scientific societies, and other groups have embraced the concept of **sustainable development**, economic development that meets the needs of people today without limiting the ability of future generations to meet their needs.

Achieving sustainable development is an ambitious goal. To sustain ecosystem processes and stem the loss of biodiversity, we must connect life science with the social sciences, economics, and the humanities. We must also reassess our personal values. As you learned in Concept 43.5, those of us living in developed nations have a larger ecological footprint than do people living in developing nations. By including the long-term costs of consumption in profit-and-loss calculations, we can learn to value the natural processes that sustain us. The following case study illustrates how the combination of scientific and personal efforts can make a significant difference in creating a truly sustainable world.

Case Study: Sustainable Development in Costa Rica

The success of conservation in Costa Rica that we discussed in Concept 43.3 has required a partnership between the national government, nongovernment organizations (NGOs), and private citizens. Many nature reserves established by individuals have been recognized by the government as national wildlife reserves and given significant tax benefits. However, conservation and restoration of biodiversity make up only one facet of sustainable development; the other key facet is improving the human condition.

How have the living conditions of the Costa Rican people changed as the country has pursued its conservation goals? Two of the most fundamental indicators of living conditions are infant mortality rate and life expectancy. From 1930 to 2010, the infant mortality rate in Costa Rica declined from 170 to 9 per 1,000 live births; over the same period, life expectancy increased from about 43 years to 79 years. Another indicator of living conditions is the literacy rate, which was 96% in 2011, compared to 97% in the United States. Such statistics show that living conditions in Costa Rica have improved greatly over the period in which the country has dedicated itself to conservation and restoration. While this result does not prove that conservation *causes* an improvement in human welfare, we can say with certainty that development in Costa Rica has attended to both nature *and* people.



▲ **Figure 43.31** Biophilia, past and present.

The Future of the Biosphere

Our modern lives are very different from those of early humans, who hunted and gathered to survive. Their reverence for the natural world is evident in the early murals of wildlife they painted on cave walls (**Figure 43.31a**) and in the stylized visions of life they sculpted from bone and ivory (**Figure 43.31b**).

Our lives reflect remnants of our ancestral attachment to nature and the diversity of life—the concept of *biophilia* that was introduced early in this chapter. We evolved in natural environments rich in biodiversity, and we still have an affinity for such settings (**Figure 43.31c, d**). E. O. Wilson makes the case that our biophilia is innate, an evolutionary product of natural selection acting on a brainy species whose survival depended on a close connection to the environment and a practical appreciation of plants and animals.

Our appreciation of life guides the field of biology today. We celebrate life by deciphering the genetic code that makes each species unique. We embrace life by using fossils and DNA to chronicle evolution through time. We preserve life through our efforts to classify and protect the millions of species on Earth. We respect life by using nature responsibly and reverently to improve human welfare.

Biology is the scientific expression of our desire to know nature. We are most likely to protect 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 ourselves and our place in the biosphere. We hope this book has served you well in this lifelong adventure.

CONCEPT CHECK 43.6

1. What is meant by the term *sustainable development*?
2. How might biophilia inspire us to conserve species and restore ecosystems?
3. **WHAT IF?** Suppose a new fishery is discovered, and you are put in charge of developing it sustainably. What ecological data might you want on the fish population? What criteria would you apply for the fishery's development?

For suggested answers, see Appendix A.

- (d) A young biologist holding a songbird



43 Chapter Review

SUMMARY OF KEY CONCEPTS

CONCEPT 43.1

Human activities threaten Earth's biodiversity (pp. 883–888)

- Biodiversity can be considered at three main levels:



- Our biophilia enables us to recognize the value of biodiversity for its own sake. Other species also provide humans with food, fiber, medicines, and **ecosystem services**.
- Four major threats to biodiversity are habitat loss, **introduced species**, overharvesting, and global change.

? Give at least three examples of key ecosystem services that nature provides for people.

CONCEPT 43.2

Population conservation focuses on population size, genetic diversity, and critical habitat (pp. 888–891)

- When a population drops below a **minimum viable population (MVP)** size, its loss of genetic variation due to nonrandom mating and genetic drift can trap it in an **extinction vortex**.
- The declining-population approach focuses on the environmental factors that cause decline, regardless of absolute population size. It follows a step-by-step conservation strategy.
- Conserving species often requires resolving conflicts between the habitat needs of **endangered species** and human demands.

? Why is the minimum viable population size smaller for a population that is more genetically diverse than it is for a less genetically diverse population?

CONCEPT 43.3

Landscape and regional conservation help sustain biodiversity (pp. 891–895)

- The structure of a landscape can strongly influence biodiversity. As habitat fragmentation increases and edges become more extensive, biodiversity tends to decrease. **Movement corridors** can promote dispersal and help sustain populations.
- Biodiversity hot spots** are also hot spots of extinction and thus prime candidates for protection. Sustaining biodiversity in parks and reserves requires management to ensure that human activities in the surrounding landscape do not harm the protected habitats. The **zoned reserve** model recognizes that conservation efforts often involve working in landscapes that are greatly affected by human activity.

? Give two examples that show how habitat fragmentation can harm species in the long term.

CONCEPT 43.4

Earth is changing rapidly as a result of human actions (pp. 895–900)

- Agriculture removes plant nutrients from ecosystems, so large supplements are usually required. The nutrients in fertilizer can pollute groundwater and surface water, where they can stimulate excess algal growth (eutrophication).
- The release of toxic wastes has polluted the environment with harmful substances that often persist for long periods and become increasingly concentrated in successively higher trophic levels of food webs (**biological magnification**).
- Because of the burning of wood and fossil fuels and other human activities, the atmospheric concentration of CO₂ and other greenhouse gases has been steadily increasing. The ultimate effects include significant global warming and other changes in climate.

? In the face of biological magnification of toxins, is it healthier to feed at a lower or higher trophic level? Explain.

CONCEPT 43.5

The human population is no longer growing exponentially but is still increasing rapidly (pp. 900–902)

- Since about 1650, the global human population has grown exponentially, but within the last 50 years, the rate of growth has fallen by half. While some nations' populations are growing rapidly, those of others are stable or declining in size.
- The carrying capacity of Earth for humans is uncertain. **Ecological footprint** is the aggregate land and water area needed to produce all the resources a person or group of people consume and to absorb all of their wastes. It is one measure of how close we are to the carrying capacity of Earth. With a world population of more than 7 billion people, we are already using many resources in an unsustainable manner.

? How are we humans different from other species in being able to "choose" a carrying capacity?

CONCEPT 43.6

Sustainable development can improve human lives while conserving biodiversity (pp. 902–903)

- The goal of the Sustainable Biosphere Initiative is to acquire the ecological information needed for the development, management, and conservation of Earth's resources.
- Costa Rica's success in conserving tropical biodiversity has involved a partnership between the government, other organizations, and private citizens. Human living conditions in Costa Rica have improved along with ecological conservation.
- By learning about biological processes and the diversity of life, we become more aware of our close connection to the environment and the value of other organisms that share it.

? *Why is sustainability such an important goal for conservation biologists?*

TEST YOUR UNDERSTANDING

Level 1: Knowledge/Comprehension

1. One characteristic that distinguishes a population in an extinction vortex from most other populations is that
 - a. its habitat is fragmented.
 - b. it is a rare, top-level predator.
 - c. its effective population size is much lower than its total population size.
 - d. its genetic diversity is very low.
 - e. it is not well adapted to edge conditions.
2. The main cause of the increase in the amount of CO₂ in Earth's atmosphere over the past 150 years is
 - a. increased worldwide primary production.
 - b. increased worldwide standing crop.
 - c. an increase in the amount of infrared radiation absorbed by the atmosphere.
 - d. the burning of larger amounts of wood and fossil fuels.
 - e. additional respiration by the rapidly growing human population.
3. What is the single greatest threat to biodiversity?
 - a. overharvesting of commercially important species
 - b. introduced species that compete with native species
 - c. pollution of Earth's air, water, and soil
 - d. disruption of trophic relationships as more and more prey species become extinct
 - e. habitat alteration, fragmentation, and destruction

Level 2: Application/Analysis

4. Which of the following is a consequence of biological magnification?
 - a. Toxic chemicals in the environment pose greater risk to top-level predators than to primary consumers.
 - b. Populations of top-level predators are generally smaller than populations of primary consumers.
 - c. The biomass of producers in an ecosystem is generally higher than the biomass of primary consumers.
 - d. Only a small portion of the energy captured by producers is transferred to consumers.
 - e. The amount of biomass in the producer level of an ecosystem decreases if the producer turnover time increases.
5. Which of the following strategies would most rapidly increase the genetic diversity of a population in an extinction vortex?
 - a. Capture all remaining individuals in the population for captive breeding followed by reintroduction to the wild.
 - b. Establish a reserve that protects the population's habitat.

- c. Introduce new individuals transported from other populations of the same species.
 - d. Sterilize the least fit individuals in the population.
 - e. Control populations of the endangered population's predators and competitors.
6. Of the following statements about protected areas that have been established to preserve biodiversity, which one is *not* correct?
 - a. About 25% of Earth's land area is now protected.
 - b. National parks are one of many types of protected areas.
 - c. Most protected areas are too small to protect species.
 - d. Management of a protected area should be coordinated with management of the land surrounding the area.
 - e. It is especially important to protect biodiversity hot spots.

Level 3: Synthesis/Evaluation

7. **DRAW IT** Using Figure 43.26 as a starting point, extend the x -axis to the year 2100. Then extend the CO₂ curve, assuming that the CO₂ concentration continues to rise as fast as it did from 1974 to 2011. What will be the approximate CO₂ concentration in 2100? What ecological factors and human decisions will influence the actual rise in CO₂ concentration? How might additional scientific data help societies predict this value?
8. **SCIENTIFIC INQUIRY**
DRAW IT Suppose that you are managing a forest reserve, and one of your goals is to protect local populations of woodland birds from parasitism by the brown-headed cowbird. You know that female cowbirds usually do not venture more than about 100 m into a forest and that nest parasitism is reduced when woodland birds nest away from forest edges. The reserve you manage extends about 6,000 m from east to west and 1,000 m from north to south. It is surrounded by a deforested pasture on the west, an agricultural field for 500 m in the southwest corner, and intact forest everywhere else. You must build a road, 10 m by 1,000 m, from the north to the south side of the reserve and construct a maintenance building that will take up 100 m² in the reserve. Draw a map of the reserve, showing where you would put the road and the building to minimize cowbird intrusion along edges. Explain your reasoning.
9. **FOCUS ON EVOLUTION**
One factor favoring rapid population growth by an introduced species is the absence of the predators, parasites, and pathogens that controlled its population in the region where it evolved. In a short essay (100–150 words), explain how evolution by natural selection would influence the rate at which native predators, parasites, and pathogens in a region of introduction attack an introduced species.
10. **FOCUS ON INTERACTIONS**
In a short essay (100–150 words), identify the factor or factors that you think may ultimately be most important in regulating the human population, and explain your reasoning.

For selected answers, see Appendix A.

MasteringBiology®

Students Go to **MasteringBiology** for assignments, the eText, and the Study Area with practice tests, animations, and activities.

Instructors Go to **MasteringBiology** for automatically graded tutorials and questions that you can assign to your students, plus Instructor Resources.

