10 Sustaining Terrestrial Biodiversity: The Ecosystem Approach

CORE CASE STUDY Reintroducing Gray Wolves to Yellowstone

Around 1800 at least 350,000 gray wolves (Figure 10-1), roamed over the lower 48 states, especially in the West, and survived mostly by preying on bison, elk, caribou, and mule deer. But between 1850 and 1900, most of them were shot, trapped, and poisoned by ranchers, hunters, and government employees. When Congress passed the U.S. Endangered Species Act in 1973, only a few hundred gray wolves remained outside of Alaska, primarily in Minnesota and Michigan. In 1974, the gray wolf was listed as an endangered species in the lower 48 states.


Tom Kitchin/Tom Stack & Associates

Figure 10-1 **Natural capital restoration:** the *gray wolf.* After becoming almost extinct in much of the western United States, in 1974 the gray wolf was listed and protected as an endangered species. Despite intense opposition by ranchers, hunters, miners, and loggers 41 members of this keystone species were reintroduced to their former habitat in the Yellowstone National Park and central Idaho in 1995 and 1996. By 2007, there were about 171 gray wolves in the park.

Ecologists recognize the important role this keystone predator species once played in parts of the West , especially in the northern Rocky Mountain states of Montana, Wyoming, and Idaho where Yellowstone National Park is located. The wolves culled herds of bison, elk, caribou, and mule deer, and kept down coyote populations. They also provided uneaten meat for scavengers such as ravens, bald eagles, ermines, grizzly bears, and foxes. When wolves declined, herds of plant-browsing elk, moose, and mule deer expanded and devastated vegetation such as willow and aspen trees often found growing near streams and rivers. This increased soil erosion and threatened habitats of other wildlife species such as beavers, which, as foundation species (p. 96), helped to maintain wetlands.

In 1987, the U.S. Fish and Wildlife Service (USFWS) proposed reintroducing gray wolves into the Yellowstone National Park ecosystem to help restore and sustain its biodiversity. The proposal brought angry protests, some from area ranchers who feared the wolves would leave the park and attack their cattle and sheep. Other objections came from hunters who feared the wolves would kill too many big-game animals, and from mining and logging companies fearing that the government would halt their operations on wolf-populated federal lands.

In 1995 and 1996, federal wildlife officials caught gray wolves in Canada and relocated 41 of them in Yellowstone National Park. Scientists estimate that the long-term carrying capacity of the park is 110 to 150 gray wolves. In 2007, the park had 171 gray wolves. Overall, this experiment in ecosystem restoration has helped to re-establish and sustain some of the biodiversity that the Yellowstone ecosystem once had, as discussed later in this chapter.

In 2008, the USFWS decided to remove the gray wolf from protection under the Endangered Species Act in the states of Montana, Wyoming, and Utah. Several conservation groups filed suits to have the courts overturn this decision. The wolves in the park will remain protected. But 6 of the park's 11 wolf packs travel outside of the park boundaries during part of every year. If the courts allow removing the wolves from the endangered species list, it will be legal to kill any of these packs' individuals found outside the park.

Biologists warn that human population growth, economic development, and poverty are exerting increasing pressure on ecosystems and the services they provide to sustain biodiversity. This chapter is devoted to helping us understand and sustain the earth's forests, grasslands, and other storehouses of terrestrial biodiversity.

Key Questions and Concepts

10-1 What are the major threats to forest ecosystems?

CONCEPT 10-1A Forest ecosystems provide ecological services far greater in value than the value of raw materials obtained from forests.

CONCEPT 10-1B Unsustainable cutting and burning of forests, along with diseases and insects, made worse by global warming, are the chief threats to forest ecosystems.

CONCEPT 10-1C Tropical deforestation is a potentially catastrophic problem because of the vital ecological services at risk, the high rate of tropical deforestation, and its growing contribution to global warming.

10-2 How should we manage and sustain forests?

CONCEPT 10-2 We can sustain forests by emphasizing the economic value of their ecological services, protecting old-growth forests, harvesting trees no faster than they are replenished, and using sustainable substitute resources.

10-3 How should we manage and sustain grasslands?

CONCEPT 10-3 We can sustain the productivity of grasslands by controlling the number and distribution of grazing livestock and by restoring degraded grasslands.

10-4 How should we manage and sustain parks and nature reserves?

CONCEPT 10-4 Sustaining biodiversity will require protecting much more of the earth's remaining undisturbed land area as parks and nature reserves.

10-5 What is the ecosystem approach to sustaining biodiversity?

CONCEPT 10-5A We can help to sustain biodiversity by identifying severely threatened areas and protecting those with high plant diversity (biodiversity hotspots) and those where ecosystem services are being impaired.

CONCEPT 10-5B Sustaining biodiversity will require a global effort to rehabilitate and restore damaged ecosystems.

CONCEPT 10-5C Humans dominate most of the earth's land, and preserving biodiversity will require sharing as much of it as possible with other species.

Note: Supplements 2 (p. S4), 4 (p. S20), 5 (p. S31), 9 (p. S53), and 13 (p. S78) can be used with this chapter.

There is no solution, I assure you,
to save Earth's biodiversity other than preservation
of natural environments in reserves large enough
to maintain wild populations sustainably.

EDWARD O. WILSON

10-1 What Are the Major Threats to Forest Ecosystems

▶ **CONCEPT 10-1A Forest ecosystems provide ecological services far greater in value than the value of raw materials obtained from forests.**

▶ **CONCEPT 10-1B Unsustainable cutting and burning of forests, along with diseases and insects, made worse by global warming, are the chief threats to forest ecosystems.**

▶ **CONCEPT 10-1C Tropical deforestation is a potentially catastrophic problem because of the vital ecological services at risk, the high rate of tropical deforestation, and its growing contribution to global warming.**

Forests Vary in Their Make-Up, Age, and Origins

Natural and planted forests occupy about 30% of the earth's land surface (excluding Greenland and Antarctica). Figure 7-8 (p. 146) shows the distribution of the world's boreal, temperate, and tropical forests. Tropical forests (Figure 7-15, top, p. 154) account for more than half of the world's forest area, and boreal (northern coniferous) forests (Figure 7-15, bottom) account for one quarter.

Forest managers and ecologists classify natural forests into two major types based on their age and structure. The first type is an **old-growth forest:** an uncut or regenerated primary forest that has not been seriously disturbed by human activities or natural disasters for

Kevin Schafer/Peter Arnold, Inc.

Mark Taylor/Warren Photographic/Bruce Coleman USA

Figure 10-2 **Natural capital:** an old-growth forest in the U.S. state of Washington's Olympic National Forest (left) and an old-growth tropical rain forest in Queensland, Australia (right).

200 years or more (Figure 10-2). Old-growth or primary forests are reservoirs of biodiversity because they provide ecological niches for a multitude of wildlife species (Figure 7-16, p. 155, and Figure 7-17, p. 156).

The second type is a **second-growth forest:** a stand of trees resulting from secondary ecological succession (Figure 5-17, p. 117, and Figure 7-15, center photo, p. 154). These forests develop after the trees in an area have been removed by human activities, such as clear-cutting for timber or cropland, or by natural forces, such as fire, hurricanes, or volcanic eruption.

A **tree plantation,** also called a **tree farm** or **commercial forest** (Figure 10-3), is a managed tract with uniformly aged trees of one or two genetically uniform species that usually are harvested by clear-cutting as soon as they become commercially valuable. The land

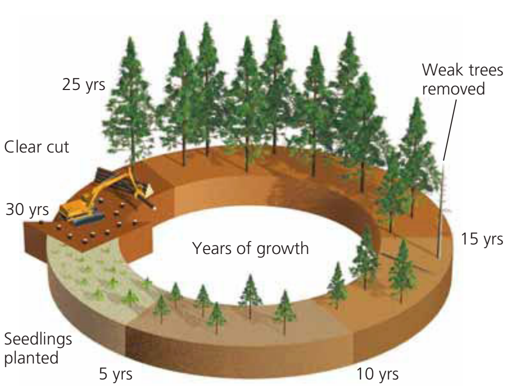

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Figure 10-3 Short (25- to 30-year) rotation cycle of cutting and regrowth of a monoculture tree plantation used in modern industrial forestry. In tropical countries, where trees can grow more rapidly year-round, the rotation cycle can be 6–10 years. Old-growth or second-growth forests are clear-cut to provide land for growing most tree plantations (see photo, right). **Question:** What are two ways in which this process can degrade an ecosystem?

is then replanted and clear-cut again in a regular cycle. When managed carefully, such plantations can produce wood at a fast rate and thus increase their owners' profits. Most of this wood goes to paper mills and to mills that produce composites used as a substitute for natural wood.

But tree plantations with only one or two tree species are much less biologically diverse and probably less sustainable than old-growth and second-growth forests because they violate nature's biodiversity **principle of sustainability** (see back cover). And repeated cycles of cutting and replanting can eventually deplete the soil of nutrients and lead to an irreversible ecological tipping point that can hinder the growth of any type of forest on the land. There is also controversy over the increased use of genetically engineered tree species whose seeds could spread to other areas and threaten the diversity of second- and old-growth forests.

According to 2007 estimates by the FAO, about 60% of the world's forests are second-growth forests, 36% are old-growth or primary forests, and 4% are tree plantations (6% in the United States). In order, five countries—Russia, Canada, Brazil, Indonesia, and Papua New Guinea—have more than three-fourths of the world's remaining old-growth forests. In order, China (which has little original forest left), India, the United States, Russia, Canada, and Sweden account for about 60% of the world's tree plantations. Some conservation biologists urge establishing tree plantations only on land that has already been cleared or degraded instead of putting them in place of existing old-growth or secondary forests. One day, tree plantations may supply most of the world's demand for industrial wood, and this will help to protect the world's remaining forests.

Forests Provide Important Economic and Ecological Services

Forests provide highly valuable ecological and economic services (Figure 10-4 and **Concept 10-1A**). For example, through photosynthesis, forests remove CO_2 from the atmosphere and store it in organic compounds (biomass). By performing this ecological service, forests help to stabilize the earth's temperature and to slow global warming as a part of the global carbon cycle (Figure 3-18, p. 68). Scientists have attempted to estimate the economic value of the ecological services provided by the world's forests and other ecosystems (Science Focus, p. 218).

RESEARCH FRONTIER

Refining estimates of the economic values of ecological services provided by forests and other major ecosystems. See **academic.cengage.com/biology/miller**.

NATURAL CAPITAL

Forests

Ecological Services	Economic Services
Support energy flow and chemical cycling	Fuelwood
Reduce soil erosion	Lumber
Absorb and release water	Pulp to make paper
Purify water and air	Mining
Influence local and regional climate	Livestock grazing
Store atmospheric carbon	Recreation
Provide numerous wildlife habitats	Jobs

Figure 10-4 Major ecological and economic services provided by forests (**Concept 10-1A**). **Question:** Which two ecological services and which two economic services do you think are the most important?

Most biologists believe that the clearing and degrading of the world's remaining old-growth forests is a serious global environmental threat because of the important ecological and economic services they provide (**Concept 10-1A**). For example, traditional medicines, used by 80% of the world's people, are derived mostly from natural plants in forests, and chemicals found in tropical forest plants are used as blueprints for making most of the world's prescription drugs (Figure 9-8, p. 190). Forests are also habitats for about two-thirds of the earth's terrestrial species. In addition, they are home to more than 300 million people, and one of every four people depend on forests for their livelihoods.

Unsustainable Logging Is a Major Threat to Forest Ecosystems

Along with highly valuable ecological services, forests provide us with raw materials, especially wood.

The first step in harvesting trees is to build roads for access and timber removal. Even carefully designed logging roads have a number of harmful effects (Figure 10-5, p. 218)—namely, increased erosion and sediment runoff into waterways, habitat fragmentation (see Science Focus, p. 195, and *The Habitable Planet,*

SCIENCE FOCUS

Putting a Price Tag on Nature's Ecological Services

The long-term health of an economy cannot be separated from the health of the natural systems that support it. Currently, forests and other ecosystems are valued mostly for their economic services (Figure 10-4, right). But suppose we took into account the monetary value of the ecological services provided by forests (Figure 10-4, left).

In 1997, a team of ecologists, economists, and geographers—led by ecological economist Robert Costanza of the University of Vermont—estimated the monetary worth of the earth's ecological services and the biological income they provide. They estimated the latter to be at least \$33.2 trillion per year—close to the economic value of all of the goods and services produced annually throughout the world. The amount of money required to provide such interest income, and thus the estimated value of the world's natural capital, would have to be at least \$500 trillion—an average of about \$73,500 for each person on earth!

According to this study, the world's forests provide us with ecological services worth at least \$4.7 trillion per year—hundreds of times more than their economic value. And these are very conservative estimates.

Costanza's team examined many studies and a variety of methods used to estimate the values of ecosystems. For example, some researchers estimated people's *willingness to pay* for ecosystem services that are not marketed, such as natural flood control and carbon storage. These estimates were added to the known values of marketed goods like timber to arrive at a total value for an ecosystem.

The researchers estimated total global areas of 16 major categories of ecosystems, including forests, grasslands, and other terrestrial and aquatic systems. They multiplied those areas by the values per hectare of various ecosystem services to get the estimated economic values of these forms of natural capital. Some of the results for forests are shown in Figure 10-A. Note that the collective value of these ecosystem services is much greater than the value of timber and other raw materials extracted from forests (**Concept 10-1A**).

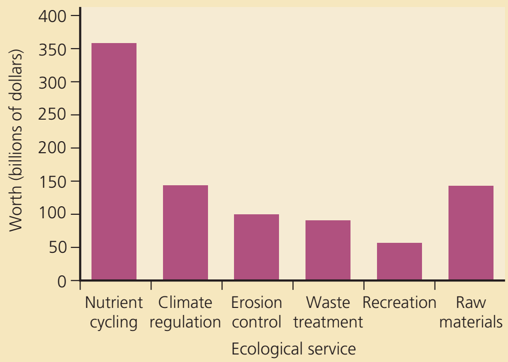

Figure 10-A Estimated annual global economic values of some ecological services provided by forests compared to the raw materials they produce (in billions of dollars).

These researchers hope their estimates will alert people to three important facts: the earth's ecosystem services are essential for all humans and their economies; their economic value is huge; and they are an ongoing source of ecological income as long as they are used sustainably.

However, unless such estimates are included in the market prices of goods and services—through market tools such as regulations and taxes that discourage biodiversity degradation and through subsidies that protect biodiversity—the world's forests and other ecosystems will continue to be degraded. For example, the governments of countries such as Brazil and Indonesia provide subsidies that encourage the clearing or burning of tropical forests to plant vast soybean and oil palm plantations. This sends the powerful message that it makes more economic sense to destroy or degrade these centers of biodiversity than it does to leave them intact.

Critical Thinking

Some analysts believe that we should not try to put economic values on the world's irreplaceable ecological services because their value is infinite. Do you agree with this view? Explain. What is the alternative?

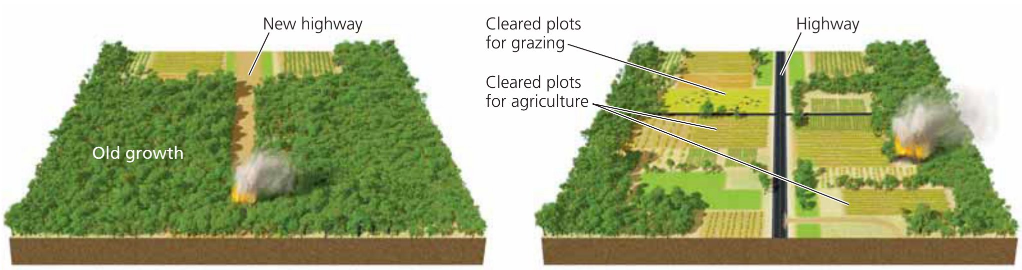

Figure 10-5 **Natural capital degradation:** Building roads into previously inaccessible forests paves the way to fragmentation, destruction, and degradation.

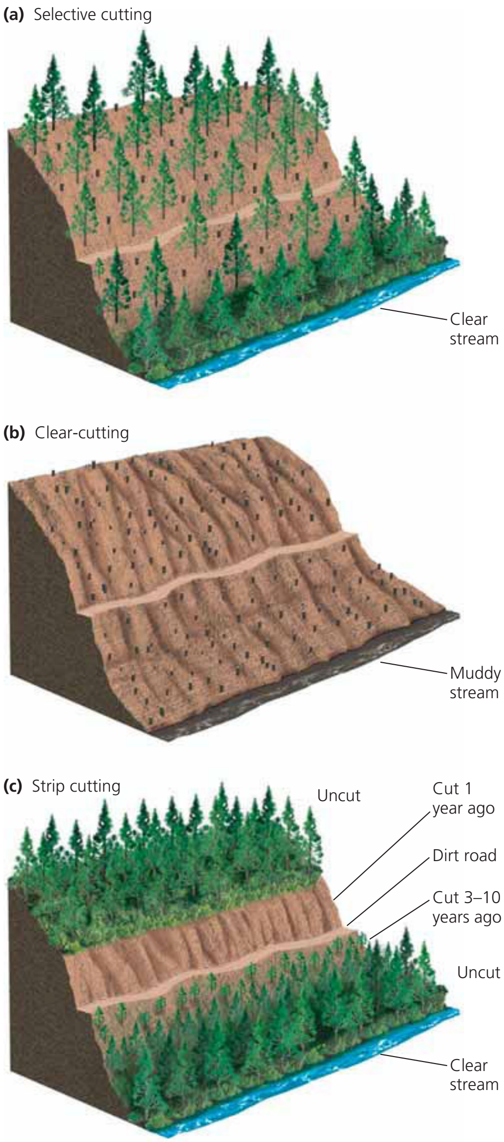

Figure 10-6 Major tree harvesting methods. **Question:** If you were cutting trees in a forest you owned, which method would you choose and why?

Video 9, at **www.learner.org/resources/series209.html**), and loss of biodiversity. Logging roads also expose forests to invasion by nonnative pests, diseases, and wildlife species. And they open once-inaccessible forests to farmers, miners, ranchers, hunters, and off-road vehicle users.

Once loggers reach a forest area, they use a variety of methods to harvest the trees (Figure 10-6). With *selective cutting,* intermediate-aged or mature trees in an uneven-aged forest are cut singly or in small groups (Figure 10-6a). But often, loggers remove all the trees from an area in what is called a *clear-cut* (Figures 10-6b and 10-7). Clear-cutting is the most efficient way for a logging operation to harvest trees, but it can do considerable harm to an ecosystem.

For example, scientists found that removing all the tree cover from a watershed greatly increases water runoff and loss of soil nutrients (Chapter 2 Core Case Study, p. 28). This increases soil erosion, which in turn causes more vegetation to die, leaving barren ground that can be eroded further, an example of a harmful positive feedback loop (Figure 2-11, p. 45, and **Concept 2-5A**, p. 44). More erosion also means more pollution of streams in the watershed. And loss of vegetation destroys habitat and degrades biodiversity. Figure 10-8 (p. 220) summarizes some advantages and disadvantages of clear-cutting.

CONCEPT LINK

CENGAGE**NOW**™ Learn more about how deforestation can affect the drainage of a watershed and disturb its ecosystem at CengageNOW™.

A variation of clear-cutting that allows a more sustainable timber yield without widespread destruction is *strip cutting* (Figure 10-6c). It involves clear-cutting a strip of trees along the contour of the land within a corridor narrow enough to allow natural regeneration within a few years. After regeneration, loggers cut another strip next to the first, and so on.

Daniel Dancer/Peter Arnold, Inc.

Figure 10-7 Clear-cut logging in the U.S. state of Washington.

TRADE-OFFS

Clear-Cutting Forests

Advantages	Disadvantages
Higher timber yields	Reduces biodiversity
Maximum profits in shortest time	Destroys and fragments wildlife habitats
Can reforest with fast-growing trees	Increases water pollution, flooding, and erosion on steep slopes
Good for tree species needing full or moderate sunlight	Eliminates most recreational value

Figure 10-8 Advantages and disadvantages of clear-cutting forests. **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

Biodiversity experts are alarmed at the growing practice of illegal, uncontrolled, and unsustainable logging taking place in 70 countries, especially in Africa and Southeast Asia (**Concept 10-1B**). Such logging has ravaged 37 of the 41 national parks in the African country of Kenya and now makes up 73–80% of all logging in Indonesia.

Complicating this issue is global trade in timber and wood products. For example, China, which has cut most of its own natural forests, imports more tropical rain forest timber than any other nation. Much of this timber is harvested illegally and unsustainably and is used to make furniture, plywood, flooring, and other products that are sold in the global marketplace.

Fire, Insects, and Climate Change Can Threaten Forest Ecosystems

Two types of fires can affect forest ecosystems. *Surface fires* (Figure 10-9, left) usually burn only undergrowth and leaf litter on the forest floor. They may kill seedlings and small trees but spare most mature trees and allow most wild animals to escape.

Occasional surface fires have a number of ecological benefits. They burn away flammable ground material and help to prevent more destructive fires. They also free valuable mineral nutrients tied up in slowly decomposing litter and undergrowth, release seeds from the cones of lodgepole pines, stimulate the germination of certain tree seeds such as those of the giant sequoia and jack pine, and help control tree diseases and insects. Wildlife species such as deer, moose, muskrat, and quail depend on occasional surface fires to maintain their habitats and provide food in the form of vegetation that sprouts after fires.

Another type of fire, called a *crown fire* (Figure 10-9, right), is an extremely hot fire that leaps from treetop

David J. Moorhead/The University of Georgia

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Figure 10-9 Surface fires (left) usually burn undergrowth and leaf litter on a forest floor. They can help to prevent more destructive crown fires (right) by removing flammable ground material. In fact, carefully controlled surface fires are deliberately set sometimes to prevent buildup of flammable ground material in forests. They also recycle nutrients and thus help to maintain the productivity of a variety of forest ecosystems. **Question:** What is another way in which a surface fire might benefit a forest?

Figure 10-10 **Natural capital degradation:** some of the nonnative insect species and disease organisms that have invaded U.S. forests and are causing billions of dollars in damages and tree loss. The light green and orange colors in the map show areas where green or red overlap with yellow. (Data from U.S. Forest Service)

to treetop, burning whole trees. Crown fires usually occur in forests that have not experienced surface fires for several decades, a situation that allows dead wood, leaves, and other flammable ground litter to accumulate. These rapidly burning fires can destroy most vegetation, kill wildlife, increase soil erosion, and burn or damage human structures in their paths.

As part of a natural cycle, forest fires are not a major threat to forest ecosystems. But they are serious threats in parts of the world where people intentionally burn forests to clear the land, mostly to make way for crop plantations (**Concept 10-1B**). This can result in dramatic habitat losses, air pollution, and increases in atmospheric CO_2.

Accidental or deliberate introductions of foreign diseases and insects are a major threat to forests in the United States and elsewhere. Figure 10-10 shows some nonnative species of pests and disease organisms that are causing serious damage to certain tree species in parts of the United States.

There are several ways to reduce the harmful impacts of tree diseases and insect pests on forests. One is to ban imported timber that might introduce harmful new diseases or insects; another is to remove or clear-cut infected and infested trees. We can also develop tree species that are genetically resistant to common tree diseases. Another approach is to control insect pests by applying conventional pesticides. Scientists also use biological control (bugs that eat harmful bugs) combined with very small amounts of conventional pesticides.

On top of these threats, projected climate change from global warming could harm many forests. For example, sugar maples are sensitive to heat, and in the U.S. region of New England, rising temperatures could kill these trees and, consequently, a productive maple syrup industry. Rising temperatures would also make many forest areas more suitable for insect pests and increase the size of pest populations. The resulting combination of drier forests and more dead trees could increase the incidence and intensity of forest fires (**Concept 10-1B**). This would add more of the greenhouse gas CO_2 to the atmosphere, which would further increase atmospheric temperatures and cause even more forest fires in a runaway positive feedback loop (Figure 2-11, p. 45).

We Have Cut Down Almost Half of the World's Forests

Deforestation is the temporary or permanent removal of large expanses of forest for agriculture, settlements, or other uses. Surveys by the World Resources Institute (WRI) indicate that over the past 8,000 years, human activities have reduced the earth's original forest cover by about 46%, with most of this loss occurring in the last 60 years.

Deforestation continues at a rapid rate in many parts of the world. The U.N. Food and Agricultural Organization (FAO) and World Resources Institute (WRI) surveys indicate that the global rate of forest cover loss between 1990 and 2005 was between 0.2% and 0.5% per year, and that at least another 0.1–0.3% of the world's forests were degraded every year, mostly to grow crops and graze cattle. If these estimates are correct, the world's forests are being cleared or degraded exponentially at a rate of 0.3–0.8% per year, with much higher rates in some areas.

These losses are concentrated in developing countries, especially those in the tropical areas of Latin America, Indonesia, and Africa (Figure 3, pp. S24–S25, in Supplement 4). In its 2007 *State of the World's Forests* report, U.N. Food and Agricultural Organization estimated that about 130,000 square kilometers (50,000 square miles) of tropical forests are cleared each year (Figure 10-11)—equivalent to the total area of Greece or the U.S. state of Mississippi. We examine tropical forest losses further in the next subsection.

In addition to losses of tropical forests, scientists are concerned about the increased clearing of the northern boreal forests of Alaska, Canada, Scandinavia, and Russia, which together make up about one-fourth of the world's forested area. These vast coniferous forests (Figure 7-15, bottom photo, p. 154) are the world's greatest terrestrial storehouse of organic carbon and play a major role in the carbon cycle (Figure 3-18, p. 68) and in climate regulation for the entire planet. They also contain more than 70,000 plant and animal species. Surveys indicate that the total area of boreal forests lost every year is about twice the total area of Brazil's vast rain forests. In 2007, a group of 1,500 scientists from around the world signed a letter calling for the Canadian government to protect half of Canada's threatened boreal forests (of which only 10% are protected now) from logging, mining, and oil and gas extraction.


S. Chamnanrith-UNEP/Peter Arnold, Inc.

Figure 10-11 Natural capital degradation: extreme tropical deforestation in Chiang Mai, Thailand. The clearing of trees that absorb carbon dioxide increases global warming. It also dehydrates the soil by exposing it to sunlight. The dry topsoil blows away, which prevents the reestablishment of a forest in this area.

According to the WRI, if current deforestation rates continue, about 40% of the world's remaining intact forests will have been logged or converted to other uses within 2 decades, if not sooner. Clearing large areas of forests, especially old-growth forests, has important short-term economic benefits (Figure 10-4, right), but it also has a number of harmful environmental effects (Figure 10-12).

HOW WOULD YOU VOTE?

Should there be a global effort to sharply reduce the cutting of old-growth forests? Cast your vote online at **academic .cengage.com/biology/miller**.

In some countries, there is encouraging news about forest use. In 2007, the FAO reported that the net total forest cover in several countries, including the United States (see Case Study below), changed very little or increased between 2000 and 2005. Some of the increases resulted from natural reforestation by secondary ecological succession on cleared forest areas and abandoned croplands. But such increases were also due to the spread of commercial tree plantations.

NATURAL CAPITAL DEGRADATION

Deforestation

- Decreased soil fertility from erosion
- Runoff of eroded soil into aquatic systems
- Premature extinction of species with specialized niches
- Loss of habitat for native species and migratory species such as birds and butterflies
- Regional climate change from extensive clearing
- Release of CO_2 into atmosphere
- Acceleration of flooding

Figure 10-12 Harmful environmental effects of deforestation, which can reduce biodiversity and the ecological services provided by forests (Figure 10-4, left). **Question:** What are three products you have used recently that might have come from old-growth forests?

CASE STUDY

Many Cleared Forests in the United States Have Grown Back

Forests that cover about 30% of the U.S. land area provide habitats for more than 80% of the country's wildlife species and supply about two-thirds of the nation's surface water. Old-growth forests once covered more than half of the nation's land area. But between 1620 when Europeans first arrived and 1920, the old-growth forests of the eastern United States were decimated.

Today, forests (including tree plantations) cover more area in the United States than they did in 1920. Many of the old-growth forests that were cleared or partially cleared between 1620 and 1920 have grown back naturally through secondary ecological succession (Figure 5-17, p. 117). There are fairly diverse second-growth (and in some cases third-growth) forests in every region of the United States, except much of the West. In 1995, environmental writer Bill McKibben cited forest regrowth in the United States—especially in the East—as "the great environmental story of the United States, and in some ways, the whole world."

Every year, more wood is grown in the United States than is cut and the total area planted with trees increases. Protected forests make up about 40% of the country's total forest area, mostly in the *National Forest System*, which consists of 155 national forests managed by the U.S. Forest Service (USFS).

On the other hand, since the mid-1960s, an increasing area of the nation's remaining old-growth and fairly diverse second-growth forests has been cut down and replaced with biologically simplified tree plantations. According to biodiversity researchers, this reduces overall forest biodiversity and disrupts ecosystem processes such as energy flow and chemical cycling. And if such plantations are harvested too frequently, it could also deplete forest soils of key nutrients. Many biodiversity researchers favor establishing tree plantations only on land that has already been degraded instead of cutting old-growth and second-growth forests in order to replace them with tree plantations.

Tropical Forests Are Disappearing Rapidly

Tropical forests (Figure 7-15, top photo, p. 154) cover about 6% of the earth's land area—roughly the area of the lower 48 U.S. states. Climatic and biological data suggest that mature tropical forests once covered at least twice as much area as they do today; the majority of tropical forest loss has taken place since 1950 (Chapter 3 Core Case Study, p. 50).

Satellite scans and ground-level surveys indicate that large areas of tropical rain forests and tropical dry forests are being cut rapidly in parts of Africa, Southeast Asia (Figure 10-11), and South America (Figure 3-1, p. 50, and Figure 10-13, p. 224). A 2006 study by the U.S. National Academy of Sciences found that between 1990 and 2005, Brazil and Indonesia led the world in tropical forest loss. Illegal tree felling in 37 of 41 of Indonesia's supposedly protected parks account for three-quarters of the country's logging. According to the United Nations, Indonesia, which currently has the world's most diverse combination of plants, animals, and marine life, has already lost an estimated

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72% of its original intact forest, and 98% of its remaining forests will be gone by 2022.

Studies indicate that at least half of the world's known species of terrestrial plants and animals live in tropical rain forests (Figure 10-14). Because of their specialized niches (Figure 7-17, p. 156, and **Concept 4-6A**, p. 91) these species are highly vulnerable to extinction when their forest habitats are destroyed or degraded. Tropical deforestation is the main reason that more than 8,000 tree species—10% of the world's total—are threatened with extinction.

Brazil has more than 30% of the world's remaining tropical rain forest and an estimated 30% of the world's terrestrial plant and animal species (Figure 10-14, left)

Compost/Peter Arnold, Inc

Compost/Peter Arnold, Inc

Figure 10-14 *Species diversity:* two species found in tropical forests are part of the earth's biodiversity. On the left is an endangered *white ukari* in a Brazilian tropical forest. On the right is the world's largest flower, the *flesh flower* (Rafflesia) growing in a tropical rain forest of West Sumatra, Indonesia. The flower of this leafless plant can be as large 1 meter (3.3 feet) in diameter and weigh 7 kilograms (15 pounds). The plant gives off a smell like rotting meat, presumably to attract flies and beetles that pollinate the flower. After blossoming once a year for a few weeks, the blood red flower dissolves into a slimy black mass.

in its vast Amazon basin, which covers an area larger than India.

According to Brazil's government and forest experts, the percentage of its Amazon basin that had been deforested or degraded increased from 1% in 1970 to 16–20% in 2005 (Figure 10-13). Between 2005 and 2007, this rate increased sharply, with people cutting forests mostly to make way for cattle ranching and large plantations of crops such as soybeans used for cattle feed. In 2004, researchers at the Smithsonian Tropical Research Institute estimated that loggers, ranchers, and farmers in Brazil were clearing and burning an area equivalent to a loss of 11 football fields a minute! (**Concept 10-1C**)

Because of difficulties in estimating tropical forest loss, yearly estimates of global tropical deforestation vary widely from 50,000 square kilometers (19,300 square miles)—roughly the size of Costa Rica or the U.S. state of West Virginia—to 170,000 square kilometers (65,600 square miles)—about the size of the South American country of Uruguay or the U.S. state of Florida. At such rates, half of the world's remaining tropical forests will be gone in 35–117 years, resulting in a dramatic loss and degradation of biodiversity and the ecosystem services it provides.

RESEARCH FRONTIER

Improving estimates of rates of tropical deforestation. See **academic.cengage.com/biology/miller**.

Causes of Tropical Deforestation Are Varied and Complex

Tropical deforestation results from a number of interconnected basic and secondary causes (Figure 10-15). Population growth and poverty combine to drive subsistence farmers and the landless poor to tropical forests, where they try to grow enough food to survive. Government subsidies can accelerate deforestation by reducing the costs of timber harvesting, cattle grazing,

NATURAL CAPITAL DEGRADATION

Major Causes of the Destruction and Degradation of Tropical Forests

Basic Causes

- Not valuing ecological services
- Crop and timber exports
- Government policies
- Poverty
- Population growth

Secondary Causes

- Roads
- Fires
- Settler farming
- Cash crops
- Cattle ranching
- Logging
- Tree plantations

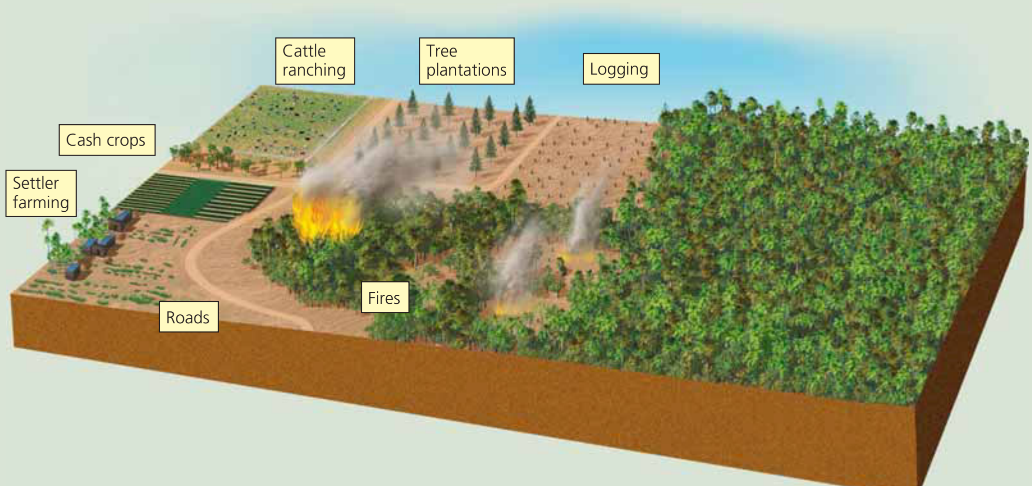

Figure 10-15 *Major interconnected causes* of the destruction and degradation of tropical forests. The importance of specific secondary causes varies in different parts of the world. **Question:** If we could eliminate the basic causes, which if any of the secondary causes might automatically be eliminated?

Herbert Giradet/Peter Arnold, Inc.

Figure 10-16 Natural capital degradation: large areas of tropical forest in Brazil's Amazon basin are burned each year to make way for cattle ranches, small-scale farms, and plantation crops such as soybeans. **Questions:** What are three ways in which your lifestyle probably contributes to this process? How, in turn, might this process affect your life?

and establishing vast plantations of crops such as soybeans and oil palm.

The degradation of a tropical forest usually begins when a road is cut deep into the forest interior for logging and settlement (Figure 10-5). Loggers then use selective cutting (Figure 10-6, top) to remove the best timber. When these big trees fall, many other trees fall with them because of their shallow roots and the network of vines connecting the trees in the forest's canopy. Thus, removing the largest and best trees by selective cutting can cause considerable ecological damage in tropical forests, although the damage is much less than that from burning or clear-cutting areas of such forests. Most of this timber is used locally and much of it is exported, but a great deal is also left to rot.

Foreign corporations operating under government concession contracts do much of the logging in tropical countries. Once a country's forests are gone, the companies move on to another country, leaving ecological devastation behind. For example, the Philippines and Nigeria have lost most of their once-abundant tropical hardwood forests and now are net importers of forest products. Several other tropical countries are following this ecologically and economically unsustainable path.

After the best timber has been removed, timber companies or the government often sell the land to ranchers. Within a few years, the cattle typically overgraze the land and the ranchers move their operations to another forest area. Then they sell the degraded land to settlers who have migrated to tropical forests hoping to grow enough food to survive. After a few years of crop growing and erosion from rain, the nutrient-poor tropical soil is depleted of nutrients. Then the settlers move on to newly cleared land to repeat this environmentally destructive process.

The secondary causes of deforestation vary in different tropical areas. Tropical forests in the Amazon and other South American countries are being cleared or burned (Figure 10-16) mostly for cattle grazing and large soybean plantations. In Indonesia, Malaysia, and other areas of Southeast Asia, tropical forests are being cut or burned and replaced with vast plantations of oil palm, whose oil is used in cooking, cosmetics, and biodiesel fuel for motor vehicles (especially in Europe). In Africa, tropical deforestation and degradation are caused primarily by individuals struggling to survive by clearing plots for small-scale farming and by harvesting wood for fuel.

Burning is widely used to clear forest areas for agriculture, settlement, and other purposes. Healthy rain forests do not burn naturally. But roads, settlements, and farming, grazing, and logging operations fragment them (Science Focus, p. 195). The resulting patches of forest dry out and readily ignite.

The burning of tropical forests is a major component of human-enhanced global warming, which is projected to change the global climate at an increasing rate. Scientists estimate that globally, these fires account for at least 20% of all human-created greenhouse gas emissions. They also produce twice as much CO_2, annually, as all of the world's cars and trucks emit (**Concept 10-1C**). The large-scale burning of the Amazon (Figure 10-16) accounts for three-fourths of Brazil's greenhouse gas emissions, making Brazil the world's fourth largest emitter of such gases.

A 2005 study by forest scientists found that widespread fires in the Amazon are changing weather patterns by raising temperatures and reducing rainfall. Resulting droughts dry out the forests and make them more likely to burn—another example of a runaway positive feedback loop **Concept 2-5A**, p. 44, and Figure 2-11, p. 45). This process is converting deforested areas of tropical forests to tropical grassland (savanna)—an example of reaching an irreversible ecological *tipping point.* When the forests disappear, rainfall declines and yields of the crops planted on the land drop sharply. Models project that if current burning and deforestation rates continue, 20–30% of the Amazon will be turned into savanna in the next 50 years, and perhaps all of it could be so converted by 2080.

CONCEPT LINK

THINKING ABOUT
Tropical Forests

Why should you care whether most of the world's remaining tropical forests are burned or cleared and converted to savanna within your lifetime? What are three things you could do to help slow the rate of this depletion and degradation of the earth's natural capital?

10-2 How Should We Manage and Sustain Forests?

CONCEPT 10-2 We can sustain forests by emphasizing the economic value of their ecological services, protecting old-growth forests, harvesting trees no faster than they are replenished, and using sustainable substitute resources.

We Can Manage Forests More Sustainably

Biodiversity researchers and a growing number of foresters have called for more sustainable forest management. Figure 10-17 lists ways to achieve this goal (**Concept 10-2**). Certification of sustainably grown timber and of sustainably produced forest products can help people consume forest products more sustainably (Science Focus, p. 228). **GREEN CAREER:** Sustainable forestry

SOLUTIONS

Sustainable Forestry

- Identify and protect forest areas high in biodiversity
- Rely more on selective cutting and strip cutting
- No clear-cutting on steep slopes
- No logging of old-growth forests
- Sharply reduce road building into uncut forest areas
- Leave most standing dead trees and fallen timber for wildlife habitat and nutrient recycling
- Plant tree plantations primarily on deforested and degraded land
- Certify timber grown by sustainable methods
- Include ecological services of forests in estimating their economic value

Figure 10-17 Ways to grow and harvest trees more sustainably (**Concept 10-2**). **Question:** Which three of these solutions do you think are the most important? Why?

We Can Improve the Management of Forest Fires

In the United States, the Smokey Bear educational campaign undertaken by the Forest Service and the National Advertising Council has prevented countless forest fires. It has also saved many lives and prevented billions of dollars in losses of trees, wildlife, and human structures.

At the same time, this educational program has convinced much of the public that all forest fires are bad and should be prevented or put out. Ecologists warn that trying to prevent all forest fires increases the likelihood of destructive crown fires (Figure 10-9, right) by allowing accumulation of highly flammable underbrush and smaller trees in some forests.

According to the U.S. Forest Service, severe fires could threaten 40% of all federal forest lands, mainly because of fuel buildup resulting from past rigorous fire protection programs (the Smokey Bear era), increased logging in the 1980s that left behind highly flammable logging debris (called *slash*), and greater public use of federal forest lands.

Ecologists and forest fire experts have proposed several strategies for reducing fire-related harm to forests and people. One approach is to set small, contained surface fires to remove flammable small trees

SCIENCE FOCUS

Certifying Sustainably Grown Timber

Collins Pine owns and manages a large area of productive timberland in the northeastern part of the U.S. state of California. Since 1940, the company has used selective cutting to help maintain the ecological and economic sustainability of its timberland.

Since 1993, Scientific Certification Systems (SCS) has evaluated the company's timber production. SCS, which is part of the non-profit Forest Stewardship Council (FSC), was formed to develop a list of environmentally sound practices for use in certifying timber and products made from such timber.

Each year, SCS evaluates Collins Pine's landholdings and has consistently found that: their cutting of trees has not exceeded long-term forest regeneration; roads and harvesting systems have not caused unreasonable ecological damage; soils are not damaged; and downed wood (boles) and standing dead trees (snags) are left to provide wildlife habitat. As a result, SCS judges the company to be a good employer and a good steward of its land and water resources.

According to the FSC, between 1995 and 2007, the area of the world's forests in 76 countries that meets its international certification standards grew more than 16-fold. The countries with the largest areas of FSC-certified forests are, in order, Canada, Russia, Sweden, the United States, Poland, and Brazil. Despite this progress, by 2007, less than 10% of the world's forested area was certified. FSC also certifies 5,400 manufacturers and distributors of wood products.

Critical Thinking

Should governments provide tax breaks for sustainably grown timber to encourage this practice? Explain.

and underbrush in the highest-risk forest areas. Such *prescribed fires* require careful planning and monitoring to try to keep them from getting out of control. As an alternative to prescribed burns, local officials in populated parts of fire-prone California use herds of goats (kept in moveable pens) to eat away underbrush.

A second strategy is to allow many fires on public lands to burn, thereby removing flammable underbrush and smaller trees, as long as the fires do not threaten human structures and life. A third approach is to protect houses and other buildings in fire-prone areas by thinning a zone of about 60 meters (200 feet) around them and eliminating the use of flammable materials such as wooden roofs.

A fourth approach is to thin forest areas vulnerable to fire by clearing away small fire-prone trees and underbrush under careful environmental controls. Many forest fire scientists warn that such thinning should not involve removing economically valuable medium-size and large trees for two reasons. First, these are the most fire-resistant trees. Second, their removal encourages dense growth of more flammable young trees and underbrush and leaves behind highly flammable slash. Many of the worst fires in U.S. history—including some of those during the 1990s—burned through cleared forest areas containing slash. A 2006 study by U.S. Forest Service researchers found that thinning forests without using prescribed burning to remove accumulated brush and deadwood can greatly increase rather than decrease fire damage.

Despite such warnings from forest scientists, the U.S. Congress under lobbying pressure from timber companies passed the 2003 *Healthy Forests Restoration Act.* It allows timber companies to cut down economically valuable medium-size and large trees in 71% of the country's national forests in return for clearing away smaller, more fire-prone trees and underbrush. However, the companies are not required to conduct prescribed burns after completing the thinning process.

This law also exempts most thinning projects from environmental reviews, which are currently required by forest protection laws in the national forests. According to many biologists and forest fire scientists, this law is likely to *increase* the chances of severe forest fires because it ignores the four strategies scientists have suggested for better management of forest fires. Critics of the Healthy Forests Restoration Act of 2003 say that healthier forests could be maintained at a much lower cost to taxpayers by giving communities in fire prone areas grants to implement these recommendations.

HOW WOULD YOU VOTE?

Do you support repealing or modifying the Healthy Forests Restoration Act of 2003? Cast your vote online at **academic .cengage.com/biology/miller**.

We Can Reduce the Demand for Harvested Trees

One way to reduce the pressure on forest ecosystems is to improve the efficiency of wood use. According to the Worldwatch Institute and forestry analysts, *up to 60% of the wood consumed in the United States is wasted unnecessarily.* This results from inefficient use of construction materials, excess packaging, overuse of junk mail, inadequate paper recycling, and failure to reuse wooden shipping containers.

One reason for cutting trees is to provide pulp for making paper, but paper can be made out of fiber that does not come from trees. China uses rice straw and other agricultural residues to make much of its paper.

Figure 10-18 **Solutions:** pressure to cut trees to make paper could be greatly reduced by planting and harvesting a fast-growing plant known as kenaf. According to the USDA, kenaf is "the best option for tree-free papermaking in the United States" and could replace wood-based paper within 20–30 years. **Question:** Would you invest in a kenaf plantation? Explain.

Most of the small amount of tree-free paper produced in the United States is made from the fibers of a rapidly growing woody annual plant called *kenaf* (pronounced "kuh-NAHF"; Figure 10-18). Kenaf and other nontree fibers such as hemp yield more paper pulp per hectare than tree farms and require fewer pesticides and herbicides. It is estimated, that within 2 to 3 decades we could essentially eliminate the need to use trees to make paper. However, while timber companies successfully lobby for government subsidies to grow and harvest trees to make paper, there are no major lobbying efforts or subsidies for producing paper from kenaf or kudzu (Figure 9-15, p. 200).

■ **CASE STUDY**

Deforestation and the Fuelwood Crisis

Another major strain on forests, especially in tropical areas, is the practice of cutting of trees for fuelwood. About half of the wood harvested each year and three-fourths of that in developing countries is used for fuel. Fuelwood and charcoal made from wood are used for heating and cooking by more than 2 billion people in developing countries (Figure 6-13, p. 135). As the demand for fuelwood in urban areas exceeds the sustainable yield of nearby forests, expanding rings of deforested land encircle such cities. By 2050, the demand for fuelwood could easily be 50% greater than the amount that can be sustainably supplied.

Haiti, a country with 9 million people, was once a tropical paradise covered largely with forests. Now it is an ecological disaster. Largely because its trees were cut for fuelwood, only about 2% of its land is forested. With the trees gone, soils have eroded away, making it much more difficult to grow crops. This unsustainable use of natural capital has led to a downward spiral of environmental degradation, poverty, disease, social injustice, crime, and violence. As a result, Haiti is classified as one of the world's leading *failing states* (Figure 17, p. S19, Supplement 3).

One way to reduce the severity of the fuelwood crisis in developing countries is to establish small plantations of fast-growing fuelwood trees and shrubs around farms and in community woodlots. Another approach to this problem is to burn wood more efficiently by providing villagers with cheap, more fuel-efficient, and less-polluting wood stoves, household biogas units that run on methane produced from crop and animal wastes, solar ovens, and electric hotplates powered by solar- or wind-generated electricity. This will also greatly reduce premature deaths from indoor air pollution caused by open fires and poorly designed stoves.

In addition, villagers can switch to burning the renewable sun-dried roots of various gourds and squash plants. Scientists are also looking for ways to produce charcoal for heating and cooking without cutting down trees. For example, Professor Amy Smith, of MIT in Cambridge, Massachusetts (USA), is developing a way to make charcoal from the fibers in a waste product called bagasse, which is left over from sugar cane processing in Haiti. Because sugarcane charcoal burns cleaner than wood charcoal, using it could help Haitians reduce indoor air pollution.

Countries such as South Korea, China, Nepal, and Senegal, have used such methods to reduce fuelwood shortages, sustain biodiversity through reforestation, and reduce soil erosion. Indeed, the mountainous country of South Korea is a global model for its successful reforestation following severe deforestation during the war between North and South Korea, which ended in 1953. Today, forests cover almost two-thirds of the country, and tree plantations near villages supply fuelwood on a sustainable basis. However, most countries suffering from fuelwood shortages are cutting trees for fuelwood and forest products 10–20 times faster than new trees are being planted. Shifting government subsidies from the building of logging roads to the planting of trees would help to increase forest cover worldwide.

INDIVIDUALS MATTER

Wangari Maathai and Kenya's Green Belt Movement

In the mid-1970s, Wangari Maathai (Figure 10-B) took stock of environmental conditions in her native Kenya. Tree-lined streams she had known as a child had dried up. Farms and plantations that were draining the watersheds and degrading the soil had replaced vast areas of forest. The Sahara Desert was encroaching from the north.

Something inside her told Maathai she had to do something about this degradation. Starting with a small tree nursery in her backyard, she founded the Green Belt Movement in 1977. The main goal of this highly regarded women's self-help group is to organize poor women in rural Kenya to plant and protect millions of trees in order to combat deforestation and provide fuelwood. By 2004, the 50,000 members of this grassroots group had established 6,000 village nurseries and planted and protected more than 30 million trees.

The women are paid a small amount for each seedling they plant that survives. This gives them an income to help break the cycle of poverty. It also improves the environment because trees reduce soil erosion and provide fruits, fuel, building materials, fodder for livestock, shade, and beauty. Having more trees also reduces the distances women and children have to walk to get fuelwood for cooking and heating. The success of this project has sparked the creation of similar programs in more than 30 other African countries.

Charlotte Thege/Peter Arnold, Inc.

Figure 10-B Wangari Maathai was the first Kenyan woman to earn a Ph.D. and to head an academic department at the University of Nairobi. In 1977, she organized the internationally acclaimed Green Belt Movement. For her work in protecting the environment, she has received many honors, including the Goldman Prize, the Right Livelihood Award, the U.N. Africa Prize for Leadership, and the 2004 Nobel Peace Prize. After years of being harassed, beaten, and jailed for opposing government policies, she was elected to Kenya's parliament as a member of the Green Party in 2002. In 2003, she was appointed Assistant Minister for Environment, Natural Resources, and Wildlife.

In 2004, Maathai became the first African woman and the first environmentalist to be awarded the Nobel Peace Prize for her lifelong efforts. Within an hour of learning that she had won the prize, Maathai planted a tree, telling onlookers it was "the best way to celebrate." In her speech accepting the award, she said the purpose of the Green Belt program was to help people "make the connections between their own personal actions and the problems they witness in their environment and society." She urged everyone in the world to plant a tree as a symbol of commitment and hope.

In 2006, she launched a project to plant a billion trees worldwide in 2007 to help fight poverty and climate change. The project greatly exceeded expectations with the planting of 2 billlion trees in 55 countries. In 2008, the UNEP set a goal of planting an additional 5 billion trees.

Wangari tells her story in her book *The Green Belt Movement: Sharing the Approach and the Experience,* published by Lantern Books in 2003.

This in turn would help to slow global warming, as more trees would remove more of the carbon dioxide that we are adding to the atmosphere.

Governments and Individuals Can Act to Reduce Tropical Deforestation

In addition to reducing fuelwood demand, analysts have suggested other ways to protect tropical forests and use them more sustainably. One way is to help new settlers in tropical forests to learn how to practice small-scale sustainable agriculture and forestry. Another is to harvest some of the renewable resources such as fruits and nuts in rain forests on a sustainable basis. And strip cutting (Figure 10-6c) can be used to harvest tropical trees for lumber.

In Africa's northern Congo Republic, some nomadic forest-dwelling pygmies go into the forests carrying hand-held satellite tracking devices in addition to their traditional spears and bows. They use these Global Positioning System (GPS) devices to identify their hunting grounds, burial grounds, water holes, sacred areas, and areas rich in medicinal plants. They then download such information on computers to provide a map of areas that need to be protected from logging, mining, and other destructive activities.

Debt-for-nature swaps can make it financially attractive for countries to protect their tropical forests. In such swaps, participating countries act as custodians of protected forest reserves in return for foreign aid or debt relief. In a similar strategy called *conservation concessions,* governments or private conservation organizations pay nations for concessions to preserve their natural resources.

Loggers can also use tropical forests more sustainably by using gentler methods for harvesting trees. For example, cutting canopy vines (lianas) before felling a tree and using the least obstructed paths to remove the logs can sharply reduce damage to neighboring trees. In addition, governments and individuals can mount efforts to reforest and rehabilitate degraded tropical forests and watersheds (see Individuals Matter, at left) and clamp down on illegal logging.

Finally, each of us as consumers can reduce the demand that fuels illegal and unsustainable logging in tropical forests. For building projects, we can use substitutes for wood such as bamboo and recycled plastic building materials (**Concept 10-2**). Recycled waste lumber is another alternative, now marketed by companies such as TerraMai and EcoTimber.

We can also buy only lumber and wood products that are certified as sustainably produced (Science Focus, p. 228). Growing awareness of tropical deforestation and the resulting consumer pressure caused the giant retail company Home Depot to take action. It reported in 2007 that 80% of the wood it carries meets such certification standards.

These and other ways to protect tropical forests are summarized in (Figure 10-19).

SOLUTIONS

Sustaining Tropical Forests

Prevention

Protect the most diverse and endangered areas

Educate settlers about sustainable agriculture and forestry

Subsidize only sustainable forest use

Protect forests with debt-for-nature swaps and conservation concessions

Certify sustainably grown timber

Reduce poverty

Slow population growth

Restoration

Encourage regrowth through secondary succession

Rehabilitate degraded areas

Concentrate farming and ranching in already-cleared areas

Figure 10-19 Ways to protect tropical forests and use them more sustainably (**Concept 10-2**). **Question:** Which three of these solutions do you think are the most important? Why?

10-3 How Should We Manage and Sustain Grasslands?

▶ **CONCEPT 10-3 We can sustain the productivity of grasslands by controlling the number and distribution of grazing livestock and by restoring degraded grasslands.**

Some Rangelands Are Overgrazed

Grasslands provide many important ecological services, including soil formation, erosion control, nutrient cycling, storage of atmospheric carbon dioxide in biomass, and maintenance of biodiversity.

After forests, the ecosystems most widely used and altered by human activities are grasslands. **Rangelands** are unfenced grasslands in temperate and tropical climates that supply *forage,* or vegetation, for grazing (grass-eating) and browsing (shrub-eating) animals. Cattle, sheep, and goats graze on about 42% of the world's grassland. The 2005 Millennium Ecosystem Assessment estimated that continuing on our present course will increase that percentage to 70% by 2050. Livestock also graze in **pastures**—managed grasslands or enclosed meadows usually planted with domesticated grasses or other forage.

Blades of rangeland grass grow from the base, not at the tip. So as long as only the upper half of the blade is eaten and its lower half remains, rangeland grass is a renewable resource that can be grazed again and again.

Moderate levels of grazing are healthy for grasslands, because removal of mature vegetation stimulates rapid regrowth and encourages greater plant diversity. The key is to prevent both overgrazing and undergrazing by domesticated livestock and wild herbivores. **Overgrazing** occurs when too many animals graze for too long and exceed the carrying capacity of a rangeland area (Figure 10-20, left, p. 232). It reduces grass cover, exposes the soil to erosion by water and wind, and compacts the soil (which diminishes its capacity

Figure 10-20 **Natural capital degradation:** overgrazed (left) and lightly grazed (right) rangeland.

USDA, Natural Resources Conservation Service

to hold water). Overgrazing also enhances invasion by species such as sagebrush, mesquite, cactus, and cheatgrass, which cattle will not eat.

Scientists have also learned that, before settlers made them into rangeland, natural grassland ecosystems were maintained partially by periodic wildfires sparked by lightning. Fires were important because they burned away mesquite and other invasive shrubs, keeping the land open for grasses. Ecologists have studied grasslands of the Malpai Borderlands—an area on the border between the southwestern U.S. states of Arizona and New Mexico—where ranchers, with the help of the federal government, not only allowed overgrazing for more than a century, but also fought back fires and kept the grasslands from burning. Consequently, trees and shrubs replaced grasses, the soil was badly eroded, and the area lost most of its value for grazing.

Since 1993, ranchers, scientists, environmentalists, and government agencies have joined forces to restore the native grasses and animal species to the Malpai Borderlands. Land managers conduct periodic controlled burns on the grasslands, and the ecosystem has now been largely reestablished. What was once a classic example of unsustainable resource management became a valuable scientific learning experience and a management success story.

About 200 years ago, grass may have covered nearly half the land in the southwestern United States. Today, it covers only about 20%, mostly because of a combination of prolonged droughts and overgrazing, which created footholds for invader species that now cover many former grasslands.

Limited data from FAO surveys in various countries indicate that overgrazing by livestock has caused as much as a fifth of the world's rangeland to lose productivity. Some grasslands suffer from **undergrazing,** where absence of grazing for long periods (at least 5 years) can reduce the net primary productivity of grassland vegetation and grass cover.

We Can Manage Rangelands More Sustainably

The most widely used method for more sustainable management of rangeland is to control the number of grazing animals and the duration of their grazing in a given area so that the carrying capacity of the area is not exceeded (**Concept 10-3**). One way of doing this is *rotational grazing* in which cattle are confined by portable fencing to one area for a short time (often only 1–2 days) and then moved to a new location.

Livestock tend to aggregate around natural water sources, especially thin strips of lush vegetation along streams or rivers known as *riparian zones,* and around ponds established to provide water for livestock. Overgrazing by cattle can destroy the vegetation in such areas (Figure 10-21, left). Protecting overgrazed land from further grazing by moving livestock around and by fencing off these areas can eventually lead to its natural ecological restoration (Figure 10-21, right). Ranchers can also move cattle around by providing supplemental feed at selected sites and by strategically locating water holes and tanks and salt blocks.

A more expensive and less widely used method of rangeland management is to suppress the growth of unwanted invader plants by use of herbicides, mechanical

Figure 10-21 **Natural capital restoration:** in the mid-1980s, cattle had degraded the vegetation and soil on this stream bank along the San Pedro River in the U.S. state of Arizona (left). Within 10 years, the area was restored through natural regeneration after the banning of grazing and off-road vehicles (right) (**Concept 10-3**).

removal, or controlled burning. A cheaper way to discourage unwanted vegetation in some areas is through controlled, short-term trampling by large numbers of livestock.

Replanting barren areas with native grass seeds and applying fertilizer can increase growth of desirable vegetation and reduce soil erosion. But this is an expensive way to restore severely degraded rangeland. The better option is to prevent degradation by using the methods described above and in the following case study.

■ **CASE STUDY**

Grazing and Urban Development in the American West—Cows or Condos?

The landscape is changing in ranch country. Since 1980, millions of people have moved to parts of the southwestern United States, and a growing number of ranchers have sold their land to developers. Housing developments, condos, and small "ranchettes" are creeping out from the edges of many southwestern cities and towns. Most people moving to the southwestern states value the landscape for its scenery and recreational opportunities, but uncontrolled urban development can degrade these very qualities.

For decades some environmental scientists and environmentalists have sought to reduce overgrazing on these lands and, in particular, to reduce or eliminate livestock grazing permits on public lands. They have not had the support of ranchers or of the government. They have also pushed for decreased timber cutting and increased recreational opportunities in the national forests and grasslands. These efforts have made private tracts of land, especially near protected public lands, more desirable and valuable to people who enjoy outdoor activities and can afford to live in scenic areas.

Now, because of this population surge, ranchers, ecologists, and environmentalists are joining together to help preserve cattle ranches as the best hope for sustaining the key remaining grasslands and the habitats they provide for native species. They are working together to identify areas that are best for sustainable grazing, areas best for sustainable urban development, and areas that should be neither grazed nor developed. One strategy involves land trust groups, which pay ranchers for *conservation easements*—deed restrictions that bar future owners from developing the land. These groups are also pressuring local governments to zone the land in order to prevent large-scale development in ecologically fragile rangeland areas.

Some ranchers are also reducing the harmful environmental impacts of their herds. They rotate their cattle away from riparian areas (Figure 10-21), use far less fertilizer and pesticides, and consult with range and wildlife scientists about ways to make their ranch operations more economically and ecologically sustainable.

10-4 How Should We Manage and Sustain Parks and Nature Reserves?

▶ **CONCEPT 10-4** **Sustaining biodiversity will require protecting much more of the earth's remaining undisturbed land area as parks and nature reserves.**

National Parks Face Many Environmental Threats

Today, more than 1,100 major national parks are located in more than 120 countries (see Figure 7-12, top, p. 151; Figure 7-18, p. 157; Figure 7-19, p. 157; and Figure 8-8, p. 168). However, most of these national parks are too small to sustain a lot of large animal species. And many parks suffer from invasions by nonnative species that compete with and reduce the populations of native species and worsen ecological disruption.

Parks in developing countries possess the greatest biodiversity of all parks, but only about 1% of these parklands are protected. Local people in many of these countries enter the parks illegally in search of wood, cropland, game animals, and other natural products for their daily survival. Loggers and miners operate illegally in many of these parks, as do wildlife poachers who kill animals to obtain and sell items such as rhino horns, elephant tusks, and furs. Park services in most developing countries have too little money and too few personnel to fight these invasions, either by force or through education.

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■ **CASE STUDY**

Stresses on U.S. Public Parks

The U.S. national park system, established in 1912, includes 58 major national parks, sometimes called the country's crown jewels. States, counties, and cities also operate public parks.

Popularity is one of the biggest problems for many parks. Between 1960 and 2007, the number of visitors to U.S. national parks more than tripled, reaching 273 million. The Great Smoky Mountains National Park in the states of Tennessee and North Carolina, the country's most frequently visited national park, hosts about 9 million visitors each year. Many state parks are located near urban areas and receive about twice as many visitors per year as do the national parks. Visitors often expect parks to have grocery stores, laundries, bars, and other such conveniences.

During the summer, users entering the most popular parks face long backups and experience noise, congestion, eroded trails, and stress instead of peaceful solitude. In some parks and other public lands, noisy and polluting dirt bikes, dune buggies, jet skis, snowmobiles, and other off-road vehicles degrade the aesthetic experience for many visitors, destroy or damage fragile vegetation (Figure 10-22), and disturb wildlife. There is controversy over whether these machines should be allowed in national parks.

THINKING ABOUT
National Parks and Off-Road Vehicles

Do you support allowing off-road vehicles in national parks? Explain. If you do, what restrictions, if any, would you put on their use?

Parks also suffer damage from the migration or deliberate introduction of nonnative species. European wild boars (imported to the state of North Carolina in 1912 for hunting) threaten vegetation in parts of the Great Smoky Mountains National Park. Nonnative mountain goats in Washington State's Olympic National Park trample native vegetation and accelerate soil erosion. Nonnative species of plants, insects, and worms entering the parks on vehicle tires and hikers' gear also degrade the biodiversity of parklands.

SCIENCE FOCUS

Effects of Reintroducing the Gray Wolf to Yellowstone National Park

For over a decade, wildlife ecologist Robert Crabtree and a number of other scientists have been studying the effects of reintroducing the gray wolf into the Yellowstone National Park (**Core Case Study**). They have put radio-collars on most of the wolves to gather data and track their movements. They have also studied changes in vegetation and the populations of various plant and animal species. Results of this research have suggested that the return of the gray wolf, a keystone predator species, has sent ecological ripples through the park's ecosystem.

CORE CASE STUDY

Elk, the main herbivores in the Yellowstone system, are the primary food source for the wolves, but wolves also kill some moose, mule deer, and bison. Not surprisingly, elk populations have declined with the return of wolves. However, drought, grizzly bears (which kill elk calves), and a severe winter in 1997 have contributed to this decline. Leftovers of elk killed by wolves provide an important food source for grizzly bears and other scavengers such as bald eagles and ravens.

Before the wolves returned, elk had been browsing on willow shoots and other vegetation near the banks of streams and rivers. With the return of wolves, the elk retreated to higher ground. This has spurred the regrowth of aspen, cottonwoods, and willow trees in these riparian areas and increased populations of riparian songbirds.

This regrowth of trees has in turn helped to stabilize and shade stream banks, which lowered the water temperature and made it better habitat for trout. Beavers seeking willow and aspen for food and dam construction have returned. The beaver dams established wetlands and created more favorable habitat for aspens.

The wolves have also cut in half the population of coyotes—the top predators in the absence of wolves. This has resulted in fewer coyote attacks on cattle and sheep on surrounding ranches and has increased populations of red fox and smaller animals such as ground squirrels, mice, and gophers hunted by coyotes, eagles, and hawks.

Elk in the park are hunted in limited numbers, but wolves, as a protected species, are not hunted. However, wolves kill one another in clashes between packs, and a few have been killed by cars. The wolves also face threats from dogs that visitors bring to the park. The dogs carry parvovirus, which can kill wolf pups.

Wolves are an important factor in the Yellowstone ecosystem. But there are many other interacting factors involved in the structure and functioning of this complex ecosystem. Decades of research will be needed to unravel and better understand these interactions. For more information, see *The Habitable Planet,* Video 4, at **www.learner.org/resources/series209.html**.

Critical Thinking

Do you approve or disapprove of the reintroduction of the gray wolf into the Yellowstone National Park system? Explain.

At the same time, native species—some of them threatened or endangered—are killed or removed illegally in almost half of all U.S. national parks. This is what happened with the gray wolf until it was successfully reintroduced into Yellowstone National Park after a half century's absence (Science Focus, above). Not all park visitors understand the rules that protect species, and rangers have to spend an increasing amount of their time on law enforcement and crowd control instead of on conservation management and education.

Many U.S. national parks have become threatened islands of biodiversity surrounded by a sea of commercial development. Nearby human activities that threaten wildlife and recreational values in many national parks include mining, logging, livestock grazing, use of coal-burning power plants, oil drilling, water diversion, and urban development.

Polluted air, drifting hundreds of kilometers from cities, kills ancient trees in California's Sequoia National Park and often degrades the awesome views at Arizona's Grand Canyon. The Great Smoky Mountains, named for the natural haze emitted by their lush vegetation, ironically have air quality similar to that of Los Angeles, California, and vegetation on their highest peaks has been damaged by acid rain. According to the National Park Service, air pollution, mostly from coal-fired power plants and dense vehicle traffic, degrades scenic views in U.S. national parks more than 90% of the time.

Another problem, reported by the U.S. General Accounting Office, is that the national parks need at least \$6 billion for long overdue repairs of trails, buildings, and other infrastructure. Some analysts say more of these funds could come from private concessionaires who provide campgrounds, restaurants, hotels, and other services for park visitors. They pay franchise fees averaging only about 6–7% of their gross receipts, and many large concessionaires with long-term contracts pay as little as 0.75%. Analysts say these percentages could reasonably be increased to around 20%.

Figure 10-23 (p. 236) lists other suggestions made by various analysts for sustaining and expanding the national park system in the United States.

Nature Reserves Occupy Only a Small Part of the Earth's Land

Most ecologists and conservation biologists believe the best way to preserve biodiversity is to create a worldwide network of protected areas. (See the chapter opening quote on p. 215.) Currently, only 12% of the earth's land area is protected strictly or partially in nature reserves, parks, wildlife refuges, wilderness, and other areas. This 12% figure is misleading because no more than 5% of the earth's land is strictly protected from potentially harmful human activities. In other words, *we have*

SOLUTIONS

National Parks

- Integrate plans for managing parks and nearby federal lands
- Add new parkland near threatened parks
- Buy private land inside parks
- Locate visitor parking outside parks and provide shuttle buses for people touring heavily used parks
- Increase federal funds for park maintenance and repairs
- Raise entry fees for visitors and use resulting funds for park management and maintenance
- Seek private donations for park maintenance and repairs
- Limit the number of visitors in crowded park areas
- Increase the number of park rangers and their pay
- Encourage volunteers to give visitor lectures and tours

Figure 10-23 Suggestions for sustaining and expanding the national park system in the United States. **Question:** Which two of these solutions do you think are the most important? Why? (Data from Wilderness Society and National Parks and Conservation Association).

reserved 95% of the earth's land for human use, and most of the remaining area consists of ice, tundra, or desert—places where most people do not want to live.

Conservation biologists call for full protection of at least 20% of the earth's land area in a global system of biodiversity reserves that would include multiple examples of all the earth's biomes (**Concept 10-4**). But powerful economic and political interests oppose this idea.

Protecting more of the earth's land from unsustainable use will require action and funding by national governments and private groups, bottom-up political pressure by concerned individuals, and cooperative ventures involving governments, businesses, and private conservation organizations. Such groups play an important role in establishing wildlife refuges and other reserves to protect biological diversity.

For example, since its founding by a group of professional ecologists in 1951, The Nature Conservancy—with more than 1 million members worldwide—has created the world's largest system of private natural areas and wildlife sanctuaries in 30 countries. In the United States, efforts by The Nature Conservancy and private landowners have protected land, waterways, and wetlands in local and state trusts totaling roughly the area of the U.S. state of Georgia.

Eco-philanthropists are using some of their wealth to buy up wilderness areas in South America, and they are donating the preserved land to the governments of various countries. For example, Douglas and Kris Tompkins have created 11 wilderness parks in Latin America. In 2005, they donated two new national parks to Chile and Argentina.

In the United States, private, nonprofit *land trust groups* have protected large areas of land. Members pool their financial resources and accept tax-deductible donations to buy and protect farmlands, grasslands, woodlands, and urban green spaces.

Some governments are also making progress. By 2007, the Brazilian government had officially protected 23% of the Amazon—an area the size of France—from development. However, many of these areas are protected only on paper and are not always secure from illegal resource removal and degradation.

Most developers and resource extractors oppose protecting even the current 12% of the earth's remaining undisturbed ecosystems. They contend that these areas might contain valuable resources that would add to economic growth. Ecologists and conservation biologists disagree. They view protected areas as islands of biodiversity and natural capital that help to sustain all life and economies and serve as centers of future evolution. See Norman Myer's Guest Essay on this topic at CengageNOW.

HOW WOULD YOU VOTE?

Should at least 20% of the earth's land area be strictly protected from economic development? Cast your vote online at **academic.cengage.com/biology/miller**.

Designing and Connecting Nature Reserves

Large reserves sustain more species and provide greater habitat diversity than do small reserves. They also minimize exposure to natural disturbances (such as fires and hurricanes), invading species, and human disturbances from nearby developed areas.

In 2007, scientists reported on the world's largest and longest running study of forest fragmentation, which took place in the Amazon. They found that conservation of large reserves in the Amazon was even more important than was previously thought. Because the Amazon rain forest is so diverse, a large expanse of it may contain dozens of ecosystem types, each of which is different enough from the others to support unique species. Therefore, developing just a part of such a large area could result in the elimination of many types of habitats and species.

However, research indicates that in other locales, several well-placed, medium-sized reserves may better protect a wider variety of habitats and preserve more biodiversity than would a single large reserve of the same total area. When deciding on whether to recommend large- or medium-sized reserves in a particular area, conservation biologists must carefully consider its various ecosystems.

Whenever possible, conservation biologists call for using the *buffer zone concept* to design and manage nature

Biosphere Reserve

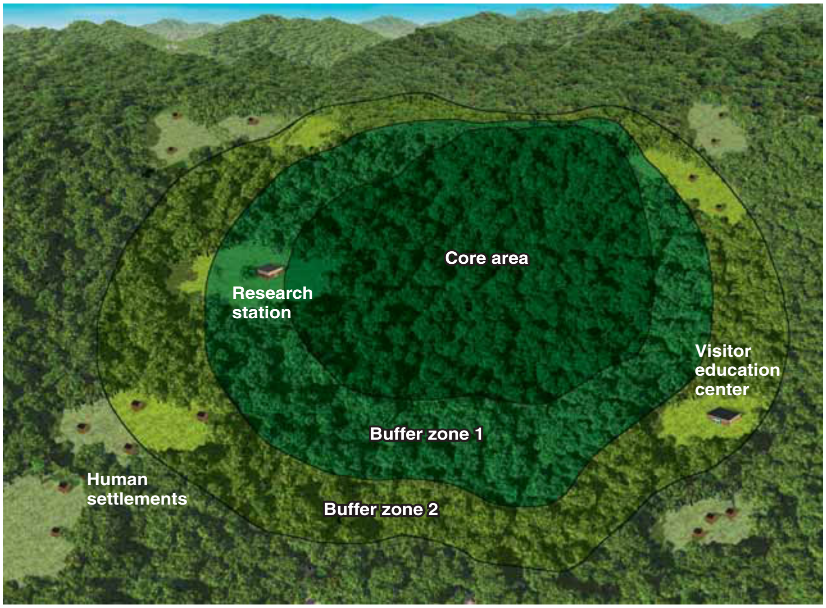

Figure 10-24 **Solutions:** a model *biosphere reserve.* Each reserve contains a protected inner core surrounded by two buffer zones that local and indigenous people can use for sustainable logging, growing limited crops, grazing cattle, hunting, fishing, and ecotourism. **Question:** Do you think some of these reserves should be free of all human activity, including ecotourism? Why or why not?

reserves. This means protecting an inner core of a reserve by usually establishing two buffer zones in which local people can extract resources sustainably without harming the inner core. Instead of shutting people out of the protected areas and likely creating enemies, this approach enlists local people as partners in protecting a reserve from unsustainable uses such as illegal logging and poaching.

The United Nations has used this principle in creating its global network of 529 biosphere reserves in 105 countries (Figure 10-24). According to Craig Leisher, an economist for The Nature Conservancy, "Local people are often the best people in developing countries to manage these conservation areas, because they want them to survive in the long term as well."

So far, most biosphere reserves fall short of these ideals and receive too little funding for their protection and management. An international fund to help make up the shortfall would cost about $100 million per year—about the amount spent every 90 minutes on weapons by the world's nations.

Establishing protected *habitat corridors* between isolated reserves helps to support more species and allows migration by vertebrates that need large ranges. Corridors also permit migration of individuals and populations when environmental conditions in a reserve deteriorate, forcing animals to move to a new location, and they support animals that must make seasonal migrations to obtain food. Corridors may also enable some species to shift their ranges if global climate change makes their current ranges uninhabitable.

On the other hand, corridors can threaten isolated populations by allowing movement of pest species, disease, fire, and invasive species between reserves. They also increase exposure of migrating species to natural predators, human hunters, and pollution. In addition, corridors can be costly to acquire, protect, and manage. Nevertheless, an extensive study, reported in 2006, showed that areas connected by corridors host a greater variety of birds, insects, small mammals, and plant species. And in that study, nonnative species did not invade the connected areas.

The creation of large reserves connected by corridors on an eco-regional scale is the grand goal of many conservation biologists. This idea is being put into practice in places such as Costa Rica (see the following Case Study).

RESEARCH FRONTIER

Learning how to design, locate, connect, and manage networks of effective nature preserves. See **academic.cengage.com/biology/miller**.

■ CASE STUDY

Costa Rica—A Global Conservation Leader

Tropical forests once completely covered Central America's Costa Rica, which is smaller in area than the U.S. state of West Virginia and about one-tenth the size of France. Between 1963 and 1983, politically powerful ranching families cleared much of the country's forests to graze cattle.

Despite such widespread forest loss, tiny Costa Rica is a superpower of biodiversity, with an estimated 500,000 plant and animal species. A single park in Costa Rica is home to more bird species than are found in all of North America.

In the mid-1970s, Costa Rica established a system of nature reserves and national parks that, by 2006, included about a quarter of its land—6% of it reserved for indigenous peoples. Costa Rica now devotes a larger proportion of its land to biodiversity conservation than does any other country.

The country's parks and reserves are consolidated into eight zoned *megareserves* (Figure 10-25). Each reserve contains a protected inner core surrounded by two buffer zones that local and indigenous people can use for sustainable logging, crop farming, cattle grazing, hunting, fishing, and ecotourism.

Costa Rica's biodiversity conservation strategy has paid off. Today, the country's largest source of income is its $1-billion-a-year tourism business, almost two-thirds of which involves ecotourism.

To reduce deforestation, the government has eliminated subsidies for converting forest to rangeland. It also pays landowners to maintain or restore tree coverage. The goal is to make it profitable to sustain forests. Between 2007 and 2008, the government planted nearly 14 million trees, which helps to preserve the country's biodiversity. As they grow, the trees also remove carbon dioxide from the air and help the country to meet its goal of reducing net CO_2 emissions to zero by 2021.

The strategy has worked: Costa Rica has gone from having one of the world's highest deforestation rates to having one of the lowest. Between 1986 and 2006, the country's forest cover grew from 26% to 51%.

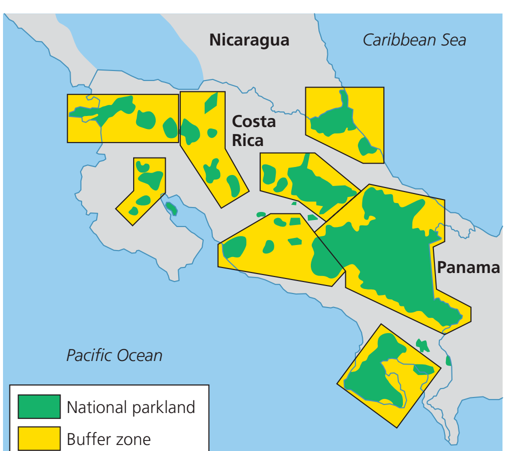

Figure 10-25 **Solutions:** Costa Rica has consolidated its parks and reserves into eight zoned *megareserves* designed to sustain about 80% of the country's rich biodiversity. Green areas are protected reserves and yellow areas are nearby buffer zones, which can be used for sustainable forms of forestry, agriculture, hydropower, hunting, and other human activities.

Protecting Wilderness Is an Important Way to Preserve Biodiversity

One way to protect undeveloped lands from human exploitation is by legally setting them aside as large areas of undeveloped land called **wilderness** (**Concept 10-4**). Theodore Roosevelt (Figure 4, p. S34, in Supplement 5), the first U.S. president to set aside protected areas, summarized what we should do with wilderness: "Leave it as it is. You cannot improve it."

Wilderness protection is not without controversy (see the following Case Study). Some critics oppose protecting large areas for their scenic and recreational value for a relatively small number of people. They believe this is an outmoded ideal that keeps some areas of the planet from being economically useful to people here today. But to most biologists, the most important reasons for protecting wilderness and other areas from exploitation and degradation involve long-term needs. One such need is to *preserve biodiversity* as a vital part of the earth's natural capital. Another is to protect wilderness areas *as centers for evolution* in response to mostly unpredictable changes in environmental conditions. In other words, wilderness serves as a biodiversity bank and an eco-insurance policy.

■ CASE STUDY
Controversy over Wilderness Protection in the United States

In the United States, conservationists have been trying to save wild areas from development since 1900. Overall, they have fought a losing battle. Not until 1964 did Congress pass the Wilderness Act (Figure 6, p. S35, in Supplement 5). It allowed the government to protect undeveloped tracts of public land from development as part of the National Wilderness Preservation System.

The area of protected wilderness in the United States increased tenfold between 1970 and 2007. Even so, only about 4.6% of U.S. land is protected as wilderness—almost three-fourths of it in Alaska. Only 1.8% of the land area of the lower 48 states is protected, most of it in the West. In other words, Americans have reserved at least 98% of the continental United States to be used as they see fit and have protected less than 2% as wilderness. According to a 1999 study by the World Conservation Union, the United States ranks 42nd among nations in terms of terrestrial area protected as wilderness, and Canada is in 36th place.

In addition, only 4 of the 413 wilderness areas in the lower 48 states are large enough to sustain the species they contain. The system includes only 81 of the country's 233 distinct ecosystems. Most wilderness areas in the lower 48 states are threatened habitat islands in a sea of development.

Scattered blocks of public lands with a total area roughly equal to that of the U.S. state of Montana could qualify for designation as wilderness. About 60% of such land in the national forests. For more than 20 years, these areas were temporarily protected under the Roadless Rule—a federal regulation that put undeveloped areas of national forests off-limits to road building and logging while they were evaluated for wilderness protection.

For decades, politically powerful oil, gas, mining, and timber industries have sought entry to these areas—which are owned jointly by all citizens of the United States—to develop resources there. Their efforts paid off in 2005 when the secretary of the interior ended protection of roadless areas within the national forest system that were being considered for classification as wilderness. The secretary also began allowing states to classify old cow paths and off-road vehicle trails as roads (Figure 10-22), which would disqualify their surrounding areas from protection as wilderness.

THINKING ABOUT

Protecting Wolves and Wild Lands

CORE CASE STUDY

How do you think protecting wolves, in part by reintroducing them to areas such as Yellowstone National Park (**Core Case Study**), helps to protect the forest areas where they live?

10-5 What Is the Ecosystem Approach to Sustaining Biodiversity?

CONCEPT 10-5A We can help to sustain biodiversity by identifying severely threatened areas and protecting those with high plant diversity (biodiversity hotspots) and those where ecosystem services are being impaired.

CONCEPT 10-5B Sustaining biodiversity will require a global effort to rehabilitate and restore damaged ecosystems.

CONCEPT 10-5C Humans dominate most of the earth's land, and preserving biodiversity will require sharing as much of it as possible with other species.

We Can Use a Four-Point Strategy to Protect Ecosystems

Most biologists and wildlife conservationists believe that we must focus more on protecting and sustaining ecosystems, and the biodiversity contained within them, than on saving individual species. Their goals certainly include preventing premature extinction of species, but they argue the best way to do that is to protect threatened habitats and ecosystem services. This *ecosystems approach* generally would employ the following four-point plan:

- Map global ecosystems and create an inventory of the species contained in each of them and the ecosystem services they provide.
- Locate and protect the most endangered ecosystems and species, with emphasis on protecting plant biodiversity and ecosystem services.
- Seek to restore as many degraded ecosystems as possible.
- Make development *biodiversity-friendly* by providing significant financial incentives (such as tax breaks and write-offs) and technical help to private landowners who agree to help protect endangered ecosystems.

Some scientists have argued that we need new laws to embody this strategy. In the United States, for example, there is support for amending the Endangered Species Act, or possibly even replacing it with a new law focused on protection of ecosystems and biodiversity.

Protecting Global Biodiversity Hotspots Is an Urgent Priority

In reality, few countries are physically, politically, or financially able to set aside and protect large biodiversity reserves. To protect as much of the earth's remaining biodiversity as possible, some conservation biologists urge adoption of an *emergency action* strategy to identify and quickly protect **biodiversity hotspots** (**Concept 10-5A**)—an idea first proposed in 1988 by environmental scientist Norman Myers. (See his Guest Essay on this topic at CengageNOW.) These "ecological arks" are areas especially rich in plant species that are found nowhere else and are in great danger of extinction. These areas suffer serious ecological disruption, mostly because of rapid human population growth and the resulting pressure on natural resources. (See Case Study p. 240.) Myers and his colleagues at Conservation International relied primarily on the diversity of plant species to identify biodiversity hotspot areas because data on plant diversity was more readily available and was also thought to be an indicator of animal diversity.

Figure 10-26 shows 34 global terrestrial biodiversity hotspots identified by conservation biologists and Figure 10-27 shows major biodiversity hotspots in the United States. In the 34 global areas, a total of 86% of the habitat has been destroyed. They cover only a little more than 2% of the earth's land surface, but they contain an estimated 50% of the world's flowering plant species and 42% of all terrestrial vertebrates (mammals, birds, reptiles, and amphibians). They are also home for a large majority of the world's endangered or critically endangered species. Says Norman Myers, "I can think of no other biodiversity initiative that could achieve so much at a comparatively small cost, as the hotspots strategy."

One drawback of the biodiversity hotspots approach is that some areas rich in plant diversity are not necessarily rich in animal diversity. And when hotspots are protected, local people can be displaced and lose access to important resources. However, the goal of this approach—to protect the unique biodiversity in areas under great stress from human activities—remains urgent. Despite its importance, this approach has not succeeded in capturing sufficient public support and funding.

■ **CASE STUDY**

A Biodiversity Hotspot in East Africa

The forests covering the flanks of the Eastern Arc Mountains of the African nation of Tanzania contain the highest concentration of endangered animals on earth.

Plants and animals that exist nowhere else (species *endemic* to this area) live in these mountainside forests in considerable numbers. They include 96 species of vertebrates—10 mammal, 19 bird, 29 reptile, and 38 amphibian—43 species of butterflies, and at least 800 endemic species of plants, including most species of African violets.

An international network of scientists, who had extensively surveyed these mountain forests, reported these findings in 2007. They also reported newly discovered species in these forests, including a tree-dwelling monkey called the Kipunji and some surprisingly large reptiles and amphibians.

This area is a major biodiversity hotspot because humans now threaten to do what the ice ages could not do—kill off its forests. Farmers and loggers have cleared 70% of the ancient forests. This loss of habitat, along with hunting, has killed off many species, including elephants and buffalo, and now 71 of the 96 endemic species are threatened, 8 of them critically, with biological extinction.

These species are now forced to survive within 13 patches of forest that total an area about the size of the U.S. state of Rhode Island. Most of these forests are contained within 150 government reserves. New settlements are not allowed, but people still forage in these reserves for fuelwood and building materials, severely degrading some of the forests. Fire is also a threat, because the shrinking, degraded patches of forest are drying out, and this is likely to get worse as global warming takes hold.

CENGAGENOW™ Learn more about biodiversity hotspots around the world, what is at stake there, and how they are threatened at CengageNOW.

RESEARCH FRONTIER

Identifying and preserving all of the world's terrestrial and aquatic biodiversity hotspots. See **academic.cengage.com/biology/miller**.

Protecting Ecosystem Services Is Also an Urgent Priority

Another way to help sustain the earth's biodiversity and its people is to identify and protect areas where vital *ecosystem services* (orange items in Figure 1-3, p. 8) are being impaired enough to reduce biodiversity or harm local residents. This approach has gotten more attention since the release in 2005 of the U.N. *Millennium Ecosystem Assessment*—a 4-year study by 1,360 experts from 95 countries. It identified key ecosystem services that provide numerous ecological and economic benefits. (Those provided by forests are summarized in Figure 10-4.) The study pointed out that human activities are degrading or overusing about 62% of the earth's natural services in various ecosystems around the world, and it outlined ways to help sustain these vital ecosystem services for human and nonhuman life.

This approach recognizes that most of the world's ecosystems are already dominated or influenced by human activities and that such pressures are increasing as population, urbanization, and resource use increase and the human ecological footprint increases (Figure 1-10, p. 15, and Figure 3, p. S24–S25, in Supplement 4). Proponents of this approach recognize that it is vital to set aside and protect reserves and wilderness areas and to protect highly endangered biodiversity hotspots (Figure 10-26). But they contend that such efforts by themselves will not significantly slow the steady erosion of the earth's biodiversity and ecosystem services.

These analysts argue that we must also identify highly stressed *life raft ecosystems*. In such areas, people live in severe poverty, and a large part of the economy depends on various ecosystem services that are being degraded severely enough to threaten the well-being of people and other forms of life. In these areas, residents, public officials, and conservation scientists are urged to work together to develop strategies to protect both biodiversity and human communities. Instead of emphasizing

CENGAGENOW™ **Active Figure 10-26 Endangered natural capital:** 34 biodiversity hotspots identified by ecologists as important and endangered centers of terrestrial biodiversity that contain a large number of species found nowhere else. Identifying and saving these critical habitats requires a vital emergency response (**Concept 10-5A**). Compare these areas with those on the map of the human ecological footprint in the world as shown in Figure 3, pp. S24–S25, in Supplement 4. According to the IUCN, the average proportion of biodiversity hotspot areas truly protected with funding and enforcement is only 5%. *See an animation based on this figure at* CengageNOW. **Questions:** Are any of these hotspots near where you live? Is there a smaller, localized hotspot in the area where you live? (Data from Center for Applied Biodiversity Science at Conservation International).

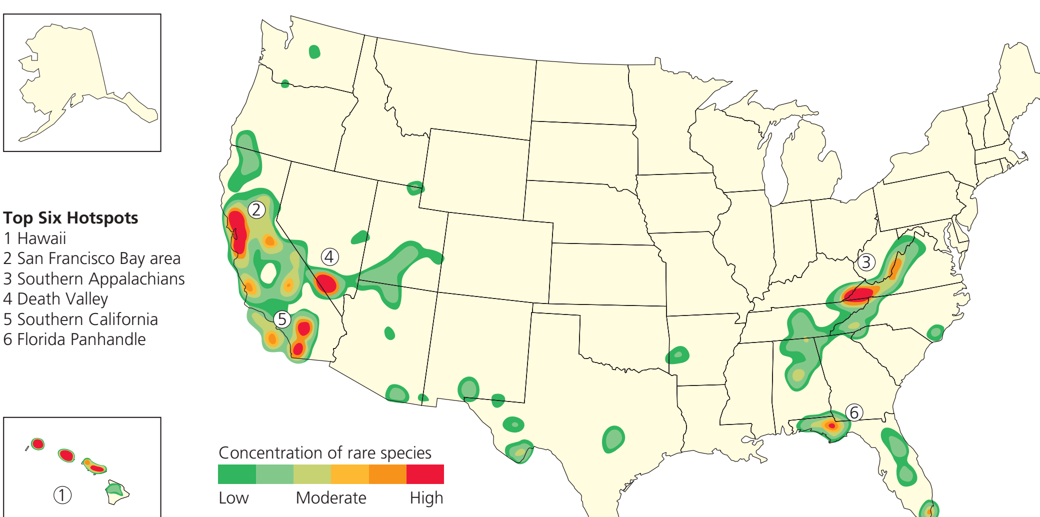

Figure 10-27 Endangered natural capital: biodiversity hotspots in the United States that need emergency protection. The shaded areas contain the largest concentrations of rare and potentially endangered species. Compare these areas with those on the map of the human ecological footprint in North America shown in Figure 7, pp. S28–S29, in Supplement 4. **Question:** Do you think that hotspots near urban areas would be harder to protect than those in rural areas? Explain. (Data from State Natural Heritage Programs, The Nature Conservancy, and Association for Biodiversity Information)

SCIENCE FOCUS

Ecological Restoration of a Tropical Dry Forest in Costa Rica

Costa Rica is the site of one of the world's largest *ecological restoration* projects. In the lowlands of its Guanacaste National Park (Figure 10-25), a small tropical dry forest was burned, degraded, and fragmented by large-scale conversion to cattle ranches and farms. Now it is being restored and relinked to the rain forest on adjacent mountain slopes. The goal is to eliminate damaging nonnative grasses and reestablish a tropical dry forest ecosystem over the next 100–300 years.

Daniel Janzen, professor of biology at the University of Pennsylvania and a leader in the field of restoration ecology, helped galvanize international support for this restoration project. He used his own MacArthur grant money to purchase this Costa Rican land to be set aside as a national park. He also raised more than $10 million for restoring the park.

Janzen realized that the original forests had been maintained partly by large native animals that ate the fruit of the Guanacaste tree and spread its seeds in their droppings. But these animals disappeared about 10,000 years ago. About 500 years ago, horses and cattle introduced by Europeans also spread the seeds, but farming and ranching took their toll on the forest's trees. Janzen decided to speed up restoration of this tropical dry forest by incorporating limited numbers of horses and cattle as seed dispersers in his recovery plan.

Janzen recognizes that ecological restoration and protection of the park will fail unless the people in the surrounding area believe they will benefit from such efforts. His vision is to see the nearly 40,000 people who live near the park play an essential role in the restoration of the degraded forest, a concept he calls *biocultural restoration.*

By actively participating in the project, local residents reap educational, economic, and environmental benefits. Local farmers make money by sowing large areas with tree seeds and planting seedlings started in Janzen's lab. Local grade school, high school, and university students and citizens' groups study the park's ecology during field trips. The park's location near the Pan American Highway makes it an ideal area for ecotourism, which stimulates the local economy.

The project also serves as a training ground in tropical forest restoration for scientists from all over the world. Research scientists working on the project give guest classroom lectures and lead field trips.

In a few decades, today's children will be running the park and the local political system. If they understand the ecological importance of their local environment, they will be more likely to protect and sustain its biological resources. Janzen believes that education, awareness, and involvement—not guards and fences—are the best ways to restore degraded ecosystems and to protect largely intact ecosystems from unsustainable use.

Critical Thinking

Would such an ecological restoration project be possible in the area where you live? Explain.

nature-versus-people, this approach focuses on finding win–win ways to protect both people and the ecosystem services that support all life and economies.

We Can Rehabilitate and Restore Ecosystems That We Have Damaged

Almost every natural place on the earth has been affected or degraded to some degree by human activities. Much of the harm we have inflicted on nature is at least partially reversible through **ecological restoration:** the process of repairing damage caused by humans to the biodiversity and dynamics of natural ecosystems. Examples include replanting forests, restoring grasslands, restoring wetlands and stream banks, reclaiming urban industrial areas (brownfields), reintroducing native species (**Core Case Study**), removing invasive species, and freeing river flows by removing dams.

CORE CASE STUDY

Evidence indicates that in order to sustain biodiversity, we must make a global effort to rehabilitate and restore ecosystems we have damaged (**Concept 10-5B**). An important strategy is to mimic nature and natural processes and let nature do most of the work, usually through secondary ecological succession (Figure 5-17, p. 117).

By studying how natural ecosystems recover, scientists are learning how to speed up repair operations using a variety of approaches. They include the following measures:

- *Restoration:* returning a particular degraded habitat or ecosystem to a condition as similar as possible to its natural state.
- *Rehabilitation:* turning a degraded ecosystem into a functional or useful ecosystem without trying to restore it to its original condition. Examples include removing pollutants and replanting to reduce soil erosion in abandoned mining sites and landfills and in clear-cut forests.
- *Replacement:* replacing a degraded ecosystem with another type of ecosystem. For example, a productive pasture or tree plantation may replace a degraded forest.
- *Creating artificial ecosystems:* for example, creating artificial wetlands to help reduce flooding or to treat sewage.

Researchers have suggested a science-based four-point strategy for carrying out most forms of ecological restoration and rehabilitation.

- Identify what caused the degradation (such as pollution, farming, overgrazing, mining, or invasive species).

University of Wisconsin Arboretum

University of Wisconsin Arboretum

Figure 10-28 **Solutions:** *Curtis Prairie,* in the University of Wisconsin's arboretum, Madison, Wisconsin (USA), was restored from abandoned farm fields. It serves as a highly instructive example of successful prairie restoration and is studied by restoration ecology students from around the world. The inset photo, taken in about 1934, shows part of the process of restoration: a controlled burn to prepare the land for establishment of prairie plants. These researchers have just burned a part of the vegetation to simulate a prairie fire, which is an important natural event in the prairie ecosystem. The second person from the left in this photo is the pioneering conservation biologist Aldo Leopold (Individuals Matter, p. 22).

- Stop the abuse by eliminating or sharply reducing these factors. This would include removing toxic soil pollutants, adding nutrients to depleted soil, adding new topsoil, preventing fires, and controlling or eliminating disruptive nonnative species (Science Focus, left).
- If necessary, reintroduce species—especially pioneer, keystone, and foundation species—to help restore natural ecological processes, as was done with wolves in the Yellowstone ecosystem (**Core Case Study**).
- Protect the area from further degradation (Figure 10-21, right).

Most of the tall-grass prairies in the United States have been plowed up and converted to crop fields. However, these prairies are ideal subjects for ecological restoration for three reasons. *First,* many residual or transplanted native plant species can be established within a few years. *Second,* the technology involved is similar to that of gardening and agriculture. *Third,* the process is well suited for volunteer labor needed to plant native species and weed out invading species until the natural species can take over. There are a number of prairie restoration projects in the United States, a prime example of which is Curtis Prairie in the U. S. state of Wisconsin (Figure 10-28).

RESEARCH FRONTIER

Exploring ways to improve ecological restoration efforts. See **academic.cengage.com/biology/miller**.

Will Restoration Encourage Further Destruction?

Some analysts worry that ecological restoration could encourage continuing environmental destruction and degradation by suggesting that any ecological harm we do can be undone. Restoration ecologists disagree with that suggestion. They point out that preventing ecosystem damage in the first place is cheaper and more effective than any form of ecological restoration. But they agree that restoration should not be used as an excuse for environmental destruction.

Restoration ecologists note that so far, we have been able to protect or preserve only about 5% of the earth's land from the effects of human activities, so ecological restoration is badly needed for many of the world's ecosystems. Even if a restored ecosystem differs from the original system, they argue, the result is better than no restoration at all. In time, further experience with ecological restoration will improve its effectiveness. Chapter 12 describes examples of the ecological restoration of aquatic systems such as wetlands and rivers.

HOW WOULD YOU VOTE?

Should we mount a massive effort to restore the ecosystems we have degraded, even though this will be quite costly? Cast your vote online at **academic.cengage.com/biology/miller**.

We Can Share Areas We Dominate with Other Species

In 2003, ecologist Michael L. Rosenzweig wrote a book entitled *Win–Win Ecology: How Earth's Species Can Survive in the Midst of Human Enterprise.* Rosenzweig strongly supports proposals to help sustain the earth's biodiversity through species protection strategies such as the U.S. Endangered Species Act (Case Study, p. 207).

But Rosenzweig contends that, in the long run, these approaches will fail for two reasons. *First,* fully protected reserves currently are devoted to saving only about 5% of the world's terrestrial area, excluding polar and other uninhabitable areas. To Rosenzweig, the real challenge is to sustain wild species in more of the human-dominated portion of nature that makes up 95% of the planet's terrestrial area (**Concept 10-5C**).

Second, Rosenzweig says, setting aside funds and refuges and passing laws to protect endangered and threatened species are essentially desperate attempts to save species that are in deep trouble. These emergency efforts can help a few species, but it is equally important to learn how to keep more species away from the brink of extinction. This is a prevention approach.

Rosenzweig suggests that we develop a new form of conservation biology, called **reconciliation** or **applied ecology.** This science focuses on inventing, establishing, and maintaining new habitats to conserve species diversity in places where people live, work, or play. In other words, we need to learn how to share with other species some of the spaces we dominate.

Implementing reconciliation ecology will involve the growing practice of *community-based conservation,* in which conservation biologists work with people to help them protect biodiversity in their local communities. With this approach, scientists, citizens, and sometimes national and international conservation organizations seek ways to preserve local biodiversity while allowing people who live in or near protected areas to make sustainable use of some of the resources there (Case Study, right).

For example, people learn how protecting local wildlife and ecosystems can provide economic resources for their communities by encouraging sustainable forms of ecotourism. In the Central American country of Belize, conservation biologist Robert Horwich has helped to establish a local sanctuary for the black howler monkey. He convinced local farmers to set aside strips of forest to serve as habitats and corridors through which these monkeys can travel. The reserve, run by a local women's cooperative, has attracted ecotourists and biologists. The community has built a black howler museum, and local residents receive income by housing and guiding visiting ecotourists and biological researchers.

In other parts of the world, people are learning how to protect vital insect pollinators, such as native butterflies and bees, which are vulnerable to insecticides and habitat loss. Neighborhoods and municipal governments are doing this by agreeing to reduce or eliminate the use of pesticides on their lawns, fields, golf courses, and parks. Neighbors also work together in planting gardens of flowering plants as a source of food for pollinating insect species. And neighborhoods and farmers build devices using wood and plastic straws, which serve as hives for increasingly threatened pollinating bees.

People have also worked together to help protect bluebirds within human-dominated habitats where most of the bluebirds' nesting trees have been cut and the bluebird populations have declined. Special boxes were designed to accommodate nesting bluebirds, and the North American Bluebird Society has encouraged Canadians and Americans to use these boxes on their properties and to keep house cats away from nesting bluebirds. Now bluebird numbers are growing again.

In Berlin, Germany, people have planted gardens on many large rooftops. These gardens support a variety of wild species by containing varying depths and types of soil and exposures to sunlight. Such roofs also save energy by providing insulation and absorbing less heat than conventional rooftops do, thereby helping to keep cities cooler. They also conserve water by reducing evapotranspiration. Some reconciliation ecology proponents call for a global campaign to use the roofs of the world to help sustain biodiversity. **GREEN CAREER:** Rooftop garden designer

In the U.S. state of California, San Francisco's Golden Gate Park is a large oasis of gardens and trees in the midst of a major city. It is a good example of reconciliation ecology, because it was designed and planted by people who transformed it from a system of sand dunes. There are many other examples of individuals and groups working together on projects to restore grasslands, wetlands, streams, and other degraded areas rain forest Case Study below). **GREEN CAREER:** Reconciliation ecology specialist

■ CASE STUDY

The Blackfoot Challenge—Reconciliation Ecology in Action

The Blackfoot River flows among beautiful mountain ranges in the west central part of the U.S. state of Montana. This large watershed is home to more than 600 species of plants, 21 species of waterfowl, bald eagles, peregrine falcons, grizzly bears, and rare species of trout. Some species, such as the Howell's gumweed and the bull trout, are threatened with extinction.

The Blackfoot River Valley is also home to people who live in seven communities and 2,500 rural households. A book and movie, both entitled *A River Runs*

Through It, tell of how residents of the valley cherish their lifestyles.

In the 1970s, many of these people recognized that their beloved valley was threatened by poor mining, logging, and grazing practices, water and air pollution, and unsustainable commercial and residential development. They also understood that their way of life depended on wildlife and wild ecosystems located on private and public lands. They began meeting informally over kitchen tables to discuss how to maintain their way of life while sustaining the other species living in the valley. These small gatherings spawned community meetings attended by individual and corporate landowners, state and federal land managers, scientists, and local government officials.

Out of these meetings came action. Teams of residents organized weed-pulling parties, built nesting structures for waterfowl, and developed sustainable grazing systems. Landowners agreed to create perpetual conservation easements, setting land aside for only conservation and sustainable uses such as hunting and fishing. They also created corridors between large tracts of undeveloped land. In 1993, these efforts were organized under a charter called the Blackfoot Challenge.

The results were dramatic. Blackfoot Challenge members have restored and enhanced large areas of wetlands, streams, and native grasslands. They have reserved large tracts of private land under perpetual conservation easements.

These pioneers might not have known it, but they were initiating what has become a classic example of *reconciliation ecology.* They worked together, respected each other's views, accepted compromises, and found ways to share their land with the area's plants and animals. They understood that all sustainability is local.

THINKING ABOUT
Wolves and Reconciliation Ecology

CORE CASE STUDY

What are some ways in which the wolf restoration project in Yellowstone National Park (**Core Case Study**) is similar to some reconciliation ecology examples described above?

RESEARCH FRONTIER

Determining where and how reconciliation ecology can work best. See **academic.cengage.com/biology/miller**.

Figure 10-29 lists some ways in which you can help sustain the earth's terrestrial biodiversity.

WHAT CAN YOU DO?

Sustaining Terrestrial Biodiversity

- Adopt a forest
- Plant trees and take care of them
- Recycle paper and buy recycled paper products
- Buy sustainably produced wood and wood products
- Choose wood substitutes such as bamboo furniture and recycled plastic outdoor furniture, decking, and fencing
- Help to restore a nearby degraded forest or grassland
- Landscape your yard with a diversity of plants natural to the area

Figure 10-29 **Individuals Matter:** ways to help sustain terrestrial biodiversity. **Questions:** Which two of these actions do you think are the most important? Why? Which of these things do you already do?

REVISITING Yellowstone Wolves and Sustainability

CORE CASE STUDY

SUSTAINABILITY

In this chapter, we looked at how terrestrial biodiversity is being destroyed or degraded. We also saw how we can reduce this destruction and degradation by using forests and grasslands more sustainably, protecting species and ecosystems in parks, wilderness, and other nature reserves, and protecting ecosystem services that support all life and economies. We learned the importance of preserving what remains of richly biodiverse and highly endangered ecosystems (biodiversity hotspots) and identifying and protecting areas where deteriorating ecosystem services threaten people and other forms of life.

We also learned about the value of restoring or rehabilitating some of the ecosystems we have degraded. Reintroducing keystone species such as the gray wolf into ecosystems they once inhabited (**Core Case Study**) is a form of ecological restoration that can result in the reestablishment of certain ecological functions and species interactions in such systems, thereby helping to preserve biodiversity. Finally, we explored ways in which people can share with other species some of the land they occupy (95% of all the earth's land) in order to help sustain biodiversity.

Preserving terrestrial biodiversity involves applying the four **scientific principles of sustainability** (see back cover). First, it means respecting biodiversity by trying to sustain it. If we are successful, we will also be restoring and preserving the flows of energy from the sun through food webs, the cycling of nutrients in ecosystems, and the species interactions in food webs that help prevent excessive population growth of any species, including our own.

We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect.

ALDO LEOPOLD

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 215. Describe the beneficial effects of reintroducing the keystone gray wolf species (Figure 10-1) into Yellowstone National Park in the United States (**Core Case Study**).

2. Distinguish among an **old-growth forest,** a **second-growth forest,** and a **tree plantation (tree farm or commercial forest).** What major ecological and economic benefits do forests provide? Describe the efforts of scientists and economists to put a price tag on the major ecological services provided by forests and other ecosystems.

3. What harm is caused by building roads into previously inaccessible forests? Distinguish among *selective cutting, clear-cutting,* and *strip cutting* in the harvesting of trees. What are the major advantages and disadvantages of clear-cutting forests?

4. What are two types of forest fires? What are some ecological benefits of occasional surface fires? What are four ways to reduce the harmful impacts of diseases and insects on forests? What effects might projected global warming have on forests?

5. What parts of the world are experiencing the greatest forest losses? Define **deforestation** and list some of its major harmful environmental effects. Describe the encouraging news about deforestation in the United States. What are the major basic and secondary causes of tropical deforestation?

6. Describe four ways to manage forests more sustainably. What is certified timber? What are four ways to reduce the harms to forests and to people from forest fires? What are three ways to reduce the need to harvest trees? What is the fuelwood crisis and what are three ways to reduce its severity? Describe the Green Belt Movement. What are five ways to protect tropical forests and use them more sustainably?

7. Distinguish between **rangelands** and **pastures.** Distinguish between the **overgrazing** and **undergrazing** of rangelands. What are three ways to reduce overgrazing and use rangelands more sustainably? Describe the conflict between ranching and urban development in the American West.

8. What major environmental threats affect national parks? How could national parks in the United States be used more sustainably? Describe some of the ecological effects of reintroducing the gray wolf to Yellowstone National Park in the United States (**Core Case Study**). What percentage of the world's land has been set aside and protected as nature reserves, and what percentage do conservation biologists believe should be protected?

9. How should nature reserves be designed and connected? Describe what Costa Rica has done to establish nature reserves. What is **wilderness** and why is it important? Describe the controversy over protecting wilderness in the United States. What is a **biological hotspot** and why is it important to protect such areas? Why is it also important to protect areas where deteriorating ecosystem services threaten people and other forms of life?

10. What is **ecological restoration?** What are the four parts of a prominent strategy for carrying out ecological restoration and rehabilitation? Describe the ecological restoration of a tropical dry forest in Costa Rica. Define and give three examples of **reconciliation (applied) ecology.** Describe the relationship between reestablishing wolves in Yellowstone National park (**Core Case Study**) and the four **scientific principles of sustainability**.

Note: Key Terms are in **bold** type.

CRITICAL THINKING

1. List three ways in which you could apply **Concept 10-5C** to help sustain terrestrial ecosystems and biodiversity.

2. Do you support the reintroduction of the gray wolf into the Yellowstone ecosystem in the United States (**Core Case Study**)? Explain. Do you think the reintroduction of wolves should be expanded to areas outside of the park? Explain.

3. Some argue that growing oil palm trees in plantations in order to produce biodiesel fuel will help us to lessen our dependence on oil and will cut vehicle CO_2 emis-

sions. Do you think these benefits are important enough to justify burning and clearing some tropical rain forests? Why or why not? Can you think of ways to produce biofuels, other than cutting trees? What are they?

4. In the early 1990s, Miguel Sanchez, a subsistence farmer in Costa Rica, was offered $600,000 by a hotel developer for a piece of land that he and his family had been using sustainably for many years. The land contained an old-growth rain forest and a black sand beach in an area under rapid development. Sanchez refused the offer. What would you have done if you were in Miguel Sanchez's position? Explain your decision.

5. There is controversy over whether Yellowstone National Park in the United States should be accessible by snowmobile during winter. Conservationists and backpackers, who use cross-country skis or snowshoes for excursions in the park during winter, say no. They contend that snowmobiles are noisy, pollute the air, and can destroy vegetation and disrupt some of the park's wildlife. Proponents say that snowmobiles should be allowed so that snowmobilers can enjoy the park during winter when cars are mostly banned. They point out that new snowmobiles are made to cut pollution and noise. A proposed compromise plan would allow no more than 950 of these new machines into the park per day, only on roads, and primarily on guided tours. What is your view on this issue? Explain.

6. In 2007, Lester R. Brown estimated that reforesting the earth and restoring the earth's degraded rangelands would cost about $15 billion a year. Suppose the United States, the world's most affluent country, agreed to put up half this money, at an average annual cost of $25 per American. Would you support doing this? Explain. What other part or parts of the federal budget would you decrease to come up with these funds?

7. Should developed countries provide most of the money needed to help preserve remaining tropical forests in developing countries? Explain.

8. Are you in favor of establishing more wilderness areas in the United States, especially in the lower 48 states (or in the country where you live)? Explain. What might be some drawbacks of doing this?

9. Congratulations! You are in charge of the world. List the three most important features of your policies for using and managing **(a)** forests, **(b)** grasslands, **(c)** nature reserves such as parks and wildlife refuges, **(d)** biological hotspots, and **(e)** areas with deteriorating ecosystem services.

10. List two questions that you would like to have answered as a result of reading this chapter.

Note: See Supplement 13 (p. S78) for a list of Projects related to this chapter.

ECOLOGICAL FOOTPRINT ANALYSIS

Study the data below on deforestation in five countries, and answer the questions that follow.

Country	Area of Tropical Rain Forest (square kilometers)	Area of Deforestation per Year (square kilometers)	Annual Rate of Tropical Forest Loss
A	1,800,000	50,000	
B	55,000	3,000	
C	22,000	6,000	
D	530,000	12,000	
E	80,000	700	

1. What is the annual rate of tropical rain forest loss, as a percentage of total forest area, in each of the five countries? Answer by filling in the blank column in the table.

2. What is the annual rate of tropical deforestation collectively in all of the countries represented in the table?

3. According to the table, and assuming the rates of deforestation remain constant, which country's tropical rain forest will be completely destroyed first?

4. Assuming the rate of deforestation in Country C remains constant, how many years will it take for all of its tropical rain forests to be destroyed?

5. Assuming that a hectare (1.0 hectare = 0.01 square kilometer) of tropical rain forest absorbs 0.85 metric tons of carbon dioxide per year, what would be the total annual growth in the carbon footprint (carbon emitted but not absorbed by vegetation because of deforestation) in metric tons of carbon dioxide per year from deforestation for each of the five countries in the table?

LEARNING ONLINE

Log on to the Student Companion Site for this book at **academic.cengage.com/biology/miller**, and choose Chapter 10 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.