Chapter 56

Conservation Biology and Global Change

Lecture Outline

Overview: Striking Gold

- Scientists have described and formally 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.
- Some of the greatest concentrations of species are found in the tropics. Unfortunately, tropical forests are being cleared at an alarming rate.
- Throughout the biosphere, human activities are altering trophic structures, energy flow, chemical cycling, and natural disturbance.
  - The amount of human-altered land surface is approaching 50%, and humans use more than half of the accessible surface fresh water.
  - In the oceans, stocks of most major fisheries are shrinking because of overharvesting.
- Biology is the study of life. Conservation biology is a discipline that seeks to preserve life.
  - **Conservation biology** integrates ecology, physiology, molecular biology, genetics, and evolutionary biology to conserve biological diversity at all levels.

Concept 56.1 Human activities threaten Earth's biodiversity

- Extinction is a natural phenomenon that has been occurring since life evolved on Earth.
  - The current high *rate* of extinction is what underlies the biodiversity crisis.

The three levels of biodiversity are genetic diversity, species diversity, and ecosystem diversity.

- Genetic diversity comprises not only the individual genetic variation *within* a population but also genetic variation *between* populations associated with adaptations to local conditions.
  - If a local population becomes extinct, then the entire population of that species has lost some of the genetic diversity that makes microevolution possible.
  - The loss of this diversity is detrimental to the overall adaptive potential of the species.
- Species diversity is the variety of species in an ecosystem or throughout the entire biosphere.
  - Much of the discussion of the biodiversity crisis centers on species.
- The U.S. Endangered Species Act (ESA) defines an **endangered species** as one that is "in danger of extinction throughout all or a significant portion of its range," and a **threatened species** as one likely to become endangered in the foreseeable future.
- Here are some reasons conservation biologists are concerned about species loss.

- The International Union for Conservation of Natural Resources (IUCN) reports that 12% of nearly 10,000 known bird species and 20% of nearly 5,000 known mammal species are threatened with extinction.
- The Center for Plant Conservation estimates that 200 of the 20,000 known plant species in the United States have become extinct since records have been kept, and another 730 are endangered or threatened.
- About 20% of the known freshwater species of fish in the world have become extinct or are seriously threatened.
- Since 1900, 123 freshwater animal species have become extinct in North America, and hundreds more are threatened. The extinction rate for North American freshwater fauna is about five times as high as that for terrestrial animals.
- Of all known amphibian species, 32% are either very near extinction or endangered.

- Extinction of species may be local, when a species is lost in one area but survives in an adjacent one; global extinction means that a species is lost from *all* its locales.
- Ecosystem diversity involves the variety of the biosphere's ecosystems.
- The local extinction of one species, especially a keystone predator, can affect an entire community.
    - For example, bats called "flying foxes" are important pollinators and seed dispersers in the Pacific Islands, where they face severe hunting pressure.
    - Extinction of the bats will harm the native Samoan plants, 79% of which depend on the bats for pollination or seed dispersal.
- Some ecosystems are being altered at a rapid pace.
    - Within the contiguous United States, more than 50% of wetlands have been drained and converted to other ecosystems, primarily agricultural.
    - In California, Arizona, and New Mexico, 90% of native riparian communities have been affected by overgrazing, flood control, water diversions, lowering of water tables, and invasion by nonnative plants.

Biodiversity at all three levels is vital to human welfare.

- Why should we care about biodiversity?
- One reason is what 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 for the preservation of biodiversity.
    - 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."
- Biodiversity is a crucial natural resource: Species that are threatened could provide crops, fibers, and medicines for human use.
    - 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.
- Plant breeders responded to devastating outbreaks viral disease in rice (*Oryza sativa*) by screening 7,000 populations of this species and its close relatives for resistance.
    - 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, 25% of all prescriptions dispensed from pharmacies contain substances originally derived from plants.
    - In the 1970s, alkaloids that inhibit cancer cell growth were extracted from the rosy periwinkle, a plant growing on the island of Madagascar.
    - This discovery led to effective treatments for two deadly forms of cancer, Hodgkin's disease and a form of childhood leukemia.
- The loss of species also means the loss of unique genes that may code for useful proteins.
    - The polymerase chain reaction is based on the enzyme Taq polymerase, extracted from thermophilic prokaryotes from hot springs.
    - Corporations are using DNA extracted from prokaryotes in hot springs and other extreme environments to mass-produce useful enzymes for new medicines, foods, petroleum substitutes, industrial chemicals, and other products.
- Because millions of species may become extinct before we even know about them, we will lose the valuable genetic potential held in their unique libraries of genes.
- Humans evolved in Earth's ecosystems, and we are finely adjusted to these systems.
- **Ecosystem services** encompass all the processes through which natural ecosystems and the species they contain help sustain human life on Earth. These services include:

    Purification of air and water
    Reduction of the severity of droughts and floods
    Generation and preservation of fertile soils
    Detoxification and decomposition of wastes
    Pollination of crops and natural vegetation
    Dispersal of seeds
    Cycling of nutrients
    Control of agricultural pests by natural enemies
    Protection of shorelines from erosion
    Protection from ultraviolet rays
- In a controversial 1997 article, 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 that time.
- The functioning of ecosystems and, hence, their capacity to perform particular services are linked to biodiversity.

The four major threats to biodiversity are habitat loss, introduced species, overharvesting, and global change.

- Human alteration of habitat is the single greatest threat to biodiversity throughout the biosphere.
    - Loss of habitat has been brought about by agriculture, urban development, forestry, mining, and pollution.
    - Global climate change is already altering habitats today, and its impact will increase.
    - When no alternative habitat is available or when a species is unable to move, habitat loss may mean extinction.

- The IUCN states that destruction of physical habitat is responsible for the 73% of species designated extinct, endangered, vulnerable, or rare.
- Habitat destruction may occur over immense regions.
  - Approximately 98% of the tropical dry forests of Central America and Mexico have been cut down.
  - Many natural landscapes have been broken up, fragmenting habitats into small patches.
  - Forest fragmentation is occurring at a rapid rate in tropical forests.
- In almost all cases, habitat fragmentation leads to species loss, because the smaller populations in habitat fragments have a higher probability of local extinction.
  - The prairies of southern Wisconsin now occupy less than 0.1% of the 800,000 hectares they covered when the Europeans arrived in North America.
  - Between 1948 and 1988, the remaining prairie remnants lost 8–60% of their plant species.
- Habitat loss is a major threat to aquatic biodiversity, especially on continental coasts and coral reefs.
  - About 93% of the world's coral reefs have been damaged by human activities.
  - At the present rate of destruction, 40–50% of the reefs, home to one-third of marine fish species, will be lost in the next 30–40 years.
- Aquatic habitat destruction and species loss also result from dams, reservoirs, channel modification, and flow regulation affecting most of the world's rivers.
  - By changing river depth and flow, more than 30 dams and locks built along the Mobile River basin in the southeastern United States helped drive more than 40 species of endemic mussels and snails extinct.
- **Introduced species**, also called nonnative or exotic species, are those that humans move, intentionally or accidentally, from native locations to new geographic regions.
  - Human 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, transplanted species may spread rapidly through a new region.
- Some introduced species disrupt their adopted community, often by preying on native organisms or outcompeting native species for resources.
- After World War II, the brown tree snake was accidentally introduced to the island of Guam, which had no native snakes.
  - Since then, 12 species of birds and 6 species of lizards have become extinct due to predation by the brown tree snake.
- The devastating zebra mussel was accidentally introduced into the Great Lakes of North America in 1988, most likely in the ballast water of ships arriving from Europe.
  - Zebra mussels are feeder-feeders that form dense colonies. They have extensively disrupted freshwater ecosystems, threatening native aquatic species.
  - Zebra mussels have clogged water-intake structures, disrupting domestic and industrial water supplies and causing billions of dollars in damage.
- Humans have introduced many species deliberately, often with disastrous results.
  - An Asian plant called kudzu, introduced in the southern United States to help control erosion, has taken over large areas of the landscape.

- The European starling was introduced intentionally into New York City's Central Park by a group introducing all the plants and animals mentioned in Shakespeare's plays.
- Starling populations in North America now exceed 100 million, and they have displaced many native songbirds.

- Introduced species contribute to approximately 40% of the extinctions recorded since 1750 and cost billions of dollars annually in damage and control efforts.
  - There are more than 50,000 introduced species in the United States alone.
- *Overharvesting* is the human harvesting of wild plants and animals at rates that exceed the ability of those populations to rebound.
- Species with restricted habitats, such as small islands, are particularly vulnerable to overharvesting.
  - The great auk, a large, flightless seabird living on islands in the North Atlantic Ocean, was overhunted for its feathers, eggs, and meat, and became extinct in the 1840s.
- Large organisms with low intrinsic reproductive rates are also susceptible to overharvesting.
  - The African elephant has been overhunted largely due to the ivory trade.
  - Elephant populations have declined dramatically for the past 50 years.
  - Despite a ban on the sale of new ivory, poaching continues in central and east Africa.
- Conservation biologists use molecular genetics to track the origin of tissues harvested from threatened or endangered species.
  - Researchers at the University of Washington created a DNA reference map for the African elephant using DNA isolated from dung.
  - By comparing this reference map to DNA isolated from a small sample of ivory harvested either legally or by poachers, they can determine where the elephant was killed to within a few hundred kilometers.
- The fate of the North Atlantic bluefin tuna illustrates the overfishing of what was thought to be an inexhaustible resource.
  - This big tuna brings up to $100 per pound in Japan, where it is used for sushi and sashimi.
  - With this demand, it took just ten years to reduce North American bluefin populations to 20% of their 1980 levels.
- The collapse of the northern cod fishery off Newfoundland in the 1990s shows that it is possible to overharvest what had been a very common species.
- The fourth threat to biodiversity, **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 global change factors to cause concern was *acid precipitation*.
  - The burning of wood and of fossil fuels releases oxides of sulfur and nitrogen that react with water in air, forming sulfuric acid and nitric acid.
  - The acids eventually fall to Earth's surface as rain, snow, sleet, or fog that has a pH less than 5.2, harming some aquatic and terrestrial organisms.
  - 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.
- Environmental regulations and new technologies have enabled many countries to reduce sulfur dioxide emissions.

- In the United States, sulfur dioxide emissions decreased 31% between 1993 and 2002, gradually reducing the acidity of precipitation.
- Emissions of nitrogen oxides are increasing in the United States, while emissions of sulfur dioxide and acid precipitation continue to damage forests in central and eastern Europe.

Concept 56.2 Population conservation focuses on population size, genetic diversity, and critical habitat

- Biologists who work on conservation at the population and species levels follow two main approaches: the small-population approach and the declining-population approach.

The small-population approach studies the processes that can cause very small populations to become extinct.

- Small populations are particularly vulnerable to overharvesting, habitat loss, and other threats to biodiversity.
- A small population is vulnerable to inbreeding and genetic drift which draw the population down an **extinction vortex** toward smaller and smaller numbers until extinction is inevitable.
    - One key factor driving the vortex is the loss of genetic diversity that facilitates evolutionary responses to environmental change, such as new strains of pathogens.
- Both inbreeding and genetic drift can cause a loss of genetic variation, and their effects become more harmful as a population shrinks.
    - Inbreeding often decreases fitness because individuals are more likely to be homozygous for harmful recessive traits.
- Not all populations are doomed by low genetic diversity, and low genetic variability does not automatically lead to permanently small populations.
    - Overhunting of northern elephant seals in the 1890s reduced the species to only 20 individuals—clearly a bottleneck that reduced genetic variation.
    - Since that time, however, northern elephant seal populations have rebounded to 150,000 individuals, although the genetic variation of the species remains low.
- A number of plant species have inherently low genetic variation.
    - Species of cord grass *(Spartina anglica)*, which thrive in salt marshes, are genetically uniform at many loci.
    - *S. anglica* arose from a few parent plants only about a century ago by hybridization and allopolyploidy.
    - Having spread by cloning, this species dominates large areas of tidal mudflats in Europe and Asia.

The greater prairie chicken is a case study of a small population rescued from an extinction vortex.

- The greater prairie chicken *(Tympanuchus cupido)* was common in large areas of North America a century ago.
- Agriculture fragmented the populations of this species, and its abundance declined.
    - In Illinois, greater prairie chickens numbered in the millions in the 19th century but declined to fewer than 50 birds by 1993.
    - The decline in the Illinois population was associated with a decrease in fertility.

- As a test of the extinction vortex hypothesis, the scientists imported genetic variation by transplanting 271 birds from larger populations elsewhere.
  - The Illinois population rebounded, confirming that it had been on its way down into an extinction vortex until rescued by a transfusion of genetic variation.

The size of a population starting down an extinction vortex varies with the type of organism.

- How small is too small for a population? How small does a population have to be before it starts down the extinction vortex?
  - The answer depends on the type of organism and its environment and must be determined in each individual case.
  - Large predators that feed high on the food chain usually require extensive individual ranges, resulting in low population densities.
- Not all rare species are a concern to conservation biologists.
- The minimum population size at which a species is able to sustain its numbers and survive is the **minimum viable population size (MVP)**.
  - The MVP is usually estimated for a given species using computer models that integrate many factors.
- Genetic variation is the key issue in the small-population approach.
  - The *total* size of a population may be misleading because only some members of the population successfully breed.
- A meaningful estimate of the MVP requires the researcher to determine the **effective population size** (N_e) based on the breeding potential of a population, incorporating information about the sex ratio of breeding individuals.
  - The formula is $N_e = 4N_fN_m/(N_f + N_m)$ where N_f and N_m are the numbers of females and males that successfully breed.
- Numerous life history traits influence N_e, including family size, maturation age, genetic relatedness among population members, effects of gene flow between geographically separated populations, and population fluctuations.
  - In actual populations, N_e is always some fraction of the total population.
- Whenever possible, conservation programs attempt to sustain total population sizes that include at least the minimum viable number of *reproductively active* individuals.
- The goal of sustaining N_e above MVP stems from concern that populations retain enough genetic diversity to adapt as their environment changes.
- The MVP of a population is often used in population viability analysis, which predicts a population's chances for survival, usually expressed as a specific probability of survival (such as a 95% chance) over a particular time (perhaps 100 years).
- Modeling approaches enable conservation biologists to explore the potential consequences of alternative management plans.
- Because modeling depends on reliable information about the populations under study, conservation biology is most effective when theoretical modeling is combined with field studies of the managed populations.

A population viability analysis was conducted on grizzly bears in Yellowstone National Park.

- 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 surrounding areas.
  - Grizzly bears *(Ursus arctos horribilis)* are a threatened species in the United States, where they are found in only 4 of the 48 contiguous states.
  - Grizzly bear populations in those states have been drastically reduced and fragmented.
  - In 1800, an estimated 100,000 grizzlies ranged over more than 500 million hectares of contiguous habitat, but today 1,000 individuals live in six isolated populations with a total range of less than 5 million hectares.
- Shaffer attempted to determine viable sizes for U.S. grizzly bear populations.
  - Using life history data obtained for individual bears over a 12-year period, Shaffer simulated the effects of environmental factors on survival and reproduction.
  - His models predicted that, given a suitable habitat, a total grizzly bear population of 70–90 individuals would have a 95% chance of surviving for 100 years.
- How does the actual size of the Yellowstone grizzly bear population compare with Shaffer's predicted MVP?
  - A current estimate puts the total grizzly bear population in the greater Yellowstone ecosystem at about 400 individuals.
  - The relationship of estimates of the total grizzly bear population to the effective population size, N_e, is dependent on several factors.
  - Only a few dominant males breed. It may be difficult for them to locate females because individuals inhabit such large areas.
  - Females reproduce only when there is enough food.
  - As a result of these factors, N_e is about 25% of the total population size, or about 100 bears.
- Because small populations tend to lose genetic variation over time, a number of research teams have analyzed proteins, mtDNA, and short tandem repeats to assess genetic variability in the Yellowstone grizzly bear population.
  - These analyses show that the Yellowstone population has lower levels of genetic variability than other grizzly bear populations in North America.
- The isolation and decline in genetic variability in the population appear to have been gradual and not as severe as feared, however.
  - Museum specimens collected in the early 1900s demonstrate that genetic variability among the Yellowstone grizzly bears was low even then.
- 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 into a population of 100 bears would reduce the loss of genetic variation in the population by about half.
- For small populations, finding ways to promote dispersal among populations may be one of the most urgent conservation needs.

The declining-population approach is a proactive conservation strategy for detecting, diagnosing, and halting population declines.

- The small-population approach emphasizes MVP size, and interventions include introducing genetic variation from one population into another.
- The declining-population approach is more action-oriented, focusing on threatened and endangered species even when the populations are larger than the MVP.
  - This approach emphasizes the environmental factors that caused a population to decline and evaluates population declines on a case-by-case basis.
- The declining-population approach follows five steps in the diagnosis and treatment of declining populations.
  1. Assess population data to confirm that the species is in decline or that it was formerly more abundant or more widely distributed.
  2. Study the species' natural history and review the research literature to determine its environmental needs.
  3. Develop hypotheses for all possible causes of the decline, including human activities and natural events, and list the predictions for further decline under each hypothesis.
  4. Test the most likely hypothesis first to determine whether this factor is the main cause of the decline. For example, remove the suspected agent of decline to see whether the experimental population rebounds relative to a control population.
  5. Apply the results of this diagnosis to the management of the threatened species and monitor its recovery.

The declining-population approach was applied to the red-cockaded woodpecker.

- The red-cockaded woodpecker *(Picoides borealis)* is an endangered species, endemic to the southeastern United States.
- To use the declining-population approach, biologists must understand the habitat requirements of this endangered species.
  - The red-cockaded woodpecker requires mature pine forest, preferably dominated by longleaf pine, for its habitat.
  - It drills its nest holes in mature, living pine trees and also drill small holes around the entrance to their nest cavities, which causes resin from the tree to ooze down the trunk.
  - The resin repels certain predators, such as corn snakes, that eat bird eggs and nestlings.
  - The understory of plants around the pine trunks must be low so the woodpeckers have a clear flight path into their nests.
  - Historically, periodic fires swept through longleaf pine forests, keeping the understory low.
- One factor leading to the decline of the red-cockaded woodpecker is the destruction or fragmentation of suitable habitat by logging and agriculture.
  - Recognizing the key habitat factors, protecting some longleaf pine forests, and using controlled fires to reduce forest undergrowth have helped restore habitat that can support viable populations.
- Designing a recovery program was complicated by the birds' social organization.
  - Red-cockaded woodpeckers live in groups of one breeding pair and up to four male "helpers."
  - "Helpers" are offspring that do not disperse and breed but remain behind and assist in incubating eggs and feeding nestlings. They may wait years before they attain breeding status.

- Young birds that disperse usually occupy abandoned territories or excavate nesting cavities, which can take several years.
- Individuals have a better chance of reproducing by remaining as helpers than by dispersing and excavating homes in new territories.

- Ecologists tested the hypothesis that their social behavior restricts the ability of red-cockaded woodpeckers to rebound, constructing new cavities in pine trees.
  - 18 of the 20 sites were colonized by red-cockaded woodpeckers.
- This experiment supported the hypothesis that red-cockaded woodpeckers had been leaving suitable habitats unoccupied because of an absence of breeding cavities.
- Based on this experiment, conservationists initiated a program of habitat maintenance, such as controlled burning and excavation of new breeding cavities, enabling an endangered species to begin to recover.

Conserving species involves 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' biological and ecological needs against other conflicting demands.
- Conservation biology often highlights the relationship among science, technology, and society.
  - Programs to restock wolves in Yellowstone National Park are opposed by many ranchers concerned with potential loss of livestock outside the park and recreationists concerned with human safety.
- Large, high-profile vertebrates are not always the focal point in such conflicts, but habitat use is almost always an issue.
  - Should a highway bridge be built if it destroys the only remaining habitat of a species of freshwater mussel?
- Another important consideration is the ecological roles of species.
  - We cannot save every endangered species, so we must determine which are most important for conserving biodiversity as a whole.
  - Species do not exert equal influence on community and ecosystem processes.
  - Identifying keystone species and finding ways to sustain their populations can be central to the survival of whole communities.
- Management aimed at conserving a single species carries with it the possibility of harming populations of other species.
- Management of pine forests for the benefit of red-cockaded woodpeckers might affect migratory birds associated with broadleaf temperate forests.
  - To test for such impacts, ecologists compared bird communities near clusters of nest cavities in managed pine forests with communities in forests not managed for woodpeckers.
  - The managed sites supported higher numbers and greater diversity of other birds than the control forests.
- Conservation must look beyond single species and consider the whole community and ecosystem as an important unit of biodiversity.

Concept 56.3 Landscape ecology and regional conservation seek to sustain entire biotas

- Conservation efforts often aim to sustain the diversity of entire communities, ecosystems, and landscapes.
  - This broad view requires an understanding of the principles of community, ecosystem, and landscape ecology, as well as human population dynamics and economics.
- One goal of landscape ecology is to understand past, present, and future patterns of landscape use and to make biodiversity conservation part of land-use planning.
- Landscape ecology is important in conservation biology because many species use more than one type of ecosystem and many live on the borders between ecosystems.

Edges and corridors can strongly influence landscape biodiversity.

- Boundaries, or *edges,* between ecosystems are defining features of landscapes.
- An edge has its own set of physical conditions that 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 of both areas.
  - The ruffled grouse *(Bonasa umbellatus)* requires forest habitat for nesting, winter food, and shelter.
  - The grouse also needs forest openings with dense shrubs and herbs for summer food.
- The proliferation of edge species can have positive or negative effects on biodiversity.
  - A 1997 study in Cameroon comparing edge and interior populations of the little greenbul (a tropical rain forest bird) suggested that forest edges may be important sites of speciation.
- On the other hand, ecosystems in which edges have resulted from human alterations often have reduced biodiversity and a preponderance of edge-adapted species.
  - The brown-headed cowbird *(Molothrus ater)* flourishes in areas with forests, where they parasitize the nests of migratory songbirds, and open fields, where they forage on insects.
  - The cowbird populations are burgeoning where forests are being cut and fragmented, which creates more edge habitat and open land.
  - Increasing cowbird parasitism habitat loss are correlated with declining populations of cowbird 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 in 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.
  - Researchers are clearly documenting the effects of this fragmentation on taxa ranging from bryophytes to beetles to birds.
  - Species adapted to forest interiors show the greatest declines in the smallest fragments, suggesting that landscapes dominated by small fragments support fewer species.
- **Movement corridors**, narrow strips or series of small clumps of habitat connecting otherwise isolated patches, can be deciding factors in conserving biodiversity.

- Riparian habitats often serve as corridors. Some nations prohibit alteration of these areas.

- In areas of heavy human use, artificial corridors have been constructed.
  - Bridges or tunnels can help animals cross highways.
- Movement corridors can promote dispersal and reduce inbreeding in declining populations.
  - They are especially important to species that migrate between different habitats seasonally.
- Corridors can also be harmful by aiding in the spread of disease.
  - Habitat corridors facilitated the movement of disease-carrying ticks among forest patches in northern Spain.

Conservation biologists face many challenges in setting up protected areas.

- Conservation biologists apply ecological research in establishing protected areas to slow the loss of biodiversity.
  - Governments have set aside about 7% of the world's land in various types of reserves.
- Choosing locations for protection and designing nature reserves pose many challenges.
  - If a community is subject to fire, grazing, and predation, should the reserve be managed to reduce these processes? Or should the reserve be left as natural as possible?
- Much of the focus has been on **biodiversity hot spots**, relatively small areas with numerous endemic species and a large number of threatened or endangered species.
  - Nearly 30% of all bird species are confined to only 2% of Earth's land area.
  - About 50,000 plant species (one-sixth of all known species) inhabit 18 hot spots that comprise only 0.5% of the global land surface.
  - The "hottest" of the terrestrial biodiversity hot spots total less than 1.5% of Earth's land but are home to more than one-third of all plants and vertebrates.
  - Hot spots also include aquatic ecosystems, such as coral reefs and certain river systems.
- Biodiversity hot spots are good choices for reserves, but identifying them can be difficult.
  - A hot spot for one taxonomic group may not be a hot spot for another taxonomic group.
  - Designating an area as a biodiversity hot spot is often biased toward vertebrates and plants, with less attention paid to invertebrates and microorganisms.
- Global change makes the task of preserving hot spots 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 has thousands of species of endemic plants and numerous endemic vertebrates.
  - Researchers predict that between 5% and 25% of these plant species may be extinct by 2080 because they will be unable to tolerate the dryness predicted for this region.

Nature reserves must be functional parts of landscapes.

- Nature reserves are biodiversity islands in a sea of habitat degraded by human activity.
- It is important that nature reserves are not isolated from the natural environment.
- Disturbance is common to all ecosystems, and management policies that ignore natural disturbances or attempt to prevent them generally fail.

- Setting aside an area of a fire-dependent community, such as tallgrass prairie or dry pine forest, without periodic burning is unrealistic.
- Without the dominant disturbance, fire-adapted species are usually outcompeted by other species, and biodiversity is reduced.

- A major conservation question is whether to create one large reserve or many smaller ones.
  - Large reserves are beneficial for large, far-ranging animals with low-density populations, such as the grizzly bear.
  - Large reserves have proportionately smaller perimeters and are less affected by edges.
- As conservation biologists learn more about the requirements for achieving minimum viable population sizes for endangered species, it has become clear 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 is more than ten times the combined area of Yellowstone and Grand Teton National Parks.
- Realistically, many existing parks will not be enlarged, and areas of public and private land surrounding reserves will have to contribute to biodiversity conservation.
- Several nations have adopted an approach to landscape management called zoned reserves.
- A **zoned reserve** is a large region that includes areas undisturbed by humans surrounded by lands that are used for economic gain and have been changed by humans.
- 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 area.
  - The surrounding areas are used to support human activities, but with regulations to prevent the types of extensive alterations that will affect the protected area.
  - The surrounding habitats serve as buffer zones against further intrusion into the undisturbed areas.
- Costa Rica has become a world leader in establishing zoned reserves.
  - Costa Rica has eight zoned reserves, called "conservation areas," that contain national park land.
  - The buffer zones provide a steady, lasting supply of forest products, water, and hydroelectric power, and also support sustainable agriculture and tourism.
- Zoned reserves aim to provide a stable economic base for people living there.
- Costa Rica hopes to maintain at least 80% of its native species in its zoned reserves.
  - A 2003 analysis of land cover change between 1960 and 1997 showed negligible deforestation in Costa Rica's national parks and a gain in forest cover in the 1-km buffer around the parks.
  - Significant losses in forest cover were discovered in the 10-km buffer zone around all national parks, which threatens to turn Costa Rica's parks into isolated habitat islands.
- Reserves in the ocean are far less common than reserves on land.
- Many fish populations around the world have collapsed in the face of mounting fishing pressure from increasingly sophisticated fishing equipment, which puts nearly all potential fishing grounds within human reach.
- Fiona Gell and Callum Roberts, of the University of York, England, have proposed that marine reserves be established around the world that are off-limits for fishing.

- They present strong evidence that reserves would increase fish populations within the reserves and improve fishing success in nearby areas.
- This strategy is a marine application of the zoned reserve concept.

- The United States adopted this system in establishing the Florida Keys National Marine Sanctuary in 1990.
  - Populations of marine organisms, including fishes and lobsters, recovered quickly after harvests were banned in the 9,500-km^2 preserve.
  - Larvae from the sanctuary help repopulate reefs and improve fishing outside the sanctuary.
  - The sanctuary is a favorite for recreational divers, which increases its economic value.

<u>Concept 56.4 Earth is changing rapidly as a result of human actions</u>

- 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?
  - This scenario is increasingly possible due to human-caused changes in the environment, including nutrient enrichment, accumulation of toxins, climate change, and ozone depletion.
  - Impacts from these changes and others are evident even in remotest ecosystems on Earth.

Human activities alter the environment through enrichment of nutrients, particularly nitrogen.

- Human activity removes nutrients from one part of the biosphere and adds them to another.
- On a large scale, nutrients in farm soil may run off into streams and lakes, depleting nutrients in one area, increasing them in another, and altering chemical cycles in both.
  - Humans have also added entirely novel materials—some of them toxic—to ecosystems.
- After natural vegetation is cleared from an area, the existing reserve of nutrients in the soil is sufficient to grow crops for some time.
  - In agricultural ecosystems, a substantial fraction of these nutrients is exported from the area in crop biomass.
- When North American prairie lands were first tilled, crops could be produced for decades because of the large store of organic materials in the soil.
  - Cleared land in the tropics can be farmed for only one or two years because so little of the ecosystems' nutrient load is contained in the soil.
  - In any area under intensive agriculture, the natural store of nutrients becomes exhausted.
- Nitrogen is the main nutrient lost through agriculture, which has a great impact on the nitrogen cycle.
- Plowing mixes soil and speeds 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.
  - Without plants to take up nitrates from the soil, the nitrates are likely to be leached from the ecosystem.
- Human activities have more than doubled Earth's supply of fixed nitrogen available to primary producers.
  - Industrial fertilizers provide the largest additional nitrogen source.

- Fossil fuel combustion also releases nitrogen oxides, which enter the atmosphere and dissolve in rainwater; the nitrogen ultimately enters ecosystems as nitrate.
- Increased cultivation of legumes also increases the amount of fixed nitrogen in the soil.

- The nutrient level in an ecosystem may exceed the **critical load**, the amount of added nutrient that can be absorbed by plants without damaging ecosystem integrity.
  - 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.
- The Mississippi River carries nitrogen pollution to the Gulf of Mexico, fueling a phytoplankton bloom each summer.
  - When the phytoplankton die, their decomposition creates an extensive "dead zone" of low oxygen availability along the coast.
  - Fish, shrimp, and other marine animals have also disappeared from some of the most economically important waters in the United States.
- To reduce the size of the dead zone, farmers use fertilizers more efficiently and managers are restoring wetlands in the Mississippi watershed.
- Nutrient runoff can also lead to the eutrophication of lakes.
  - 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.
  - Eutrophication of Lake Erie coupled with overfishing wiped out commercially important fishes such as blue pike, whitefish, and lake trout by the 1960s.
  - Some fish populations have rebounded, but many native species of fishes and invertebrates have not recovered.

Toxic chemicals are released into the environment.

- Humans release an immense variety of toxic chemicals, including thousands of synthetic compounds previously unknown in nature.
  - Organisms acquire toxic substances from the environment along with nutrients and water.
  - Some of the poisons are metabolized and excreted, but others accumulate in specific tissues, especially fat.
- Toxins may become more concentrated in successive trophic levels of a food web, a process called **biological magnification**.
  - Magnification occurs because the biomass at any given trophic level is produced from a much larger biomass ingested from the level below.
  - Top-level carnivores tend to be the organisms 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.
  - Many of these compounds disrupt human endocrine systems.
  - 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.

- 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.
    - DDT persists in the environment and is transported long distances by water.
- 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.
    - Accumulation of DDT in the tissues of these birds prevented deposition of calcium in their eggshells, leading to catastrophic declines in the birds' reproduction rates.
- After DDT was banned, populations of affected bird species dramatically recovered.
- In the tropics, DDT is still used to control the mosquitoes that spread malaria.
    - DDT is used sparingly and its use is coupled with mosquito netting and other low-technology solutions.
- Many toxins that cannot be degraded by microorganisms persist in the environment for years or even decades.
    - Other chemicals may be relatively harmless when released into the environment but are converted to more toxic products by reaction with other substances, by exposure to light, or by the metabolism of microorganisms.
- Mercury has been routinely expelled into rivers and the sea in an insoluble form.
    - Bacteria convert the waste to methylmercury (CH_3Hg^+), an extremely toxic soluble compound that accumulates in the tissues of organisms, including humans who consume fish from contaminated waters.

Greenhouse gases contribute to global warming.

- 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.
    - 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. At that time, the CO_2 concentration was 316 ppm.
    - Today, it exceeds 385 ppm, an increase of more than 40% since the mid-19th century.
- If CO_2 emissions continue to increase at the present rate, by the year 2075 the atmospheric concentration of this gas will be more than double what it was at the start of the Industrial Revolution.
- Increased productivity by plants is one predictable consequence of increasing CO_2 levels.
    - Because C_3 plants are more limited than C_4 plants by CO_2 availability, one effect of increasing global CO_2 concentration may be the spread of C_3 species into terrestrial habitats that currently favor C_4 plants.
    - C_3 crops such as wheat and soybeans could outproduce C_4 plants like corn in a CO_2-enriched environment.
- To assess how the increasing atmospheric concentration of CO_2 might affect temperate forests, scientists at Duke University began the Forest-Atmosphere Carbon Transfer and Storage (FACTS-I) experiment in 1995.
    - The FACTS-I experiment includes six plots in an 80-hectare (200-acre) tract of loblolly pine within the university's experimental forest.
    - In three of the six plots, the towers produce air containing about 1½ times present-day CO_2 concentrations.

- All other factors, such as temperature, precipitation, and wind speed and direction, vary normally for both experimental and adjacent control plots exposed to atmospheric CO_2.

- The FACTS-I study is testing how elevated CO_2 levels influence tree growth, carbon concentration in soils, insect populations, soil moisture, and the growth of plants in the forest understory.
  - After 12 years, trees in the experimental plots produced about 15% more wood each year than those in the control plots.
  - This increased growth is far lower than predicted from greenhouse experiments.
  - Availability of nitrogen and other nutrients seems to limit the ability of the trees to use the extra CO_2.
- The results of FACTS-I and other experiments suggest that increased atmospheric CO_2 levels will increase plant production, but far less than scientists predicted even a decade ago.
- Rising concentrations of long-lived greenhouse gases such as CO_2 are also changing Earth's heat budget.
  - Much of the solar radiation that strikes the planet is reflected back into space.
  - CO_2, water vapor, and other greenhouse gases in the atmosphere are transparent to visible light, but 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 (–2.4°F), and most life as we know it could not exist.
- The marked increase in the concentration of atmospheric CO_2 over the last 150 years concerns scientists is linked increased global temperature.
  - Most scientists are convinced that global warming is already occurring and will increase rapidly this century.
- Global models predict that by the end of the 21st century, the atmospheric CO_2 concentration will more than double, increasing average global temperature by about 3°C (5°F).
  - Supporting these models is a correlation between CO_2 levels and temperatures in prehistoric times.
- 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.
- 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.
  - Climate models suggest that there may be no summer ice in the Arctic 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.
- By studying how past periods of global warming and cooling affected plant communities, ecologists are trying to predict the consequences of future changes in temperature and precipitation.

- Analysis of fossilized pollen indicates that plant communities change dramatically with changes in temperature.
- Past climate changes occurred gradually, though, and plant and animal populations had time to migrate into areas where abiotic conditions allowed them to survive.

- 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.
  - Many habitats today are more fragmented than ever, further limiting the ability of many organisms to migrate.
  - Ecologists are debating **assisted migration**, the translocation a species to a favorable habitat beyond its native range to protect the species from human-caused threats. Most ecologists consider such an approach only as a last resort, in part because of the dangers of introducing potentially invasive species to new regions.
- We will need many tools to slow global warming.
  - Quick progress can be made in using energy more efficiently and in replacing fossil fuels with renewable solar and wind power and, more controversially, with nuclear power.
- Stabilizing CO_2 emissions will require concerted international effort and the acceptance of changes in both personal lifestyles and industrial processes.
  - That effort suffered a major setback in 2001, when the United States pulled out of the Kyoto Protocol, a 1997 pledge by industrialized nations to reduce their CO_2 output by about 5%.
  - Such a reduction would be a first step in the journey to stabilize atmospheric CO_2 concentrations.
  - Recent international negotiations, including a 2009 meeting in Copenhagen, Denmark, have yet to reach a consensus on a global strategy to reduce greenhouse gas emissions.
- Another important tool to slow global warming is reducing deforestation around the world, particularly in the tropics.
  - Deforestation currently accounts for about 12% of greenhouse gas emissions.
  - Paying countries *not* to cut forests could decrease the rate of deforestation by half within 10–20 years.
  - Reduced deforestation would not only slow the build-up of greenhouse gases in our atmosphere, it would sustain native forests and preserve biodiversity, a positive outcome for all.

Atmospheric ozone is gradually thinning.

- Like carbon dioxide and other greenhouse gases, atmospheric ozone (O_3) is also changing in concentration because of human activities.
  - Life on Earth is protected from the damaging effects of ultraviolet (UV) radiation by a layer of ozone located in the stratosphere 17–25 km above Earth's surface.
  - Satellite studies of the atmosphere show that the ozone layer has been gradually thinning since the mid-1970s.
- The destruction of atmospheric ozone results mainly from the accumulation of industrial chemicals called chlorofluorocarbons (CFCs).
  - When the breakdown products from these chemicals rise to the stratosphere, the chlorine they contain reacts with ozone, reducing it to molecular O_2.
  - Subsequent chemical reactions liberate the chlorine, allowing it to react with other ozone molecules in a catalytic chain reaction.

- The thinning of the ozone layer is most apparent over Antarctica in spring, where cold, stable air allows the chain reaction to continue.
  - The magnitude of ozone depletion and the size of the ozone hole have generally increased in recent years, and the hole sometimes extends as far as the southernmost portions of Australia, New Zealand, and South America.
  - At the more heavily populated middle latitudes, ozone levels have decreased 2–10% during the past 20 years.
- Decreased ozone levels in the stratosphere increase the intensity of UV rays reaching Earth's surface.
  - The consequences of ozone depletion for life on Earth may be severe for plants, animals, and microorganisms.
  - Some scientists expect increases in human skin cancer and cataracts, as well as unpredictable effects on crops and natural communities, especially the phytoplankton that are responsible for a large proportion of Earth's primary production.
  - Scientists have shown DNA damage and a reduction in phytoplankton growth when the ozone hole opens over the Southern Ocean each year.
- Since 1987, more than 190 nations, including the United States, have signed the Montreal Protocol, a treaty that regulates the use of ozone-depleting chemicals.
  - Many nations have ended the production of CFCs.
  - Chlorine concentrations in the stratosphere have stabilized and ozone depletion is slowing.
  - Even if all CFCs were globally banned today, chlorine molecules already in the atmosphere would continue to influence stratospheric ozone levels for at least 50 years.

Concept 56.5 Sustainable development seeks to improve human lives while conserving biodiversity

- Ecologists face difficult trade-offs in managing the Earth'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.

Ecologists use the concept of sustainability to establish long-term conservation priorities.

- Many nations, scientific societies, and other groups have embraced the concept of **sustainable development**, meeting the needs of people today without limiting the ability of future generations to meet their needs.
- The Sustainable Biosphere Initiative is a research agenda endorsed by the Ecological Society of America.
  - Its goal is to obtain the basic ecological information necessary for the responsible development, management, and conservation of Earth's resources.
  - The research agenda includes studies of global change, including interactions between climate and ecological processes, biological diversity and its role in maintaining ecological processes, and the ways in which the productivity of natural and artificial ecosystems can be sustained.
  - This initiative requires a strong commitment of human and economic resources.
- Sustainable development must include the life sciences, social sciences, economics, and humanities. Equally important is a reassessment of our values.

- People who live in wealthier nations have a larger ecological footprint than those in developing nations.
- By reducing our orientation toward short-term gain, we can learn to value the natural processes that sustain us.

Costa Rica is a case study in sustainable development.

- The success of conservation in Costa Rica has involved a partnership among the national government, nongovernmental 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.
- How have the living conditions of Costa Ricans fared as the country has pursued conservation goals?
- The infant mortality rate in Costa Rica has declined sharply during the 20th century, and life expectancy at birth has increased.
- The 2004 literacy rate in Costa Rica was 96%.
- Such statistics show that living conditions in Costa Rica improved greatly over the period in which the country dedicated itself to conservation and restoration.
- Although this result does not prove that conservation *causes* an increase in human welfare, clearly development in Costa Rica has attended to both nature *and* people.
- One of the challenges that Costa Rica faces is maintaining its commitment to conservation in the face of a growing population.
  - Costa Rica's population, currently 4 million, is predicted to grow to 6 million over the next 50 years.
- It is likely that the Costa Rican people will confront the remaining challenges of sustainable development with success.

The future of the biosphere may depend on our biophilia.

- Modern lives reflect remnants of our ancestral attachment to nature and the diversity of life—the concept of *biophilia.*
- Humans evolved in natural environments rich in biodiversity; we have an affinity for nature.
- E. O. Wilson suggests that 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 evolutionary change over time.
  - We preserve life as we work 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 a scientific expression of our desire to know nature.
  - We protect what we appreciate, and we appreciate what we understand.
- By learning about life's processes and diversity, we can understand our role in the biosphere.