Chapter 56

Conservation Biology and Restoration Ecology

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 200 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. Two disciplines within biology seek to preserve life.
  1. **Conservation biology** integrates ecology, evolutionary biology, physiology, molecular biology, genetics, and behavioral ecology to conserve biological diversity at all levels.
  2. **Restoration ecology** applies ecological principles in an effort to return degraded ecosystems to conditions as similar as possible to their natural, predegraded state.

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 *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 the genetic variation *between* populations that is often 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 prospects of the species.
- The loss of wild populations of plants also means the loss of genetic resources that could potentially be used to improve crop qualities, such as disease resistance.
  - When grassy stunt virus infected rice *(Oryza sativa),* plant breeders screened 7,000 populations of rice and its wild relatives.

- They found resistance in only one population of a single relative, Indian rice *(Oryza nivara),* and bred the resistance into commercial rice varieties.
- Today, the original disease-resistant population has gone extinct in the wild.

- 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.
  - One of the largest rapid extinctions is the ongoing loss of freshwater fishes in East Africa's Lake Victoria. About 200 of the more than 500 species of cichlids in the lake have been lost, mainly as a result of the introduction of the Nile perch in the 1960s.
  - Since 1900, 123 freshwater vertebrate and invertebrate 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 now 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?
- Perhaps the purest reason is what E. O. Wilson calls *biophilia,* our sense of connection to nature.
  - 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.

- Future human generations may be deprived of Earth's species richness.

- Biodiversity is a crucial natural resource: Species that are threatened could provide crops, fibers, and medicines for human use.
  - In the United States, 25% of all prescriptions dispensed from pharmacies contain substances originally derived from plants.
  - In the 1970s, alkaloids that inhibit two deadly cancers were extracted from the rosy periwinkle, a plant growing on the island of Madagascar.
- The loss of species also means the loss of genes.
- Each species has certain unique genes, and biodiversity represents the sum of all the genomes of all organisms on Earth.
- Such enormous genetic diversity has the potential for great human benefit.
  - The polymerase chain reaction is based on an enzyme 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 three major threats to biodiversity are habitat loss, introduced species, and overexploitation.

- 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 warming 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.
  - For instance, 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, since 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 marine 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.
  - The modern ease of 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, transplanted species may spread rapidly through a new region.
- Introduced species may disrupt their adopted community, often by preying on native organisms or outcompeting native species for resources.
  - For example, the brown tree snake was accidentally introduced to the island of Guam after World War II.
  - 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 efficient suspension feeders that form dense colonies, and 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.

- The European starling was introduced intentionally into New York City's Central Park by a citizen's group intent on 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.
- *Overexploitation* 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 overexploitation.
  - 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 overexploitation.
  - The African elephant has been overhunted largely due to the ivory trade.
  - Elephant populations have declined dramatically over the past 50 years.
  - Despite a ban on the sale of new ivory, poaching continues in central and east Africa.
- Conservation biologists now use molecular genetics to track the origin of tissues harvested from threatened or endangered species.
  - Samuel Wasser and colleagues, 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 miles.
- 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.

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

- Biologists focusing on conservation at the population and species levels follow two main approaches: the small-population approach and the declining-population approach.
- Small populations are particularly vulnerable to overexploitation, habitat loss, and other threats to biodiversity.

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

- The **extinction vortex** is a downward spiral unique to small populations.

    - A small population is at risk of positive-feedback loops of inbreeding and genetic drift that draw it into a vortex toward smaller and smaller numbers until extinction is inevitable.
    - The 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 the effects of both processes become more significant 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 population of the greater prairie chicken in the central and western states and provinces.
    - In Illinois, greater prairie chickens numbered in the millions in the 19th century but declined to 50 birds 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, the scientists imported genetic variation by transplanting 271 birds from larger populations elsewhere.
- The Illinois population of greater prairie chickens 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 very large individual ranges, resulting in very low population densities. Therefore, 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.
- 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, respectively, 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 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 (for example, a 95% chance) over a particular time (for instance, 100 years).
- Modeling approaches such as population viability analysis 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 robust 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 estimates of minimum viable population size?

- 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.
  - Usually, only a few dominant males breed. It may be difficult for them to locate females because individuals inhabit such large areas.
  - Females may reproduce only when there is abundant 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 protein, mitochondrial DNA, and nuclear microsatellite DNA to assess the 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 modeling predicts that introducing only two unrelated bears into a population of unrelated 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 requirements.
  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 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.
  - The red-cockaded woodpecker drills its nest holes in mature, living pine trees.
  - Red-cockaded woodpeckers 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-profile 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.
- Ecologists constructed new cavities in pine trees and found that 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, thus enabling an endangered species to begin to recover.

Conserving species involves weighing conflicting demands.

- Determining population numbers and habitat needs is only part of the effort 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.
  - For example, programs to restock wolves in Yellowstone National Park are opposed by many ranchers concerned with potential loss of livestock 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 negatively affecting populations of other species.
  - For example, 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 actually 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 aim to sustain entire biotas.

- Preservation 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 have access to the resources of both adjacent areas.

- For example, 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 a community's 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, communities in which edges have resulted from human alterations often have reduced biodiversity because of domination by edge-adapted species.
    - The brown-headed cowbird *(Molothrus ater)* flourishes in areas with forests, where they parasitize the nests of other birds, 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 and loss of habitat 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.
    - Researchers are clearly documenting the physical and biological effects of forest 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, mainly due to loss of interior-adapted species.
- A **movement corridor** is a narrow strip or series of small clumps of good habitat connecting otherwise isolated patches.
- Such corridors can be deciding factors in conserving biodiversity.
    - Streamside habitats often serve as corridors. Some nations prohibit alteration of these riparian 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.
- However, 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 exceptional concentrations of 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
- Together, 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 obvious 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.

Nature reserves must be functional parts of landscapes.

- It is important that nature reserves are not isolated from the natural environment.
- Disturbance is a functional component of all ecosystems, and management policies that ignore natural disturbances or attempt to prevent them are generally self-defeating.
  - For instance, 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 it is better to create one large reserve or a group of smaller ones.
  - Extensive reserves are beneficial for large, far-ranging animals with low-density populations, such as the grizzly bear.
  - More extensive areas 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.
  - For example, 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.
  - When reserve land is surrounded by commercially viable property, the use of land for agriculture or forestry must be integrated into conservation strategies.
- Several nations have adopted an approach to landscape management called zoned reserves.
- A **zoned reserve** is a large region of land that includes one or more 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 continue to be used to support the human population, but with regulations to prevent the types of extensive alterations that will affect the protected area.
  - The surrounding tracts of land serve as buffer zones against 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.
  - 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.
- However, 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.
  - Gell and Roberts 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.

Concept 56.4 Restoration ecology attempts to restore degraded ecosystems to a more natural state.

- Biological communities can recover from many types of disturbances through a series of restoration mechanisms that occur during ecological succession.
- However, the natural rate of recovery by successional processes is often slower than the rate of degradation by human activities.
  - The soils of many tropical areas quickly become unproductive and are soon abandoned after being cleared for farming.
  - Mining activities may last for several decades, but the lands are then abandoned in a degraded state.
  - Ecosystems may inadvertently be damaged by the dumping of toxic chemicals or by oil spills.
- Restoration ecology seeks to initiate or speed up the recovery of degraded ecosystems.
  - The basic assumption is that environmental damage is at least partially reversible.
  - Communities are not infinitely resilient, however.
  - Restoration ecologists work to identify and manipulate the processes that most limit the speed of recovery, in order to reduce the time it takes for a community to bounce back from disturbance.

- In extreme cases, the structure of a site may need to be restored before biological restoration can occur.
  - Restoration ecologists may reconstruct a meandering stream to slow the flow of water eroding a stream bank.
  - To restore an open-pit mine, engineers may first grade the site to reestablish a gentle slope, spreading topsoil when the slope is in place.
- Two key biological strategies in restoration ecology are bioremediation and augmentation of ecosystem processes.
- **Bioremediation** is the use of living organisms, usually prokaryotes, fungi, or plants, to detoxify polluted ecosystems.
- Restoration ecologists use various types of organisms to remove many different types of toxins from ecosystems.
  - For example, some plants adapted to soils containing heavy metals are capable of accumulating high concentrations of potentially toxic metals.
  - Restoration ecologists can use these plants to revegetate sites polluted by mining and then harvest the plants to remove the metals from the ecosystem.
- Ecologists are exploring the ability of prokaryotes to carry out bioremediation of soils and water.
  - Scientists have sequenced the genomes of at least seven prokaryotic species specifically for their bioremediation potential.
  - One species, *Shewanella oneidensis*, metabolizes more than ten diverse elements in aerobic and anaerobic conditions to generate its energy.
  - For instance, *S. oneidensis* converts soluble uranium, chromium, and nitrogen to insoluble forms that can prevent these pollutants from leaching into streams or groundwater.
  - Wei-Min Wu and colleagues, working at Oak Ridge National Laboratory, Tennessee, added ethanol to groundwater contaminated with uranium to stimulate the growth of *Shewanella* and other uranium-reducing microbes. Over the year and a half of the experiment, uranium concentrations in the groundwater dropped by 80%.
- Genetic engineering may become an increasingly important tool for improving the performance of certain species as bioremediators.
- In contrast to bioremediation, which is a strategy for removing harmful substances, **biological augmentation** uses organisms to add essential materials to a degraded ecosystem.
- Augmenting ecosystem processes requires determining what factors, such as chemical nutrients, have been removed from an area and are limiting its rate of recovery.
- Encouraging the growth of plants that thrive in nutrient-poor soils often speeds up the rate of successional changes that can lead to the recovery of damaged sites.
  - In alpine ecosystems of the western United States, nitrogen-fixing herbs such as lupines are planted to bolster nitrogen concentrations in soils disturbed by mining.
  - When these nitrogen-fixing plants become established, other native species can obtain enough nitrogen from the soil to survive.
- In systems where the soil has been severely disturbed or where topsoil is missing entirely, plant roots may lack the mycorrhizal symbionts that help them meet their nutritional needs.
  - Ecologists restoring a tallgrass prairie in Minnesota significantly accelerated the recovery of native species by adding mycorrhizal symbionts to the soil they seeded.
- Because restoration ecology is a new discipline, there is still much to learn.

- Many restoration ecologists advocate adaptive management—experimenting with several types of management to learn what works best.
- The long-term goal of restoration is to speed the reestablishment of an ecosystem as close as possible to the predisturbance ecosystem.

Concept 56.5 Sustainable development seeks to improve the human condition while conserving biodiversity.

- Ecologists face difficult trade-offs in deciding how to manage 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 and still have an affinity for such settings.
- 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 the march of 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 a 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 become more aware of ourselves and our place in the biosphere.