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14 Conservation and management

We have now more or less completed our journey through wetland ecology. We began in Chapter 1 with definitions of wetlands, and then worked through the factors that create different types of wetlands. We have seen how major properties of wetlands like zonation, and the services they provide, are shaped by these causal factors. We have considered how to conduct research and how to restore wetlands. It is now time to conclude. We are left with only a few issues.

First, we need to put the whole topic back together, looking at the current state of wetlands and humans and their interactions. Given that we know the current situation, we can then ask what next: what are our objectives for the coming decades and even centuries? In other words, where are we now, and where do we wish to go from here? That is the focus of this last chapter. It would, however, be careless and misleading to ask these questions without knowing where we have been.

14.1 Humans have greatly changed wetlands

Our current situation has arisen out of past trends. Let us therefore begin by looking at a few selected examples of wetland changes over time. When we look at familiar examples, we are inclined to think that we already understand them. Therefore, I have also chosen examples that will be less familiar and may well provide some useful insights for the future.

14.1.1 Mesopotamia

Let us now return to the ancient tale of Gilgamesh with which we opened Chapter 2. This takes us back to the pre-scientific era when people were living on floodplains, and harvesting resources, but where science and mythology had not separated. Several important books have suggested that humans have rarely been wise enough to manage their resources sustainably (Tuchman 1984; Wright 2004; Diamond 2005). So, with this in mind, let us return to *The Epic of Gilgamesh* (Sanders 1972) from Chapter 2, a flood story that appears to both pre-date, but also influence, the flood story in the Bible. It may be significant that in an early part of the epic, Gilgamesh and his companion Enkidu travel to a mysterious cedar forest (probably in north Syria or southwest Persia [now Iran]): "They gazed at the mountain of cedars, the dwelling-place of the gods . . . The hugeness of the cedar rose in front of the mountain, its shade was beautiful, full of comfort . . ." (p. 77). They encounter a monstrous guardian of the forest, Humbaba, whom they kill with their swords. "They attacked the cedars, the seven splendours of Humbaba were extinguished" (p. 83). *The Epic of Gilgamesh* therefore records an early episode of deforestation. Those of us familiar with the role of forests in wetlands will not consider it coincidental that four chapters later the gods, including Ninurta, the god of wells and canals, are "cowering like curs" as a flood sweeps downstream.

Thousands of years later humans are still interacting with wetlands in this area. The area, once the land of Gilgamesh and King (Chapter 2) was known for many years as Mesopotamia. The enormous Tigris–Euphrates river system in Iraq and Iran supports several enormous marshes, collectively called the Mesopotamian marshlands (Partow 2001) (Figure 14.1). The wetlands are dominated by enormous stands of reeds (*Phragmites australis*), with cattails (*Typha angustifolia*) at the margins. Seasonally flooded zones are often saline, and have typical wetland genera including *Carex*, *Scirpus*, and *Juncus*. At least 134 bird species have been recorded, and 18 of these are globally threatened. Three species, the Iraq babbler, Basra reed warbler, and gray hypocolius, breed here almost exclusively. Wading birds included the sacred ibis and the Goliath heron. The native lions have been exterminated but gray wolves still occur. There are also indigenous human populations, the Ma'dan or marsh Arabs, who live in reed huts.

These wetlands are now being disrupted by many forces acting simultaneously. Over the last century 32 enormous dams have been constructed, with eight more under construction and 13 more planned (Partow 2001; Lawler 2005). One of the largest dams is Turkey's Ataturk Dam. The cumulative effect of these dams allows storage of five times the volume of the entire flow of the Euphrates. The consequences for downstream wetlands include those you would expect from earlier chapters in this book: a loss of spring flood peaks, reduced flow, increased salinity, and decreased sediment. The marsh area in 1973 to 1976 was between 8926 km^2 (about the original size of the Everglades), but had shrunk to 1296 km^2 in 2000. Up to this point, the story is one typical of many riverine wetlands described in Chapter 2: widespread destruction attributable mainly to altered flow regimes.

An added problem for these marshes was the effects of the brutal war fought between Iraq and Iran from 1980 to 1988. Since the marsh Arabs were viewed as potential allies of the Iranians, Saddam

FIGURE 14.1 The Mesopotamian marshes (top; © Nature Iraq) have been affected by humans for thousands of years, most recently by drainage, dam construction, and warfare (bottom; from Lawler 2005). *Phragmites* reeds are the mainstay of marsh culture, being used as housing material, woven into mats, and fed to water buffalo. (See also color plate.)

Hussein began to deliberately drain the marshes to force the marsh Arabs to leave the border area. Pearce (1993) describes how as part of this activity, in 1993 Saddam's engineers diverted almost the entire flow of the Euphrates into a 560-km long drainage canal (known as the Third River). Construction was often carried out in a brutal manner: "artillery initially bombards a district where engineering works are planned, so as to clear the local population; troops move in, to secure the district ... Once a section has been completed, mines are laid to protect the embankments from attack."

As a consequnce of the new dams and the deliberate drainage, the vast Central Marsh which covered 3000 km^2 in 1973 had shrunk by 97%. As the marsh area fell, there were catastrophic effects upon other species. A subspecies of otter, the bandicoot rat, and an endemic bat became extinct (Lawler 2005). Some half million marsh Arabs became environmental refugees and many ended up in refugee camps (Partow 2001).

When Saddam Hussein was overthrown in 2003, "local residents jubilantly broke open the dikes and dams, reflooding nearly half of the marshes" (Lawler 2005). The degree to which the marsh will recover from Saddam Hussein's actions is still unclear. There is now the enormously increased capacity of dams constructed upstream. As well, some of the marsh Arabs have become accustomed to agriculture involving sheep, wheat, and cattle, and may object to restoration. And the boundary between Iraq and Iran continues to be a site of political tensions. Will it be possible to protect and restore these wetlands, or will they succumb to the combined effects of deforestation, dams, levees, roads, and warfare?

14.1.2 The Roman Empire and the Tiber River

The Roman Empire was one of the greatest empires the world has seen – and the Romans had problems with wetlands. The Roman civilization originated with the Etruscans, who "reclaimed Tuscany from forest and swamp" and built drainage tunnels to take the overflow from lakes (Durant 1944). The early history of Rome is little known, in part because the Gauls burned the city in 390 BC, presumably destroying most historical records. Although Rome was built on seven hills, it was not a healthy location: "rains, floods and springs fed malarial marshes in the surrounding plain and even in the lower levels of the city" (Durant 1944, p.12) but Etruscan engineers built walls and sewers for Rome, and "turned it from a swamp into a protected and civilized capital." One of the main sewers, the Cloaca Maxima, was large enough that wagons loaded with hay could pass beneath its arches; the city's refuse and rainwater passed through openings in the streets into these drains and then into the Tiber, "whose pollution was a lasting problem in Roman life" (p. 81). Meanwhile, deforestation occurred apace to provide building materials and fuel. It is unlikely to be a coincidence that the Tiber "was perpetually silting its mouth and blocking Rome's port at Ostia; two hundred vessels foundered there in one gale ... About 200 BC vessels began to put in at Puteoli, 150 miles south of Rome, and ship their goods overland to the capital."

The deforestation of the Mediterranean hills led to changes in forests, hillsides, streams, springs, valleys, and wetlands (Thirgood 1981). Some 100 years later Julius Caesar had great plans "to free Rome from malaria by draining Lake Fucinus and the Pontine marshes, and reclaiming these acres for tillage. He proposed to raise dykes to control the Tiber's floods; by diverting the course of that stream he hoped to improve the harbour at Ostia, periodically ruined by the river's silt" (p. 193). These plans were cut short when he was assassinated by a group of conspirators in 44 BC who saw in these and other ambitions the seeds of a potential monarch.

The problems of sedimentation in harbors continue 1000 years later – how much silt and burial is needed to maintain deltas and coastlines, particularly in an era which seems to include rising sea levels?

14.1.3 The Rhine and the Low Countries

The Low Countries of the Rhine delta also illustrate the long history of human interference with wetlands in Europe. The Netherlands are the delta of the Rhine river, which like most European rivers, once had extensive floodplain forests dominated by woody species such as *Acer pseudoplatanus*, *Fraxinus excelsior*, *Populus alba*, and *Quercus robur*. Altogether there may be some 40 tree species, depending upon flooding frequency and soil type (Szczepanski 1990; Wiegers 1990). Higher frequencies of flooding produce *Alnus* or *Salix* thickets. The long history of human activity such as agriculture, logging, drainage, and diking have

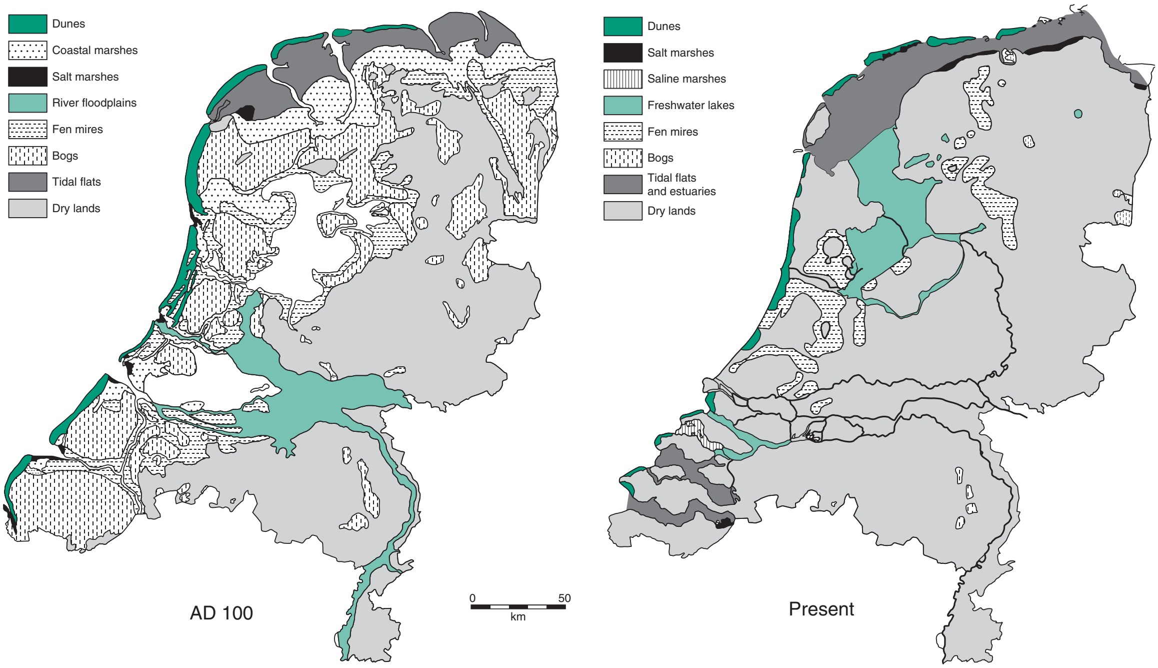

FIGURE 14.2 Human impacts upon European wetlands, as illustrated by changes in the Netherlands between AD 100 and the present. (From Wolff 1993, after Zagwijn 1986.)

eliminated most floodplain forests; in Poland, for example, only 1–2% of the landscape can be considered forested wetlands (Szczepanski 1990).

After the last Ice Age, levels of the North Sea rose rapidly, and about 6000 BP a system of barrier beaches formed along the coast (Figure 14.2). Sediments from the Rhine gradually filled the tidal basin behind the barrier coast, allowing marsh vegetation to develop. These marshes gradually changed into ombrotrophic raised bogs. In areas with higher tidal fluctuations, or less sediment, estuarine conditions persisted, and salt and brackish marshes formed, with fresh marshes and peat bogs developing at the landward. Closer to the Rhine and the Meuse, swamp forests and freshwater tidal areas formed.

Around AD 1000 years ago colonists were attracted here to build dikes and polders and reclaim bogs. In the coastal region, dikes were built first to defend farmland from flooding and then to extend the area of arable land. The Frisians in particular specialized in such work, followed by the Flemings and Hollanders, who extended their practices inland to the Elbe plain in Germany. The system consisted of digging drainage ditches to lower the water table, at first for cattle grazing and then for arable farming. Colonists were given permission to cut drainage ditches as far back from common watercourse as they wished. Thus by the twelfth and thirteenth centuries, a large area of peat bog plains was converted for agriculture. At the same time, water boards were established to co-ordinate building of dikes (van de Kieft 1991).

Drainage of peatlands is followed by subsidence, particularly if the peatlands are also burned to provide extra nutrients for agriculture. This necessitated the constriction of dams and dikes. Eventually, as sediment was deposited along watercourses, and subsidence continued, the river channels increased in elevation relative to the land behind the embankments (Wolff 1993). In the fourteenth and fifteenth centuries, large areas of agricultural land were lost to flooding (e.g. the

Dollard estuary: 150 km^2 inundated in the fourteenth to fifteenth century; the Biesbosch freshwater tidal area: 300 km^2 inundated in 1421; the Reimerswaal tidal flats in the Oosterschelde estuary: 100 km^2 in 1530). Thus, over 50% of the land area in the present Dutch province of Noord-Holland changed into lakes or disappeared back into the sea between the tenth and fourteenth centuries. This process was reversed again with technological improvements in the seventeenth century, with drainage of coastal areas reaching a maximum in the twentieth century. The present landscape reflects these extensive changes in hydrology and vegetation (Figure 14.2). There are now several hundred polders along this coast. Many occur on peatlands along rivers and are drained by pumps; others are now raised above sea level by siltation and are drained by sluice gates at ebb tide. The Zuiderzee, originally an estuary of the Rhine River, was divided in half in 1932 by a barrier dam, and the inner sections turned into four large polders fed with fresh water by the IJssel River.

During the First World War, Belgian engineers deliberately flooded parts of nearby Belgium in the Yser district by sea water in order to slow the advance of the German army. In his treatise, *Animal Ecology*, Elton (1927) summarizes work by Massart from ca. 1920:

> The sea-water killed off practically every single plant in this district, and all available places were very soon colonised by marine animals and plants . . . When the country was drained again at the end of the war, . . . the bare sea bottom was colonised by a flora of salt-marsh plants, but these gave way gradually to an almost normal vegetation until in many places the only traces of the advance and retreat of the sea were the skeletons of barnacles (*Balanus*) and mussels (*Mytilus*) on fences and notice-boards, and the presence of prawns (*Palaemonetes varians*) left behind in some of the shell holes. (pp. 24–25)

In 1970 the Haringvliet area was separated from the North Sea by a dam with 17 sluices, and, as a consequence, the daily water table fluctuations declined from ca. 150 to 30 cm. Salt marsh and brackish marsh communities disappeared within a few years. The current vegetation is largely controlled by grazing and flooding regimes, with *Phragmites* and *Scirpus* still present in wetter areas and *Agrostis stolonifera* in heavily grazed areas (van der Rijt *et al.* 1996).

The Wadden Sea, an estuarine environment that forms the northern coastline of the Netherlands, is incompletely separated from the North Sea by barrier islands. Some 1200 km^2 was designated for nature protection in 1982. De Groot (1992) has applied his system of wetland services to the Wadden Sea, of which 45% is in this protected area. Regulation services include moderating the climate and increasing precipitation on the adjoining land, primary production, and storage and recycling of nutrients. Production services include the yields of crustaceans and shellfish for human consumption, as well as sand and shells for construction. Estimating (de Groot 1992, p. 215) that all services together give goods and services in excess of US$6000/ha per year, he concludes that many tidal areas in the Netherlands have been carelessly damaged, and "Although the Dutch Wadden Sea, compared to other wetlands, is relatively well-protected and managed, it to is still threatened by many development plans and ongoing harmful human activities such as pollution and military training." (p. 218)

Overall, then, thousands of square kilometers of peatlands, salt marshes, and shallow lakes have been lost. Further nutrients and contaminants are carried into the area by the Rhine River. The remaining wetlands, however, occupy a key position on the West Palearctic flyway, and some 16% of the Netherlands is still classified as internationally important wetland (Best *et al.* 1993; Wolff 1993). These reserves "occur as small isolated patches in a matrix of agricultural land or as complexes formed by peat dredging, diking of oxbow lakes, etc." (Verhoeven *et al.* 1993, p. 33). In such small landscapes, hydrology is carefully controlled for the purpose of optimizing agricultural production in adjoining fields. Further, the remnant wetlands are being enriched with nutrients from four sources

(Verhoeven *et al.* 1993): atmospheric deposition, surface water flow from heavily fertilized agricultural areas, inputs from eutrophic river water, and infiltration of contaminated groundwater. The multiple factors of drainage, hydrological stabilization, eutrophication, grazing, and pollution pose a major challenge to conservation managers.

When Goethe (1831, p. 222) introduced Faust, the alchemist who sells his soul to the devil, he allows Faust to repent and aspire to carry out good works:

Below the hills, a marshy plain
infects what I so long have been retrieving:
that stagnant pool likewise to drain
were now my latest and my best achieving.

The Netherlands are of some interest because they illustrate land use changes in Europe as a whole, because they represent a delta of a major European river, and because they are well studied. At the other end of Europe, Greek wetlands face similar threats: 63% of wetlands have been lost and surveys report that more than half of all wetlands (and 100% of deltas) have experienced declines in water quality (Zalidis *et al.* 1997). Many others have been altered by changes in the water regime or loss of area. The extensive number of published papers on wetlands in the Low Countries (and even this section of the book) could be quite misleading: it should be borne in mind that the Netherlands comprise only 0.3% of the total area of Europe, and only 0.02% of the land area of the world (Wolff 1993). In spite of these facts, the number of papers on the Netherlands appears to outnumber the attention paid to the Pantanal, the Amazon, and the Niger.

These few examples from the history of human impacts upon wetlands suggest that little has changed from the Tiber and Rhine of antiquity to the Parana (Chapter 1) and Amazon (Chapter 4) of modernity. But there are two possible sources of cautious optimism. First, while Europeans have badly damaged their own wetlands through several millennia of landscape modification, there is no essential reason to slavishly repeat these steps elsewhere. One can hope that other regions can learn from, rather than carelessly emulate, the European experience. Second, the scientific understanding of wetlands, while still incomplete, is vastly greater than it was in the days of the Etruscans. Whether human attitudes can change and science can advance to the point where we can avoid past mistakes is one of the unanswered questions of the new millennium. It certainly extends well beyond the specific problems facing wetlands.

14.2 Wetlands have changed with time

Although humans have been a principal cause of change, particularly in the last century with expanding population and technology, we are not the only cause of change. Wetlands have existed for millions of years. If nothing else, they have changed as the fauna and flora of Earth evolved. Coal swamps dominated by *Lepidodendron* trees (Figure 11.6) no longer exist. But even these coal swamps were exposed to prolonged wet and dry periods (Figure 14.3).

When we look at a reconstruction of a coal swamp like Figure 11.6, it may seem foreign. Perhaps we feel like a peatland ecologist encountering a mangrove swamp. But if we were to look more carefully, we would probably discover that the same processes we have seen in this book were occurring then. Water level fluctuations. Fertility gradients. Disturbance. Herbivory. Primary production. Decomposition. Carbon storage. Methane production. In many ways, then, these wetlands were very similar to those of today. We must learn to seek the similarities in process at the same time as we appreciate their differences; without this, we will slide into geographic, taxonomic, and methodological Balkanization.

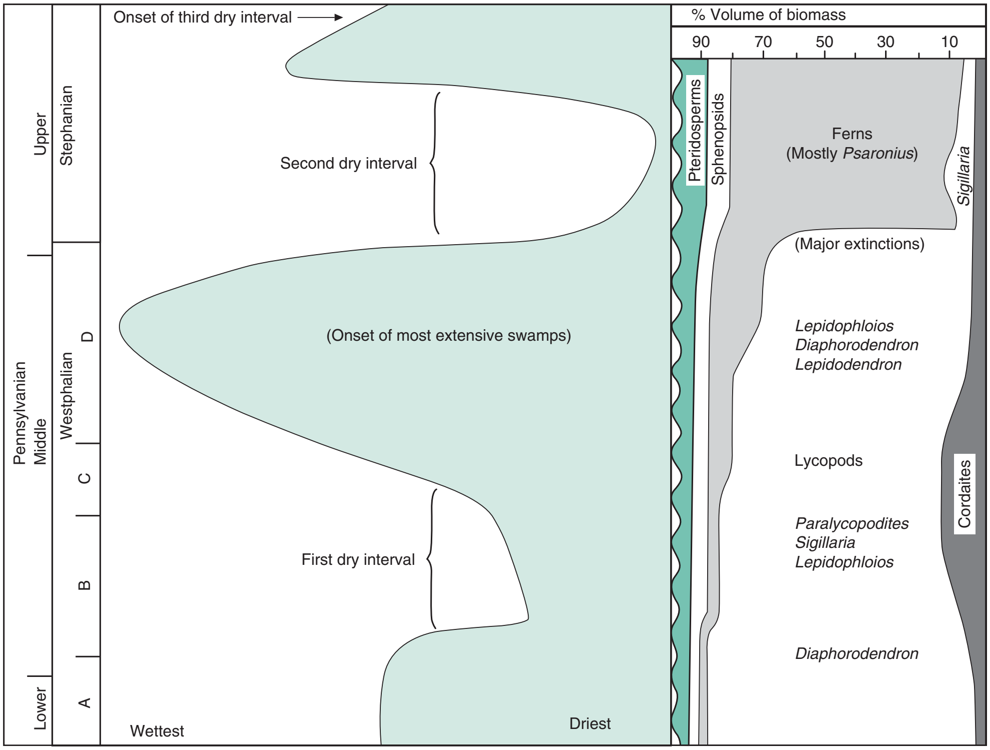

FIGURE 14.3 Wetlands have changed through time, as illustrated by the origin and disappearance of coal swamps and their associated flora and fauna. (From Stewart and Rothwell 1993.)

One need not look back millions of years to find the ebb and flow of waters. Over merely the last 30 000 years, the world has seen the formation of great pluvial lakes in Africa, southwestern North America and Australia (Figure 14.4). Most of these are now gone, although remnants persist, like Great Salt Lake in Utah and Lake Mackay in Australia. In Africa pluvial lakes reached their maximum extent around 9000 BP; in North America, between 24 000 and 12 000 BP, and in Australia earlier still, perhaps 30 000 to 26 000 BP (Flint 1971; Street and Grove 1979). Imagine the extensive areas of wetlands, and the clouds of migratory waterfowl, that must have once occupied areas of the Earth that are now sand flats or remnant saline lakes. Our own millennium appears to be one of the most arid in the late Quaternary (Figure 14.5). If at times we despair about the impacts of our own species upon wetlands, perhaps Figures 14.4 and 14.5 can put it somewhat in a larger perspective.

Wetlands change at shorter timescales too, timescales that can be easily measured in human generations. Figure 11.8 showed the changes in a European wetland as human civilization developed there. Figure 14.6 shows the estimated impacts of aboriginal civilizations on their landscape in the Americas. Figure 14.7 shows us change on a shorter timescale still – the time over which Europeans arrived and modified wetlands in eastern North America.

Humans often fear change, and so we stabilize lake water levels, build dams to stop spring flooding, channelize rivers, and put riprap along eroding river banks. As wetland ecologists we need to overcome these fears and learn to work with change. This does not mean that we must accept that all changes

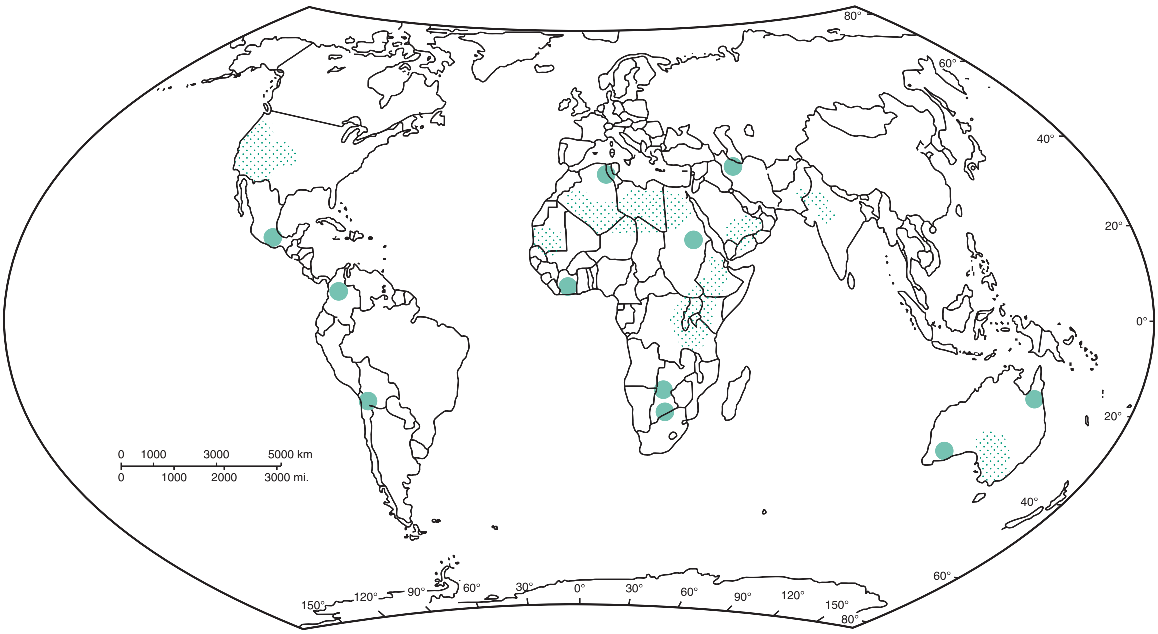

FIGURE 14.4 Over the last 30 000 years pluvial lakes have formed in and then disappeared from the shaded regions of the Earth. Well-known examples include Great Salt Lake in North America and Lake Mackay in Australia. Dots show isolated lakes. (After Street and Grove 1979.)

wrought by humans are desirable, or even acceptable. But as Botkin (1990) reminds us, and as Figures 14.2–14.7 show, working with naturally dynamic systems is the situation with which we must contend.

We need to learn to work with, not against, change in wetlands and other wild places. The third principle of wetland ecology that I introduced in Chapter 1 is *the multiple factors that produce a community or ecosystem will change through time.* Change in wetlands is nothing new. Many examples of change have been presented in this book: Amazonian wetlands responding to river erosion and deposition (Figure 4.5), the Florida Everglades responding to natural fires and droughts (Figure 4.6), Californian salt marshes changing with salinity and rainfall (Figure 4.23), deltas changing shape with changes in river channels and hurricanes (Figure 4.18). Practicing science and conservation in the light of ecosystem change has been discussed at greater length in *Discordant Harmonies* (Botkin 1990). The basic conclusion is that there are no easy answers. Humans can damage ecosystems by suppressing natural dynamics, just as much as they can by causing change by damming rivers, diking salt marshes, and draining peatlands. This is one reason why natural area systems need to be large enough for us to allow natural process such as flooding, erosion, and fire to continue without interruption.

Of course, one of the difficult problems in conservation and management is to decide which changes are acceptable and which are not. Allowing meander systems to evolve in a floodplain would seem acceptable; allowing exotic species such as purple loosestrife, water hyacinth, or nutria to spread is unacceptable. One allows a natural process to continue, the other causes a rapid change that is not intrinsic to particular wetlands. The difference will not always be so clear.

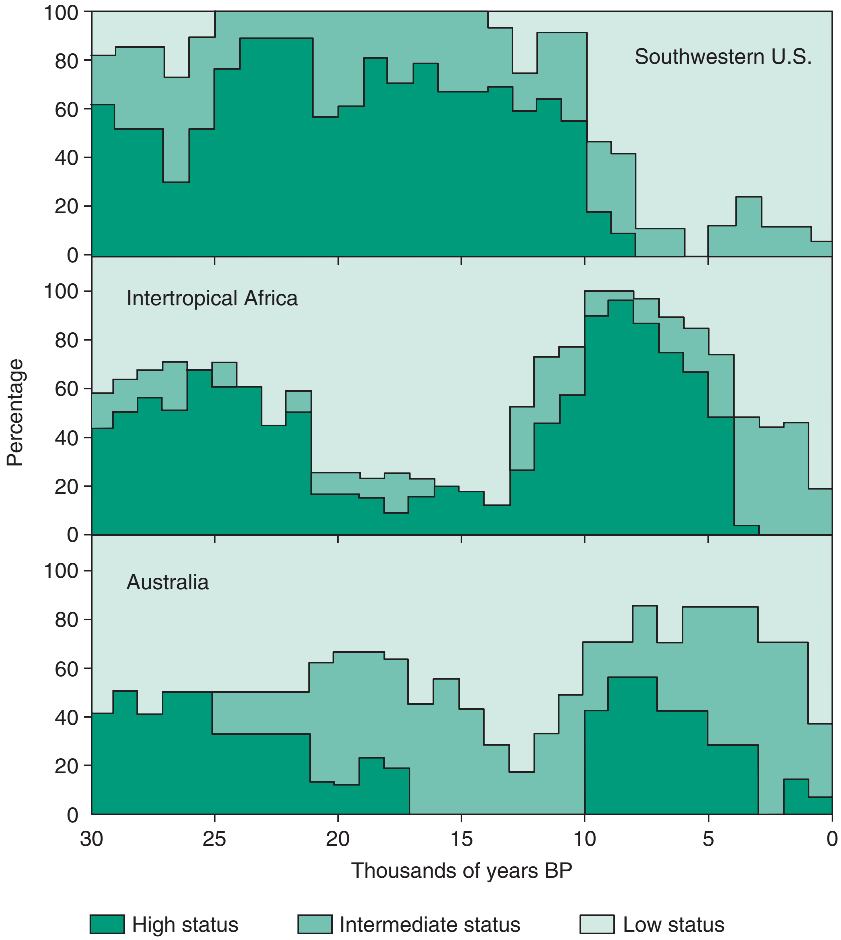

FIGURE 14.5 Lake levels for the past 30 000 years in three parts of the world. (After Street and Grove 1979.)

14.3 Two views on conservation objectives

In order for wetlands to continue to provide services to humans, we must keep wetlands in our landscape. Let us see how this is being done, and what more might be done in future. Overall, we could say that there are two perspectives on conservation of wetlands. They start from different views, but in practice tend to arrive at more or less similar results.

One view puts the focus on services. That is, we could think of wetlands as little more than living factors that provide services to humans. From this view, our task is to maintain the services. These might include flood control, water purification, muskrat or duck production, recreation, and so on. So long as these services are performed, we have achieved our management goal. The fact that they are bogs, fens, and swamps, with different plant and animal species, and different rates of disturbance and fertility, may be less important.

The other view puts the focus on more intrinsic values, as natural communities of living organisms. In order to protect them, we strive to maintain the

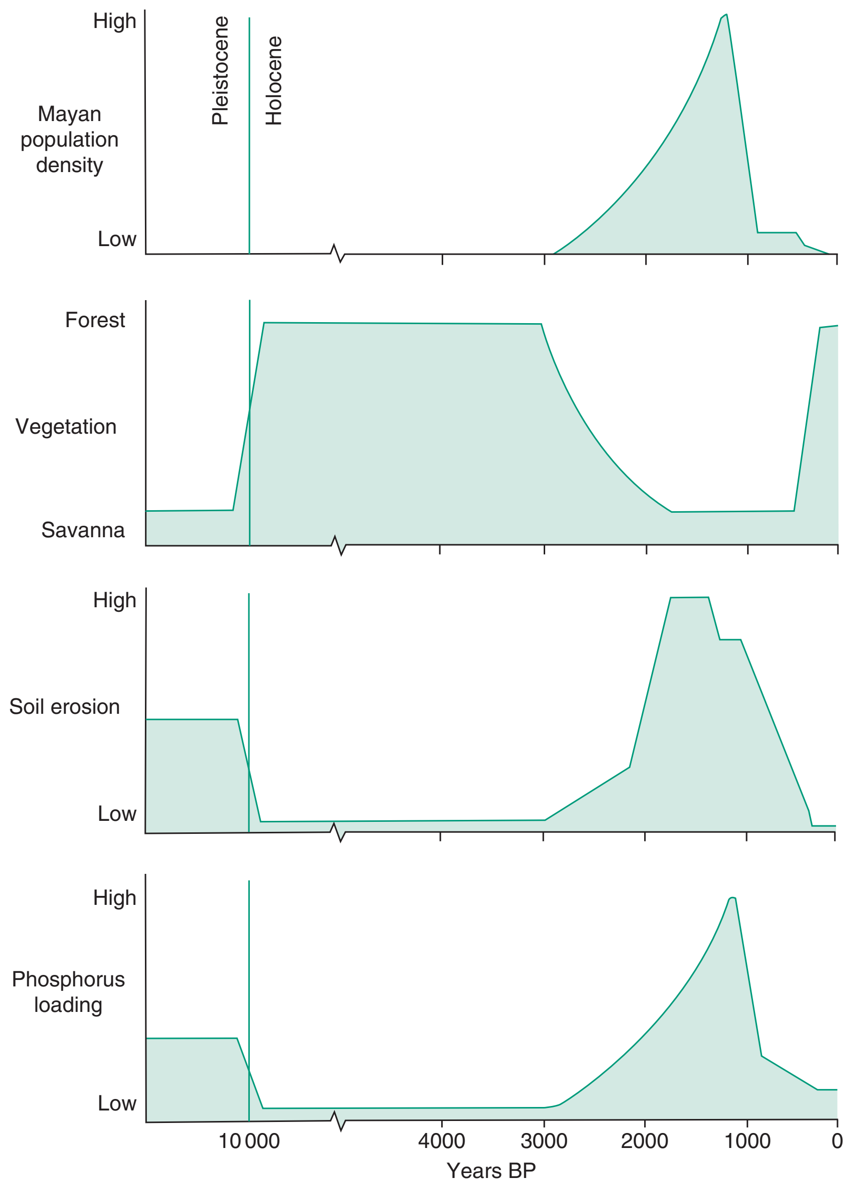

FIGURE 14.6 Aboriginal populations in America caused significant increases in erosion, as illustrated by impacts of the Mayans in Guatemala. (After Binford *et al.* 1987.)

patterns and processes within individual wetlands. One might even argue that they have a right to exist, just as our own species does. So long as we protect the full array of bogs, fens, and swamps with their normal complement of species, we argue, one may also assume that they are providing the needed services.

Both views can work together. Most wetlands, of course, have multiple services: a single wetland will have a role in controlling hydrology, yielding wildlife, producing methane, fixing nitrogen, and supplying human recreation. Since wetlands do perform multiple services, one of the most thorny problems of management is ensuring that

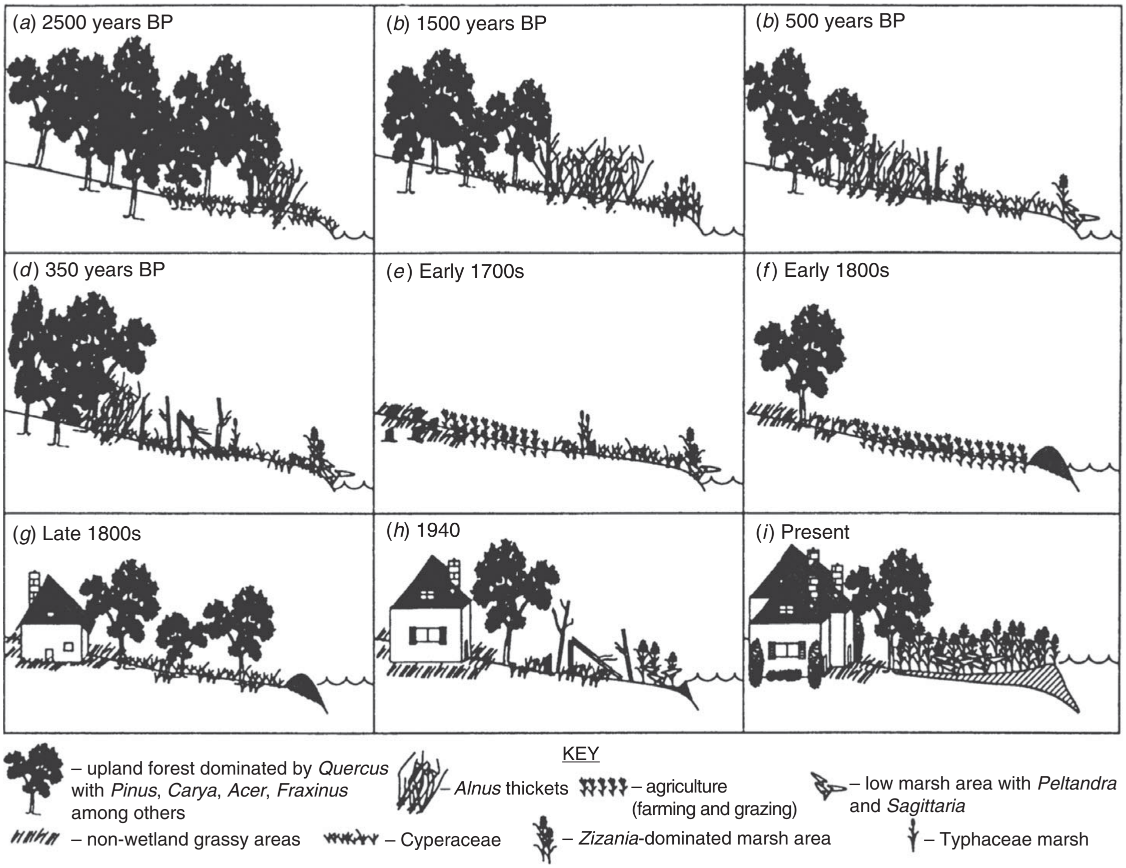

FIGURE 14.7 Changes in a New England salt marsh associated with the arrival of Europeans. (From Orson *et al.* 1992.)

management for one service or goal does not cause loss of other equally important services. Humans being what they are, it is all to easy to focus upon a single problem, a single service, or a single species, and ignore everything else.

Given the high rates of endangerment and extinction (Figure 9.25) let us look at maintaining biodiversity. Maintaining biodiversity is a service that we explored in Chapter 9. Moreover, the very presence of specific plant and animal groups can be treated as an indicator that other services are continuing to occur.

There is a further urgent reason to focus on maintaining diversity. Ehrlich and Ehrlich (1981) describe the loss of species from communities as being analogous to the loss of rivets from the wings of an aeroplane. A certain number of rivets can be lost without the wings falling off because there is some redundancy of function, but eventually if too many are lost, the function declines. As a first approximation, we may assume that most ecological services of wetlands are carried out by more than one species; this is why species fall naturally into functional groups. If one species is lost, another may perform its role. But if too many are lost, that service is no longer performed. The degree of redundancy, and hence the safety margin, is still an unknown.

14.4 Protection: creating reserve systems

Our first challenge is to ensure that significant areas of wetland are protected from further degradation. Once these areas are protected, the next generation of managers will have to grapple with their wise management; the first task in setting up reserve systems is to make their future jobs as easy as possible. In this section we will take a closer look at the creation and maintenance of reserve systems.

14.4.1 A reserve system includes core and buffer areas

One of the most important steps is finding the core areas that will provide the foundation for the reserve system (Table 14.1). The next task is to ensure that each is shielded by an appropriate buffer zone (Figure 14.8). The design of reserves, and of reserve systems, is a topic which itself deserves an entire book (e.g. Shrader-Frechette and McCoy 1993; Noss and Cooperrider 1994). Here is a brief introduction, based largely on Noss (1995).

Beginning with the **core protected areas**, the size of each protected wetland should be large enough to retain the diversity of wetland types and full array of species present. The well-documented relationship between species and area (Chapter 9) shows that in general, the bigger the site, the more species that are likely to be protected. Big areas have two particular merits. Big areas are important to maintain large predators that have large territories and are highly mobile (Weber and Rabinowitz 1996). As well, the bigger the site, the greater the possibility that natural processes can continue to generate habitat diversity. An alluvial wetland reserve, for example, ought in principle to be large enough to allow for flooding and bank erosion to continue unabated. If these processes are missing, it may be impossible to retain the biological characteristics of the reserve, and it certainly will compound the difficulties and costs of management.

Table 14.1 **Some factors to guide the selection and prioritizing of wetlands for conservation**

Factor	Comments
Size	Most ecological services increase with area
Naturalness	Minimal alteration to natural patterns and processes
Representation	An example of one or more important ecosystem types
Significance	Relative regional or global importance
Rare species	Significant species present
Diversity	Many native species present
Productivity	Production of commercial species
Hydrological services	Flood reduction, groundwater recharge, springs
Social services	Ongoing use in education, tourism, recreation
Carrier services	Contribution to global life-support system: oxygen production, nitrogen fixation, carbon storage
Food services	Harvesting for human consumption
Special services	Spawning, breeding, or nesting area; migratory stopover
Potential	Suitability for restoration
Prospects	Probability of long-term survival: future threats, buffer zones, possibilities for expansion, patrons, supporting organizations
Corridors	Existing connections to other protected areas; site itself is a corridor
Science services	Published work on site, existing use by scientists, existing research station, potential for future research

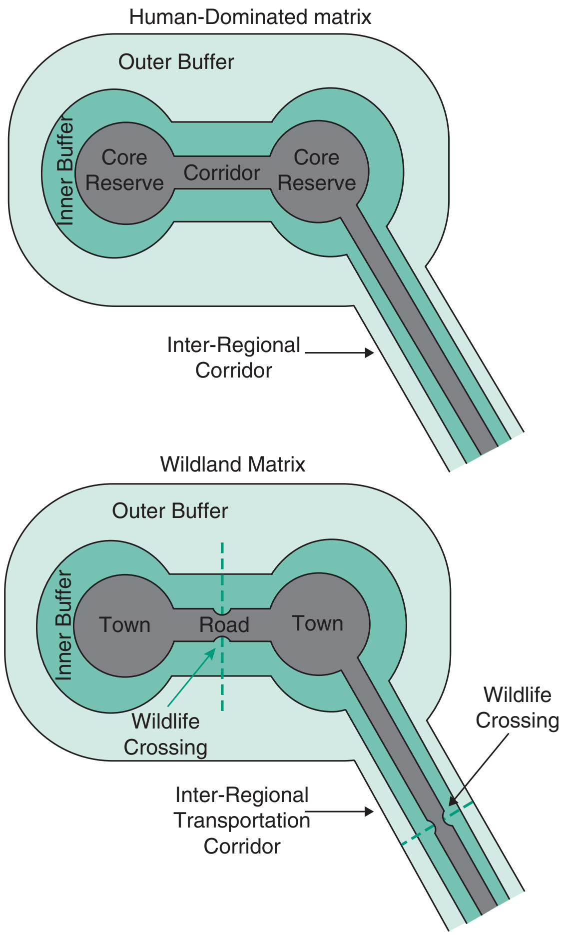

FIGURE 14.8 A typical reserve system consists of core areas surrounded by buffers and linked by corridors (top). In wilder parts of the world, the cities themselves may be surrounded by buffers with a matrix of wild lands (bottom). (From Noss 1995.)

Many other factors can be used to select core protected areas including naturalness, significance, rare species, ecological services, and value for research (Table 14.1).

The protected wetlands should **represent** habitat types than are of significance at the local, regional, or global scale. They may represent common wetland types or rare wetland types. Protection of both kinds of wetlands are complementary objectives for setting up reserve systems. At this scale, each wetland needs to be considered in the context of surrounding wetlands: are there examples of similar quality already protected? Are there more important wetland types that are not yet protected? Answers to these questions are often found through **gap analysis**, a process of identifying gaps in wetland type representation in a reserve system. Algorithms now exist to evaluate different reserve scenarios in order to maximize the value of a reserve system (Pressey *et al.* 1993). The objective is to define the smallest number of areas needed to achieve certain goals, such as providing one, two, or three protected examples of each species, or each community type.

Each core area needs to be surrounded by a **buffer zone** where land use practices are regulated to higher standards than elsewhere in order to ensure that nutrients, pollution, or exotic species are not carried into the protected site from immediately adjoining areas. Biosphere reserves (regions recognized internationally by UNESCO) provide an example of such an arrangement with protected core areas such as a national park surrounded by larger landscapes in which human use includes consideration for the viability of the core area.

Although we usually view reserves as cores surrounded by buffers, in some wild places, we may wish to turn the model inside out. That is, we may wish to treat our settlements as isolated units, and put a buffer around each settlement to ensure that the remaining landscape stays wild (Figure 14.8, bottom). We could also look at this as a longer-term model for landscape restoration, where cities and farms fit into a matrix, surrounded by wild places and supported by the services they provide.

14.4.2 Reserves are linked by corridors

The reserves must be connected with corridors so that dispersal can occur from one reserve to the next. As reserves become increasingly smaller and more isolated from one another, dispersal becomes increasingly constrained and species become increasingly broken into metapopulations with the dynamics typical of island species (MacArthur and Wilson 1967; Hanski and Gilpin 1991; Hanski 1994).

Table 14.2 **The international classification for protected areas developed by IUCN**

Category I: Strict Nature Reserve/Wilderness Protection Area An area of land and/or sea possessing some outstanding or representative ecosystems, geological, or physiological features and/or species, which is protected and managed to preserve its natural condition.

Category II: National Park Natural area of land and/or sea designated to (a) protect the ecological integrity of one or more ecosystems for present and future generations, (b) exclude exploitation or occupation inimical to the purposes of designation of the area, and (c) provide a foundation for spiritual, scientific, educational, recreational, and visitor opportunities, all of which must be environmentally and culturally compatible.

Category III: Natural Monument Area containing specific natural or natural/cultural feature(s) of outstanding or unique value because of their inherent rarity, representativeness, or esthetic qualities or cultural significance.

Category IV: Habitat/Species Management Area Area of land and/or sea subject to active intervention for management purposes so as to ensure the maintenance of habitats to meet the requirements of specific species.

Category V: Protected Landscape/Seascape Area of land, with coast or sea as appropriate, where the interaction of people and nature over time has produced an area of distinct character with significant esthetic, ecological, and/or cultural value. Safeguarding the integrity of this traditional interaction is vital to the protection, maintenance, and evolution of such an area.

Category VI: Managed Resource Protected Area Protected area managed mainly for the sustainable use of natural resources – area containing predominantly unmodified natural systems, managed to ensure long-term protection and maintenance of biological diversity, while also providing a sustainable flow of natural products and services to meet community needs.

Source: Adapted from Anonymous (1994). *Guidelines for Protected Area Management Categories*. Gland, Switzerland and Cambridge, UK: IUCN and the World Conservation Monitoring Centre. www.iucn.org/themes/wcpa/wpc2003/pdfs/outputs/pascat/pascatrev_info3.pdfhow. For data on different countries, consult Earthtrends at http://earthtrends.wri.org.

While local extinction from small areas of wetland might be entirely normal given the natural dynamics of wetlands, once reserves become isolated fragments within a landscape, there may be no local populations available to recolonize the site. Species with limited dispersal may be expected to disappear slowly from the entire reserve system. Since many wetlands are linked naturally by rivers, restoring riparian corridors may be a natural means for linking core areas.

14.4.3 Different kinds of reserves comprise the system

Most nations now have systems of protected areas. The names given to areas incorporated vary across regions and also change with management objectives. Designations can include wildlife management areas, national parks, and ecological reserves. Each kind of protected area has its own set of rules. Some rules provide strict protection, others allow many means of exploitation. To provide a way of comparing how areas are managed, the IUCN (International Union for the Conservation of Nature) has recognized six categories, I through VI, that range from strictly protected areas (I) to sustainably used areas (VI) (Table 14.2).

For wetlands in particular, there is an added category of protection – recognition under the Ramsar Convention on Wetlands (Figure 14.9). Ramsar, by the way, is not an acronym. It is the name of the city in Iran where this important international agreement on wetland conservation was signed in 1971. Since then, more than 1800 wetlands totaling more than 180 million hectares have been designated as wetlands of international importance. The Convention has three objectives: working toward

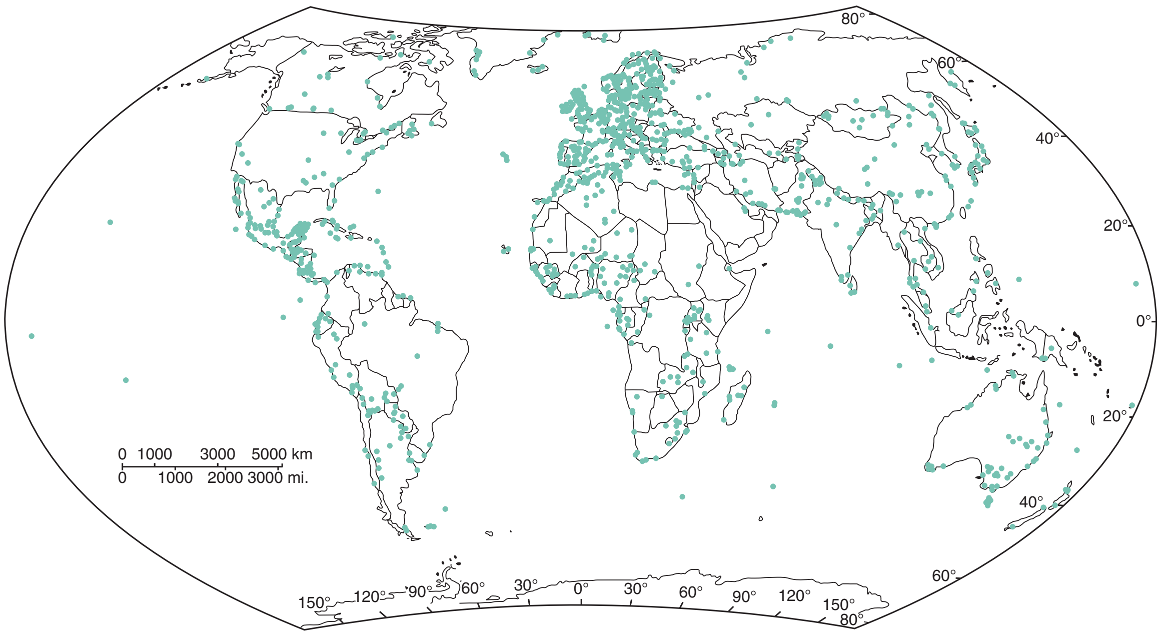

FIGURE 14.9 Ramsar sites designated as of May 2009 according to Wetlands International maps (http://ramsar.wetlands.org/GISMaps/WebGIS/tabid/809/Default.aspx) updated using the Ramsar List of Wetlands of International Importance (www.ramsar.org/sitelist.pdf).

wise use of wetlands, expanding a global ecological network of wetlands, and promoting cooperation across nations and cultures.

Wetlands in western Europe are over-represented under the Ramsar Convention, yet this is the part of the world, where, in general, wetlands are both small and degraded by human activity. We need a shopping list to set future priorities for protected wetlands, and where better to start than with the world's ten largest wetlands (Table 1.3)? Part of the reason for focusing on the largest wetlands was to encourage wetland ecologists to take the largest possible global perspective in planning their conservation strategies. From the global perspective, we must be cautious about spending too much money on the precise management of tiny fragments of wetlands in heavily populated areas if this means that resources are being directed away from globally significant wetlands such as the Amazon or the Pantanal or the Congo.

Setting up reserve systems literally is a race against time. There are growing reasons for optimism at the same time as one is discouraged by the ongoing rates of wetland destruction. Of course, it is possible to acquire degraded habitats and restore them, but this is a poor alternative to protecting areas that are still relatively pristine or that still provide important services.

14.4.4 Protected areas have economic value

One of the major obstacles to protection is the view that protecting ecosystems means withdrawing them from human use and thereby reducing human economic welfare. As we saw in Chapter 11, these areas in fact provide many valuable services. Shrimp and fish production, are, for example, dependent upon salt marshes and floodplains (Welcomme 1976; Turner 1977). For many wetlands, the issue of services may provide economic arguments for preservation. Even if these services are ignored, however, there is a further merit to protected areas; contrary to expectation, it appears that they actually stimulate economic activity (Rasker and Hackman 1996). At the local scale, most homeowners will know that owning a home near or adjoining green space increases the home's value. But let us look at a much larger example. Owing to the importance of this point, it is necessary to spend some time on this example.

Large carnivores such as lions, wolves, and tigers are some of the most difficult species to protect, because they need large areas of habitat. Too often, protection is seen as something that will damage the economy – one is given the rather bleak choices between environment and economy (Rasker and Hackman 1996). That is, there is "a belief that, however, appealing, carnivore conservation is a luxury we cannot afford because the opportunity cost in terms of jobs and resources forgone is too high." This is a commonly heard argument around the world; what may be surprising is the paucity of data for or against it. Rasker and Hackman set out to test this proposition by comparing economic indicators for two regions in northwest Montana. Four counties with large protected areas (Flathead, Lewis & Clark, Teton, Powell) are compared to three resource-extractive counties (Lincoln, Sanders, Mineral). The wilderness counties total some 3.4 million ha (839 000 protected) whereas the resource-extractive counties totaled nearly 2 million ha (33 000 protected). The latter resource-extractive counties were chosen because the conflicts between jobs and environment are intense, and because lumber harvesting and hard rock mining have traditionally played an important part in their economies. Although these are only counties, they are the size of nations in many other parts of the globe. If, indeed, "locking up" land in reserves causes economic hardship, then the counties with protected areas should show reduced economic performance relative to the counties with few protected lands. Figure 14.10 shows the striking results. A range of economic indicators including employment growth and personal income growth were above the U.S.A. and

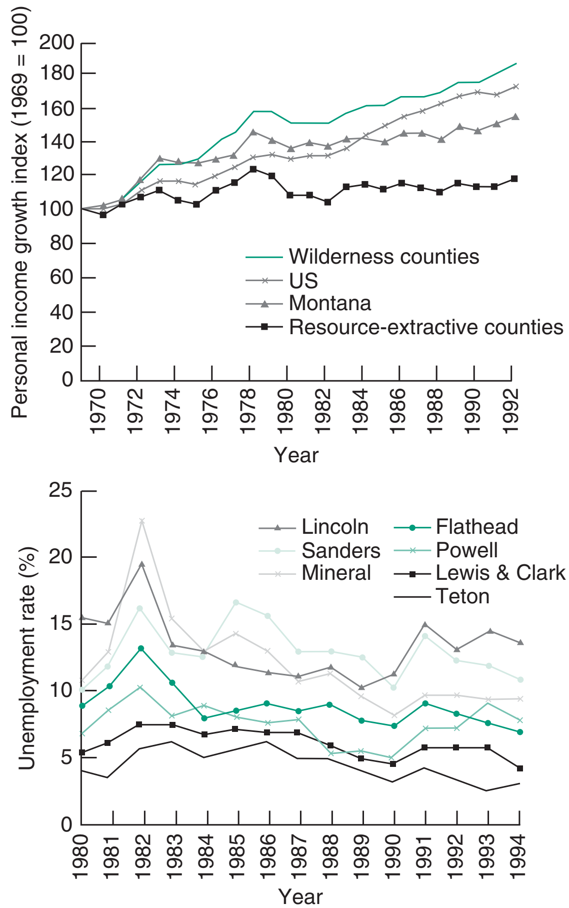

FIGURE 14.10 Employment and personal income growth in four regions: wilderness counties (green), U.S.A., Montana, and resource-extractive counties. (After Rasker and Hackman 1996.)

Montana averages and even more above the means for the resource-extractive counties. "From 1969 to 1992 wilderness counties added new jobs and income in every non-agricultural sector of the economy. The resource-extractive counties lost more than 1300 jobs in the construction, transportation, and public utilities sectors." The resource-extractive counties also suffered from higher unemployment rates. Rasker and Hackman (p. 996) conclude:

The bulk of growth in Greater Yellowstone was in industries that do not rely on natural resources extracted from the ecosystem. From 1969 to 1992

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more than 99% of all the new jobs and personal income (and 88% of existing jobs) came from industries other than mining, logging, and ranching or farming ... Research on the economy of the Greater Yellowstone has uncovered a new paradigm for economic development in the West: protection of the wild and scenic character of the landscape and the quality of life in local communities serves as a magnet to retain local people and their businesses. These qualities are a vital part of the economic well-being of local residents...

While neither of these examples is exclusively wetland, they illustrate the possibilities of progress toward protecting large reserve systems that are more than a series of islands in an agricultural landscape. Even if we focus only upon wetlands, intact watersheds are essential to maintaining hydrology and water quality; in a sense, then, any protected wetland really forces managers to focus upon the entire watershed with which the wetland interacts.

Once reserve systems have been organized, there are two further steps: (1) management plans are needed for each site and for the system as a whole, and (2) indicators are needed to provide a method for monitoring whether the management plans are achieving their goals. The next sections deal with the management of protected areas and systems of protected areas. In section 14.8, we will return to the role of indicators.

14.4.5 Maintaining reserve systems

A reserve system is set up to protect the full array of ecosystems, communities, and species that occur in a landscape. If there is systematic change within the reserve system, an entire section of the representativity may be lost. Exactly such a trend has been occurring in wetlands over the last century. Recall that hydrology and fertility are the two key factors that determine the kinds of wetland that occur in a landscape. The variation in hydrology in wetlands has been steadily declining, from factors as

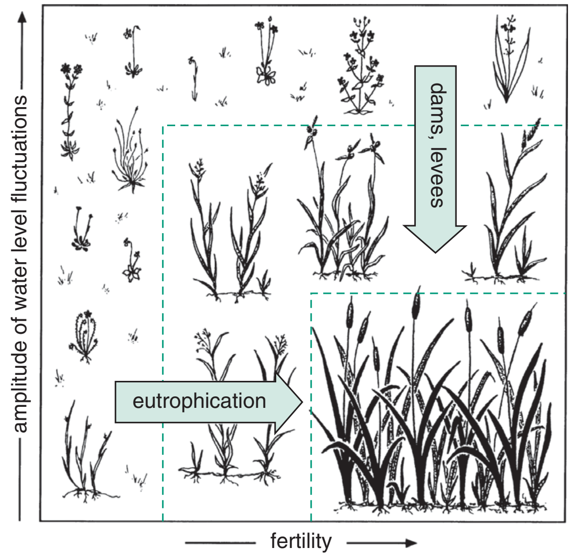

FIGURE 14.11 Human activities have compressed wetlands onto an increasingly narrow array of flooding and fertility regimes, leading to a loss of many wetland types.

diverse as drainage ditches that permanently lower the water table, to levees that prevent floodwaters from spilling onto alluvial marshes, to dams that hold back spring floods. The full array of hydrological regimes on Earth may therefore be converging upon increased stability and reduced variation. In an analogous way, there are systematic trends in fertility: a steady increase driven by eutrophication from sources including sewage from large cities, artificial production of fertilizers, burning of coal, runoff from agricultural landscapes, and atmospheric deposition. There is no need to repeat here the many examples we have seen of these processes, except to note that they are global in extent. Since the wetlands that arise in landscapes are produced by particular sets of hydrology and fertility, and since entire sets of conditions including high flooding levels and low fertility are vanishing from the landscape, we may assume that the corresponding wetland types are vanishing as well (Figure 14.11) That is to say, the array of wetland types within a landscape is being increasingly squeezed into the bottom right of the figure: eutrophic wetlands with relatively stable water levels. The invasion of woody plants into marshes, the disappearance of *Erica* heathlands, the replacement of wet meadows by *Typha* marshes, and the replacement of native species by exotics in infertile wetlands are all special cases of this widespread process of community convergence. Moreover, this change is being driven by two processes that continue largely unabated: the construction of dams, and the deposition of nutrients, as indicated by the large arrows, continue to squeeze wetlands into a progressively narrower region of possibilities. One of the high priorities for management is to reverse this process and re-establish sets of environmental conditions that represent the fuller array of possibilities in a landscape.

All too often, each problem is seen as a special case in a specific wetland. The significance is then misunderstood. For example, in the 1265-page compendium *Freshwater Wetlands and Wildlife* (Sharitz and Gibbons 1989), there are no index entries under fertility, nutrients, eutrophication, nitrogen, or phosphorus. Hence, the broad general risk to wetlands from enrichment is easily overlooked. Another example is the widespread problem of woody plant invasion, which is sometimes explained away as natural succession (Larson *et al.* 1980; Golet and Parkhurst 1981), rather than being seen as a response to degradation in hydrology.

Yet another way of viewing this problem is to envisage it as the removal of certain filters that once produced the structure in communities. Consider the plants first. Removing long periods of flooding removes the filter that kept woody plants at bay, allowing them to invade herbaceous meadows. Removing the filter of infertility allows rapidly growing plants with dense canopies to invade herbaceous meadows. We can already predict the endangered wetland plants of the future; rosette plants (e.g. *Parnassia*, *Saxifraga*, *Lobelia*), evergreen plants (e.g. *Erica*, *Eriocaulon*, *Lilaeopsis*), carnivorous plants (e.g. *Drosera*, *Dionaea*, *Utricularia*), plants of infertile sands (e.g. *Castilleja*, *Cacalia*, *Gratiola*) or eroding shorelines (e.g. *Senecio*, *Pedicularis, Sabatia*), as well as species that require unusual nutrient ratios, recurring fire, intense flooding, or high grazing pressure. What impact will this have upon animals? Presumably species that forage in wet meadows (like bog turtles, Section 5.9), species that require the above plants to complete their life cycles, insects specialized upon plants with low tissue nutrient levels, reptile species that nest in freshly deposited sands and silts, migratory birds that feed on mud flats around lakes, and, in general, any functional group that tolerates extreme flooding and unusual fertility conditions will be most at risk. Near where I am writing, spotted turtles and wood turtles, which occupy shoreline fens and sandy floodplains, are at risk, as opposed to red-winged blackbirds and Canada geese that nest in cattails and shallow water.

It is likely that so much anthropogenic wetland change has occurred that none of us has ever seen the full array of wetland types that our landscape once possessed. That is to say, our frame of reference – the landscape we grew up with – may already be so altered that it is not a useful reference point for designing and managing reserve systems. Peripheral types of wetlands (as in Figures 5.11 and 5.12) may have already disappeared. This, of course, opens a broad range of possibilities: just what is the array of wetland types we want to protect with a reserve system? Do we aim for the landscape of our childhood, the landscape of the mid nineteenth century, or the landscape that may have occurred before humans appeared upon the scene?

There is no easy answer to such questions (Leopold 1949; Botkin 1990), but one approach might be to consider the array of environmental factors that would have occurred in the landscape before humans modified it. Hydrological and sedimentation models would allow us to determine a mean and standard deviation for both flooding regimes and fertility regimes in a landscape without human impacts. Whether or not managers could ever re-create such landscapes, it would provide a realistic point of reference for management. Imagine such a model for the Rhine River valley; what was the delta once like, and what has this to say about intensive management of remaining wetland fragments? To what extent could large floodplains be removed from human use so that natural flooding regimes could be allowed to re-establish? How would the apparent costs of this balance against the cost of building dams, repairing levees, and repairing the inevitable flood damage? The Rhine or the Mississippi may be too large to start with, but are there watersheds where this process could be started on a more regional scale?

Two challenges facing managers are therefore very clear. The first is to reduce the magnitude of the forces that are still driving wetlands into convergence, that is (1) to maintain the hydrological variation of wetlands and (2) to reduce rates of eutrophication. The second is to reverse the process by re-establishing the type of habitat at the upper left of Figure 14.11; this will require re-establishing infertile conditions and high flood regimes. Re-establishing the full array of wetlands types within a landscape leads naturally to the process of wetland restoration.

Table 14.3 **Some stressors potentially affecting wetlands**

enrichment/eutrophication
organic loading and reduced dissolved oxygen
contaminant toxicity
acidification
salinization
sedimentation/burial
turbidity/shade
vegetation removal
thermal alteration
dehydration
inundation
fragmentation of habitat
road-related mortality
over-harvesting
invasive species
coarse woody debris removal

Source: Adapted from Adamus (1992).

14.4.6 Maintaining services in reserve systems

If a landscape contains a full array of wetland types, from raised bog to floodplain forest, it is reasonable to assume, at least as a first approximation, that most services are being performed. The actual rate of performance of each service could be calculated by determining the service on a square-meter basis, and then multiplying by the area of that wetland type in the landscape, a process we saw in many of the examples in Chapter 11. The first principle introduced in Chapter 1 could therefore be rephrased to state: "The services provided by any wetland are controlled by multiple environmental factors acting simultaneously." Determining such quantitative relationships is an important priority in wetland ecology; far too many studies report these services for a single wetland rather than seeking general empirical relationships between basic properties and level of service.

One way of summarizing human impacts on services provided by wetland ecosystems is to apply the framework of stressors and responses (e.g. Odum 1985; Freedman 1995). In the preceding chapters we have seen many environmental factors that can change the ecological services or species composition of wetlands. These have ranged from alterations in hydrology through eutrophication to over-hunting of alligators. Each of these human alterations can be considered a stressor, that is, "an environmental influence that causes measurable ecological detriment or change" (Freedman 1995). For each stressor (Table 14.3) we could list the expected changes in wetland service or structure. For example, increasing fertility will lead to increases in wetland production and biomass, but a probable reduction in species diversity.

In conclusion, even if important wetlands receive legal protection, they must still be managed appropriately to retain the services that they perform. This requires action by two quite different groups of people: regulators and managers. Sometimes it appears that scientists are "too conservative in speech and action," leading to confusion among regulators about the true risks of action versus non-action (Maguire 1991). Indeed, "more research" can become a substitute for action. Managers may be even more dangerous than scientists and regulators; where regulators may fail to act, managers may fail to restrain their action. Over my short career as a biologist, I have seen fens diked and flooded for enhancing waterfowl production, rare wetland plant communities flooded to maintain stocks of exotic sport fish, and infertile watersheds fertilized in order to enhance waterfowl production. These are examples of the misapplication of ecological principles, and we shall have to remain on guard for them continually.

14.5 Problems and prospects of reserve systems

The importance of large areas, and interconnected reserve systems, is reinforced by the problems that face managers in trying to protect isolated fragments of habitat. These problems are particularly severe for Europeans, where there has been a long history of human modification of the landscape. This example will likely be unfamiliar to North American readers, but this makes it all the more valuable, since, as population growth continues in North America, the pressures on the landscape will be similar to those in Europe.

Let us consider the fens of eastern England, adjacent to The Wash along the coast with the North Sea (Sheail and Wells 1983). These wetlands extend inland some 60 km from the ocean. The coastal areas are tidal marsh. In uplands, the depth and character of the peat reflects differences in local drainage. In between, along the River Nene, there are more alkaline conditions, and series of lakes created by the meandering river. The largest lake is Whittlesea Mere, which in 1697 was said to be 3 miles (5 km) broad and 6 miles (10 km) long; most of this is less than 2 m deep. The number and area of lakes may have declined since the medieval period onward, and in 1826, Whittlesea Mere dried up completely during one dry summer.

The Domesday survey carried out in 1086 outlined the various rights or privileges on fen lakes, and later documents also drew attention to value for fish production and hunting for waterfowl. Records from the manorial court at Upwood in the 1600s reveal attempts to regulate land use, including rights of grazing in the fen and of excavating turf for fuel. Farmers were forbidden from digging over "10 000 cesses of turf from the fen in one year." Proposals to drain these fens were led by "Adventurers" who in the early 1600s were granted royal charters for ambitious drainage projects; in return for their investment, they received a portion (usually about one-third) of the drained land (Fraser 1973). The fen-dwellers disapproved. Their indigenous culture included fishing, hunting, and communal grazing. Some even objected to drainage in principle, "Fens were made to be fens and must ever continue such" (Sheail and Wells 1983, p. 53). As work proceeded, there were "ugly scenes of riot and physical protest." On one occasion "a crowd of men and women armed with scythes and pitchforks uttered fierce threats against anyone who tried to drive their cattle off the fens" (p. 54). In 1637, a local resident of Ely named Oliver Cromwell became a spokesman on behalf of the fen-dwellers. (Years later, after winning the Civil War, and being declared Lord Protector of England, Cromwell was still mocked by some of his enemies as "Lord of the Fens" [Fraser 1973].)

By the 1700s the number and variety of species had begun to fall. Waterfowl were perhaps over-hunted, distinctive butterflies may have been over-collected, but habitat destruction was probably most important. In 1844 an Act of Parliament combined the drainage of the Huntingdonshire fen with the improvement of watercourses further downstream. It was not until 1850 that the last of the meres, Whittlesea Mere, could be drained. Both windmills and steam scoop wheels were used for further draining fens, and in 1851 it was the first site in England where a centrifugal pump from the Netherlands was used. In the 1890s, according to Sheail and Wells (1983), an observer remarked "all is gone – reeds, sedges, the glittering water, the butterflies, the gypsies, the bitterns, the wild fowl, and in its place . . . a dreary flat of black arable land, with hardly a jack snipe to give it a charm and characteristic attraction."

The first attempt at preservation was made in 1910, with the purchase of 137 ha of the Woodwalton Fen. The water table was falling, in part from peat cutting. Woody plants began to invade the fen; some trees had established on the nature reserve as early as the 1860s, and by 1931 most of the reserve was covered by "dense impenetrable thickets of sallow bushes." Hence, drainage ditches were partially blocked to maintain water levels during times of drought, and in 1935 a portable pump was used to raise water from neighboring drains into the reserve during dry weather. It would, of course, be possible to cut out the invading woody plants, but what would be the point if the fen was dried out? Drainage ditches were deepened further after the Second World War, and in 1972 a clay-cored bank was constructed on the northern and western perimeter of the reserve so as to reduce the amount of water percolating out of the reserve into drainage ditches. A photograph in Sheail and Wells (1983) shows a small rectangular plot of land, largely wooded, forlornly surrounded by drainage ditches and agricultural land. The Holme Fen National Nature Reserve, 256 ha set aside in 1952, is some 3 km away. It has some species associated with undrained fenland such as *Calluna vulgaris*, *Erica tetralix*, and *Cladium mariscus*, but it too is being invaded by scrub and trees as the water table falls.

Some 100 km to the east, a similar discouraging history of habitat loss has been described for the Norfolk Broadlands (Moss 1983, 1984). Some 46 shallow lakes, or broads, were created by peat cutting between the ninth and fourteenth centuries AD. Drainage by wind pumps in the late eighteenth and early nineteenth centuries, combined with intensification of agriculture and sewage disposal in the twentieth century, reduced wetland area and caused both the rapid growth of emergent macrophytes and loss of aquatic plants. The Norfolk Broads developed some of the highest total phosphorus concentrations recorded for freshwater lakes in the world (Moss 1983). Further, the coypu (called nutria in the United States, *Myocastor coypus*), a large South American rodent, was introduced for fur farming about 1929; some escaped and by the 1960s there were estimated to be 200 000 wild animals. The inevitable results of these factors has been decreased numbers of species and habitats remaining in the landscape (Figure 14.12).

These fen examples illustrate how very difficult it is to mantain isolated reserves in landscapes with large human populations. Other examples from this book have included the drainage of prairie potholes combined with falling water tables from irrigation, the construction of large dams on rivers, the impacts of grazing and canals in the Pantanal, phosphorus-laden water entering the Everglades, atmospheric deposition of nitrogen in western European heathlands, removal of annual flooding with levees along the Danube and Mississippi, possible changes in fire frequency in peatlands with global warming, and changes associated with rising sea levels. Such examples serve to re-emphasize the need for large reserves, with buffer strips, as part of an interconnected system.

In the longer run, we could restore habitat around existing core areas by re-establishing natural causal factors. Returning to eastern England, the two remnant fens near Cambridge – Holme Fen and Woodwalton Fen – will now become core areas within a 3000-ha restored wetland (Figure 14.13). This will not only add buffers around these reserves, but a corridor linking them, and a larger area of habitat. Traditional uses such as reed-cutting will continue.

Since the area of wildlife habitat is still in decline at the global scale – as illustrated by the rising numbers of species on the IUCN *Red List* (Figure 9.25), the

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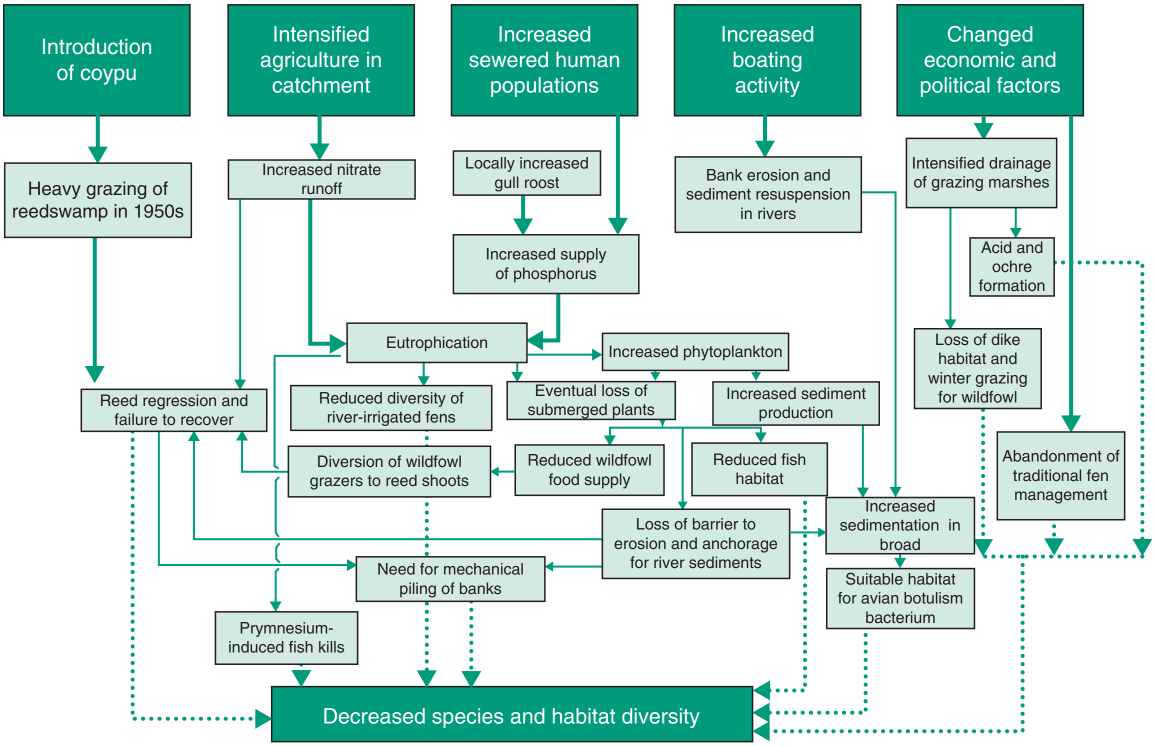

FIGURE 14.12 Cause and effect relationships resulting in loss of species and habitats in wetlands in the Broadlands, eastern England. Heavy arrows indicate major causes, thin arrows the interactions between effects, and dotted lines the major consequences. (From Moss 1983.)

challenge for conservationists and managers is not only to set up reserve systems, but to ensure that within each system, natural habitats continue to be renewed. This requires sufficiently large reserves for natural dynamics to occur, or else increasingly expensive intervention by managers to attempt to simulate these processes. Fortunately, fire and flooding provide two powerful tools for constructing landscapes and generating new patches of habitat. Indeed, these forces might allow us to begin to rebuild wilderness in fragmented landscapes east of the Mississippi River in North America (Figure 14.14).

A modest goal might be protection of 12% of the landscape within reserves (World Commission on Environment and Development 1987). This is, of course, not a definitive number – it was derived by assuming that since 4% of the landscape was reserved at the time, a goal of three times this amount might be reasonable. "There is a danger that such an ad hoc number will become a standard before we have any evidence that it is sufficient to protect biodiversity" (Sinclair *et al.* 1995). Noss (1995) therefore suggests that after the first steps (mapping out a preliminary reserve network with core reserves, buffer zones, and continuity), one should identify the species with the largest area requirements still extant in the region, and estimate the area needed to provide for both short-term and long-term viable populations of that species. A next step would be to identify the extirpated native species with the largest area requirements that could reasonably be reintroduced, and again estimate area for short-term and long-term survival. If the reserve system is not sufficient to maintain long-term viable populations of these species, plans must be made to enlarge the network or enhance connectivity within the system or to

FIGURE 14.13 The fens of eastern England have been drained at least since the reign of Charles I in the early 1600s. Over 99% have been lost. The Great Fen Project plans to restore 3000 hectares around two core remnants, Holme Fen and Woodwalton Fen (top). (Courtesy The Wildlife Trust, Cambridge.) (See also color plate.)

adjoining regions. Tools like gap analysis allow scientists to survey reserve systems and seek out landscapes that should be added to the system.

The need to re-create habitats, particularly when only isolated fragments remain, is the topic of the next section. The situation in the English fens – or the Everglades, or the Pine Barrens, or the Mississippi delta, or the Sundarbans – illustrate the challenges to be faced in the coming decades.

14.6 More on restoration

Designing a reserve system and managing it appropriately is a challenging mixture of basic and applied science. In Chapter 1, the second principle stated: *to understand and manage wetlands we must determine the quantitative relationships between environmental factors and the properties of wetlands.* Since *wetlands are the product of many environmental factors acting simultaneously,* it follows that we manipulate wetlands by changing one or more of these factors – by changing flooding regimes, by reducing phosphorus in the water entering the wetlands, by reintroducing natural grazers, or allowing fire. Each modification of an environmental factor is an act of management. Any management program should be undertaken only with a specific goal in mind, and with an understanding of the known quantitative linkages that allow one to forecast the results of the manipulation. All management should have a clearly articulated goal, because it is only when the goal is articulated that we can later determine whether or not the management has been successful. And what should the goal be? Here we can re-emphasize Leopold's (1949) essay on land ethics with which Noss (1995) begins: "A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise."

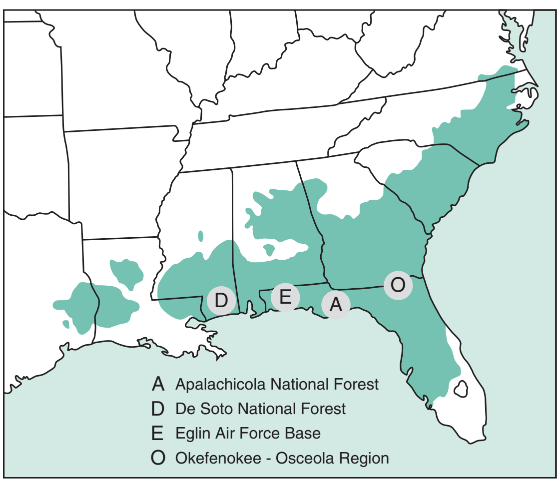

FIGURE 14.14 Four regions east of the Mississippi River have core areas which could, with restoration, each eventually provide large areas of wetland where flooding and fire occur with minimal human intervention. Such sites would also provide habitat for reintroduction of large carnivores such as red wolves and panthers. The shaded area indicates the natural distribution of longleaf pine (*Pinus palustris*) ecosystems. (From Keddy 2009.)

Leopold did not explain what he meant by integrity, and although the word is increasingly used by managers, it is still poorly defined (e.g. Woodley *et al.* 1993; Noss 1995; Higgs 1997). Noss is of the opinion that the difficulty in defining integrity does not reduce its value – other terms like justice, freedom, love, and democracy are also vague and slippery, and this has not kept scientists, philosophers, and policy-makers from thinking about them and being guided by their intent (Rolston 1994). Rather than enter this discussion here, let us adopt the view that integrity has three essential components: (1) maintaining biological diversity, (2) ensuring ecosystem persistence through time, and (3) maintaining performance of ecological services. These are all relatively measurable, even if the term integrity is not. All three are also interrelated, in that if diversity declines, services will naturally be impaired. Similarly, the continued performance of services is probably essential for persistence. The proliferation of terms for wise management should not distract us from setting clear goals and ensuring that the best possible science is brought to bear for achievement of those goals.

Managers will rarely inherit a watershed with entirely intact and pristine wetland ecosystems; in most cases there already will have been considerable loss in wetland area, reductions in services, and declines in biological diversity. Two of the principal challenges facing mangers will therefore be (1) deciding to what degree it is possible to reverse these undesirable changes and (2) implementing the programs to make these reversals. In Chapter 13 we saw some of the tools that are available, and some examples of progress.

A principal distinction between North American and European perspectives on restoration and ecosystem management is their different biological reference points: there is a tendency for Europeans to set the goal of maintaining a familiar historical landscape created by humans (e.g. species-rich meadows typical of the eighteenth and nineteenth centuries), whereas the North American tendency is to set the goal of re-creating the ecosystems judged to have been present before humans of European ancestry altered the landscape. Further, Europeans accept intensive management (e.g. cattle grazing, peat-cutting, mowing) whereas North Americans tend to prefer natural controlling factors (erosion, fire, and flooding). One can hope for increasing overlap between these two views of management; in densely populated areas of Asia and North America, there may have to be increasing use of European management experience in order to maintain small examples of desired ecosystem types. Equally, Europeans may begin to value the possibility of managing larger areas of landscape for their original composition rather than for their cultural familiarity.

14.7 So what shall we create with restoration?

Restoration is a growing field of applied ecology. In the United States of America there is a "no-net-loss" policy for wetlands; damage to wetlands is to be avoided, but if damage is necessary, it must be mitigated, which means that compensatory wetlands must be constructed to equal or exceed the services that were performed by the damaged site. More precisely, mitigation is defined as "the avoidance, minimization, rectification, and reduction or elimination of negative impacts or compensation by replacement or substitution" (Office of Technology Assessment, in Zedler 1996). Successful mitigation means "providing a habitat that is functionally equivalent to the one that will be lost" (Zedler 1996), and assumes that ecosystems can be made to order.

The first step is to ensure that replacement wetlands are hydrologically equivalent to the lost wetlands, since hydrology provides the template for the development of the wetland on a site. "Any attempt to replace wetlands with ecologically or hydrologically equivalent types must be based on an understanding of the relationship of individual wetlands to the landscape" (Bedford 1996). The three key hydrological variables, she asserts, are: (1) relative importance of various water sources, (2) mineral element and nutrient content, and (3) spatial and temporal dynamics. This comes close to the first three factors used in this book: hydrology, fertility, and disturbance.

Surveys of the kinds of wetlands being constructed for mitigation (Figure 14.15) suggest that shallow-water wetlands along rivers are relatively easy to create, whereas wet meadows (lacustrine fringe, riverine fringe) are not. Mitigation, while well intended, is therefore actually changing the nature of wetlands in the landscape. This problem is not necessarily restricted to mitigation: restoration could equally lead to such problems if the original distribution of wetland types and controlling factors in the landscape is not used as a reference point

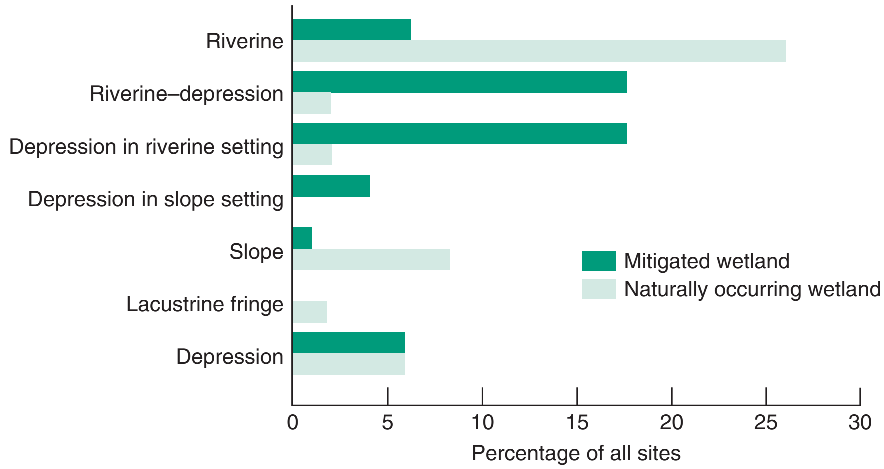

FIGURE 14.15 The relative frequency of seven types of wetland in naturally occurring as opposed to mitigated wetlands. Note that the mitigated wetlands have an over-representation of two types of wetlands, "riverine–depression" and "depression in riverine setting." Other wetland types, such as "slope" wetlands and "lacustrine fringe" wetlands, are rarely re-created. (Data from the northwestern United States; courtesy M. Kentula and U.S. Environmental Protection Agency.)

against which to set the targets and judge the results of individual projects.

Our task at hand is therefore clear: increased protection for wetland habitats around the world, better scientific management of them, and restoration of wetlands in areas where they have been lost. Two further tasks remain. The first is identifying indicators to measure our performance, the second is the systematic application of scientific principles in order to solve practical problems. Consider them in turn.

14.8 Indicators: setting goals and measuring performance

In seeking to re-create, restore, or simply manipulate natural wetlands, we need some procedure to measure success. This procedure must be based upon credible scientific criteria. The number of acres managed, or the amount of money spent, means nothing if the wetlands involved have been damaged by our management.

This is where indicators are helpful, indeed essential (e.g. Keddy 1991a; Adamus 1992, 1996; McKenzie *et al.* 1992; Woodley *et al.* 1993; Tiner 1999). Indicators provide an instrument panel for wetland management. As Tansley said in 1914 (long before the advent of computer controlled recording devices): "The mere taking of an instrument in the field and recording of observations … is no guarantee of scientific results." At present, we have difficulty in choosing indicators because ecology is not well enough developed as a science to tell us what the essential properties of wetlands are. We can, however, divide the task into three steps: selecting the appropriate state variables for use as indicators, setting critical limits to them, and then testing the indicators in monitoring programs.

14.8.1 Selecting state variables

What properties of communities should we measure to guide our decision-making? In the past, indicators have been developed haphazardly, often reflecting the interests of specific user groups and value systems, rather than according to more broad-scale ecological criteria. This history is reflected in the kinds of databases we currently have. The following criteria might guide our efforts to select indicators.

(1) Ecologically meaningful: closely related to maintenance of essential environmental processes (e.g. water level fluctuations) and ecosystem services (e.g. primary production).
(2) Large scale: measuring the state of entire systems or key processes rather than small pieces or selected species.
(3) Pragmatic: guided by measurable or empirical attributes of systems rather than conceptual or theoretical concepts and notions.
(4) Sensitive: quick response to stresses and perturbations, to minimize lag and give maximum response times for decision-makers.
(5) Simple: easy to measure, therefore inexpensive.

With these criteria in mind, there are at least three categories of indicators (Table 14.4).

Table 14.4 **Some potential indicators for monitoring wetland management**

Abiotic factors
duration of flooding
nutrient levels in water (particularly N, P, Ca)
pH
dissolved oxygen
suspended sediment
Biotic factors
number of species
number of rare, significant, or threatened species
selected indicator species
indices of floristic quality
indices of biotic integrity
Services
fish production
waterbird production
fur production
reed production
water storage

Abiotic factors

We might measure abiotic environmental factors that maintain and control the community type. Obvious factors include duration of flooding, water nutrient concentrations, salinity, or road density. We know that factors like these are important in controlling the composition of wetlands and the services they provide. At one time, physical factors alone were monitored. Cairns *et al.* (1992) recall that in 1948, "most pollution assessment was carried out by what were then called sanitary engineers (waste treatment specialists) and chemists. The accepted procedure was that if certain limited chemical/physical conditions were met . . . there was little or no need to examine the biota" (p. ix). Physical factors are likely to be of continued use, particularly in systems where one or only a few physical factors really have an overwhelming importance. Thus, the concentration of phosphorus in lakes (Figure 12.3), or in water crossing the Everglades (Section 13.2.2), is so important that we can learn a great deal by simply monitoring this single factor. The same is likely true of salinity in major deltas like the Mississippi River delta (Figure 8.8).

Biotic factors

Measuring biotic factors can have advantages. First, species can integrate the effects of many physical factors, so monitoring the presence of a species or group of species may tell you more than the same effort invested in physical factors. At its most simplistic level this approach uses indicators species, selected species that are particularly sensitive to certain factors thought to be of interest. Carnivorous plants, for example, are indicators of infertile conditions (Section 3.2). Or, looking at Figure 8.18, the presence of forest cover – indicated by green – tells you a good deal about the situation in the Ganges delta. Indeed, forest cover is often an important factor for water quality (Figure 7.17) and wetland quality (Figure 8.13).

Rather than focus on individual indicator species, in many cases it may be useful to assess wetland status or monitor management performance by combining observations on many species. If we measure the sensitivity of plants to an environmental factor (e.g. nutrient levels), pooling the species results for a wetland should provide an indicator of the

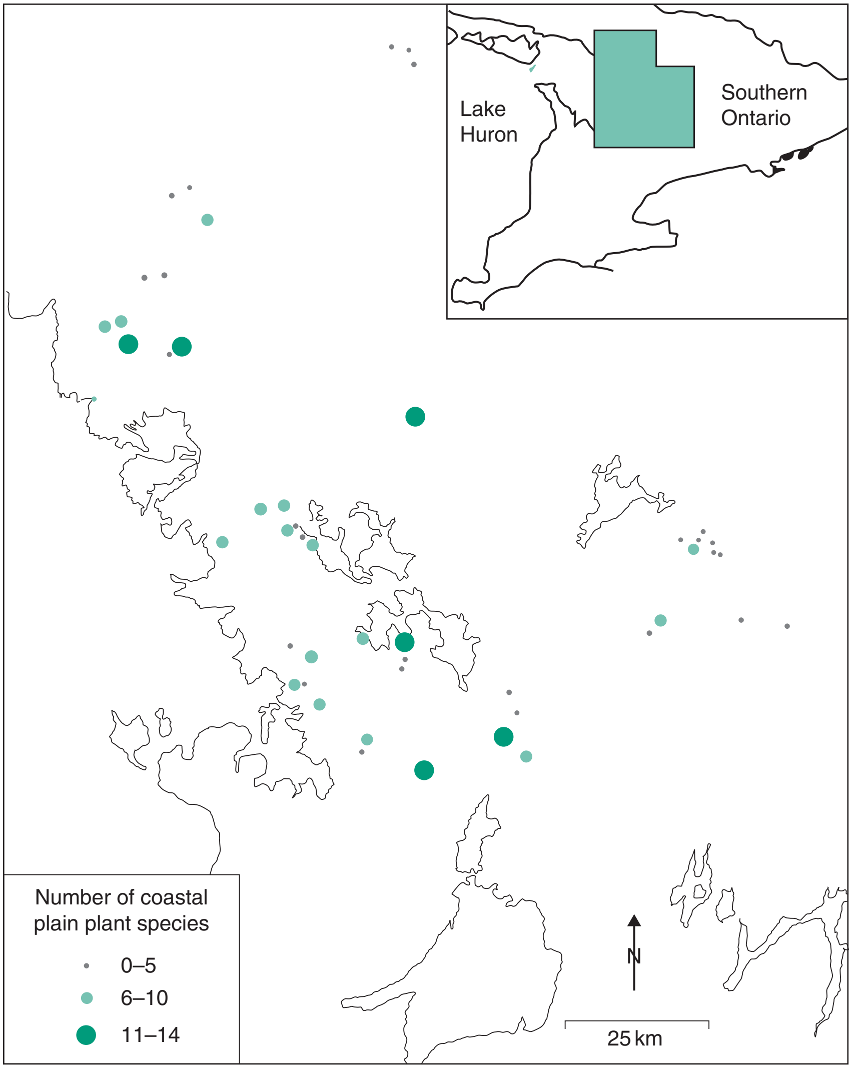

FIGURE 14.16 A simple indicator for comparing wetland sites is the total number of significant species they contain, as in this set of 49 lakeshore wetlands near Georgian Bay, Canada. (From Keddy and Sharp 1994.)

factor's significance for the wetland itself. For example, by adding up the number of significant plant species in lakes, one can rank lakes in terms of the significance of their shoreline wetlands (Figure 14.16). Adding measures of species abundance or global conservation status would provide more information still.

The index of conservatism (Section 12.6.7) is a good example of using information for many species simultaneously. In this system, you will recall, an expert panel assigns every native plant species a score for how dependent the species is upon natural vegetation types with minimal human alteration. Widespread and common wetland species such as *Phragmites australis* and *Typha latifolia* receive a score of 1, while species that depend upon small fragments of undisturbed habitat like *Platanthera leucophaea* receive a score of 10. To obtain a score for a entire wetland, one makes a complete list of the n species present, and obtains the coefficient of conservatism, C, for each from a reference table. One can then calculate two values. The first, C, is simply the mean coefficient of conservatism: $\overline{C} = (\Sigma C)/n$. The second, the floristic quality index, FQI, is $(\Sigma C)/\sqrt{n}$. These scores provide an objective tool for comparing sites based upon how sensitive the species are to human perturbations, or how likely the site is to represent a system that is relatively unaffected by human perturbations. This is an improvement upon data such as Figure 14.16, since it not only shows how many species are in a site, but how significant they are. In practice, there is likely to be a strong relationship between rare species and those with high degrees of conservatism, at least in regions with highly disturbed landscapes. However, in principle, a species can be highly indicative of pristine conditions without being rare or threatened.

Consider three examples.

In Wisconsin 554 lakes were assessed using C values assigned to 128 emergent and aquatic plants (Nichols 1999). Scores for species ranged from 1 (e.g. *Phragmites australis*, *Typha latifolia*) to 10 (e.g. *Littorella uniflora*, *Myriophyllum tenellum*, *Gratiola aurea*). Over all lakes, the median number of species was 13 (range 1–44), the mean coefficient of conservatism was 6 (range 2–9.5), while the mean FQI was 22.2 (range 3.0 to 44.6). Thus, any specific lake can be ranked relative to other lakes based upon its FQI, and further, with monitoring, changes in the FQI can be tracked through time.

In North Dakota FQI values were used to compare a natural wetland complex with three restored wetlands (Mushet *et al.* 2002). In addition, however, the study used data from 204 wetlands in the region to assist in the evaluation. These wetlands included natural wetlands within native prairie, drained wetlands, and restored wetlands. Restored wetlands generally had lower FQI indices (usually less than 20) than natural wetlands (usually greater than 22), but of course, both were well above highly degraded wetlands. An additional feature of thus study was a comparison of the expert systems approach (using opinions of expert botanists) and with indices of conservatism calculated from the 204 regional wetlands. Both were used to independently calculate measures of conservatism and FQI. The results were so similar that the use of expert opinions alone appears justified in future FQI studies.

More generally, Swink and Wilhelm (1994) suggest that a wetland restoration effort is a success if it can achieve a C of 3.0–3.5 and an FQI value of 25–35 after 5 years. These values, are, however relatively low, since their lower criterion for a significant terrestrial site is 35. In nearby Michigan, areas with FQI higher than 35 are considered significant, while areas above 50 "are extremely rare and represent a significant component of Michigan's native biodiversity and natural landscapes" (Herman *et al.* 2001).

Other state variables

Some of the services that wetlands provide can also be useful indicators. The abundance of commercially valuable species, or harvest yields, can provide information on the status of wetlands. Many have the added advantage of having good historical records. Fish harvests, waterfowl harvests, and oyster harvests are three such examples.

In certain cases, it may be useful to find specific measures of the stress a system is under (Woodwell and Whittaker 1968; Rapport 1989; Odum 1985; Rapport *et al.* 1985; Schindler 1987; Freedman 1995). Ecosystems that are under stress appear to display certain similar responses. These include increased community respiration, increased nutrient loss, decreased diversity of native species, and increased presence of invasive species. In wetlands, indicators of stress might include a decline in the number of obligate wetland species, or increasing abundance of species such as *Typha* or *Phragmites*. In rivers it might be high sediment loads (Figure 7.2) or high nitrate concentrations (Figure 3.8). In lakes it might be a high N : P ratio, or an abundance of algae (Figure 12.3).

Combining indicators

Many wetland evaluation systems combine a series of indicators. The Ontario system introduced in Table 12.1 includes biological, social, and hydrological factors, as well as species features such as rare species and colonial bird nesting sites. In this system, the combined total score allows us to rank wetlands in terms of their significance and quality, up to a total score of 1000.

Let us look at another example, from a part of the world where rare types of wetlands are colliding with urbanization: New Jersey. Here one encounters wetlands that have low fertility, large numbers of significant species including carnivorous plants, and rapid intensification of human land use. What factors might be used as indicators of habitat quality?

To put the data into context, the New Jersey Pine Barrens have arisen on the east coast of North America on top of a vast sand and gravel deposit produced by coastal events dating back through hundreds of millions of years, including deposition by ancient versions of the Hudson River (Gibson *et al.* 1999). About a half million hectares was once dominated by pine–oak forest with patches of ericaceous shrubs and grasslands, as well as pools, bogs, and wet meadows. Fire and flooding played important roles in producing, and maintaining, this vegetation mosaic. Humans have not only altered the system in obvious ways such as logging and urban sprawl, but in far more complex ways, through changing the fire regime, altering hydrology, increasing nutrient levels in the water, drawing down the water table, and constructing roads. Hence, there are multiple factors causing the degradation of wetlands in the Pine Barrens. To explore the effects of humans on the wetlands might require more than one indicator. Thus, as part of an ecological integrity assessment, Zampella *et al.* (2006) combined two physical factors (specific conductance and pH) with measurements of composition including stream vegetation, fish, and frogs. These were collected from 88 locations in the Mullica River basin, and analyzed with multivariate methods. Not surprisingly, the most important factor controlling all of these was the degree of perturbation by humans (Figure 14.17). As the effects of humans intensify, the number of Pine Barrens species declines, and the number of non-native species increases. The Pinelands typify the conflicts that arise between growing human populations and wild places, and the current status of Pinelands National Reserve could be seen as an uneasy and still-evolving compromise with an unknown future.

14.8.2 Setting critical limits

Once indicators are selected, an added useful step is to set acceptable and desirable levels for them. For each indicator, there would be a range of values specified, one limit being the tolerable level and the other being the desirable. The purpose is to identify a threshold beyond which it is clear that degradation is proceeding. If the system moved outside this specified range, managers would know that remedial action was needed to restore integrity. For example, one might set a goal of zero exotics as desirable for a rare wetland vegetation type, and two exotics as being tolerable. If more exotics than this invaded the site, one would investigate the reasons for the invasion, and then take the appropriate remedial action. Or, as in the Everglades, one might set the upper limit of 10 µg/l phosphorus in the water (Section 13.2.2). The FQI provides another way of accomplishing this with upper values of 50 being highly significant, and lower values of 25 being marginal (Section 14.8.1). In wet meadows, one might specify that biomass values should remain below 200 g/0.25 m^2 (Section 9.4).

In the long run, managers need a handbook that (1) lists major wetland types, and (2) specifies for each the appropriate indicators with their desirable and acceptable levels. Some indicators (e.g. exotics) might have similar levels for all wetland types, whereas others (e.g. amphibian biomass) might have different critical limits for each wetland or habitat type.

14.8.3 Monitoring

Selecting indicators and setting critical limits is obviously part of an evolutionary process. As

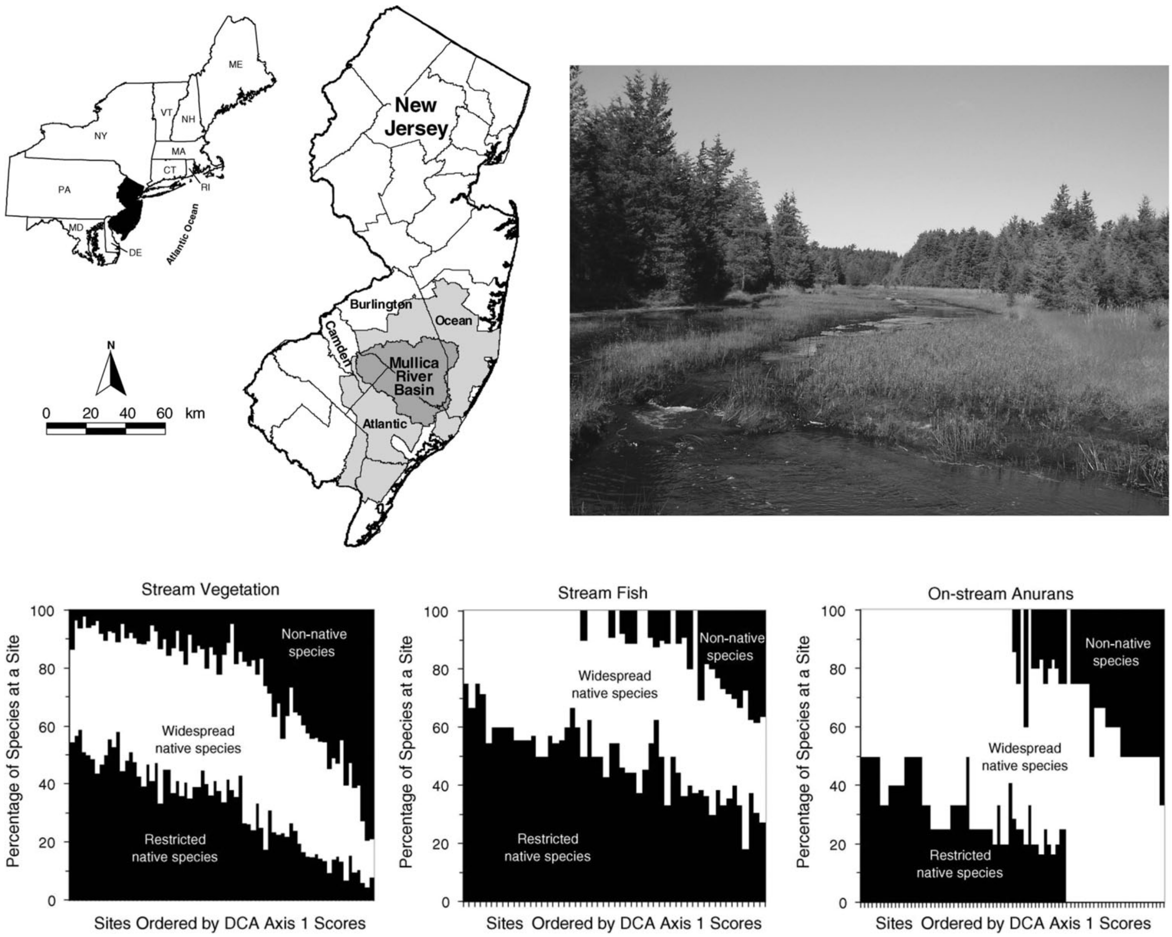

FIGURE 14.17 The composition of plants, stream fish, and frogs/toads changes along a gradient of human impact. These 88 sites from the Mullica River basin in New Jersey are ordered by scores obtained from detrended correspondence analysis (DCA) from least impacted by humans (left) to most impacted by humans (right). (From Zampella *et al.* 2006; photo of Tulpehocken Creek courtesy J. F. Bunnell.) (See also color plate.)

scientific knowledge of community ecology and experience with ecosystem management increase, we need to remain open to changing both indicators and critical limits. Indicators would therefore evolve to reflect our constantly improving knowledge. It is therefore essential to monitor as projects occur, and then to use the information from monitoring to revise criteria for future projects (e.g. Holling 1978; Beanland and Duinker 1983; Noss 1995; Rosenberg *et al.* 1995).

In many cases, of course, the restoration ecologist inherits a perturbed site. In such a case, it is up to the recovery team to decide what the desired composition is, and what indicator levels are intended. That is, the restoration needs explicit targets. These could be based upon historical data from the site, published data from other sites that provide the desired end point, or new data from other less-perturbed sites. One might even choose a different ecological

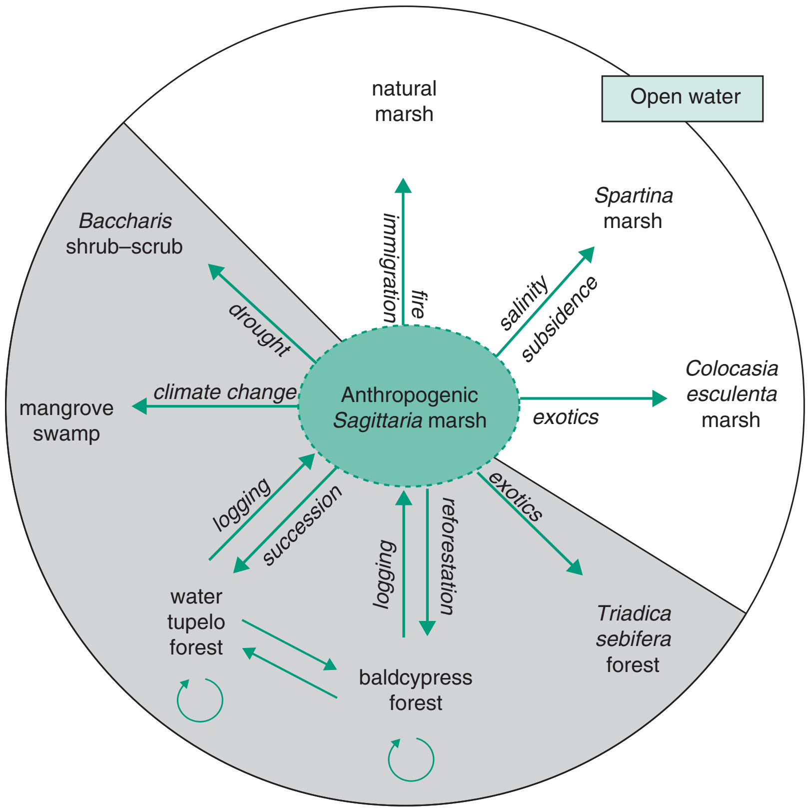

FIGURE 14.18 A perturbed wetland (such as a *Sagittaria* marsh created by logging, Figures 4.16, 6.15; see also color plate) can change into many different future states depending upon the environmental factors affected by human activity. It may be possible to restore the site to cypress swamp (bottom), but other possibilities have to be evaluated and considered, particularly if sea level or river channels change. (From Keddy *et al.* 2007.)

state, perhaps one that is disappearing from the landscape. It is not always clear which target is appropriate.

Consider an example from coastal Louisiana, an area of degraded wetland which was once cypress swamp, and is now herbaceous wetland (Figure 14.18). The current state is a human created (anthropogenic) *Sagittaria* marsh, with multiple drainage ditches. One possible target is to restore the wetland to cypress swamp (bottom). This could require steps such as increasing the input of fresh water and nutrients, controlling herbivory from nutria, and backfilling drainage ditches. It might also require artificial planting or control of invasive exotics. Returning the area to cypress is probably the most desirable option. But there are other possibilities – a simple one-way reversal to cypress swamp is not the only option. Other options exist and may even be imposed by circumstances. Invasive exotic species such as *Colocasia esculenta* and *Triadica sebifera* may establish their own vegetation types (right). If, for example, rising sea levels will increase salinity, and the construction of new levees will decrease flooding, then another ecological state may have to be accepted, such as brackish marsh, or *Spartina* marsh. If nothing is done, the site may revert to open water (upper right). Depending upon climate, it might even be possible to convert the area to mangroves (left).

Any management program should begin with a thorough understanding of the history of the system, and the possible scenarios for future states. Once the decision is made – that is, once the recovery state is defined – the task of the wetland ecologist is to move the community from the current damaged state back into the desired region. Again, one has to be realistic about what is possible: there is little point, say, in promising freshwater cypress swamp in an area exposed to rising sea levels and expanded levee systems.

Overall, then, we could end up with a shopping list:

(1) Protect representative wetlands in a systematic way.
(2) Plan reserve systems to maintain ecological services.
(3) Provide buffer zones to protect the cores areas.
(4) Provide corridors to link the core areas.
(5) Maintain natural forces that create the wetlands and their surrounding landscape.
(6) Carry out gap analysis to ensure that the system is complete.
(7) Monitor the system and adjust and expand it to ensure continued survival of the species, the wetland types and the ecological services.
(8) Build a body of scientific understanding to allow items (1)–(7) to occur as efficiently and effectively as possible.

14.9 Humans as the biggest problem

Wetlands continue to be damaged by human activities, even in areas that are well recognized as national and international priorities – the Mississippi River delta and the Everglades being but two North American examples. Every part of the world has its own problems. The Yangtze River delta is now being harmed by the Three Gorges Dam, just as the Peace River delta was disrupted some 40 years ago by the Bennett Dam, and new dams are planned for major rivers including the Congo and the Amazon. Such problems rarely arise because of scientific limitations (that is, from a lack of understanding of the external world). Nor do they arise from lack of money. It seems that most wetlands are threatened, in the end, by human attitudes (that is, the inner realm of human thoughts and feelings). Greed and denial are powerful emotional states that we encounter. As scientists we are trained to dissect and analyze living systems with exquisite care, but we can blunder into human interactions like drunken elephants in a minefield.

Our biggest challenge may be managing greed and cronyism. There are good evolutionary reasons why humans always crave more, and why we prefer to work with members of our own tribe, but these two motives in combination may produce disaster (Wright 2004; Diamond 2005). At very least, let us remember that many of the obstacles to wetland research and conservation do not exist in the field where we can measure them with our instruments, but inside the heads of fellow citizens. Wetland management therefore has two separate components (Figure 14.19). If we ignore the left-hand one, we are like a general who will not admit that a minefield or mountain range is an obstacle to his campaign.

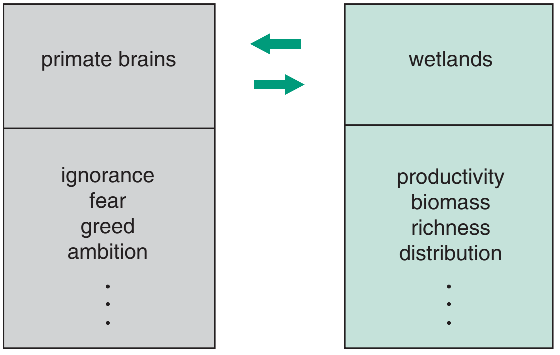

FIGURE 14.19 Wetland conservation and management require not only an understanding of wetlands (right), but an appreciation of human perceptions and motivations (left). There is considerable evidence that humans are incapable of making rational decisions regarding the sustainable use of their own landscapes.

CONCLUSION

We are at a difficult point in human history. Wetlands are increasingly threatened by the activities of our own species. Even if we doubt the likelihood of the most gloomy scenarios such as nuclear war and nuclear winter, or desertification and mass starvation, we cannot doubt the accumulating insidious effects of many less dramatic effects such as deforestation, desertification, soil erosion, drainage of wetlands, and rising rates of extinction. Or the threat of rapid climate change, the melting of the Greenland ice sheet, and the flooding of coastal communities. In this sense, ecologists are like the legendary thin red line of British soldiers; we are a minority who stand between our civilization and the ecosystems upon which we all depend. These ecosystems are mute. We alone provide them with voices. This is a heavy responsibility to bear, and one may wish that instead of being a biologist, one had instead become a lawyer, a small-town doctor, or a store manager.

One may wish that instead of this book one had read a murder mystery or a romance. But given knowledge, we now have the duty to act. We could seek counsel from another professional organization where responsibility, duty, and the exercise of power are valued, the military.

> It is an honor to serve in the armed forces … It is also a duty of our citizens to serve in the armed forces, as volunteers or in accordance with our nation's laws, and to perform the military missions that this service may require. If the day should come when a large proportion of our citizens regard this service as less than an honor, and less than an obligation of citizenship, our proud nation will have begun the descent to lie beside other peoples who were unable or unwilling to fight for their principles or for the retention of their freedoms. (Crocker 1990, p. 31.)

Action has several components. With respect to our own activities, there is the responsibility to work on significant problems rather than allowing our minds to flit about and occupy us with each autecological curiosity that catches our attention. We can avoid conducting research that is simply haphazardly selected problems in haphazardly selected sites of attractive species with no consideration of the literature outside of one's own geographic region and taxonomic group. There is also the responsibility to speak clearly and act with integrity in defense of the world's ecosystems. To remain silent in the face of folly is irresponsible. Of course, there are costs. You may wish to read *Death in the Everglades* (McIver 2003) about Guy Bradley, who was hired by the Audubon Society to help protect some of the last egret rookeries in Florida from poachers. On July 8, 1905, Bradley approached Walter Smith who, with his son and a friend, were killing egrets at Oyster Keys rookery. Bradley was shot and killed. He was buried on a shell ridge at Cape Sable overlooking Florida Bay. The grave was later washed away in a storm.

Before putting the book down, we must ask ourselves where we go from here. Figure 14.20 reminds us that fundamentally our path is straightforward.

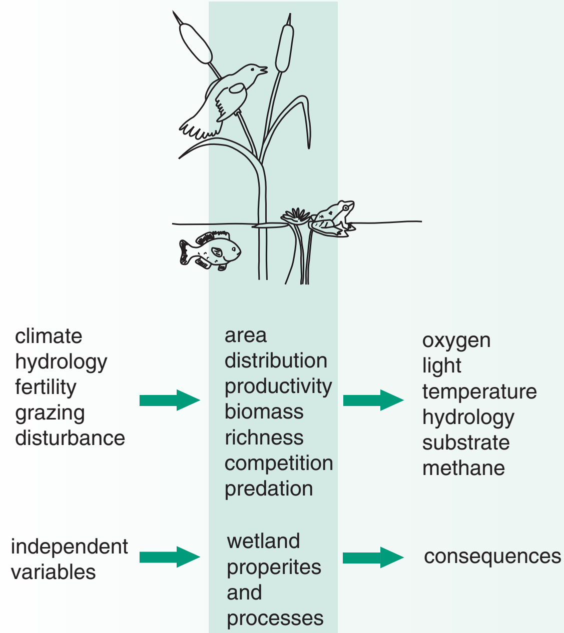

FIGURE 14.20 A general framework for wetland ecology. Wetland ecology is the study of the independent or causal factors (left) that determine wetland properties and processes (center), as well as the measurement and evaluation of consequences arising from these properties and processes (right).

There is a set of causal factors that create wetlands. These produce measurable properties in wetlands. In turn, wetlands provide services that extend well beyond their own borders. Our responsibility is to determine the relationships and convey them clearly and effectively to those around us in order to ensure that wetlands are conserved and managed wisely. Certainly, as Guy Bradley made the leap of faith that if he protected the egrets from extinction during his lifetime, people in the future would carry on protecting wild birds and wild places with the same dedication. The future will certainly require continued efforts in both research and conservation if we are to succeed in understanding and protecting the world's wetlands.