CHAPTER 9

Ecological Restoration

The Florida Everglades from the air looks like a field of water islands and grasslike water plants. One of the largest ecological restoration projects is an attempt to help this national park.

LEARNING OBJECTIVES

Ecological restoration is the part of ecosystem management that deals with the recovery of ecosystems that have been damaged by human activities. It is a relatively new field. In this chapter, we explore the concepts of ecological restoration. After reading this chapter, you should understand . . .

- What it means to "restore" an ecosystem, since ecological systems are always changing;
- The main goals of restoration ecology;
- Basic approaches, methods, and limits of restoration;
- The general principles and processes of restoration ecology;
- The role of adaptive management in restoration;
- The criteria used to judge the success of restoration.

CASE STUDY

The Florida Everglades

The Florida Everglades is one of the nation's most valuable ecological treasures, listed by the United Nations as a World Heritage Site. The Everglades is also interconnected with a large area of the rest of Florida, beginning with a series of small lakes near Orlando, Florida (near the center of the state), and extending southward to the Florida Bay. The area south of Lake Okeechobee—about 175 km (110 mi) south of Orlando—is a long, wide system of shallow wetlands with slow-moving water. You can imagine the Everglades as a very wide, grass-filled, slow-moving, shallow river. Everglades National Park is at the very southern end of the system and extends out into Florida Bay to about the Florida Keys. Much of the flow of the Everglades is funneled through a location known as Shark Slough, and the velocity of flow of the lower Everglades, while still slow, is greater than that to the north.

Tourists from all over the world come to the Everglades to see its unusual landscape and wildlife. It is home to more than 11,000 species of plants, several hundred species of birds, and numerous species of fish and mammals. It is the last remaining habitat for approximately 70 threatened or endangered species or subspecies, including the Florida manatee (a subspecies of the West Indian manatee), the Florida panther (a subspecies of the American mountain lion), and the American crocodile. Unfortunately, in the past century, much of the Everglades has been drained for agriculture and urban development; today only 50% of the original wetlands remain (Figure 9.1a and b).

Restoration of the Everglades is complicated by agriculture and urbanization—several million people live in south Florida. All—agriculture, people, and the National Park—compete for the water resources. One of the major issues is to somehow arrive at a plan that will ensure long-term sustainability and quality of the water supply for the Everglades and also supply water for agriculture, towns, and cities.[1] This plan will involve the following:

- Reducing the area in agriculture and/or the water use per hectare in agriculture.
- Reducing the flow of agricultural fertilizers and pesticides from farmland into the Everglades.
- Managing land development that encroaches upon the Everglades.
- Managing access to the Everglades by people.
- Removing introduced exotic species that are dangerous to people, or threaten native species with extinction, or disrupt the presettlement ecosystems.

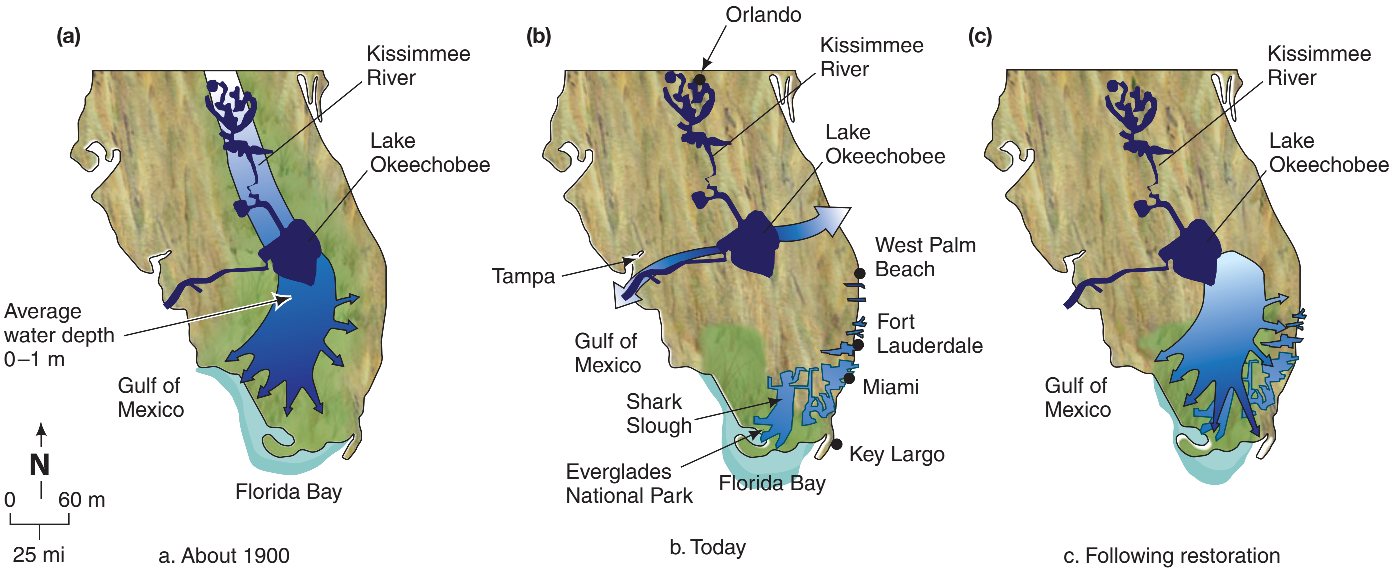

FIGURE 9.1 **The Florida Everglades from about 1900 to the present (a and b) and projected into the future following restoration (c).** Water flow (both surface and ground water) is shown in blue. Land development and water diversions changed the dominant flow from north-south to east-west. (*Sources*: Modified from the U.S. Geological Survey and Comprehensive Everglades Restoration Plan.)

- Developing scientific methods and theory to better predict the possible consequences of changes to the geologic, hydrologic, and biologic parts of the Everglades as restoration goes forward.
- Restoring the original large-scale water flow in south Florida—that grass-filled, slow-moving, shallow river. (Today the flow of water in the northern part of the Everglades is controlled by a complex system of canals, locks, and levees for a variety of purposes, including agriculture, flood control, and water supply.)

The Everglades restoration is the largest wetland-restoration project in the world. Known as the Comprehensive Everglades Restoration Plan, the project was developed by a number of government agencies, both local and federal, and is slated to continue over a 30-year period at a total cost of about $10 billion. To date, about $2.4 billion has been spent. Land acquired in 2008 that will be removed from agriculture and returned as part of the Everglades will enlarge the park's area by approximately 728 km^2 (281 mi^2). The acquired land will allow restoration of the hydrology of the Everglades in a much more significant way, as it is in the northern part of the system, where much of the water was used for agricultural purposes. Goals for the Florida Everglades include the following:

- Restoration of a more natural water flow (Figure 9.1c).
- Recovery of native and endangered species.
- Removal of invasive exotic species that are causing problems to the ecosystems and to people.
- Restoration of water quality, especially control of nutrients from agricultural and urban areas.
- Habitat restoration for wildlife that use the Everglades.

Progress to date has been significant. The amount of pollutants flowing into the Everglades from a variety of sources has been reduced by about 50%. Thousands of hectares have been treated to remove invasive, exotic species, including the Brazilian pepper tree and tilapia (a fish from Africa). In recent years, the Burmese python, which can grow to over 7 m (21 ft) and weigh over 100 kg (220 lbs), has become established in the Everglades (Figure 9.2). The snakes are an exotic, invasive species introduced by people who purchased small pythons as pets and released them into the wild when they became too large and difficult to keep. They have established a rapidly growing population in the Everglades (and elsewhere in Florida) and are becoming a top predator there, with increasing capacity to deplete populations of native birds and mammals. Recently, a large python killed and attempted to swallow a seven-foot alligator! A program is now under way to attempt to control the growing population of pythons (estimated to exceed 100,000), but it's unlikely that they can be completely eradicated.

FIGURE 9.2 **Burmese python, an exotic, invasive species.** Released by people who purchased them as pets, it has established a large population in the Everglades.

A purpose of this chapter is to provide an understanding of what is possible and what can be done to restore damaged ecosystems.

9.1 What Is Ecological Restoration?

Ecological restoration is defined as providing assistance to the recovery of an ecosystem that has been degraded, damaged, or destroyed.[2] As such, ecological restoration is applied science and derives from the science of restoration ecology. Some general principles for restoration are listed below.

- Ecosystems are dynamic, not static (change and natural disturbance are expected).
- No simple set of rules will be applicable to a specific restoration project.
- Adaptive management, using the best science, is necessary for restoration to succeed.
- Careful consideration of ecosystems (life), geology (rocks, soils), and hydrology (water) plays an important role in all restoration projects.

Of particular importance is the principle that ecosystems are dynamic, not static—that is, they are always changing and subject to natural disturbance. Any restoration plan must consider disturbance and how resilient the restored system will be. Also important is **adaptive management**, the application of science to the management process. Hypotheses may be tested, and, as restoration goes forward, flexible plans may be developed to accommodate change. Probably the most common projects involve river restoration and the restoration of freshwater and coastal wetlands.[3]

9.2 Goals of Restoration: What Is "Natural"?

If an ecosystem passes naturally through many different states and all of them are "natural," and if the change itself, caused by wildfire, flood, and windstorm, is natural, then what is its natural state? And how can restoration that involves such disturbance occur without damage to human life and property? Can we restore an ecological system to any one of its past states and claim that this is natural and successful restoration?

In Chapters 3 and 5, we discussed the ideas of steady-state and non-steady-state ecological systems. We argued that until the second half of the 20th century the predominant belief in Western civilization was that any natural area—a forest, a prairie, an intertidal zone—left undisturbed by people achieved a single condition that would persist indefinitely. This condition, as mentioned in Chapter 3, has been known as the balance of nature. The major tenets of a belief in the balance of nature are as follows:

- Left undisturbed, nature achieves a permanency of form and structure that persists indefinitely.
- If it is disturbed and the disturbance is removed, nature returns to exactly the same permanent state.
- In this permanent state of nature, there is a "great chain of being," with a place for each creature (a habitat and a niche) and each creature in its appropriate place.

These ideas have their roots in Greek and Roman philosophies about nature, but they have played an important role in modern environmentalism as well. In the early 20th century, ecologists formalized the belief in the balance of nature. At that time, people thought that wildfires were always detrimental to wildlife, vegetation, and natural ecosystems. *Bambi*, a 1942 Walt Disney movie, expressed this belief, depicting a fire that brought death to friendly animals. In the United States, Smokey Bear is a well-known symbol used for many decades by the U.S. Forest Service to warn visitors to be careful with fire and avoid setting wildfires. The message is that wildfires are always harmful to wildlife and ecosystems.

All of this suggests a belief that the balance of nature does in fact exist. But if that were true, the answer to the question "restore to what?" would be simple: restore to the original, natural, permanent condition. The way to do it would be simple, too: Get out of the way and let nature take its course. Since the second half of the 20th century, though, ecologists have learned that nature is not constant, and that forests, prairies—all ecosystems—undergo change. Moreover, since change has been a part of natural ecological systems for millions of years, many species have adapted to change. Indeed, many require specific kinds of change in order to survive. This means that we can restore ecosystem processes (flows of energy, cycling of chemical elements) and help populations of endangered and threatened species increase on average, but the abundances of species and conditions of ecosystems will change over time as they are subjected to internal and external changes, and following the process of succession discussed in Chapter 5.

Dealing with change—natural and human-induced— poses questions of human values as well as science. This is illustrated by wildfires in forests, grasslands, and shrublands, which can be extremely destructive to human life and property. From 1990 to 2009, three wildfires that started in chaparral shrubland in Santa Barbara, California, burned about 1,000 homes. The wildfire hazard can be minimized but not eliminated. Scientific understanding tells us that fires are natural, and that some species require them. But whether we choose to allow fires to burn, or even light fires ourselves, is a matter of values. **Restoration ecology** depends on science to discover what used to be, what is possible, what an ecosystem or species requires to persist, and how different goals can be achieved. But selecting goals for restoration is a matter of human values.

Some possible goals of restoration are listed in Table 9.1. Which state we attempt to restore a landscape to (pre-industrial to modern) depends on more-specific goals and possibilities that, again, are linked to values. For example, restoring the Florida Everglades to a pre-industrial state is not possible or desirable (a value) given the present land and water use that supports the people of Florida. The goal instead is to improve biodiversity, water flow through the Everglades, and water quality (see opening Case Study).

Table 9.1 SOME POSSIBLE RESTORATION GOALS

GOAL	APPROACH
1. Pre-industrial	Maintain ecosystems as they were in A.D. 1500
2. Presettlement (e.g., of North America)	Maintain ecosystems as they were about A.D. 1492
3. Preagriculture	Maintain ecosystems as they were about 5000 B.C.
4. Before any significant impact of human beings	Maintain ecosystems as they were about 10,000 B.C.
5. Maximum production	Independent of a specific time
6. Maximum diversity	Independent of a specific time
7. Maximum biomass	Independent of old growth
8. Preserve a specific endangered species	Whatever stage it is adapted to
9. Historical range of variation	Create the future like the known past

9.3 What Is Usually Restored?

Ecosystems of all types have undergone degradation and need restoration. However, certain kinds of ecosystems have undergone especially widespread loss and degradation and are therefore a focus of attention today. Table 9.2 gives examples of ecosystems that are commonly restored.

Attention has focused on forests, wetlands, and grasslands, especially the North American prairie; streams and rivers and the riparian zones alongside them; lakes; beaches; and habitats of threatened and endangered species. Also included are areas that people desire to restore for aesthetic and moral reasons, showing once again that restoration involves values. In this section, we briefly discuss the restoration of rivers and streams, wetlands, and prairies.

Rivers, Streams, and Wetlands Restoration: Some Examples

Rivers and streams and wetlands probably are restored more frequently than any other systems. Thousands of streams have been degraded by urbanization, agriculture, timber harvesting, and channelization (shortening, widening, and even paving over or confining the channel to culverts). In North America, large areas of both freshwater and coastal wetlands have been greatly altered during the past 200 years. It is estimated that California, for example, has lost more than 90% of its wetlands, both freshwater and coastal, and that the total wetland loss for the United States is about 50%. Not only the United States has suffered; wetlands around the world are affected.

Table 9.2 SELECTED EXAMPLES OF RESTORATION PROJECTS

SYSTEM	OBJECTIVE
Rivers/Streams	Improve biodiversity, water quality, bank stability. Very common practice across the U.S.
Coastal Wetlands	Improve biodiversity and water quality, store water, provide a buffer to erosion from storms to inland areas. Very common practice along all U.S. coastal areas.
Freshwater Wetlands	Improve biodiversity and water quality, store water, and, for river systems, reduce the flood hazard.
Beaches	Sustain beaches and their ecosystems. Most often involve sand supply.
Sand Dunes	Improve biodiversity in both inland and coastal areas.
Landscape	Increase biodiversity and conserve endangered species. Often a very complex process.
Land Disturbed by Mining	Reestablish desired ecosystems, reduce erosion, and improve water quality.

Rivers and Streams

One of the largest and most expensive restoration projects in the United States is the restoration of the Kissimmee River in Florida. This river was channelized, or straightened, by the U.S. Army Corps of Engineers to provide ship passage through Florida. However, although the river and its adjacent ecosystems were greatly altered, shipping never developed, and now several hundred million dollars must be spent to put the river back as it was before. The task includes restoring the meandering flow of the river and replacing the soil layers in the order in which they had lain on the bottom of the river prior to channelization.[4]

The Kissimmee at one time had an unusual hydrology because it inundated its floodplain for prolonged periods (Figure 9.3). The floodplain and river supported a biologically diverse ecosystem, including wetland plants, wading birds, waterfowl, fish, and other wildlife. Few people lived in the Kissimmee basin before about 1940, and the land use was mostly agricultural. Due to rapid development and growth in the past 50 years and a growing flood hazard as a result of inappropriate land use, people asked the federal government to design a flood-control plan for southern Florida. The channelization of the Kissimmee River occurred between 1962 and 1971 as part of the flood-control plan. About two-thirds of the floodplain was drained, and a straight canal was excavated. Turning the meandering river into a straight canal degraded the river ecosystem and greatly reduced the wetlands and populations of birds, mammals, and fish (Figure 9.4).

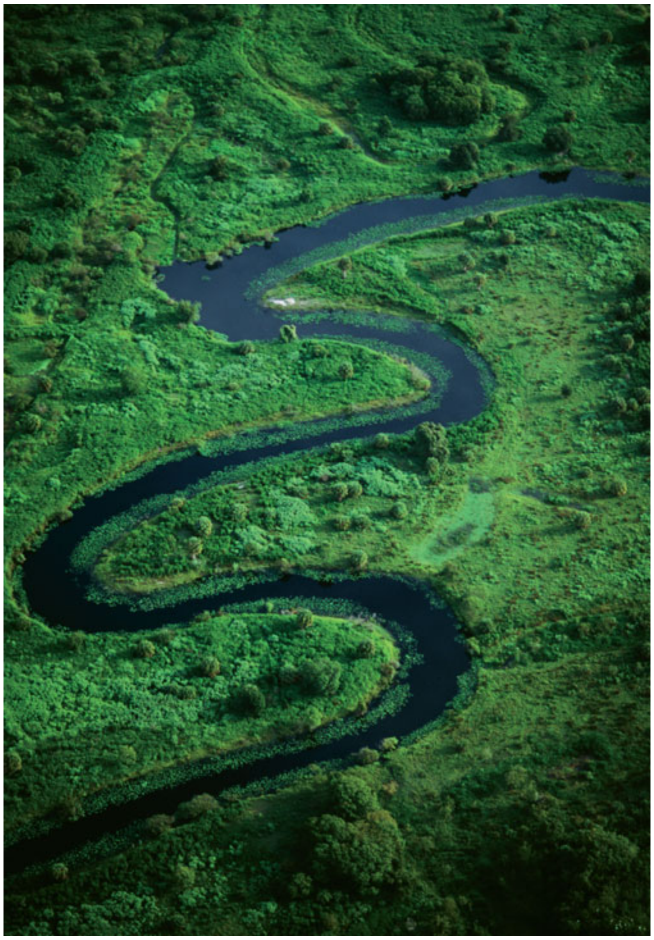

FIGURE 9.3 The Kissimmee River before channelization.

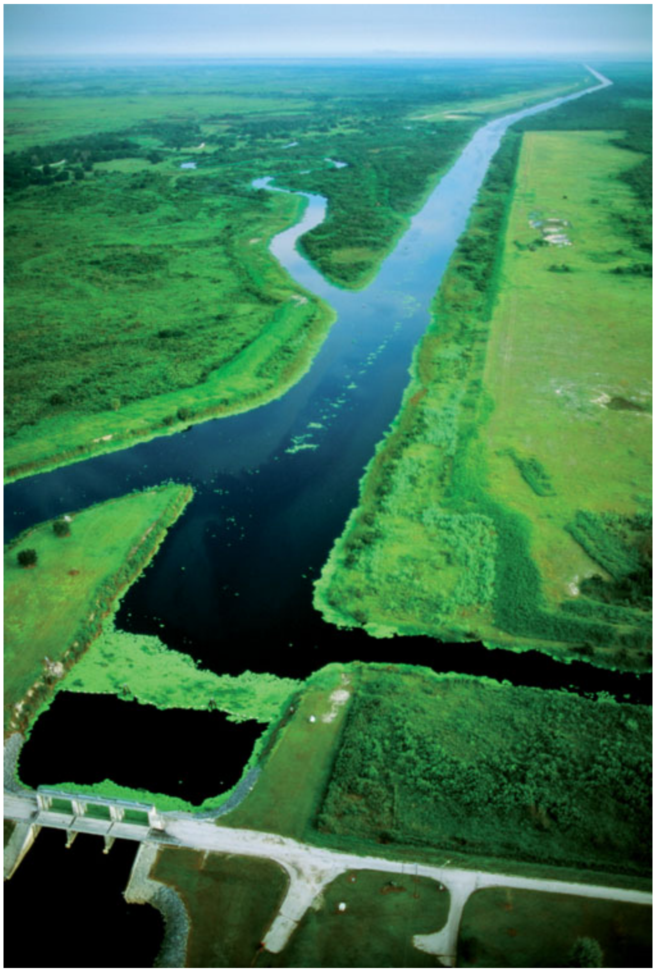

FIGURE 9.4 The Kissimmee River after channelization that produced a wide, straight ditch.

Criticism of the loss of the river ecosystem went on for years, finally leading to the current restoration efforts. The purpose of the restoration is to return part of the river to its historical meandering riverbed and wide floodplain. Before-and-after photos and specifics of the restoration plan are shown in Figure 9.5 and include restoring as much as possible of the historical biodiversity and ecosystem function; re-creating patterns of wetland plant communities as they existed before channelization; reestablishing prolonged flooding of the floodplain; and re-creating a river floodplain environment and connection to the main river similar to the way it used to be.[4]

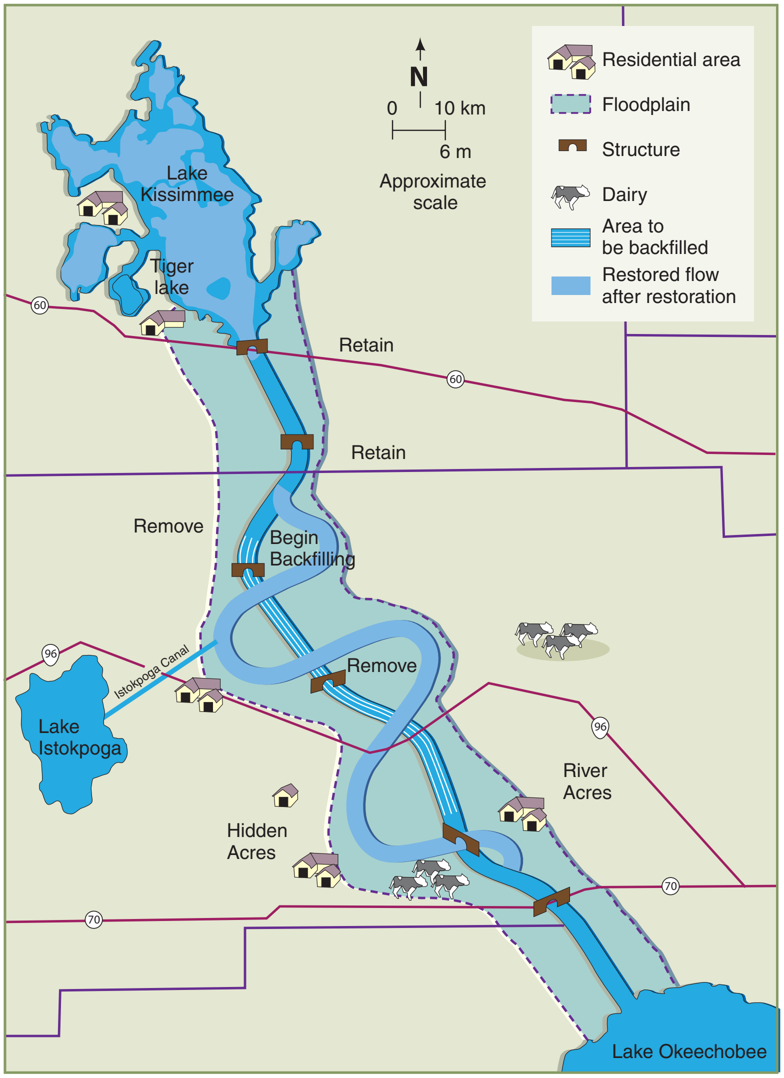

FIGURE 9.5 Map showing part of the Kissimmee River restoration plan. A major objective is to re-create the historical river floodplain environment that is wet much of the year, improving biodiversity and ecosystem function. (*Source*: Modified from South Florida Water Management District.)

The cost of the restoration of the Kissimmee River is several times greater than it was to channelize it. Thus, the decision to go forward with the restoration reflects the high value that people in south Florida place on conserving biological diversity and providing for recreational activities in a more natural environment.

Yellowstone National Park is another interesting case. It is the site of an unanticipated stream restoration resulting from the reintroduction of wolves. Wolves were eliminated from Yellowstone by the 1920s and were introduced back into the park in 1995–1996. Initially, 66 wolves were introduced, and by 2007 the wolf population had grown to about 1,500, with about 171 in Yellowstone itself (Figures 9.6 and 9.7), 700–800 in Idaho (outside the park), and the rest in other areas.

Mountain streams in Yellowstone generally consist of stream channels, beds, and banks composed of silt, sand, gravel, and bedrock. Cool, clean water is supplied via the hydrologic and geologic system from snowmelt and rain that infiltrate the rocks and soil to seep into streams. The water supports life in the stream, including fish and other organisms, as well as streamside vegetation adjacent to stream channels. The riparian vegetation is very different from vegetation on adjacent uplands. Stream bank vegetation helps retard erosion of the banks and thus the amount of sediment that enters the stream.

Riparian vegetation, such as cottonwood and willow trees, is also a popular food source for animals, such as elk. Extensive browsing

The restoration project was authorized by the U.S. Congress in 1992, in partnership with the South Florida Water Management District and the U.S. Army Corps of Engineers. It is an ongoing project, and by 2001 approximately 12 km of the nearly straight channel had been restored to a meandering channel with floodplain wetlands about 24 km long. As a result, water again flowed through a meandering channel and onto the floodplain, wetland vegetation was reestablished, and birds and other wildlife returned. The potential flood hazard is being addressed. Some of the structures that control flooding will be removed, and others will be maintained. Flood protection is a main reason the entire river will not be returned to what it was before channelization.

FIGURE 9.6 Wolves in Yellowstone National Park.

dramatically reduces the abundance of riparian plants, damaging the stream environment by reducing shade and by increasing bank erosion, which introduces fine sediment into the water. Fine sediment, such as fine sand and silt, not only degrades water quality but also may fill the spaces between gravel particles or seal the bed with mud, damaging fish and aquatic insect habitat.[5]

Before the wolves arrived in the mid-1990s, willows and other streamside plants were nearly denuded by browsing elk. It soon became apparent, however, that the wolves were most successful in hunting elk along streams, where the elk had to negotiate the complex, changing topography. The elk responded by avoiding the dangerous stream environment. Over a four-year period, from 1998 to 2002, the number of willows eaten by elk declined greatly, and the riparian vegetation recovered. As it did so, the stream channel and banks also recovered and became more productive for fish and other animals.

In sum, although the reintroduction of wolves to Yellowstone is controversial, the wolves are a *keystone species*—a species that, even if not overly abundant, plays an important role in maintaining an ecological community. By hunting elk and scaring them away from the streams, wolves improve the stream banks, the water quality, and the broader ecologic community (in this case, the stream ecosystem). The result is a higher-quality stream environment.[5]

Still, the debate about wolf introductions is complex. In Yellowstone, just over 90% of wolf prey is elk; there are far fewer bison, deer, and other animals. Land-use issues associated with grazing for cattle and sheep are more difficult to assess. How we choose to manage wolf populations will reflect both science and values.[5, 6]

FIGURE 9.7 **Wolf hunting elk in Yellowstone National Park.**

Wetlands

The famous cradle of civilization, the land between the Tigris and Euphrates rivers, is so called because the waters from these rivers and the wetlands they formed made possible one of the earliest sites of agriculture, and from this the beginnings of Western civilization. This well-watered land in the midst of a major desert was also one of the most biologically productive areas in the world, used by many species of wildlife, including millions of migratory birds. Ironically, the huge and famous wetlands between these two rivers, land that today is within Iraq, have been greatly diminished by the very civilization that they helped create. "We can see from the satellite images that by 2000, all of the marshes were pretty much drained, except for 7 percent on the Iranian border," said Dr. Curtis Richardson, director of the Duke University Wetland Center.[7]

A number of events of the modern age led to the marsh's destruction. Beginning in the 1960s, Turkey and Syria began to build dams upriver, in the Tigris and Euphrates, to provide irrigation and electricity, and now these number more than 30. Then in the 1980s Saddam Hussein had dikes and levees built to divert water from the marshes so that oil fields under the marshes could be drilled. For at least 5,000 years, the Ma'adan people—the Marsh Arabs—lived in these marshes. But the Iran–Iraq War (1980–1988) killed many of them and also added to the destruction of the wetlands (Figure 9.8a and b).[8]

Today efforts are under way to restore the wetlands. According to the United Nations Environment Program, since the early 1970s the area of the wetlands has increased by 58%.[9] But some scientists believe that there has been little improvement, and the question remains: Can ecosystems be restored once people have seriously changed them?

Prairie Restoration

Tallgrass prairie is also being restored. Prairies once occupied more land in the United States than any other kind of ecosystem. Today, only a few small remnants of prairie exist. Prairie restoration is of two kinds. In a few places, one can still find original prairie that has never been plowed. Here, the soil structure is intact, and restoration is simpler. One of the best known of these areas is the Konza Prairie near Manhattan, Kansas. In other places, where the land has been plowed, restoration is more complicated. Nevertheless, the restoration of prairies has gained considerable attention in recent decades, and restoration of prairie on previously plowed and farmed land is occurring in many midwestern states. The Allwine Prairie, within the city limits of Omaha,

(a)

(b)

FIGURE 9.8 **(a)** A Marsh Arab village in the famous wetlands of Iraq, said to be one of the places where Western civilization originated. The people in this picture are among an estimated 100,000 Ma'adan people who now live in their traditional marsh villages, many having returned recently. These marshes are among the most biologically productive areas on Earth. **(b)** Map of the Fertile Crescent, where the Marsh Arabs live, called the cradle of civilization. It is the land between the Tigris (the eastern river) and Euphrates (the western river) in what is now Iraq. Famous cities of history, such as Nineveh, developed here, made possible by the abundant water and good soil. The gray area shows the known original extent of the marshes, the bright green their present area.

Nebraska, has been undergoing restoration from farm to prairie for many years. Prairie restoration has also been taking place near Chicago.

About 10% of North American original tallgrass prairie remains in scattered patches from Nebraska east to Illinois and from southern Canada south to Texas (in the Great Plains physiographic province of the United States). A peculiarity of prairie history is that although most prairie land was converted to agriculture, this was not done along roads and railroads; thus, long, narrow strips of unplowed native prairie remain on these rights-of-way. In Iowa, for example, prairie once covered more than 80% of the state—11 million hectares (28 million acres). More than 99.9% of the prairie land has been converted to other uses, primarily agriculture, but along roadsides there are 242,000 hectares (600,000 acres) of prairie—more than in all of Iowa's county, state, and federal parks. These roadside and railway stretches of prairie provide some of the last habitats for native plants, and restoration of prairies elsewhere in Iowa is making use of these habitats as seed sources.[5]

Studies suggest that the species diversity of tallgrass prairie has declined as a result of land-use changes that have led to the loss or fragmentation of habitat.[9] For example, human-induced changes that nearly eliminated bison (another keystone species) from the prairie greatly changed the community structure and biodiversity of the ecosystem. Scientists evaluating the effects of grazing suggest that, managed properly, grazing by bison can restore or improve biodiversity of tallgrass prairie[9] (Figure 9.9). The effect of grazing by cattle is not as clear. Range managers have for years maintained that cattle grazing is good for ecosystems, but such grazing must be carefully managed. Cattle are not bison. Bison tend to range over a wider area and in a different pattern. Cattle tend to stay longer in a particular area and establish grazing trails with denuded vegetation. However, both cattle and bison, if too many of them are left too long in too small an area, will cause extensive damage to grasses.

Fire is another important factor in tallgrass prairies. Spring fires enhance the growth of the dominant tall grasses that bison prefer. Tallgrass prairie is a mixture of taller grasses, which prefer warm, dry environments, and other grasses, forbs, and woody plants, which prefer cooler, wetter conditions. The tall grasses often dominate and, if not controlled by fire and grazing, form a thick cover (canopy) that makes it more difficult for shorter plants to survive. Grazing opens the canopy and allows more light to reach closer to the ground and support more species. This increases biodiversity. Long ago, fires set by lightning and/or people helped keep the bison's grazing lands from turning into forests. Today, ecological restoration

FIGURE 9.9 American bison grazing in tallgrass prairie ecosystem, Custer State Park, South Dakota.

has attempted to use controlled burns to remove exotic species and woody growth (trees). However, fire alone is not sufficient in managing or restoring prairie ecosystem biodiversity. Moderate grazing is the hypothetical solution. Grazing of bison on degraded grassland will have negative impacts, but moderate grazing by bison or cattle on "healthy prairies" may work.

One of the newest threats to tallgrass prairie ecosystems is atmospheric nitrogen from automobile emissions. Nitrogen helps some species, but too much of it causes problems for tallgrass prairie ecosystems, whose diversity and productivity are significantly influenced by the availability of nitrogen. Fire and millions of grazing bison regulated nitrogen availability during prehistoric and pre-automobile times.

A CLOSER LOOK 9.1

Island Fox on Santa Cruz Island

The island fox is found on the Channel Islands, eight islands off the coast of Southern California (Figure 9. 10a). The fox evolved over the past 20,000 years into a separate species of its recent ancestors, the California gray fox. Due to isolation on the islands, as the island fox evolved, it became smaller, and today it is about the size of a house cat (Figure 9.10b).[10]

Island fox most likely reached the islands off the coast of Santa Barbara about 20,000 years ago, when sea levels were more than 120 meters lower than they are today and the distance to the mainland was much shorter, increasing the likelihood of animals' reaching the offshore environment. At that time, this consisted of one large island known as Santa Rosae. By the time Native Americans arrived, about 12,000 years ago, the island fox had become well established. Native Americans evidently kept the foxes as pets, and some burial sites suggest that foxes were, in fact, buried with their owners. The island

(a)

(b)

FIGURE 9.10 (a) The Santa Barbara Channel and Channel Islands; (b) Island fox.

(a)

(b)

FIGURE 9.11 (a) Golden eagle eating an island fox on Santa Cruz Island and (b) a bald eagle hunting fish.

fox in the Channel Islands lived to ages unheard of for mainland gray foxes. Many of them lived more than 10 years, and a few even about 12 years. A number of them became blind in their old age, from either cataracts or accident, and could be seen feeding on beaches and other areas despite their handicap.

A subspecies of the island fox evolved on the six islands on which they are found today, and until fairly recently they had no natural enemies. But in the 1990s, the populations of Island fox on several islands suddenly plummeted. On San Miguel Island, for example, a population of approximately 400 foxes in 1994 was reduced to about 15 in only five years. Similar declines occurred on Santa Rosa and Santa Cruz islands. At first it seemed that some disease must be spreading rapidly through the fox population. On Catalina Island, in fact, an occurrence of canine distemper did lead to a decline in the number of foxes on that island. On other islands, particularly in the Santa Barbara Channel, the cause was not so easily determined.

Ecologists eventually solved the mystery by discovering that foxes were being killed and eaten by golden eagles (Figure 9.11a), which had only recently arrived on the islands after the apparent demise of the islands' bald eagles (Figure 9.11b). The bald eagles primarily eat fish and hadn't bothered the foxes. Bald eagles are also territorial and kept golden eagles off the islands. It is believed that the bald eagles became endangered because the use of DDT in the 1970s and later led to increasing concentrations of the pesticide in fish that bald eagles ate, causing their eggshells to become too soft to protect the embryos. The golden eagles moved in and colonized the islands in the 1990s, apparently attracted by the amount of food they could easily obtain from their daylight hunting, as well as by the absence of bald eagles. The golden eagles found young feral pigs much to their liking and evidently also found island foxes to be easy targets.

Remains of island foxes have been found in eagle nests, and it is now generally agreed that the golden eagles are responsible for the decline in the fox populations. In fact, of 21 fox carcasses studied on Santa Cruz Island in the 1990s, 19 were apparently victims of golden eagle predation.[11,12]

To conserve the island fox on the three Channel Islands in Santa Barbara Channel, which are part of Channel Islands National Park, a management program was developed. The plan has five steps:[12]

1. Capture remaining island foxes and place them in protected areas.
2. Begin a captive breeding program to rebuild the fox populations.
3. Capture golden eagles and transfer them to the mainland. (The idea is to put them in suitable habitat far from the islands so they will not return.)
4. Reintroduce bald eagles into the island ecosystem. (It is hoped that the birds will establish territories and that this will prevent the return of golden eagles.)
5. Remove populations of feral pigs, which attract golden eagles to the islands.

This five-step program has been put into effect; foxes are now being bred in captivity at several sites, and new kits have been born. By 2009, golden eagles on Santa Cruz Island had been mostly removed, the pigs had also been removed, bald eagles had been reintroduced, and foxes raised in captivity had been released. The historical average population of fox on the islands is 1,400. By 2004 fewer than 100 were present, but by 2009 there were about 700—a remarkable recovery. If all the steps necessary to save the island fox are successful, then the island fox will again take its place as one of the keystone species on the Channel Islands.

9.4 Applying Ecological Knowledge to Restore Heavily Damaged Lands and Ecosystems

An example of how ecological succession can aid in the restoration (termed **reclamation** for land degraded by mining) of heavily damaged lands is the ongoing effort to undo mining damage in Great Britain, where some mines have been used since medieval times and approximately 55,000 hectares (136,000 acres) have been damaged. Recently, programs have been initiated to remove toxic pollutants from the mines and mine tailings, to restore these damaged lands to useful biological production, and to restore the attractiveness of the landscape.[13]

One area damaged by a long history of mining lies within the British Peak District National Park, where lead has been mined since the Middle Ages and waste tailings are as much as 5 m (16.4 ft) deep. The first attempts to restore this area used a modern agricultural approach: heavy application of fertilizers and planting of fast-growing agricultural grasses to revegetate the site rapidly. These grasses quickly green on the good soil of a level farm field, and it was hoped that, with fertilizer, they would do the same in this situation. But after a short period of growth, the grasses died. The soil, leached of its nutrients and lacking organic matter, continued to erode, and the fertilizers that had been added were soon leached away by water runoff. As a result, the areas were shortly barren again.

When the agricultural approach failed, an ecological approach was tried, using knowledge about ecological succession. Instead of planting fast-growing but vulnerable agricultural grasses, ecologists planted slow-growing native grasses, known to be adapted to mineral-deficient soils and the harsh conditions that exist in cleared areas. In choosing these plants, the ecologists relied on their observations of what vegetation first appeared in areas of Great Britain that had undergone succession naturally.[14] The result of the ecological approach has been the successful restoration of damaged lands (Figure 9.12).

FIGURE 9.12 **Long-abandoned lead-mining area in Great Britain undergoing restoration** (upper half of photograph). Restoration includes planting early-successional native grasses adapted to low-nutrient soil with little physical structure. The bottom hall of the photo shows the unrestored area.

FIGURE 9.13 **Restoration of a limestone quarry on Vancouver Island, Canada**, in 1921 resulted in a tourist attraction known as Butchart Gardens that draws about 1 million visitors each year.

Heavily damaged landscapes can be found in many places. Restoration similar to that in Great Britain is done in the United States, Canada, and many other places to reclaim lands damaged by strip mining. Butchart Gardens, an open-pit limestone quarry on Vancouver Island, Canada, is an early-20th-century example of mine restoration. The quarry, a large, deep excavation where Portland cement was produced, was transformed into a garden that attracts a large number of visitors each year (Figure 9.13). The project was the vision of one person, the wife of the mine owner. One person can make all the difference!

9.5 Criteria Used to Judge the Success of Restoration

Criteria used to evaluate whether a specific restoration has been successful, and, if so, how successful, will vary, depending on details of the project and the target (reference) ecosystem to which the restoration is compared. Criteria used to judge the success of the Everglades restoration (with issues of endangered species) will be much different from criteria used to evaluate the success of **naturalization** of an urban stream to produce a greenbelt. However, some general criteria apply to both.[2]

- The restored ecosystem has the general structure and process of the target (reference) ecosystem.

- The physical environment (hydrology, soils, rocks) of the restored ecosystem is capable of sustainably supporting the stability of the system.
- The restored ecosystem is linked with and appropriately integrated into the larger landscape community of ecosystems.
- Potential threats to the stability of the restored ecosystem have been minimized to an acceptable level of risk.
- The restored ecosystem is sufficiently adapted to normally withstand expected disturbances that characterize the environment, such as windstorms or fire.
- The restored ecosystem is, as nearly as possible, as self-sustaining as the target (reference) ecosystem. It therefore undergoes the natural range of variation over time and space; otherwise it cannot be self-sustaining.

In the final analysis, restoration, broadly defined to include naturalization, is successful if it improves the environment and the well-being of the people who are linked to the environment. An example is development of city parks that allow people to better communicate with nature.

CRITICAL THINKING ISSUE

How Can We Evaluate Constructed Ecosystems?

What happens when restoring damaged ecosystems is not an option? In such cases, those responsible for the damage may be required to establish alternative ecosystems to replace the damaged ones. An example involved some saltwater wetlands on the coast of San Diego County, California.

In 1984, construction of a flood-control channel and two projects to improve interstate freeways damaged an area of saltwater marsh. The projects were of concern because California had lost 91% of its wetland area since 1943, and the few remaining coastal wetlands were badly fragmented. In addition, the damaged area provided habitat for three endangered species: the California least tern, the light-footed clapper rail, and a plant called the salt-marsh bird's beak. The California Department of Transportation, with funding from the Army Corps of Engineers and the Federal Highway Administration, was required to compensate for the damage by constructing new areas of marsh in the Sweetwater Marsh National Wildlife Refuge. To meet these requirements, eight islands, known as the Connector Marsh, with a total area of 4.9 hectares, were constructed in 1984. An additional 7-hectare area, known as Marisma de Nación, was established in 1990. Goals for the constructed marsh, which were established by the U.S. Fish and Wildlife Service, included the following:[14]

1. Establishment of tide channels with sufficient fish to provide food for the California least tern.
2. Establishment of a stable or increasing population of salt-marsh bird's beak for three years.
3. Selection of the Pacific Estuarine Research Laboratory (PERL) at San Diego State University to monitor progress on the goals and conduct research on the constructed marsh. In 1997, PERL reported that goals for the least tern and bird's beak had been met, but that attempts to establish a habitat suitable for the rail had been only partially successful (see Table 9.3).

During the past decade, PERL scientists have conducted extensive research on the constructed marsh to determine the reasons for its limited success. They found that rails live, forage, and nest in cordgrass more than 60 centimeters tall. Nests are built of dead cordgrass attached to stems of living cordgrass so that the nests can remain above the water as it rises and falls. If the cordgrass is too short, the nests are not high enough to avoid being washed out during high tides.[14]

Researchers suggested that the coarse soil used to construct the marsh did not retain the amount of nitrogen needed for cordgrass to grow tall. Adding nitrogen-rich fertilizer to the soil resulted in taller plants in the constructed marsh, but only if the fertilizer was added on a continuing basis.

Another problem is that the diversity and numbers of large invertebrates, which are the major food source of the rails, are lower in the constructed marsh than in natural marshes. PERL researchers suspect that this, too, is linked to low nitrogen levels. Because nitrogen stimulates the growth of algae and plants, which provide food for small invertebrates, and these in turn provide food for larger invertebrates, low nitrogen can affect the entire food chain.[15, 16, 17]

Table 9.3 GOALS, PROGRESS, AND STATUS AS OF 2006

SPECIES	MITIGATION GOALS	PROGRESS IN MEETING REQUIREMENTS	STATUS AS OF 2006
California	Tidal channels with 75% of the fish species and 75% of the number of fish found in natural channels	Met standards	FWS recommended change from endangered to threatened
Salt-marsh bird's beak	Through reintroduction, at least 5 patches (20 plants each) that remain stable or increase for 3 years	Did not succeed on constructed islands but an introduced population on natural Sweetwater Marsh thrived for 3 years (reached 140,000 plants); continue to monitor because plant is prone to dramatic fluctuations in population	Still listed as endangered
Light-footed clappeer rail	Seven home ranges (82 ha), each having tidal channels with:	Constructed	Still listed as endangered; in 2005, eight captive-raised birds were released
	a. Forage Species equal to 75% of the invertebrate species and 75% of the number of invertebrates in natural areas	Met standards	
	b. High marsh areas for rails to find refuge during high tides	Sufficient in 1996 but two home ranges fell short in 1997	
	c. Low marsh for nesting with 50% coverage by tall cordgrass **d.** Population of tall cordgrass that is self-sustaining for 3 years	All home ranges met low marsh acreage requirement and all but one met cordgrass requirement and six lacked suffcient tall cordgrass Plant height can be increased with continual use of fertilizer but tall cordgrass is not self-sustaining	

Note: FWS stands for U.S. Fish and Wildlife Service

Critical Thinking Questions

1. Make a diagram of the food web in the marsh showing how the clapper rail, cordgrass, invertebrates, and nitrogen are related.
2. The headline of an article about the Sweetwater Marsh project in the April 17, 1998, issue of *Science* declared, "Restored Wetlands Flunk Real-World Test." Based on the information you have about the project, would you agree or disagree with this judgment? Explain your answer.
3. How do you think one can decide whether a constructed ecosystem is an adequate replacement for a natural ecosystem?
4. The term *adaptive management* refers to the use of scientific research in ecosystem management. In what ways has adaptive management been used in the Sweetwater Marsh project? What lessons from the project could be used to improve similar projects in the future?

SUMMARY

- Ecological restoration is the process of helping degraded ecosystems to recover and become more self-sustaining, and therefore able to pass through their natural range of conditions.
- Overarching goals of ecological restoration are to help transform degraded ecosystems into sustainable ecosystems and to develop new relationships between the natural and human-modified environments.
- Adaptive management, which applies science to the restoration process, is necessary if restoration is to be successful.
- Restoration of damaged ecosystems is a relatively new emphasis in environmental sciences that is developing into a new field. Restoration involves a combination of human activities and natural processes. It is also a social activity.
- Disturbance, change, and variation in the environment are natural, and ecological systems and species have evolved in response to these changes. These natural variations must be part of the goals of restoration.

REEXAMINING THEMES AND ISSUES

Human Population

If we degrade ecosystems to the point where their recovery from disturbance is slowed or they cannot recover at all, then we have reduced the local carrying capacity of those areas for human beings. For this reason, an understanding of the factors that determine ecosystem restoration is important to developing a sustainable human population.

Sustainability

Heavily degraded land, such as land damaged by pollution or overgrazing, loses the capacity to recover. By helping degraded ecosystems to recover, we promote sustainability. Ecological principles are useful in restoring ecosystems and thereby achieving sustainability.

Global Perspective

Each degradation of the land takes place locally, but such degradation has been happening around the world since the beginnings of civilization. Ecosystem degradation is therefore a global issue.

Urban World

In cities, we generally eliminate or damage the processes of succession and the ability of ecosystems to recover. As our world becomes more and more urban, we must learn to maintain these processes within cities, as well as in the countryside. Ecological restoration is an important way to improve city life.

People and Nature

Restoration is one of the most important ways that people can compensate for their undesirable effects on nature.

Science and Values

Because ecological systems naturally undergo changes and exist in a variety of conditions, there is no single "natural" state for an ecosystem. Rather, there is the process of succession, with all of its stages. In addition, there are major changes in the species composition of ecosystems over time. While science can tell us what conditions are possible and have existed in the past, which ones we choose to promote in any location is a question of values. Values and science are intimately integrated in ecological restoration.

KEY TERMS

adaptive management **172**
naturalization **180**
reclamation **180**
restoration ecology **172**

STUDY QUESTIONS

1. Develop a plan to restore an abandoned field in your town to natural vegetation for use as a park. The following materials are available: bales of hay; artificial fertilizer; and seeds of annual flowers, grasses, shrubs, and trees.
2. Oil has leaked for many years from the gasoline tanks of a gas station. Some of the oil has oozed to the surface. As a result, the gas station has been abandoned and revegetation has begun to occur. What effects would you expect this oil to have on the process of succession?
3. Refer to the Everglades in the opening case study. Assume there is no hope of changing water diversion from the upstream area that feeds water to the Everglades. Develop a plan to restore the Everglades, assuming the area of wetlands will decrease by another 30% as more water is diverted for people and agriculture in the next 20 years.
4. How can adaptive management best be applied to restoration projects?

FURTHER READING

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Higgs, E., ***Nature by Design: People, Natural Process, and Ecological Restoration*** (Cambridge, MA: MIT Press, 2003). A book that discusses the broader perspective on ecological restoration, including philosophical aspects.

Society for Ecological Restoration International Science and Policy Working Group, ***The SER International Primer on Ecological Restoration,*** 2004. www.ser.org. A good handbook on everything you need to know about ecological restoration.