Chapter contents

13 Restoration

It is really quite easy to make a wetland. In many parts of the world, if you dig a depression below the water table, or build a small dam across a drainage ditch, in short order, you have a wetland. Within several years, it may even have a good deal of biological diversity. I have both dug ponds and dammed ditches myself, with satisfactory results, creating habitat for everything from yellow water lilies to otters to snapping turtles. So why, someone practical might ask, is wetland restoration such a big deal? Why bother to study it at all – why not just buy a back hoe and get to work? Why are there conferences, and symposia, and workshops, and books, and book chapters (like this one) addressing wetland restoration? In this chapter we will approach the topic of restoration in the following steps. We will begin looking at some simple examples of wetland restoration. Then we will consider just what the word restoration really means, and the issue of why these simple wetlands are often insufficient. We will then look at another set of examples. We will then look at some common problems that cause restoration to fail. Finally, we will look at some conceptual issues that provide a scientific framework for the task of restoration.

13.1 The importance of understanding wetland restoration

Discussing wetland restoration is important for three main reasons.

First, even though it may seem easy, it really is not. In one study, only two out of 34 restoration projects succeeded in creating the desired ecological community (Lockwood and Pimm 1999)! What about wetlands in particular? One study of 22 wetlands in Virginia found that the created wetlands had fewer kinds of birds and fewer individuals than nearby natural wetlands – and that it was wetland-dependent species that were particularly poor (Desrochers *et al.* 2008). In their words, "Created wetlands that we surveyed failed to completely replicate the bird and plant communities that we observed in nearby natural reference salt marshes . . . ." A larger data set consists of the more than 6800 ha (17 000 acres) lost each year in the United States from 1993 to 2000. These losses are permitted by the U.S. Army Corps of Engineers under section 404 – with the understanding that there will be 1.78 hectares of mitigation (that is, new wetlands created) for every lost hectare. In fact, the permitted projects attained only 0.69 ha, a success rate of well under 50% – for students, this would be the same as a course grade of 39%. At the finer scale, an examination of 70 sites in Massachusetts showed that all the replacement wetlands contained fewer species than reference wetlands. Hence, not only are areas of wetland not being re-created according to targets, but those that are created do not contain the full array of species. Whether this is because of lack of effort, corruption, and ignorance, or inherent difficulties of restoration, is harder to say. It is entirely possible that some types of damage to wetlands are simply irreversible (Zedler and Kercher 2005). One lesson seems clear. The restoration of wetlands is not as easy as it seems. Hence, it is necessary to look at some simple techniques that are used to create wetlands, and possible problems that can arise.

Second, and probably by far the most important, is the distinction between making a wetland and making a specific type of wetland. Some wetlands are easy to make – say a cattail patch with red-winged blackbirds nesting. These sorts of wetlands are often even made unintentionally when humans block drainage with highways or subdivisions. Other types of wetlands are very hard to make – say species-rich fens, vernal pools, and peat bogs. Often a wetland is valued for the biota it contains. Overall, it is easy to make habitat for painted turtles, hard to make habitat for spotted turtles. Easy to make habitat for red-winged blackbirds and Canada geese, hard to make habitat for Everglades snail kites and wood storks. Easy to make habitat for cattails and rushes, hard to make habitat for *Calopogon* orchids and Venus fly-traps. Hence, we could say that the real difficulty in making wetlands is making those specific kinds of wetlands that are most biologically useful. The difficulty lies in predicting how actions taken now will determine the species composition and ecological services provided by the constructed wetland, and, further, in ensuring that these persist through time. This added element – persistence through time – is an important one, since at least in the case of plants, one can buy many types of plants from nurseries, and plant them at a site, but if all but a few kinds die, then the restoration would hardly be judged a success. In summary, then, at its simplest, wetland restoration requires *the creation of a specified composition that will persist through time.*

Third, we should not forget that it is human nature to try to inflate the importance of one's work, and one way to inflate its importance is to pretend that it is very hard to do. Scientists would soon be out of work if they admitted that some of their work really is not that difficult. So they have to invent difficulty. Indeed, says Paul Ehrlich, "The National Academy of Sciences would be unable to give a unanimous decision if asked whether the sun would rise tomorrow."

Actually, the topic is complicated somewhat by multiple meanings of the word restoration. Or, perhaps, careless use of the term when it is not really appropriate.

13.2 Three examples

Let us begin by considering three simple examples of wetland restoration: plugging drainage ditches, the restoration of the Everglades, and removing levees on the Danube River.

13.2.1 Plugging drainage ditches: the author's own property in Canada

Many areas of wetland have been drained by ditches. Therefore, probably the easiest way to make a wetland is to plug one or more of those drainage ditches. Or, one can wait for a beaver to do it. This is remarkably efficient. Figure 13.1 shows aerial photographs of my own property in Canada. I have put my money where my mouth is and bought a wetland complex to protect it. The left-hand image, taken in 1946, shows only one pond, at the upper left. Much of the land has been deforested entirely, and the low wet areas are being used to produce marsh hay. Over the next 60 years, as the farms were abandoned, beaver populations recovered. More than ten ponds now occur in the same landscape. These ponds have a rich array of wetland plants (e.g. *Nuphar lutea*, *Sagittaria rigida*, *Pontederia cordata*, *Zizania aquatica*), many kinds of frogs (bullfrogs, green frogs, leopard frogs, gray tree frogs), nesting waterbirds (e.g. great blue herons, blue-winged teal, kingfishers), and mammals (muskrats, otters, beavers).

So this all seems like good news. One of the problems with such restoration lies in the details. For example, small areas of seepage and floodplain do not show up obviously on the photos, so the relative lack of change in these wetlands could be overlooked. The oblong depression at the lower right was already wetland in 1946 – a wet meadow. The flooding by beavers has changed it from a type of wetland that is relatively significant to one that is relatively common. Indeed, one might argue that beavers are not only able to turn old farmland into shallow water, they are also very good at turning seepage

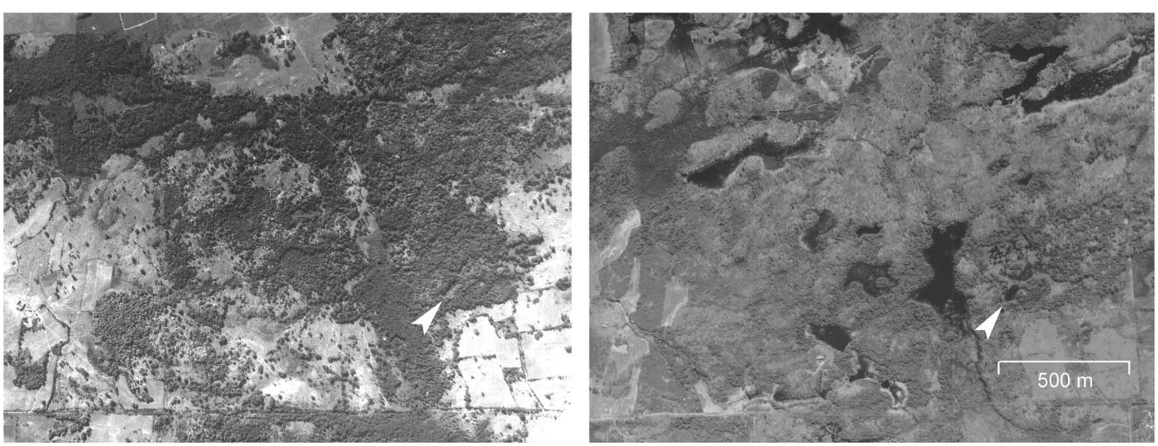

FIGURE 13.1 Aerial images of the author's property in 1946 (left) and 1991 (right) showing how beavers have restored wetlands to one landscape. Arrows show wet meadow (1946) converted to pond (1991).

FIGURE 13.2 Four stages of restoration in one of the author's wetlands: former wetland dried out by drainage ditches (upper left), replacing old beaver dam and filling ditches with earth (upper right), first year (lower left), second year (lower right). The wetland is now a breeding site for wood frogs, leopard frogs, mink frogs, spring peepers, American toads, gray tree frogs, green frogs, and bullfrogs. (See also color plate.)

areas, wet meadows, and small fens into shallow water.

In some cases where wetlands have been degraded, it may be impractical to wait for beavers. Or the food supply may be insufficient to support beavers. In this case, one can use an earth dam to accomplish the same task. One of the ponds in Figure 13.1 had been abandoned by the beavers, turned into wet meadow with species of *Eleocharis*, *Scirpus*, and *Sparganium*, and then began to dry out further through old drainage ditches (Figure 13.2, upper left). If we had waited long enough, the beavers would undoubtedly have rebuilt the dam, but our management objective was to maintain the diversity of animals and plants near our home. Therefore, over the main drainage ditch we built a small earth dam (Figure 13.2, upper right) which created a typical shallow water flora and fauna (Figure 13.2, lower left) surrounded by large areas of wet meadow. Within a single year the site had revegetated (Figure 13.2, lower right) and now has breeding populations of all the frogs known to occur in this wetland complex. This accomplished my management objectives, which included providing wet meadow for breeding frogs so we could hear native frogs calling at night, and for viewing waterbirds and turtles from my office.

As you learned in Chapter 2, water level fluctuations are an important part of maintaining wetland diversity, and wet meadows are particularly high in diversity. A solid and permanent dam might allow water levels to fall enough to create wet meadows. Our plan is to fluctuate the water levels over a 5-year cycle. Occasional low-water periods will ensure that we maintain wet meadows around the edge of the pond to maintain plant diversity, and to increase wildlife habitat. Even the lowest low will, however, have a nucleus of standing water to ensure that frogs and turtles have some habitat in which to hibernate.

I include this example first partly to show that I have practical experience in this topic, and partly to show how easy it is. At the same time, there are subtleties here, that require knowledge of wetland ecology. Too often, people use a bulldozer to dig a deep pond with steep sides and then have mowed lawn to the water edge. Instead, we have made at least five science-based modifications to maximize plant and animal diversity: (1) native vegetation surrounds the pond, (2) water levels will fluctuate among years to ensure that wet meadows remain, and (3) a nucleus of deeper water will remain even during the low-water year to ensure the survival of truly aquatic species. Moreover, (4) we left the gentle natural contours, so that small changes in water level will create large areas of wet meadows. Finally, (5) stumps and logs have been left where they lay to provide coarse woody debris.

13.2.2 Everglades

Now let us leap to the other extreme – the vast, and vastly expensive – effort to restore the Everglades. The Everglades, the famous “river of grass” (Figure 13.3), are one of the most intensively studied wetlands in North America. They are also part of one of the most expensive restoration programs yet undertaken – the Comprehensive Everglades Restoration Plan (CERP) – priced at more than \$8 billion. The Everglades were once a vast rain-fed wetland, with extremely low nutrient levels, and steady flow from north to south, producing a distinctive sedge-dominated vegetation type adapted to wet infertile conditions (Loveless 1959; Davis and Ogden 1994; Sklar *et al.* 2005). They were, in the words of Grunwald (2006, p. 9) “not quite land and not quite water but a soggy confusion of the two.” The slow but steady flow of water, combined with extremely low nutrients, appears to have been a defining ecological feature in controlling the vegetation. Superimposed upon this were dry periods which controlled fire regimes (recall Figure 4.6).

Phosphorus concentrations across most of the Everglades were likely as low as 4 to 10 μg/l and loading rates averaged less than 0.1 g P/m^2 per year. The Everglades thus illustrate the characteristics of the type of low-fertility wetlands described in Chapter 3. These extremely low nutrient levels produced distinctive periphyton. The main groups of periphyton are diatoms, cyanobacteria, and green algae, which grow attached to plants, on the soil, or in the water. These begin a distinctive food web, as well as providing oxygen for shallow-water species. Recall from Chapter 2 that this food web supports many wading birds including great egrets, white ibis, wood storks, and roseate spoonbills. Nesting is timed to coincide with seasonal low-water periods which force prey species to concentrate in the remaining few wet areas. Another well-known bird in the Everglades is the snail kite (*Rostrhamus sociabilis*) which feeds almost exclusively on apple snails (*Pomacea paludosa*) which are themselves controlled by the nutrient levels and water regime.

The Everglades have now been heavily impacted by humans (Ingebritsen *et al.* 1999; Sklar *et al.* 2005). Drainage began in the 1880s, and now enormous canals have been constructed, both with the intention of draining the Everglades, and with the intention of moving water for rapidly growing cities (Figure 13.4). At the same time, the sugar industry began to exploit the northern Everglades, and increasing amounts of nutrient-rich water poured south out of the cane fields, fertilizing the Everglades. Plume hunters

FIGURE 13.3 A scene from the Everglades. The Comprehensive Everglades Restoration Plan aims to protect and restore the conditions that maintain the native biota of the Everglades. (From Dugan 2005.) (See also color plate.)

deliberately targeted wading birds for their feathers. Finally, there were deliberate attempts to modify the vegetation by introducing exotic species.

The changes are measurable in many ways: reduction in the area of wetlands, lower water levels, increased frequency of droughts, a 90% decline in wading birds, increasing populations of exotic species, and even reduction in landscape features like the characteristic tree islands. A multibillion-dollar program is now attempting to restore the Everglades while maintaining water flow to adjoining urban areas. One objective is to reduce nutrient concentrations in the water to below 10 μg/l phosphorus. This has required the building of enormous (18 000 ha) treatment wetlands (stormwater treatment areas) to reduce nutrient loads in runoff before this water enters the Everglades (Sklar *et al.* 2005; Chimney and Goforth 2006). Another proposed objective is the restoration of the annual drying periods that support nestlings of wading birds (Brosnan *et al.* 2007). Some would argue that these are irreconcilable objectives – that you cannot continue to modify water quality, flow regime, and availability of water for humans without large-scale detrimental effects on other species. Others believe otherwise.

The Comprehensive Everglades Restoration Plan, which aims to reconcile these conflicting needs, is a work in progress which students will need to follow. A good beginning for the bigger picture is

FIGURE 13.4 Enormous canals have altered the natural hydrology of the Everglades, and provided a conduit for nutrient enriched water to enter the wetlands. (See also color plate.)

The Swamp (Grunwald 2006), which led one reviewer to conclude:

> Half the original Everglades has disappeared, the remainder is slowly dying and the pressures of population growth and development in Florida continue unabated. (The sugar fields may one day give way to something even worse: condominiums.) Good intentions, and lots of government money, may not be enough. (Grimes 2006)

13.2.3 Removing levees: the Danube River

Although natural levees occur along many rivers, humans have often built much higher artificial levees to prevent spring flooding. Well-known examples include levees along the Danube River in Europe and the Mississippi River in North America (Figure 2.25). One way to restore habitat along these rivers is simply remove, or breach, the levees (Schiemer *et al.* 1999; Roni *et al.* 2005). Remove the levee, and when floodwaters return, wetlands re-establish. Let us look at an example from the Danube River, where levee removal has begun. Marius Condac, a wildlife warden, witnessed one levee being opened: “It was spring, the water was very high,” he said. “So as soon as the machine had dug a hole, the water broke through with great power. We all cheered. The river was winning back its land.” (Simons 1997)

Some geographical context. The Danube River flows from west to east across Europe, from the Black Forest of Germany to the Danube delta at the Black Sea. It crosses through ten countries, and drains more than 800 000 km^2 in its course. Like most rivers (Dynesius and Nilsson 1994), it has been heavily altered by humans – over 700 dams and

FIGURE 13.5 Removing artificial levees will also restore wetlands. (left) Prior to dike removal. (right) After removing some 6 km of dikes, natural flood regimes were restored and in 2004 the Danube River flowed freely over Tataru Island. (Courtesy World Wildlife Fund.) (See also color plate.)

weirs have been built along the river and its tributaries. As a consequence, the floodplain wetlands have shrunk from more than 40 000 to less than 8000 km^2 – a loss in excess of 80%.

The Danube delta in the Black Sea, nearly 800 000 ha, is the largest in Europe, and it supports 176 species of breeding birds and 45 species of freshwater fish (Gastescu 1993; Schiemer *et al.* 1999). It lies largely in Romania, with about one-fifth being in Ukraine. Like many other wetlands, it too has been crisscrossed with dredged canals (1750 km of them) and surrounded by embankments and levees. As but one example, dikes were built around Tataru Island in Ukraine "in order to drain around half the 738 ha island for forestry and horticulture. Under strict forestry laws, the local forestry service had to sell 1000 m^3 of wood, 3 tons of meat, 700 kg of honey, 3000 muskrats, and 0.5 tons of medicinal plants to the state every year. Pigs, sheep, horses, and other domestic animals were kept on the island . . ." (WWF 2003).

Now some political context. Although Tataru Island is in Ukraine, much of the delta lies in adjoining Romania, once ruled by the Communist dictator, Nicolae Ceausescu, who, in the mid 1980s, had decreed that large areas of the delta should be transformed into agricultural land (Simons 1997). He sent 6000 men to build dikes, pump the land dry, and convert it into grain fields. Readers will be relieved to know that he was executed by a firing squad in 1989.

In fall 2003, restoration began in the delta. On Tataru Island, in adjoining Ukraine, some 6 km of dikes that surrounded that island were removed, restoring natural flooding. In 2004 the Danube flowed freely over the island (Figure 13.5). A guest house has been built to accommodate visitors, so you can one day visit this site for yourself. In 1994 and 1996, dikes were also opened in two former agricultural polders, Babina (2100 ha) and Cernovca (1560 ha), in Romania (Schneider *et al.* 2008). Monitoring has documented the recovery of a wide range of wetland species, as well as increased retention of nitrogen and phosphorus from the river. Seventeen major floodplain restoration sites have been identified along the Danube, as part of a larger plan to re-create a green corridor along the river (World Wildlife Fund 1999).

13.3 More on principles of restoration

Now that we have explored three examples of wetland restoration let us take a step back and look more closely at the underlying principles.

13.3.1 What does the word restoration really mean?

The word restoration is often carelessly used to mean many different things. A word that means too many things often seems to end up meaning nothing. Hence, let us use the word precisely, guided by Figure 13.6. We start at the upper left, with the original state of the system, which could also be termed a pre-perturbed system, or in some circumstances, a natural or pristine system. One or more forces has damaged (rapid change) or degraded (gradual change) the site (first solid line) so that the present state is different from this original state. So starting from the present state, what are the options? There are four. The most obvious is that the system could degrade further (second solid line). Should humans intervene, they have three options shown by the dashed lines:

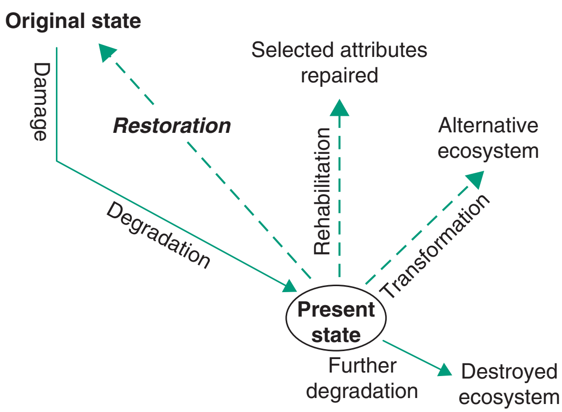

FIGURE 13.6 The present state of this system is degraded from its original state. There are several future states possible, and only one process should be called restoration. (After Magnuson *et al.* 1980; Cairns 1989; SER (2004) terminology.)

(1) Convert the site to an alternative ecosystem
(2) Repair certain selected attributes of the system
(3) Restore the site to its original state.

Hence, the term **restoration** means the action of returning an area of landscape to a specified previously occurring ecological state. Note the components. First, restoration has a specified target state, and second, there is evidence that this state existed in the past. Since there are so many terms used to describe human activities in wetlands, here are a few related to conservation and restoration, with restoration first for comparison.

Restoration Returning an area of landscape to a specified previously occurring ecological state. (Example: removing embankments to allow a river to annually flood a former wetland with the objective of recreating a wet prairie.)

Mitigation Purchasing or creating wetlands to compensate for damage being done elsewhere. (Example: paying for restoration of one cypress swamp to compensate for building a subdivision on another.) A legal rather than scientific term that is most commonly used in the United States of America.

Rehabilitation Making specified changes to an existing wetland in order to improve one or more services. (Example: a group such as Ducks Unlimited removes patches of cattails to create pools of open water for ducks and wading birds.)

Preservation Maintaining an existing highly valued wetland in its valued state. (Example: a group such as The Nature Conservancy purchases a set of vernal pools with the intention of keeping populations of endangered species at their current level.)

Creation Making a new wetland in an area where it was not previously present. (Example: making a pond in a city to attract wildlife. This could be called restoration if there are historical records of similar ponds there before the city was built.)

Conservation A general term that implies a wetland will be retained more or less green and wet but without specifying exactly how it will be managed. Often a group of stakeholders will be allowed to choose the future state. (Example: the Atchafalaya Swamp is still being heavily altered by humans but with the general agreement that it will remain a wetland.)

The more precise the restoration target or desired ecological state, the better. Thus, the goal "to create a nice wetland" is insufficient. A better goal would be "to create a wetland dominated by specific plant species to provide habitat for specific animal species." For example, in the Everglades, one could specify the goal of creating "a cypress prairie wetland with sheet flow of water through shallow ponds dominated by muhly grass (*Muhlenbergia capillaris*) and saw grass (*Cladium jamaicense*), and containing reproducing populations of apple snails (*Pomacea paludosa)* to support snail kites (*Rostrhamus sociabilis*)."

Although this is better, it is still vague. Consider. What will the rate of sheet flow be, and how will this vary among seasons? What will be the nutrient quality of the water? How many other plant species will coexist with the two dominant ones mentioned? Which ones will be planted and which ones will be expected to regenerate naturally? How many apple snails will be produced per year per hectare? Will there be suitable nesting habitat nearby for snail kites?

According to the definition above, restoring a site requires us to know what it was once like. We know that all systems change with time, even without human interference – specific examples you have already seen include the Great Lakes (Figure 2.4), peatlands (Figures 7.9, 7.11), the Everglades (Figure 4.6), and the Mississippi River delta (Figure 7.18). Humans are not the only cause of change, although human impacts are certainly increasing. We can learn about earlier states of wetlands from a variety of sources. There may be older scientific studies that we can use for reference, there may be information from pollen or sediment analyses, or there may be relatively pristine sites nearby. All of these may need to be used for evidence in order to decide what the original state of the system was.

Consider the Great Lakes again. Some 25 000 years ago the Great Lakes were filled with glaciers. The original state of the Great Lakes, for restoration purposes, is therefore usually considered to be the period before European humans arrived and began extensive changes to the environment through commercial fishing, dam construction, and deforestation. That would be roughly the 1600s. This of course, raises the legitimate question of to what extent the local ecosystems had already been modified by the earlier wave of immigrants across the Bering Strait – aboriginals also cleared land, burned forests, hunted, and fished. Overall, their impacts seem to have been much smaller. If, as seems to be the case, they also caused the extinction of much of North America's original megafauna (Figures 6.11, 6.12), their impacts may have been more widespread and significant (Janzen and Martin 1982). Hence, in asking which time one should choose for a restoration, there is no single entirely right answer. However, whenever you are involved in restoration, you should be aware of the available background information on the ecological history of the site, and at least show that you have considered these issues in choosing the restoration target. (If you have not, and there is a public hearing, someone will likely ask you to justify your choice, and thoroughly embarrass you if you have been too lazy to think it through first.)

In some, indeed, perhaps many, cases, there is doubt that one can restore a site. Key species that once occupied the site may be extinct. Since some Great Lakes fish species are now extinct (Christie 1974), food webs are bound to be different in restored wetlands. Other key factors that produced wetlands, like pulse flooding, sheet flow, herds of bison, or fire, may no longer be possible because of adjoining urban areas. In this case, we should use a word that does not imply the idea of re-creating the original system. Rehabilitation might be the appropriate word for such cases. Let us move from the Great Lakes to the Louisiana coastline. While working in Louisiana, I was surprised at how many people would talk about restoring the wetlands in the most vague way, apparently unaware that a restored wetland should have bison (now restricted to sites much further west), red wolves (now restricted to a few sites much further east), large alligators (now heavily hunted, with altered population size and size-class structure), no nutria (which were introduced in the 1930s), and enormous spring floods (now controlled by the presence of levees along the river). True restoration may be very difficult. That is not to say it is not desirable – there is no reason why a large-scale restoration could not occur. It is simply that real restoration would require changes including (1) reintroduction of bison and red wolves, (2) larger alligator populations, (3) extirpation of nutria, (4) large flood pulses, (5) filling canals and leveling spoil banks, and (6) allowing natural changes in river channels.

There is a third possibility shown in Figure 13.6. One may have to admit that restoration cannot be achieved, and even rehabilitation is doubtfully possible. Here, the best one can do is create an alternative ecosystem that is admittedly artificial. This system may have elements of the original natural system, such as selected plant and bird species, but could not be considered natural. Examples might include ponds on golf courses, cypress swamps used for treatment of freshwater sewage, or stormwater treatment ponds in subdivisions. This is not to downplay the importance of such sites in the landscape – the challenge is to make them useful to as many species as possible. But it is misleading to call them restoration.

Before one begins a restoration project, one has to know whether one is restoring, rehabilitating, or simply building a wet spot to treat sewage or store stormwater. They all have their place. But they should not be confused with one another. And in each case there should be specific goals stated in advance – as well as monitoring to ensure they are attained. Which brings us naturally to the topic of monitoring.

13.3.2 Monitoring

Monitoring consists of making predetermined measurements of selected physical or biological factors at regular intervals. Common factors to measure include water depth, dissolved nutrients, and number of calling amphibians or birds. The challenge in monitoring is to choose the minimum number of variables that will produce the maximum amount of information. It is actually a real scientific challenge to choose the correct variables. In physics, for example, we know that the essential variables for a system will usually include mass, pressure, volume, and temperature. We do not yet have a predetermined set of essential variables in ecology, but consensus is being reached on which factors it is useful to monitor – a topic we will return to in Section 14.8. Let us restrict ourselves here to the purpose of monitoring.

The basic objective of a monitoring program is to determine whether the objective of a project has been met. Is there a wetland? Does it have the desired composition? Without monitoring, it is impossible to decide whether or not restoration has occurred.

The second basic objective of a monitoring program is to provide an opportunity to correct emerging problems, that is, for adaptive environmental assessment (Holling 1978, Walters 1997). However well a project as been designed and thought out, problems happen. It may not even be related to the design of the project – perhaps the climate is changing or new invasive species are present. Adaptive environmental assessment allows one to change the restoration project while it is in progress to respond to unexpected events.

Table 13.1 **Five questions for monitoring and adaptive management**

(1) What are the ecological properties/indicators that should be measured to assess the integrity of the ecosystem? (Water quality? Primary production? Abundance of selected species?)
(2) What is the best way to measure these properties/indicators? (Size of sample units? Number of sample units? Distribution of sample units in space and time? Stratification procedures?)
(3) How will the data be collected, stored, analyzed, and shared? (Agency responsible? Instruments? Software? Backups? Type of analysis?)
(4) What are the acceptable ranges for each property/indicator? (Are there warning values that indicate unacceptable high or low levels? Are there long-term climate cycles or fire frequencies that must be taken into account?)
(5) What is the adaptive action if a property reaches a specified unacceptable level? (Who is responsible for making the decision? Who is responsible for carrying out the management?)

The ideal monitoring program, therefore, continues through time.

As a manager of a specific wetland, you may find that three of your most important duties are (1) monitoring, (2) interpreting the results, and (3) making adaptive changes to your management plan. Table 13.1 provides a list of the questions you need to ask yourself in designing an adaptive management plan. In Chapter 14 we shall look at some potential indicators.

13.3.3 When does restoration succeed?

It is easy to throw out the word success. It is quite another to define it clearly and measure it properly. Here is where some basic theory will help us think clearly about the situation. Returning to the definition of restoration above, one way to think about restoration is to ask what the composition of the original system was, and how it has been perturbed. There are good quantitative tools for doing so. A useful way to think about this draws upon the quantitative ecological technique of ordination (Bloom 1980). From this perspective, the original state, or the target state, can be defined by a set of samples described by a centroid and 95% confidence envelope. A perturbation is then defined quite specifically as a change that pushes the composition of the system outside of the envelope; restoration consists of changes that push it back inside this envelope. In Figure 13.7 the original composition is defined by the boxes and a centroid (dark dot).

Another approach that accomplishes the same goal is to use reference wetlands. These would be wetlands that have a long history of protection, perhaps wetlands surrounded by native vegetation and with a minimal history of human disturbance. The composition of the communities in these reference wetlands then illustrates the target area for restoration, the area inside the box in Figure 13.7. Indeed, one of the reasons for having a protected areas system is to provide natural areas that represent the original state of ecosystems to provide reference points for understanding the impacts humans are having upon the rest of the landscape. Maintaining such reference wetlands within a landscape requires a properly designed reserve system (Section 14.4).

Overall, restoration is an enormous challenge. There is much to learn. As we saw in Section 13.1, some restoration projects fail to even create wetlands! As we shall see in Section 14.4.1, even when wetlands are created, they continue to rank below natural wetlands when measured quantitatively (Mushet *et al.* 2002).

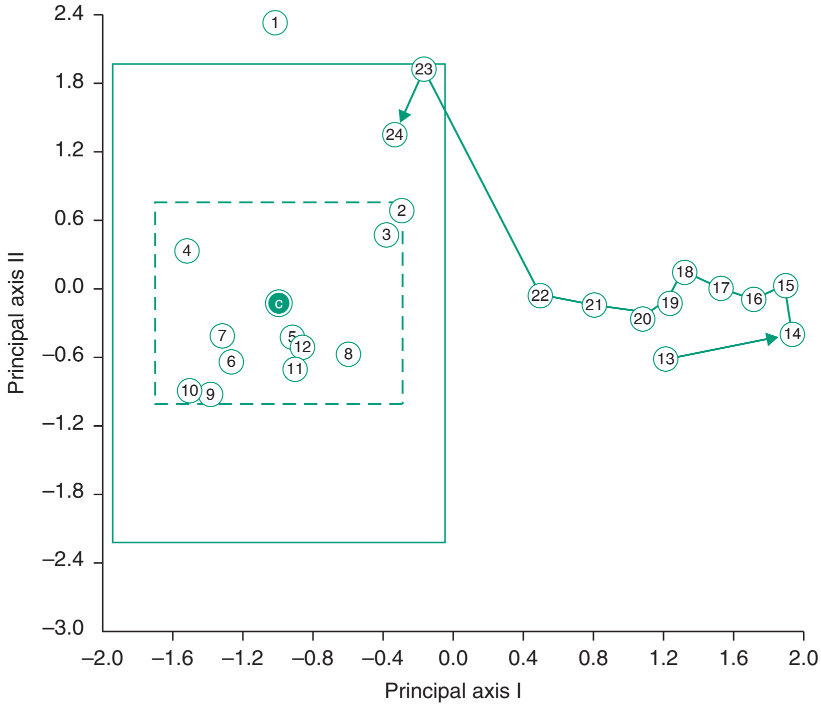

FIGURE 13.7 Defining and charting the recovery of a community after perturbation from a multivariate perspective. The data are from a benthic community, with sample units 1–12 before perturbation and sample units 13–24 after perturbation. The solid and dashed boxes represent two procedures for calculating a 95% polygon around the centroid (c) using parametric and non-parametric methods, respectively. (From Bloom 1980.)

13.4 More examples

We started with the proposition that it was easy to make a wetland. We then saw that it is not as easy at it seems, particularly if one has specific targets for the type of wetland community. This, of course, takes us back to the earlier chapters in the book where we saw how small differences in water level, nutrient status, or grazing can have a major impact upon species composition. This led us through the topics of monitoring and adaptive management, keeping a certain amount of flexibility so one can refine the management to help achieve the desired targets. Let us look at three larger examples of restoration where the challenges are rather more daunting. The first is restoring wetlands along a river in an area that has been densely populated for centuries. The second is restoring wetlands in a delta that has been degraded by multiple human impacts. The third is rebuilding wetlands where the original system has been entirely removed.

13.4.1 Yangtze River

The Yangtze is the third largest river in the world, being 6300 km long and draining an area of 1.8 million km^2. The headwaters arise in the Himalayas of Tibet at an elevation of more than 5 km above sea level, and the river flows eastward to empty into the East China Sea at Shanghai (Figure 13.8). The headwaters have one of the world's largest high-altitude wetlands, Ruoergai, on the eastern edge of the Tibetan plateau, with 600 000 hectares of peat bogs, marshes, and meadows. One the way to the sea, the river passes through China's two largest freshwater lakes. And at the sea it has built a large delta with coastal marshes.

The Yangtze makes an interesting and important case history of how to reconcile human activity with wetland restoration. Consider. More than 400 million people live in this drainage basin, more than the

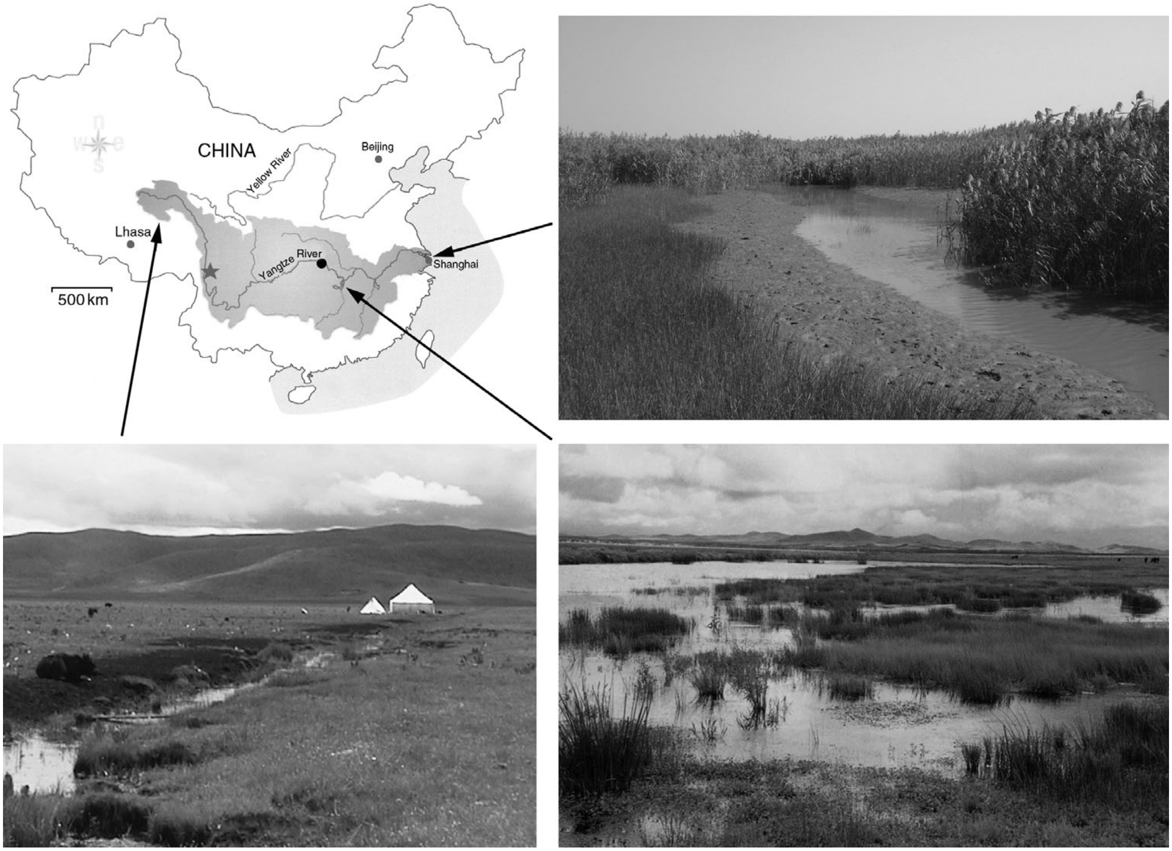

FIGURE 13.8 The Yangtze River is the third longest river in the world. It begins in the highlands of Tibet, amidst some of the world's largest high-altitude peatlands (Ruoergai peatland, bottom left; courtesy Wetlands International). Here it also flows through mountains which comprise one of the world's biodiversity hotspots, the mountains of Southwest China (star, top left). Further east it passes through large lakes such as Dongting Lake (lower right; from www.hbj.hunan.gov.cn/dongT1/default.aspx). Where it enters the sea there are large deltaic wetlands (top right; courtesy M. Zhijun). The world's largest dam, the Three Gorges Dam (Fig. 2.21), is indicated by the black dot (top left). (See also color plate.)

entire population of the United States of America. The basin has also supported human populations for millennia. There was conversion of wetlands for agriculture as early as the "Southern Song" dynasty (AD 420–479). But in the Communist era reclamation reached unprecedented levels. From 1950 to 1980, 12 000 km^2 of lakes and wetlands were impoldered along the Yangtze (China Development Brief 2004). The basin contains the two largest freshwater lakes in China, Dongting Lake and Poyang Lake. And, like the rest of the world, the Yangtze faces problems created by megaprojects like the Three Gorges Dam.

Let us look in particular at the two freshwater lakes. The value of these wetlands is illustrated by their rich biodiversity – 300 bird species, 200 fish species, 90 reptile species, and 60 amphibian species. A few noteworthy examples include Yangtze dolphin (*Lipotes vexillifer*), Yangtze alligator (*Alligator sinensis*), Chinese sturgeon (*Acipenser sinensis*), and white-naped crane (*Grus vipio*). Water levels in the

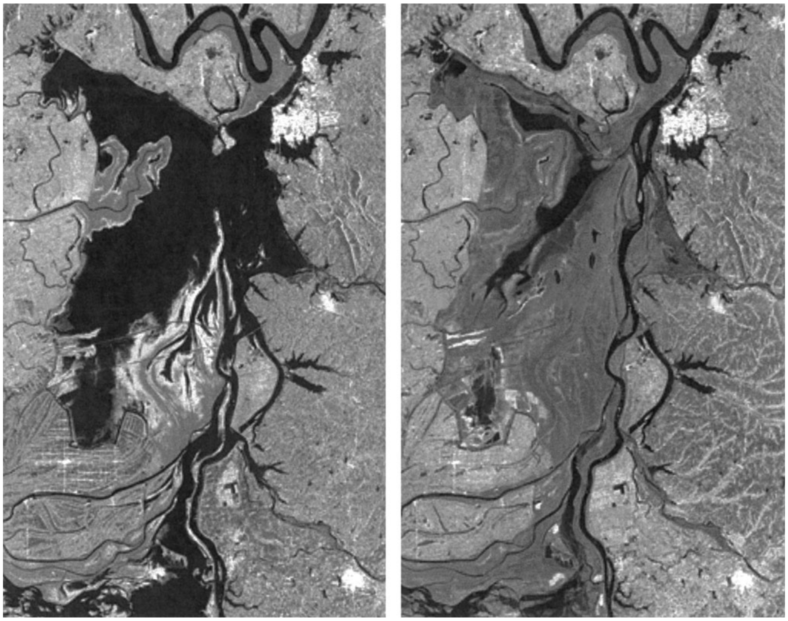

FIGURE 13.9 The water levels in Dongting Lake, the second largest freshwater lake in China, change from high (left, July 2006) to low (right, October 2006) depending upon inputs from the Yangtze River. (Courtesy Institute of Space and Information Science, Chinese University of Hong Kong.)

lakes fluctuate (Figure 13.9). During summer flood period, the marshes become open water with villages occurring on islands; flood levels are highest during El Niño events. Large areas of wetland around both lakes have been converted to agriculture (a process termed impoldering: Zhao and Fang 2004). Since impoldering reduces the capacity of the lake to accommodate floodwaters, the result has been increased flood levels, with catastrophic flooding in 1998 (Shankman *et al.* 2006). In Dongting Lake, the rate of conversion to agriculture was high between 1920 and 1970 (Zhao and Fang 2004). Hence, as one of its conservation priorities, the World Wildlife Fund has set the specific target of restoring the wetlands of Dongting Lake to the 4350 km^2 extent they occupied in the 1950s. Note the date, here. Earlier in the chapter, we addressed the issue of what time in the past should be the reference point. The 1950s may provide a practical target, but clearly one that is far from the original state of this landscape.

Consider the example of the Quinshan Polder, built on the edge of Dongting Lake in 1975 (China Development Brief 2004). This polder required 30 000 laborers in Hunan Province to invest around 1 million working days shoveling earth and rubble to create a system of dikes to turn 11 km^2 of lake into agricultural land. Although the soil in the polder was composed of fertile silts, the labor costs to maintain the embankments were so high that agricultural return from crops such as rice was in fact marginal. In 2003 the dikes were opened to reflood the land. This required relocating 5700 people, some of whom farm in other polders or now fish in the newly flooded area. The area has also been included within the Muping Hu Nature Reserve. Thousands of waterbirds have now returned.

13.4.2 Breeching levees with engineered control structures: Louisiana

The next example comes from Louisiana. As with the Danube River, the Mississippi River has been bordered by many levees to control flooding. These levees also prevent water from flowing overland, and thereby prevent spring flood pulses from carrying fresh water, sediment, and nutrients into adjoining swamps and marshes. Simultaneously, the wetlands along the river, particularly in the delta, have been

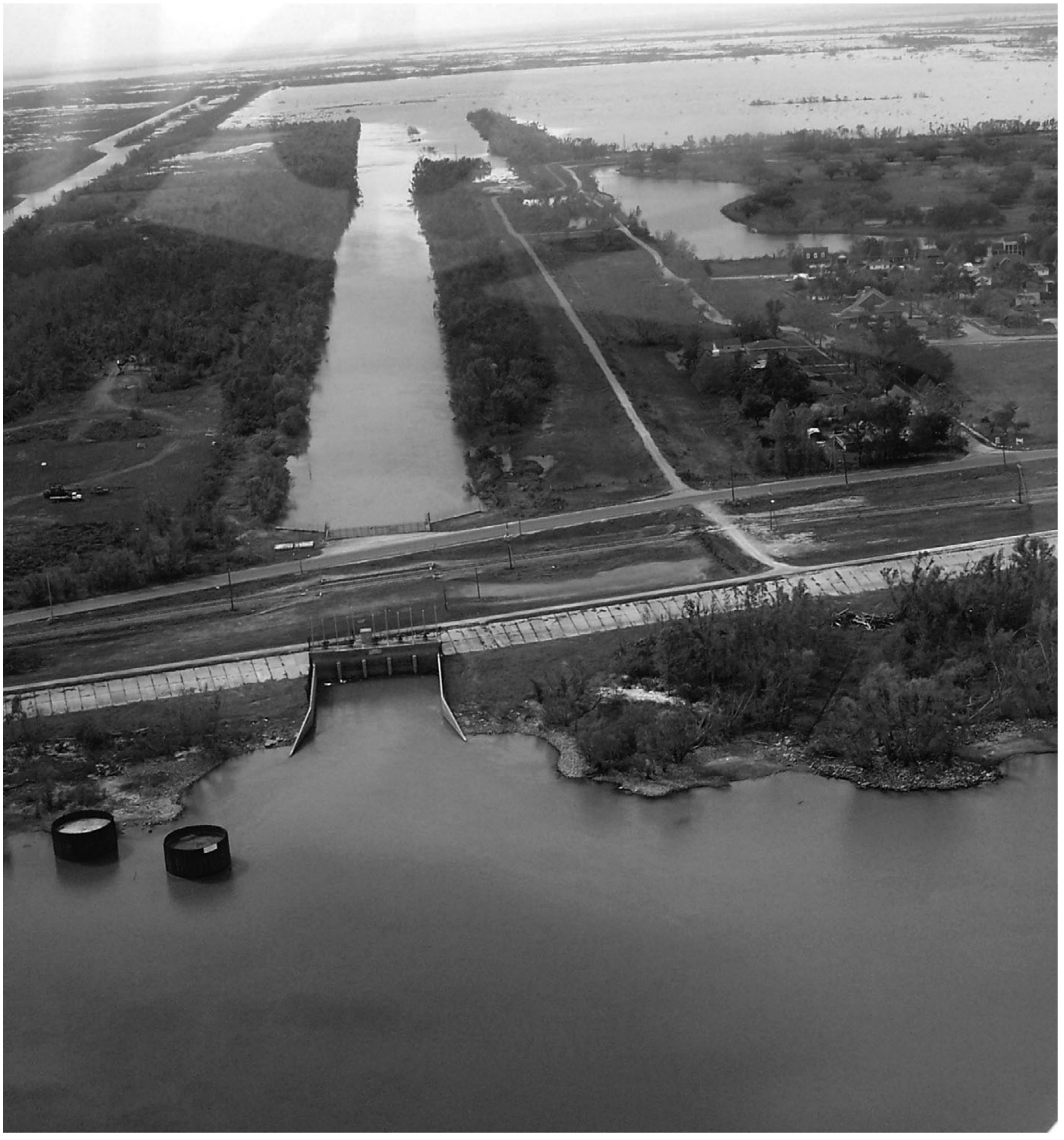

FIGURE 13.10 The Caernarvon Diversion structure on the Mississippi River allows floodwaters to pass through an artificial levee and enter the wetlands of Breton Sound in the distance. (Courtesy J. Day.) (See also color plate.)

crisscrossed by canals built for shipping, logging, and the oil and gas industry. As a consequence, vast areas of swamp and marsh are slowly becoming open water.

The problems caused by levee construction are exhaustively documented, but owing to human fears of flooding, few levees have been removed. The Caernarvon Freshwater Diversion Project was an early attempt to breach the levee to allow floodwater to pass into marshes of Breton Sound, while at the same time maintain complete human control over the water (Figure 13.10). Here is a summary of the project

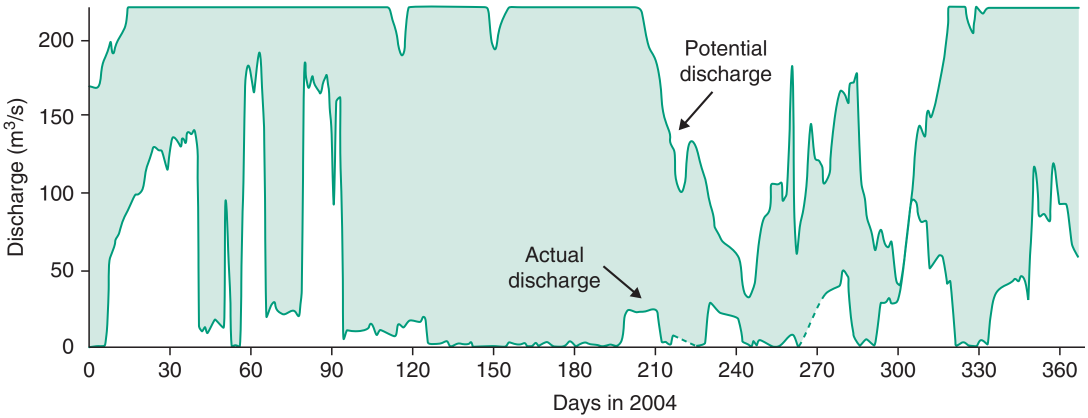

FIGURE 13.11 Actual discharge and potential discharge through the Caernarvon Freshwater Diversion Project in 2004. (Courtesy J. Lopez.)

from a website maintained by the Louisiana government.

The project consists of a diversion structure containing five 15-foot square gated culverts and inflow and outflow channels. The design discharge is 8,000 cubic feet per second; however, the actual amount of diverted flow depends on a detailed operational plan. The Corps of Engineers constructed the project and the Louisiana Department of Natural Resources is responsible for its operation. The Caernarvon Interagency Advisory Group consisting of 14 representatives of federal and state agencies, fisheries, and landowners provides overall operational oversight. Construction was completed in February 1991 at a cost of $26.1 million. The federal share was 75% of the costs and the State of Louisiana's share was 25%. (www.lacoast.gov/programs/Caernarvon/factsheet.htm)

Although this project was far more expensive than the Tataru Island project, and far more technologically sophisticated, it seems to have accomplished, at best, more or the less the same objective of breaching a levee to allow spring flood pulses from a river to rejuvenate adjoining marshes.

Remarkably, large construction projects have another problem – they are subjected to human interference. Far from allowing normal flood pulses, continual political interference actually has greatly restricted the flow of spring floodwaters from the Mississippi River through the Caernarvon Diversion. Indeed, at a recent meeting I attended, it was clear that the flow regime was not only much below capacity, but when pulses did occur, they were often at entirely the wrong season. Naturally I enquired why such a thing would be allowed, and was told that a mélange of complaints from hunters, fisherman, boaters, and local landowners had produced this highly artificial flow regime. Figure 13.11 shows the flow regime encountered in 2004; superimposed upon this is the flow regime that would have resulted if the structure were operated wide open. Thus, from the point of view of the wetland, the expensive control structures had actually produced a less desirable result than if the levee had simply been gapped by a bulldozer.

Problems such as these raise many questions about the value of highly engineered solutions to wetland restoration. Since so much money is being invested in building, running and monitoring such projects, the U.S. Environmental Protection Agency hired a scientific committee to review their utility. After reviewing projects around the United States, they submitted their report in 1998. Their conclusions? The first two (Sanzone and McElroy 1998, p. iii) were:

> The collective experience around the country has shown that unintended, unanticipated, and sometimes undesirable effects have resulted from structural management of marsh hydrology. Although marsh management practices have evolved over the years to include more sophisticated structures and management approaches for controlling water levels, there is insufficient information at present to determine whether these new structural approaches are inherently better than those used in the past.

More generally, they concluded (p. 42), a structure

> generally restricts the supply of mineral sediments needed to accrete soil, does not seem to protect wetlands, and may even hasten their demise. There may be a better case for the application of SMM [Structures in Marsh Management] in protecting tidal freshwater wetlands with highly organic or even floating soils. However, critical scientific appraisals of the effectiveness of SMM in such environments have yet to be performed.

So, we have started with the idea that it is easy to create a wetland, and ended with the conclusions that in many cases, high-profile technological solutions have not been demonstrated to work effectively. Why should such a simple process end in ambiguity? One is reminded of the Scottish poet Robert Burns, who wrote in 1785 a poem titled “To a Mouse”: “The best laid schemes o’mice an’ men, Gang aft a-gley” (that is, the best laid plans frequently fail). Or, the more recent Murphy’s law – if something can go wrong, it will.

13.4.3 Prairie potholes

An extreme case of the challenge posed by restoration is re-establishment of prairie pothole wetlands in areas that have been drained and sown to row crops for at least 25 years. Galatowitsch and van der Valk (1996) examined the success of an entire set of such restoration projects. From a total of 62 restoration projects, ten were selected on hydric soils that had been tile drained and completely cultivated for corn and soybeans for 25–75 years. That is, in each of these sites, restoration involved re-creation of a wetland where it had been absent for decades and where there was little reason to expect any residual seed bank. Given the importance of hydrology as a controlling factor or filter in the establishment of wetland communities, it might seem reasonable, at least as a first approximation, to assume that appropriate hydrology alone would re-establish wetlands. Perhaps steps as simple as plugging drainage ditches or removing tiles would suffice. In a comparison of ten “restored” wetlands to ten adjacent natural wetlands, the natural wetlands had a mean of 46 species compared to a mean of only 27 for the restored wetlands. Further, there were differences among functional groups; the restored sites had more species of submersed aquatics, but fewer species of sedge meadows. The seed banks of the communities also differed; natural sites had nearly twice as many species (15 vs. 8) and more than twice as high a density of buried seeds (7300/m^2 vs. 3000/m^2). Submersed aquatics, wet prairie and wet meadow species were all absent from the seed banks of the restored wetlands. Even the zonation patterns of individual species differed between the restored and natural sites. Galatowitsch and van der Valk propose the term “efficient-community hypothesis” for the view that vegetation will re-establish itself rapidly after hydrology has been restored, and reject this hypothesis as a reasonable basis for restoration in prairie potholes. Part of the explanation may lie with rates of loss of wetland seeds; both seed densities and species richness decline with the duration a wetland has been drained. After 50 years, seed densities are $<$1000/m^2 (compared with 3000–7000/m^2 in natural sites) and species richness is three species (compared with 12 in natural sites) (van der Valk *et al.* 1992).

There is also evidence that aquatic invertebrates are under-represented in restored wetlands (Galatowitsch and van der Valk 1994). Species with poor dispersal capabilities will likely have to be reintroduced during restoration in order to re-establish the original ecological communities.

13.5 One big problem: invasive species

While the example is fresh in our mind, let us use the Everglades to introduce this widespread problem, a problem that increasingly is likely to obstruct the best intentions of restoration ecologists.

The invasion of exotic species is a global problem. In the book *Ecological Imperialism* (Crosby 1993, p. 7) we read:

> On the pampa, Iberian horses and cattle have driven back the guanaco and rhea; in North America, speakers of Indo-European languages have overwhelmed speakers of Algonkin and Muskhogean and other Amerindian languages; in the antipodes, the dandelions and house cats of the Old World have marched forward, and kangaroo grass and kiwis have retreated. Why?

Why? is the all important question. While it seems obvious that some species possess traits that allow them to invade other areas successfully, we are still unraveling what these traits might be. Meanwhile the list of exotic invasive species continues to grow. Wetlands provide many examples. In North America, the list of exotic invasive species impacting wetlands includes plants (purple loosestrife, *Lythrum salicaria*; water hyacinth, *Eichhornia crassipes*), mammals (nutria, *Myocastor coypus*; wild boar, *Sus scrofa*), invertebrates (zebra mussels, *Dreissena polymorpha*; quagga mussels, *Dreissena rostriformis*; Charru mussels, *Mytella charruana*), fish (northern snakehead, *Channa argus*; common carp, *Cyprinus carpio*; bighead carp, *Hypophthalmichthys nobilis*), toads (cane toads, *Bufo marinus*), and even snakes (Burmese python, *Python molurus*).

For restoration purposes, it is important to distinguish between two similar definitions, an exotic species and an invasive species.

An **exotic species** is one that did not naturally occur in a specified geographical area. Historical records often allow us to document which species naturally occurred in an area, and which arrived after Europeans began to alter the landscape, and this is noted in many identification manuals. Archeological investigations can provide good evidence on which species were present, or at least being harvested, hundreds of years ago.

Note the phrase "specified geographical area." A species might be exotic in all of North America (e.g. the melaleuca tree, introduced to Florida, but native to Asia). Or a species might be native in one state or biogeographical region, but exotic nearby. In general, it is best to try to always obtain locally grown restoration material from local seed sources to avoid such problems.

An **invasive species** is one that has the potential to rapidly spread and replace native species. Many of the most dangerous invasive species are also exotic. However, some apparently native species have the capacity to dominate wetlands. Examples include *Typha* species, *Phalaris arundinacea*, and *Phragmites australis* (Zedler and Kercher 2004). The most invasive cattail, however, is a hybrid known as *Typha* × *glauca*. If you are planning a restoration project, you must consider not only the possibility of exotic species dominating the site, but also the possibility that unwanted native species may quickly invade and dominate the project.

Invasive species, exotic or native, may already be present in the landscape as buried seeds, waiting to invade a newly created wetland. They may arrive on machinery used in building the wetland. They may arrive with nursery stock used in planting. They may arrive attached to visitors or their boats. They are already a problem in many wetlands, and they promise to be an ever larger problem in the future. Let us continue to use the Everglades as the study system.

Melaleuca (*Melaleuca quinquenervia*) is an evergreen subtropical tree that is both exotic and invasive in the Everglades; it was intentionally introduced to Florida (Ewel 1986). Melaleuca is native to coastal lowlands in Australia, New Caledonia, and New Guinea where it forms open nearly monospecific stands that burn regularly. It was introduced to Florida on multiple occasions, and seeds were even spread from airplanes as part of a deliberate attempt to afforest the Everglades (Dray *et al.* 2006)! One of the early proponents of its introduction (although not the first) was Dr. John Gifford, the first American to hold a doctorate in forestry:

As a bank official, nurseryman, and land-development company entrepreneur, Gifford quickly joined the drainage movement to reclaim the Everglades. His primary interest was experimentation with introduced trees that would absorb water and dry up the south Florida wetlands. In 1906, Gifford introduced the cajupet melaleuca, an Australian native, to Florida, planting seeds at his home on Biscayne Bay and at a nursery in Davie, Broward County. (http://everglades.fiu.edu/reclaim/bios/gifford.htm)

Once established, melaleuca tolerates extended flooding, moderate drought, and some salinity on almost any soil in South Florida. By 1920 it had begun to spread. Melaleuca has flaky outer bark and oil-laden foliage which burn readily, and within weeks of a fire can flower and produce serotinous capsules each with about 250 tiny seeds. A single burned melaleuca can produce millions of seeds.

To explore its potential as an invasive species, Myers (1983) introduced some 22 000 000 seeds into six mature communities and two disturbed communities, finding that germination was only 0.01% in mature communities, but an order of magnitude greater at 0.14% in disturbed communities. If one bypassed the germination phase using out-planted seedlings, melaleuca also had much higher survival in disturbed communities (ca. 90% survival) as opposed to native communities (ca. 25% survival). Disturbance seems to be an important prerequisite for establishment. This need not seem surprising, since disturbance is also essential for many native species to flourish, creating the gaps in which seedlings can establish (Section 4.4). Everything from digging ditches to building impoundments may create ideal conditions for invasive species to establish. Even simple features like access roads can be dangerous to the native flora.

In habitats where disturbances are natural, invasive species may have regular opportunities for invasion. Both fire and fluctuating water levels provide disturbance essential for the maintenance of plant diversity in southern Florida (Figure 4.6), and this may provide added invasion opportunities for species such as melaleuca. There is much ongoing study of control methods for melaleuca (e.g. Ewel 1986; Mazzotti *et al.* 1997; Rayamajhi *et al.* 2002; Serbesoff-King 2003). But the species now occurs some 200 000 ha (500 000 acres) of South Florida. In other areas, the species may still be absent because of low seed mobility. Therefore, Ewel (1986) suggests that resource managers might be well advised to concentrate on eliminating seed sources nearest the pine–cypress ecotones into which melaleuca is pre-adapted to spread. Once the species is well established, such as in areas of the Everglades, both fire and herbicide can be used to control melaleuca. Prescribed burns remove the trees from a large area, but a potential problem is that melaleuca debris produces hot fires that may damage organic soils (Mazzotti *et al.* 1997) and stands can re-establish from seeds or sprouts (Turner *et al.* 1998). Herbicide is particularly effective at more local scales, although costs are in the order of $400/ha ($1000/acre). Since 1995, the South Florida Water Management District alone has spent more than $2 million a year on melaleuca control (Laroche and Baker 2001). Biological control by insects is also being explored. Likely a combination of all of these will be necessary to obtain control (Turner *et al.* 1998). It is not yet clear whether we can reasonably hope for melaleuca removal (its extermination from wild areas) or merely control (keeping it at relatively low levels through repeated intervention).

There are new species arriving continually. *Lygodium microphyllum* (Old World climbing fern) began spreading in the 1960s. This species can create a leafy covering up tree trunks and into the canopy – changing the shading regime, smothering trees, and most importantly, increasing the frequency and intensity of fire (Pemberton *et al.* 2002; Wu *et al.* 2006). Moreover, it can spread long distances by microscopic spores to colonize newly disturbed sites.

Not all invasive species are exotic species. Several species of cattails (*Typha* spp.) are native to North America, although there is still some debate about their origins. They have been historically absent from many types of wetlands. As a consequence of recent changes in the environment of the Everglades, *Typha* has now been able to invade and replace the native *Cladium jamaicense* (saw grass). From the air one can see how plumes of invading cattail now appear to track where nutrients flow into the Everglades from agricultural areas. There are several hypotheses that might account for this invasion. Nutrients are the most likely cause, but there have also been significant changes in hydrology over the years. Perhaps there is some interaction of factors, say increased standing water combined with increased nutrient levels. Nor is the list limited to these two factors, since other factors such as changes in fire frequency might also be contributing to this invasion. Hence, this is a perfect example of the need to consider multiple hypotheses that might explain an observed change, and then devise tests among them (e.g. Newman *et al.* 1996, 1998). One can then respond intelligently. In the northern Everglades, for example, it appears that increased phosphorus is the first factor, and then changes in hydrology or fire come next, depending upon the area studied (Newman *et al.* 1998). Current work in the Everglades strongly suggests a predominant role for nutrients as the cause, and time will tell whether the planned reduction in phosphorus loading to the Everglades will be sufficient for saw grass to displace the cattails. The possibility that herbicides or fire might accelerate the conversion back to saw grass is also being explored.

The role of cattails is complex. As well as being a visible invasive species, cattails are also an indicator of changes in many other species, particularly in the distinctive periphyton (comprising more than 100 species of diatoms, cyanophytes, and green algae) and other species dependent upon this unusual Everglades trophic group such as roseate spoonbills and wood storks (Gottlieb *et al.* 2006). Hence, one has to think about this problem carefully: when we talk about cattail invasion, are we referring simply to the presence of a single unwanted species, or are we referring to the complex ecosystem changes that are occurring as indicated by the presence of this species?

The case of cattails in the Everglades illustrates a more general problem with cattail invasion elsewhere. As we saw in the chapter on competition (Chapter 5), clonal species with dense canopies can exclude many other native species from wetlands, and the centrifugal model (recall Figure 5.11) illustrates the catastrophic effects this can have on plant diversity, and upon organisms that require open conditions. The impacts of invasive species – including everything from trees like melaleuca to floating plants like water hyacinth (Figure 13.12) – will continue to complicate attempts at restoring natural habitats and protecting threatened species.

13.6 A brief history of restoration

Ecosystem restoration is the process of re-creating an ecological community (e.g. Cairns 1980; Jordan *et al.* 1987; Dahm *et al.* 1995). It is "an emerging profession within the science of ecology" (Bonnicksen 1988). It is attracting billions of dollars and producing an enormous stream of published

papers. While it is true that the field is growing rapidly, we should not fall into the trap of saying that restoration is somehow entirely "new." Bonnicksen, like many other writers in this field, only traces the roots of restoration ecology back as far as Aldo Leopold in 1949.

More than a decade earlier, however, Clements (1935) wrote an essay titled "Experimental ecology in the public service" in which he described the applications of ecology to a wide range of applied problems. He referred to the need for "natural landscaping" (p. 359) and laid out its basic rules:

The chief of these is that nature is to be followed as closely as possible and hence native materials alone are to be employed, preferably from the outset but

> invariably in the final composition . . . The process of succession by which nature reclothes bare areas is to be utilized as the chief tool of landscaping, but the process is often to be hastened or telescoped to secure more rapid and varied results. (p. 360)

Clements even noted the need for indicators:

> a necessary adjunct is the use of indicators to record existing conditions and their gradual change into grazing communities of the desired composition and yield. (p. 353)

The history of restoration pre-dates Clements, too. Half a century before Clements, in 1883, Phipps wrote a book on the restoration of forests, and Larson (1996) has described what appears to be one of the earliest practical restoration projects in North America, the replanting of a forest in a gravel pit near the University of Guelph by Professor William Brown, an arboriculturalist from Scotland. In Beard's classic book on the vegetation of the Caribbean islands (Beard 1949), there is also a discussion of forest restoration activities in the early 1900s. In wetlands, the use of *Spartina angelica* for "reclamation" of coastal mud flats was also of interest early in the last century (Chung 1982). In the 1930s, the British blocked drainage ditches and used portable pumps to raise water levels in the Woodwalton Fen (Sheail and Wells 1983).

There is no need for us pretend that restoration is something entirely new to human thinking. We should know something about the historical origins of our scientific discipline. Indeed, it is vital that we learn from past mistakes. What may be new is the scope of the projects and the number of people involved in them.

Currently, restoration ecology has one important potential benefit to the history and development of ecology. This is the potential to bring together a wide range of scientific activities. It challenges conservationists, applied ecologists, and theoreticians in different ways. Conservationists are challenged to shift some energy from protecting remnant fragments of habitat toward the longer-term goal of restoring and reconnecting entire landscapes. The Wild Earth proposal for North America (Wild Earth 1992) is one example. There is now the Society for Ecological Restoration International too. Applied ecologists are being challenged to move from manipulating single species, such as a few species of fish or waterbirds, to the reconstruction of entire ecosystems. Theoretical ecologists are challenged to develop practical tools to guide restoration and monitor its success with indicators.

CONCLUSION

We have covered a lot of ground in this chapter – from the author's own property in Canada to the Everglades to the Danube River to the Yangtze. All of these projects do have certain principles in common. You have seen, for example, that modifying hydrology and fertility can have enormous impacts, positive and negative. If you are going to be involved in restoration yourself, these examples also remind you of the importance of having *clear goals, realistic methods, measurable indicators, and feedback mechanisms (adaptive management).* Let us close this chapter by dealing with each of these in turn. We will spend more time on each in the final chapter.

If restoration is to succeed, it must first have a clear **goal.** This goal is most likely to be obvious if it can be shown as a single map illustrating the desired outcome of the project. Restoration cannot proceed without such a clearly articulated goal. One still sees too many maps of methods, rather than goals.

Maps of ditches, embankments, culverts, and so on are nothing more than a map of expenditures and methods. The map of outcomes shows predicted habitats accompanied by a list of desirable outcomes. If you have the task of evaluating a restoration proposal, looking for a clear statement of the goal is likely to tell you a great deal about the rest of the project. In the author's project (Figure 13.2) an explicit goal is to maintain the number of native species of breeding frogs. In the Everglades (Figure 13.3) an explicit goal is to increase the number of individuals and species of wading birds, both of which require creating wetlands with specific types of plant communities such as wet meadows.

There are many reasons to be careful to state our goals explicitly. First, it keeps us honest: what is it that we are trying to do? It is easy to throw around the word "restoration" without being clear about one's plans. Choosing the right plan requires us to know something about the natural world, and to approach restoration with an attitude of respect and modesty. How do we know if we are on the right track? "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." This statement by Aldo Leopold (*A Sand County Almanac*, 1949) could be a useful topic of contemplation while planning a restoration project. Being explicit about our goals forces us to think about whether what we are proposing to do is right – *sensu* Leopold.

A good restoration plan also has clearly laid out **methods** that we believe will enable us to achieve our targets. The tools of restoration (ditches, embankments, fires, planting) come into play only once we have set out the goal. Each tool should be aimed to achieve a specific outcome. Each stage of the restoration plan should address which causal factors are being manipulated, and what the projected outcomes are, based upon our best scientific knowledge. However, as noted above, often managers leap to methods before specifying targets. Targets must come first. Once we have decided, say, to reduce salinity in coastal wetlands in Louisiana, large freshwater diversions (Figure 13.10) are one of the methods we can apply. In advance of construction we must decide whether we want fresh water alone, or fresh water with sediment, and whether we will let the river dictate flow volumes or whether we wish to control flow volumes. Costs vary greatly among these methods. Often it may be much cheaper and more effective to simply remove levees as was done along the Danube (Figure 13.5).

To know whether we are making progress toward our goals we need measurable **indicators** and their target values. Thus, I have a list of expected species of frogs in my own wetland, and they will be monitored by listening for different mating calls. In the Everglades, a much more expensive monitoring program will track the abundance of wading birds. If certain frogs or birds do not appear, then something has gone wrong. If we set a target, and fail to meet it, we know something is wrong, and we can set about trying to fix it. We will therefore return to the topic of indicators in Chapter 14 to introduce some specific tools that you might use.

Once we have been explicit about our goals, objectives, methods, and indicators, we can proceed. If later experience shows that we have failed to meet our objectives, we can modify our methods, or even go back and question the validity of our targets. This is the period in which monitoring the indicators allows us to modify our management – **adaptive management.** In adaptive environmental management we anticipate that there are likely to be certain failures, and we have back-up plans to address them (Holling 1978; Walters 1997). There is a risk that adaptive management will be used to cover up ignorance and poor planning, of course – Holling himself was very clear that adaptive management did not give a license for simply messing around. But we also, as scientists, have to admit to failure – our knowledge of nature is imperfect. We must do the very best possible job under the circumstances, then modestly admit that failure is still possible – and be prepared for it.