Freshwater wetlands and water bodies

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Abstract and Keywords
This chapter discusses the management of open bodies of water and wetlands on seasonally or permanently waterlogged soil. It concentrates on freshwater habitats, but briefly discusses management of brackish habitats, such as coastal grazing marshes, where they form a continuum with freshwater ones. Topics covered include principles of manipulating water levels, water quality, methods of improving the value of deep water bodies (>1 m) and large, shallow (less than about 1 m) for wildlife; temporary pools, permanent ponds and water-filled ditches, rivers, swamps and fens, bogs, wet scrub, wet woodland, wet grasslands.

Keywords: bodies of water, wetlands, freshwater habitat, pools, ponds, rivers, swamps, fens, bogs, wet scrub

This chapter discusses the management of open bodies of water and wetlands on seasonally or permanently waterlogged soil. It concentrates on freshwater habitats, but briefly discusses management of brackish habitats, such as coastal...
grazing marshes, where they form a continuum with freshwater ones. Management of saltmarsh and other saline habitats is discussed in Chapter 9.

There is a wide range of often confusing terms used to describe types of wetland. Fens and bogs are waterlogged habitats, which differ in their main sources of water and associated nutrients. Fens are fed by groundwater and precipitation and described as minerotrophic. They typically contain relatively species-rich vegetation dominated by bulky monocotyledons and often tall, perennial, herbaceous forbs. Bogs receive the majority of their water and nutrients from precipitation. They are described as ombrotrophic. Fens tend to have relatively nutrient-rich and base-rich water, especially where they receive this from calcareous substrates. Bogs have low nutrient levels and acid conditions. There are, though, types of wetland that do not easily fit into these categories. Base-poor fens (known as poor fens) have a low pH, while some other fens receive nutrient-poor water. Bogs are always peat-forming, but fens can be either peat-forming or occur on mineral substrates.

There are two broad types of fen. These differ in their water movement. Fens with predominantly vertical movement are known as topogenous, whereas those with predominantly lateral water movement are known as soligenous. Bogs can be convex in shape (raised bogs; sometimes known as raised mires), relatively flat, or sloping.

The term mire is used to describe a range of usually peat-forming wetlands, including fens and bogs. Marsh is a term commonly used to describe waterlogged areas dominated by short grasses (i.e. wet grassland) or tall, bulky, monocotyledons such as common reeds (hereafter referred to as reeds) and bulrushes/cattails. Swamp has two different meanings. It is either used to refer to species-poor vegetation dominated by bulky, emergent monocotyledons on seasonally or permanently submerged substrates (i.e. in wetter areas than fens) or wetland vegetation dominated by trees and shrubs. In this chapter we use the first definition and discuss wet scrub and wet woodland separately.

Wet grasslands are those with a high water table and/or which hold surface water. They occur on soils with impeded
drainage, often in association with other low-lying wetlands. In areas of high rainfall, wet grasslands can occur at higher altitude and on slopes.

8.1 Principles of manipulating water levels
Management of wetlands for conservation commonly involves manipulation of water levels. This requires a basic understanding of hydrology, particularly of whether there will be sufficient water to achieve target levels, and, if not, the volume of additional water that would be needed of estimating these requirements are straightforward, although the detail can be complex. It involves calculating a water balance. This can be carried out for the site as a whole or, where relevant, separately for individual hydrological units; that is, areas that are hydrologically isolated from one another.

A water balance is based on the simple principle that the:

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\text{Change in quantity of water stored in a hydrological unit} = \text{the quantity of water entering the hydrological unit} - \text{the quantity of water leaving the hydrological unit}
\]

From this it is possible to estimate the change in quantity of water stored within the hydrological unit by estimating the quantities of water entering and leaving it. Because of seasonal variations in target water levels and inputs and outflows of water, water balances are usually calculated separately for different periods of the year. They are often calculated for each month, to determine during which periods of the year there will be an excess, or lack, of water.

The main ways that water can enter a hydrological unit are by:

- precipitation falling on it as rain, sleet, or snow;
- flow from watercourses; that is, through rivers, streams, and ditches;
- groundwater flow.

The main ways it can leave a hydrological unit are by:

- evapotranspiration comprising the combined losses of water to the atmosphere through evaporation from the soil surface and transpiration from plants;
• **drainage into watercourses** such as through rivers, streams, and ditches;
• **groundwater flow**, especially seepage to adjacent, drained land with a lower water table.

*(p.231)* Inputs of water through overland flow will usually be negligible. Rates of input and output of water will also vary between years. It is therefore usual to calculate water balances taking account of these annual variations and, for example, estimate the quantity of additional water that will be required to maintain target water levels in 75% of years.

In most temperate wetlands there is usually an excess of water in winter when precipitation is higher or similar to that in summer, but evapotranspiration is lower due to the cooler weather and lack of plant growth. In cold climates winter precipitation will be locked up as snow. Wetlands fed by snowmelt will tend to have high water levels in late winter and spring.

Water levels will fall in most wetlands through late spring to autumn as evapotranspiration rates increase and precipitation usually remains similar to, or is lower than, in winter. Where this is the case management will often involve minimizing losses of water to maintain suitably high water levels within the wetland, especially in small sites surrounded by drained land. Water loss can be prevented by installing dams and sluices into watercourses, constructing bunds, reducing seepage losses and providing additional water. When installing dams and sluices, it is important to consider their potential impediment to fish movement (Section 4.2.2). Seepage rates vary greatly depending on the porosity of the soil, which depends on soil type and structure. Seepage rates will be greatest on sands, gravels, and well-structured peat and lowest on poorly structured and compacted soils, especially clays.

Methods of reducing seepage losses include:

• increasing water levels on surrounding land (i.e. creating a buffer) to reduce the difference in water-table height between the wetland and surrounding land and thereby reduce the rate of flow of water from the wetland;
• installing an impermeable membrane or cut-off curtain down to as far as any impermeable soil.

Wetlands can also be designed so that water lost through seepage from one area feeds other areas of wetland habitat that require slightly lower water levels. Additional water for the wetland can be provided by:
• diverting inflows;
• abstracting water from elsewhere, particularly from watercourses;
• storing excess winter rainfall or water abstracted in winter in reservoirs for use in spring and summer.

Methods for avoiding use of poor-quality water when obtaining additional water are considered in the following section.

(p.232) 8.2 Water quality

Water quality is a complex subject. For practical site management, the most important aspects are the water’s nutrient levels and pH. Pesticide residues may also be an issue at some sites. Salinity is important in saline wetlands (Chapter 9). pH affects the flora and fauna, some species being typical of acidic, neutral, and base-rich conditions.

Nutrient levels are especially important, since they will affect plant growth and consequently the abundance and type of vegetation and its associated fauna. The two nutrients that most commonly limit plant growth in aquatic systems are nitrogen and phosphorus. If one of these is limiting, then increasing its quantity will increase plant growth. The process of increasing nutrient levels is known as eutrophication. Increasing levels of nutrients increases plant growth, favouring more competitive plant species typical of higher nutrient levels. At phosphorus concentrations above about 100 µg/l the water body may continue to support larger, submerged plants, or lose these and become dominated by suspended, microscopic algae (phytoplankton; see Moss et al. 1996). This process removes habitat for aquatic invertebrates and food for birds. It is, though, still usually possible to provide botanically poor shallow water habitat that is of high value for wetland birds using relatively nutrient-rich water. At very high trophic states (hypertrophic conditions), the water may become de-oxygenated and cause fish kills.
Eutrophication caused by artificially high levels of nitrogen and phosphorus is widespread in intensively managed lowlands. The main source of high nitrogen levels is run-off of nitrate from fertilizer application. Nitrate is highly water-soluble and leaches readily into watercourses. The main source of high phosphate levels is from treated sewage effluent. Phosphorus binds to colloids, such as clay particles, and is less water-soluble. It often occurs in high concentrations in sediment, which release phosphate into the water above. Because of widespread eutrophication, wetlands with low nutrient levels are rare and generally highly valued in most lowland areas, particularly for their nutrient-poor flora and associated invertebrate fauna.

Nutrient and pesticide inputs into wetlands can be minimized by avoiding poor-quality water. Nutrient levels in water inputs can be tested to determine whether they are within a tolerable range. Nutrient levels vary greatly over time, and with rates of water flow. It is necessary to take a minimum of six samples per year, and preferably more, to obtain a reasonable measure of nutrient levels. In practice, though, there is rarely any choice of water source, and a comparison has to be made between using nutrient-rich water and allowing the wetland to dry out. The only long-term solution for reducing nutrient levels entering wetlands is to reduce inputs of nutrients into their catchments.

Where water is abstracted from rivers for use in a wetland, the timing of abstraction can be adjusted to minimize nutrient inputs. Abstraction is usually only allowed when river flows are high. Nutrient levels in rivers will often be high when a period of dry weather is followed by heavy rainfall that leaches nutrients into it. Nutrient levels will also be high when periods of widespread fertilizer application are followed by heavy rain. It is therefore best to abstract in winter after nutrients have been flushed through. Storage of abstracted water in reservoirs might allow some phosphorus-rich sediment to settle out before the water is used to feed the wetland.

Inputs of nutrient-rich water are particularly damaging to wetlands otherwise fed by nutrient-poor, calcareous, or acidic groundwater. In small, isolated, groundwater-fed wetlands, lowering the substrate to raise the height of the water table
relative to its surface (Section 8.8.4) will be preferable to raising water levels using nutrient-rich water.

Nutrient levels in water within catchments can be reduced by:

- stripping phosphate from sewage effluent;
- reducing fertilizer inputs;
- minimizing leaching of sediment and nitrate into watercourses using vegetated filter strips-buffer strips.

The second two measures are incorporated into some agri-environment schemes and conservation programs aimed at reducing so-called diffuse pollution (Section 3.3). Vegetated filter strips-buffer strips consist of vegetated land beside watercourses. They trap sediment washed off cultivated fields and denitrify nitrate run-off before it reaches the watercourse. Vegetated filter strips-buffer strips do not retain phosphorus compound permanently, though. In general, the strips need to be a minimum of 30 m or so wide to significantly reduce sediment and nitrate inputs into watercourses (Hickey and Doran 2004). Vegetated filter strips-buffer strips can themselves be managed to provide good wildlife habitat.

There has been some success in removing nutrients from inputs of water using reedbed treatment systems and sediment traps to reduce phosphate, and by providing sacrificial areas of wetland to remove nutrients before the water enters more sensitive areas.

Attempts to reverse the effects of eutrophication in shallow lakes require first reducing inputs of phosphorus and/or nitrogen. Additional techniques may then be required to switch the phytoplankton-dominated flora into one dominated by vascular plants and stoneworts Charophyta. These include:

- removal of accumulated phosphate-rich sediment that would otherwise continually re-release phosphorus back into the water; *(p.234)*
- removal of zooplankton-eating fish (so-called biomanipulation) to increase densities of zooplankton that feed on the phytoplankton;
- reintroduction of submerged, vascular plants to provide refuges from fish predation for zooplankton. This may need to be accompanied by
protection of these plants from herbivorous wildfowl.

Restoration of shallow lakes is complex, and its success has been variable (e.g. Gulati and van Donk 2002). Moss et al. (1996) provides a good, practical guide.

Growth of algae and cyanobacteria (blue-green algae) can be controlled by adding barley straw (e.g. Everall and Lees 1997; Barrett et al. 1999). The straw should be held in loose bundles, nets, cages, or bags and, if necessary, attached to floats to prevent it from sinking to more than a metre below the surface. These bundles are commonly known as straw sausages. They should be applied twice a year, in early spring and autumn, at rates of between 10 and 50 g of straw/m² of surface water (see Centre for Ecology and Hydrology 2004).

8.3 Large, deep water bodies

The two principal methods of improving the value of deep water bodies (>1 m) for wildlife are by:

- making their margins shallower by infilling or including shallow margins in their initial design (Figure 8.1) to provide suitable conditions for emergent vegetation and other shallow-water plant species and associated fauna;
- providing islands or rafts for nesting waterbirds.

Fish ponds can be of high value for feeding waterbirds. The main way of increasing their value for birds is by ensuring they also contain suitable nesting habitat (Figure 8.2).

8.3.1 Islands and rafts

Islands for nesting waterbirds can be created during excavation of water bodies or created in shallow water by deposition of material. The islands can be covered in shingle to provide a suitable substrate for open-ground nesting species, especially terns, and plovers. Coating islands with cockle shells (a by-product of the cockle industry) can be used to encourage nesting terns. In the absence of management, though, islands usually become increasingly vegetated. This will improve their suitability for nesting wildfowl, but make them less suitable for these open-ground nesting species.

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One technique for helping maintain open conditions on islands is to design them so they are covered by water in winter and exposed by falling water levels immediately prior to nesting. The flooding helps rot down and disperse vegetation that has grown on them.

Where winter flooding is not practical, vegetation growth can be reduced by covering islands with sheets of geotextile for weed and root control, and then covering this with shingle or other inert material. The geotextile prevents plants from extending their roots deep into the more nutrient-rich substrate below the shingle. However, where large numbers of birds are present, particularly roosting flocks, geotextile sheeting can encourage vegetation establishment by trapping nutrient-rich bird faeces in the surface layer of shingle above it. It can similarly trap silt within the shingle when flooded by high water levels.

Vegetation that becomes established in islands can be removed by cutting, hand-pulling, and burning. However, once sufficient organic matter has accumulated.

Fig. 8.1 Shallow margins. The value of otherwise deep water bodies such as gravel pits can be enhanced by including shallow margins and pools around their edges.

The open, silty margins of these gravel pits support a distinctive beetle fauna comprising many species that are rare in this region. These open margins often become colonized by taller vegetation including scrub and trees, and it can be difficult to maintain their open nature in the long term (Dungeness, Kent, England).
within the shingle or other inert material, even vegetation removal before and after the nesting season may be no longer sufficient to maintain open-enough conditions as vegetation regrows during the breeding season. In these situations the only option to maintain open conditions is to re-excavate and/or re-coat the islands with shingle or other suitable material. Sometimes, just replacing the surface substrate with material excavated from below can re-create suitable conditions. Islands low enough to be flooded during winter are likely to suffer from erosion, particularly in larger, deeper water bodies, and require periodic re-building.

Even if surrounded by deep water, birds nesting on islands can still be subject to severe predation by mammals that can swim out to islands. Mammalian predators can be prevented from

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Fig. 8.2 Fish ponds. These can provide important habitat for waterbirds, particularly fisheating species that prey on both commercial and non-commercial fish in them. The value of fish ponds for breeding waterbirds can be increased by allowing emergent vegetation to grow around their margins to provide nesting habitat. These fish ponds support high densities of breeding great bitterns, *Botaurus stellaris* (Beloe Fish Ponds, Gomel Region, Belarus).
reaching islands by surrounding them with underwater fencing (Figure 8.3).

Islands can be difficult to construct in deep water. Nests on low-lying islands can be vulnerable to flooding on water bodies with fluctuating water levels.  

An alternative method for providing nesting areas for terns is by using anchored nest rafts covered with shingle or other suitable material (see Burgess and Hirons 1992). The rafts need to have raised sides to prevent chicks from falling into the surrounding deep water. Approximately a quarter of Scotland’s breeding Arctic loons, *Gavia arctica*, nest on specially constructed, floating rafts. Raft-nesting Arctic loons have far higher productivity than those using natural nest sites, which are often flooded (Hancock 2000).

8.4 Large, shallow water bodies

Large, shallow (less than about 1 m), nutrient-rich water bodies are very productive habitats and can be of particular importance for waterbirds. Water levels in large, shallow, nutrient-rich water bodies can be manipulated, sometimes in combination with other forms of management, to:

- increase food supply for waterbirds by periodically drying out water bodies and using moist-soil management to increase supply of seeds for wintering wildfowl;

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- provide shallow-water, mud, and open marginal habitat to increase the accessibility of food for waders/shorebirds, herons, egrets, wildfowl, and other waterbirds and provide suitable habitat for marginal plants and invertebrates;
- alter the relative proportions of open water and emergent vegetation.

In addition, nesting islands can also be created and managed for birds as described in Section 8.3.1. Using water levels to manipulate the proportions of emergent vegetation and open water and the effects of other management on emergent vegetation is discussed in Section 8.8.2. Eutrophication is an issue in many shallow, lowland lakes (Section 8.2).

8.4.1 Increasing food supply for waterbirds: moist-soil management

Seeds are an important source of food for many wildfowl species in winter. The abundance of suitable seeds can be increased by lowering water levels in spring and summer to provide moist mud for prolific, seed-producing annuals and other valuable wildfowl food plants to germinate and grow on. Some important wildfowl food plants also germinate in very shallow water. Lowering water levels is known as a drawdown. These seeds can be made available to wildfowl by re-flooding in autumn. This technique is known as moist-soil management (Smith and Kadlec 1983; Haukos and Smith 1993; Figure 8.4).

Following the initial drawdown the soil needs to be kept moist to maintain suitable conditions for germination and growth of desirable wetland plants and to discourage unwanted dry-ground plants. Areas may subsequently require subsequent irrigation during the summer to keep them suitably moist.

Invertebrate biomass tends to be highest in early successional (i.e. recently flooded) wetlands (e.g. Danell and Sjöberg 1982). This is attributed to high overall productivity fuelled by release of soluble nutrients from freshly inundated soil and decomposition of flooded terrestrial vegetation, and low levels of predation by predatory invertebrates and fish. As the wetland matures, nutrients released from decaying terrestrial plant material decline, numbers of predatory invertebrates and fish increase, and total invertebrate biomass tends to decline. Invertebrate biomass in shallow water bodies can therefore be increased by periodically drying them out and re-flooding them. Drying out will also kill any fish. Re-colonization by fish following re-flooding is usually
accompanied by high levels of recruitment of small fish of suitable size for feeding herons, egrets, and other birds.

The most important factors affecting the vegetation that establishes, other than the composition of the seedbank, are the timing and rate of drawdown. The (p.239) timing of drawdown will affect the composition of the vegetation and of desirable seed-producing plants. Drawdowns are usually referred to as being early, mid-, or late season. For example, in the Playa Lakes region of North America, drawdowns in April are recommended to maximize seed production of smartweeds, Polygonum spp. (Haukos and Smith 1993). The rate of drawdown will also influence vegetation composition. Rapid drawdowns will produce more uniform soil-moisture conditions across an area of given substrate height and tend to result in more uniform vegetation. Slower drawdowns create more variation in soil-moisture conditions, with different areas drying out at different times of year and under different temperature conditions. Slower rates of drawdown are recommended during the latter part of the summer, when temperatures and evaporation rates are higher and there is a risk that a sudden drawdown will create a large expanse of ground that dries out rapidly and becomes unsuitable for moist-soil plants. If there is insufficient growth of ruderal vegetation, areas can be quickly disked and planted with additional prolific seed-producing plants, such as sorghum, (p.240) to bolster seed

Fig. 8.4 Moist-soil management. This is used to maximize seed for wintering wildfowl. It involves lowering water levels during the growing season, in this case in an artificially created impoundment, to provide moist soil conditions for the germination and growth of prolific, seed-producing, annual plants.

Re-flooding in autumn suspends these seeds and makes them available to feeding wildfowl (Blackwater National Wildlife Refuge, Maryland, USA).
production prior to re-flooding. Areas managed by moist-soil management can also become dominated by large stands of plants that do not provide valuable wildfowl food, for example cocklebur, *Xanthium* spp., in North America and by woody vegetation such as willows. Most of these problem species are typical of drier conditions. Moist-soil managed areas can also be colonized by unwanted stands of tall monocotyledons, although many of these provide valuable wildfowl food and habitat for other species. Undesired vegetation can be controlled by diskng or burning and re-flooding for short periods to drown them. Reduction of unwanted emergent vegetation is also discussed in Section 8.8.2.

To maintain dominance by a desired range of annual plants in the long term, it is common practice to set up a 2–4-year rotation with different timings of drawdowns and re-flooding between years. In practice, moist-soil management is a bit of an art. Even though it is useful to have these rotations, management in any one year needs to be based on an assessment of the conditions and abundance of desirable and undesirable plant species. Introducing summer drawdowns to sites without a recent history of them might not initially result in very prolific growth of ruderal vegetation initially, due to lack of an existing seedbank.

Completely draining water bodies in spring and early summer will conflict with the requirements of most breeding waders/shorebirds, wildfowl, and crakes, that feed in shallow water, and of birds that would otherwise nest on islands free from ground predators. A compromise is to partially lower water levels in spring and early summer to allow germination of ruderal vegetation over a proportion of the area, while still retaining sufficient shallow water for feeding birds and deep enough water around islands to help protect nesting birds from mammalian predators. This is only feasible if there is sufficient variation in topography. An alternative is to carry out a drawdown in only a proportion of hydrological units. This should take place before birds settle to nest on islands that will become vulnerable to mammalian predators as water levels fall.

A potential problem with moist-soil management is that it may also allow the germination and establishment of perennial emergent plants. While this will be desirable when seeking to increase the area of swamp (Section 8.8.2), it may not be
where seeking to maintain areas of open water and mud for 
waterfowl and invertebrate interest. Grazing by livestock will 
suppress the growth of unwanted emergents but also that of 
desirable ruderal vegetation. Grazing by wildfowl, particularly 
geese, can also reduce or prevent the growth of ruderal 
vegetation.

Incorporation of plant material into the substrate using these 
methods can also be used to increase the quantity of coarse 
detritus for invertebrates to feed on and hence increase their 
biomass. It can also be used to maintain more open conditions 
for waders/shorebirds and to increase the ease that waders/ 
shorebirds can (p.241) probe into what often become a fairly 
heavily compacted substrate. The benefits of this to waders/ 
shorebirds and other invertebrate-feeding waterbirds will vary 
between sites. Gray et al. (1999) found that soil disturbance 
during drawdowns reduces the biomass of large invertebrate 
prey for wildfowl the following winter, probably because it 
reduces the quantity of above-ground detritus for them to feed 
on.

Moist-soil managed areas should be re-flooded in the autumn/ 
fall, typically September, to suspend the seeds and make them 
available to returning, wintering wildfowl. Re-flooding playa 
wetlands in the southern USA in September results in a higher 
biomass of aquatic invertebrates (predominantly ramshorn 
snails, Planorbidae) the following winter than does re-flooding 
in November (Anderson and Smith 2000). In wetlands where 
the benthic fauna is dominated by non-biting midge larvae, 
Chironomidae, invertebrate biomass is likely to be higher in 
winter and early the following spring if they are re-flooded in 
autumn, while adult midges are still active and ovipositing.

8.4.2 Providing shallow-water, mud, and open marginal habitat 
Water levels can be manipulated to provide suitable shallow 
water for waders/shorebirds, dabbling ducks, herons, egrets, 
and other species to feed in at particular times of year. Water 
levels are typically lowered, or allowed to draw down 
naturally, in spring and autumn to provide suitable conditions 
for migrating waders/shorebirds, but kept high during winter 
to provide suitable conditions for wintering waterfowl and to 
flood vegetation on nesting islands (Section 8.3.1). Gradually 
falling water levels through spring to autumn will also provide
a variety of conditions for different marginal plants and invertebrates.

Highest numbers of bird species are typically found in water 10–20 cm deep, with few wader species using water deeper than 40 cm (e.g. Elphick and Oring 1998, 2003). Plovers and some other species feed mainly on bare mud exposed by falling water levels. The range of feeding opportunities available at any one time can be increasing by enhancing topographic variation within the area flooded.

Providing shallow-water habitat by lowering or raising water levels will have slightly different effects on food supply for birds. Lowering water levels has the advantage of concentrating aquatic invertebrate prey, fish, and shrimps, and providing bare mud containing stranded benthic invertebrates on which waders/shorebirds and other birds can feed. Creating suitable water depths by raising water levels to flood new habitat may temporarily raise productivity by increasing the availability of detritus (see above), and provide a short-lived (and probably largely one-off) abundance of displaced terrestrial invertebrates, particularly on grassland.

(p.242) Where a number of such water bodies are under independent hydrological control, feeding conditions for waterfowl can be optimized by sequentially lowering water levels in different water bodies, to provide a continuity of suitable feeding conditions. It is worth considering lowering water levels at times of year when there is a lack of shallow water available in the surrounding area (Taft et al. 2002).

8.5 Temporary pools
Temporary pools are water bodies that experience a recurring dry phase at a more or less predictable time of year, or else only fill with water intermittently. Water bodies present only in winter and spring are known as vernal pools. The fauna of temporary pools comprise a selection of more cosmopolitan species also found in permanent water bodies and species largely or completely confined to temporary pools, the latter including a range of crustaceans (e.g. King et al. 1996; Williams 1997). These specialists are largely restricted to ancient temporary pools or those close to them. Temporary water bodies also provide critical breeding habitat for amphibians. The regular drying out benefits breeding
amphibians by preventing fish and high densities of large, predatory invertebrates becoming established, which would predate their larvae.

The basic principle of managing temporary pools with existing conservation interest is to maintain their historical hydrological regime. In particular, temporary pools should never be drained or deepened to create permanent water bodies. Lengthening the period that pools hold water allows species with longer aquatic stages to complete their life cycles (e.g. King et al. 1996), but might allow pools to be colonized by species that out-compete the existing fauna. Reducing the period that ponds hold water might prevent existing species from completing their annual cycle.

Periodic drying out helps retain temporary pools in an early successional state. Some vegetation removal is often necessary to preserve the characteristic, open nature of many temporary pools and prevent them from becoming dominated by tall and rank vegetation. Grazing can also influence the duration of inundation (Figure 8.5).

8.6 Permanent ponds and water-filled ditches

Water-filled ditches (dykes or dikes) can support important relict assemblages of invertebrates (e.g. Drake 1998; Watson and Ormerod 2005) and wetland plants, providing they have not been impoverished through past insensitive management and eutrophication. They often support the only remnants of wetland habitat remaining following large-scale drainage.

Larger ditch/dike networks (p.243)

comprising open water and areas of swamp and fen vegetation support breeding wildfowl, while their shallow margins can provide suitable feeding conditions for waders/meadow birds nesting on adjacent grassland.
Management of permanent ponds and water-filled ditches are based on similar principles. Networks of water-filled ditches are effectively large, highly branched water bodies containing an enormously high proportion of edge habitat. Some ditches, especially larger ones, have a greater flow and are more similar to canalized rivers.

Fig. 8.5  Vernal pools, climate change, and grazing management. Ancient, vernal pools in California’s Central Valley support an endangered fauna comprising branchiopods and the Californian tiger salamander, Ambystoma californiense. All are sensitive to changes in the length of inundation.

Experimental manipulations and modelling of Californian vernal pools suggests that cattle grazing as well as changes in precipitation can influence their hydrology (Pyke and Marty 2004). While climate change will influence the quantity and timing of precipitation and evapotranspiration, the period of inundation can also be influenced by whether the pools are grazed. The study found that 3 years after removal of grazing, flooding durations had decreased by an average of 50 days per year. This was probably because there was less soil compaction meaning that water drained from the pools more easily, and also increased loss of water through transpiration from the taller vegetation (San Luis National Wildlife Refuge, California, USA).

(p.244) The basic principle of managing permanent pools and water-filled ditches is to maximize the variation in ditch profiles and successional stages from open water to swamp and fen to maximize the range of conditions for wetland plants and invertebrates. Management may in some cases aim to provide a greater proportion of particular successional stages, vegetation types, and water depths, depending on the specific interest of the site. A range of successional stages can be provided by:

- periodically clearing out sections of vegetation to set back succession;
• if necessary, re-profiling the water body to provide suitable water depths;
• removing vegetation and providing disturbance along the margins to help maintain open conditions and a variety of different microhabitats;
• maintaining desired water depths by manipulating water levels.

Water quality will also be important in influencing the flora and fauna (see, for example, Watson and Ormerod 2004). Water bodies fed by groundwater will usually have higher water quality that those fed by run-off from surrounding agricultural areas. The value of existing ponds and networks of drainage ditches can also be enhanced by excavating new areas of wetland habitat. Brackish ditches support a more limited range of species than fresh ones, but including a variety of species not found in freshwater, particularly species of beetles. They also support a different aquatic flora, although this tends to be species-poor and lacking many characteristic species. The key to maintaining the interest of brackish ditches is to maintain a range of salinities throughout the entire ditch network. Raising water levels by increasing freshwater inputs has the potential to reduce overall salinity, which will reduce their existing interest, or at least restrict ditches with higher salinity to areas closer to the sea or adjacent estuary.

8.6.1 Clearing out vegetation to set back succession

Manual removal of vegetation and sediment is best because it can be carried out sensitively and on a small scale. However, this is impractical in all but the smallest water bodies (but see Section 11.1.3). Larger-scale removal of vegetation from pools and water-filled ditches can be carried out with an excavator, using either a ditch-cleaning bucket, or weed-cutting Bradshaw bucket. Typical ditch-cleaning buckets scoop up both the vegetation and some of the silt beneath it. Weed-cutting buckets only cut and remove the vegetation and their use is considered less damaging to the aquatic fauna and flora. Amphibious weed-cutters can be used in larger channels.

The ideal is to only clear out a small proportion of the vegetation in a pool, or short stretches of any ditch/dike network, at any one time to maximize the chance of plants and animals re-colonizing these cleared areas. As a rule of thumb (p.245) only clear out about a third of the vegetation and accumulated sediment in pools at any one time. For water-
filled ditches, only clear out one side of the ditch at any one
time, to enable rapid colonization from the un-cleared side.
This is often impractical when managing very narrow ditches
using an excavator. For narrow ditches, an alternative is to
clear out the whole width of the ditch/dike, but only along very
short stretches (Figure 8.6). The potential benefits of these
more intricate forms of management have to be set against
their higher costs.

**Fig. 8.6** Succession and sensitive ditch/dike management. The flora and fauna of
water-filled ditches changes with the
length of time since they were last cleaned out. Management of ditch
networks usually aims to range of these
different stages to help maintain the
widest selection of species.

Many submerged aquatic plants, notably
in this example sharp-leaved pondweed,
*Potamogeton acutifolius*, at one of only a
handful of UK sites, are largely restricted
to open water in the early stages of
succession following ditch clearance (a).
Conversely, some species, such as the
little ramshorn whirlpool snail, *Anisus
vorticulus*, are restricted to mid-to-late-
successional ditches with abundant
emergent vegetation, but are also
intolerant of complete shading. The little
ramshorn whirlpool snail is very rare in
this region, but occurs in the
unexceptional-looking ditch (c). (b) shows
a ditch of intermediate successional
stage.

Clearance of ponds and
ditches should not be
carried out
during the
bird nesting
season. In
practice
mechanical
clearance is
usually
carried out in
autumn after
the breeding
season and
before
conditions
become too
wet for
machinery.

The frequency
of clearance
will depend
on the desired
proportions of
different
successional
stages.
Optimal
requirements
for aquatic
plants and invertebrates can conflict. Much of the
conservation interest of aquatic plants in ditches is associated
with earlier successional stages, because these tend to support less competitive plants that have declined in lowland areas as a result of eutrophication. Conversely, important assemblages of aquatic invertebrates are often associated with later successional stages dominated by a small number of emergent plants. In practice, though, it is usually possible to cater for both groups by maintaining a range of different successional stages. Maintaining stretches of silted-up, vegetation-choked ditches may, though, conflict with the need to maintain open water for wet fencing (see below) and water transport. One option is to maintain choked conditions in specially excavated stretches of ditch, which do not need to perform these other functions (Section 8.6.5).

The rate at which ditches become choked with emergent vegetation will be faster where nutrient levels are high and ditches shallow and narrow. Succession tends to be slower in brackish water. Ditch-cleaning rotations vary widely, from once every 2 years to as infrequently as once every 15–30 years. In some cases there may be reasons for carrying out ditch/dike clearance on a very short rotation to maintain a high proportion in an early successional stage. However, the benefits of doing this have to be set against the disadvantages of continually removing propagules of vascular plants and stoneworts and the associated risk that they may not re-colonize. Otherwise, since clearing out ditches is always a damaging (and expensive) operation, it is far better to only clear out individual ditches when absolutely necessary to retain the overall desired proportions of different successional

Both suites of species require periodic cleaning out of ditches to set back succession and maintain suitable conditions for them. However, the snail is extremely poor at re-colonizing ditches that have been cleaned out along their entirety. The solution successfully trailed at this site is to only clean out 10-m stretches of mid-to-late-successional ditch at a time, to increase the snail’s ability to re-colonize stretches as they become suitable for it again (Arun Valley, Sussex, England).
stages, rather than simply adhere to a pre-determined rotation.

8.6.2 Re-profiling to provide suitable water depths

Re-profiling can be used to provide a range of suitable water depths across the profile of the water body. It is mainly used to introduce shallow, sloping margins on steeper-sided ditches.

Wetland plants and invertebrates vary in their water-depth requirements, but there is typically no marked increase in species richness of invertebrates as water depths increase beyond about 60 cm. Shallow water and muddy margins are favoured by feeding waders/meadow birds that nest on adjacent wet grasslands. It is, though, still useful to provide areas of deeper water to help maintain open water for submerged plants that are not shaded by tall emergent plants and to (p.247) help maintain at least some water during periods of drought (Figure 8.7). Deeper water is also necessary to maintain the roles of ditches within grassland as wet fences to contain livestock and help transfer water around and off the site. Spoil should ideally be spread away from the margins of ditches and ponds to help maintain an open, shallow profile.

Steeper-sided ditches will also support their own distinctive fauna. Those that are un-grazed or only periodically grazed will provide suitable bankside habitat for water voles, *Arvicola terrestris*. Steeper-sided ditches may also be valuable (p.248) for some invertebrates, such as some ground beetles, that require permanently moist, vegetated conditions. Moisture levels on steep-sided margins remain more constant for a given change in water level than on shallow margins.
8.6.3 Management of marginal vegetation

The margins of water-filled ditches can be managed by cutting or grazing, or they can be left unmanaged. If the latter, the margins of ponds and water-filled ditches will usually become dominated by emergent vegetation, rank grasses, and forbs, and in some cases by trees and shrubs. Emergent vegetation will provide suitable habitat for songbirds and invertebrates associated with tall, swampy vegetation and provide nest sites for waterfowl where associated with open water. Scattered, riverside trees and shrubs can be of high value for invertebrates, but will shade ditches and reduce their value for aquatic plants. Scattered trees and bushes on wet grassland will reduce its value for waders/meadow birds and wildfowl (Section 8.12). Rank, grassy vegetation on the margins of ditches will provide suitable conditions for small mammals, including water voles.

As with ditch clearance, the usual approach is to provide a variety of ditch-edge conditions to cater for a range of interests. There will usually be a presumption to maintain open ditch margins in large expanse of grassland important for open-ground breeding waders/meadow birds and wildfowl. A sensible compromise is to maintain grazed, open margins within a large, core area to maximize its value for open-ground birds, while maintaining tall, emergent vegetation along ditches in areas that are otherwise unsuitable for them, such

Fig. 8.7 Profiles of ditch edges and pond margins and the effects of grazing. Creating and maintaining shallow, sloping margins of ditches and ponds provides a variety of habitat conditions in close proximity. The vegetation that develops on these is heavily influenced by grazing or other vegetation removal on their margins.

Grazing shallow margins (a), especially using cattle, creates an open and often diverse mix of marginal and submerged plants and shallow water. Excluding grazing from the margins, for example by fencing (b), usually allows the shallow margins to become dominated by tall, emergent plants, which shade out other marginal and submerged vegetation.
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as on their margins, below power lines, and in areas subject to disturbance.

Where ditches run through wet, grazed grasslands their margins can be grazed by livestock. On arable land, cutting will be the only practical method of managing marginal vegetation. Moderate levels of grazing are far better at creating variation in vegetation along ditches than cutting and, because it is less catastrophic, will be less damaging to its fauna. Higher frequencies of cutting, for example once or twice a year, will tend to increase plant species richness compared to less frequent or no cutting (Milsom et al. 2004), but will be more damaging to the invertebrate and small-mammal fauna. To minimize these damaging effects, cutting should only be undertaken along short stretches and on only one side of a ditch in any one year. It should also obviously not be carried out during the bird nesting season.

Cattle are far better than either ponies or sheep in creating variation in conditions along the margins of ditches and ponds. Cattle create more small-to-medium-scale variation in vegetation structure, trample more, and will readily enter shallow water and graze and disturb vegetation in it. The overall effect of (p.249) cattle grazing is to reduce the abundance of tall emergents within their reach, and to replace these with patches of bare ground and lower-growing, grazing-tolerant vegetation (Figure 8.7). Cattle grazing is valuable in providing open shallow-water and marginal habitat for feeding waders/meadow birds and bare and disturbed wet and dry mud for a range of invertebrates, especially beetles and flies.

Sheep are particularly poor at creating variation in conditions on the margins of water bodies. They tend to graze adjacent areas uniformly short (Section 5.4.1) and are reluctant to enter water. However, sheep can be useful where the aim is to graze the surrounding grassland, but retain tall, ungrazed swampy vegetation, especially reeds in ditches. The effects of ponies are intermediate between those of cattle and sheep.

8.6.4 Management of water levels

Water levels need to be kept relatively high along suitable profiled ditches to maximize the variety of conditions along them (e.g. Twisk et al. 2003). A gradual spring/summer drawdown will provide open mud and damp conditions for
feeding waders/meadow birds on wet grasslands and marginal invertebrates and plants.

8.6.5 Creating new water bodies within existing networks of ditches
Existing networks of ditches can be enhanced by excavating additional water bodies. This may be particularly valuable in creating ditches that do not need to contain open water to maintain their role as wet fencing or to transport water, and which can therefore be left to become choked with silt and emergent vegetation (Figure 8.8).

8.7 Rivers
Most rivers in intensively managed lowland areas have been highly modified to increase their rate of flow and role in land drainage and to maintain suitable conditions for navigation (Figure 8.9). This modification has involved:

• straightening and deepening of their channel;
• isolation of the river from its floodplain to prevent it from flooding farmland and habitation;
• removal of woody debris;
• periodic cutting of weed and dredging.

Debris has also been removed with the aim of removing obstacles to fish migration. In practice, fish can migrate past such woody debris during periods of high river flow, and large woody debris is incredibly important in providing suitable habitat for fish by creating heterogeneity within the river channel (e.g. see Middleton 1999).
Most management of rivers for conservation and other environmental benefits involves re-introduction of variation in channel morphology, and in some cases re-connection of the river to its floodplain (Figure 2.5). A range of additional methods have been used to improve rivers for fishing interests, especially for salmonid fish. These include:

- restoration of spawning habitat;
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- Increasing cover for fish;
- Removal of artificial barriers to fish migration;
- Management of bankside and channel vegetation.

River and floodplain restoration is a large and complex subject outside of the scope of this book. Otherwise, the best form of management of rivers for conservation is benign neglect, so far as is possible while still maintaining their other uses. Coarse, woody debris in rivers is an especially valuable habitat and should be left intact wherever possible. Smaller woody debris is also very valuable for invertebrates. Frequent weed-cutting is damaging to the aquatic vegetation, while dredging will damage the benthic fauna, especially freshwater mussels, Unionidae. If dredging is necessary to maintain suitable conditions for drainage and navigation, then it should be restricted to the centre of the channel as far as possible. Weed cutting should be minimized and only undertaken in separate and alternating blocks at any one time to maintain refuges for species in uncut areas (e.g. Aldridge 2000; Baattrup-Pedersen et al. 2002; Vereecken et al. 2006).

Heavy grazing beside rivers can result in excessive erosion and inputs of sediment that may smother gravelly fish spawning habitat. Lack of vegetation beside rivers also allows more run-off of fertilizers and pesticides into the water (Section 8.2). Heavy grazing can also damage valuable riverine scrub, and should therefore be avoided beside rivers, although...

Fig. 8.9 Heterogeneity in river channels. Rivers obviously vary enormously in their natural state, but key elements in most are variations in flow and depth that create a variety of conditions for plants and animals. This relatively unmodified stretch of the Rio Almonte in Extremadura, Spain, contains fast-flowing and deep areas in its main channel, shallower cut-off channels and almost stagnant pools, muddy and stony areas, and a variety of herbaceous vegetation and scrub on its margins.

Heavy grazing beside rivers can result in excessive erosion and inputs of sediment that may smother gravelly fish spawning habitat. Lack of vegetation beside rivers also allows more run-off of fertilizers and pesticides into the water (Section 8.2). Heavy grazing can also damage valuable riverine scrub, and should therefore be avoided beside rivers, although...
the benefits of other forms of grazing will depend on the habitats abutting the river.

8.8 Swamps and fens
The relative proportions of shallow, open water, swamp, fen, and scrub and the structure of the vegetation will be important in influencing the wetland fauna. Vegetation structure will be especially important in influencing conditions for invertebrates. The overall proportions and distribution of the different successional stages will influence conditions for birds. Densities of breeding wildfowl are highest where there are equal proportions of swamp and open water (Kaminski and Prince 1981; Linz et al. 1996; Smith et al. 2004a). Densities of breeding waterfowl tend to be highest where there is a high level of interspersion of swamp and open water (e.g. de Szalay and Resh 1997; Kaminski and Prince 1981).

In shallow, moderately to very nutrient-rich wetlands in much of Europe reed most commonly attains dominance in the absence of significant disturbance. These reed-dominated swamps are known as reedbeds and in Europe support a characteristic invertebrate and bird fauna (e.g. Hawke and José 1996; Poulin et al. 2002). Much of the experience and knowledge of managing swamps and tall-herb fens in Europe is from managing reed-dominated habitats.

The composition of the avifauna of reed-dominated habitat in Europe is strongly influenced by the following (from Van der Hut 1986; Graveland 1998; Jenkins and Ormerod 2002; Poulin et al. 2002; Adamo et al. 2004; Brambilla and Rubolini 2004; Gilbert et al. 2005a, 2005b):

- extent of open water;
- length and nature of the swamp/open-water interface;
(p.253)
- physical structure and dominant plant species in the swamp and fen;
- duration and timing of flooding;
- extent of scrub.
Management for birds has often focused on restoring and maintaining early successional reed that is covered by water in spring and summer (wet, or water reed) and its interface with open water (e.g. Self 2005), since these contain a characteristic, albeit limited, avifauna. Maintaining a large proportion of wet edge also provide habitat for breeding waterfowl.

Micro-habitats considered to support the richest invertebrate fauna are marginal, transitional, and edge habitats, and area with a significant accumulation of litter; be they in winter-flooded areas with summer dry mud, or other seasonally wet or at most shallowly winter-flooded ground. The presence of scattered scrub adds additional species to the fauna, without the loss of these reedbed invertebrates (Kirby 1992b). Hence, there are potential conflicts of interest when managing particular areas of reedbed to benefit breeding birds and existing invertebrate assemblages. Reed-dominated swamps tend to contain few other plant species. Drier areas of fen in which reed can be an important component can be very botanically rich. There are therefore again potential conflicts between maintaining the botanical interest of reed-dominated habitats and creating wet reedbed and open water to benefit key bird species. In practice, though, the requirements of all these groups can generally be catered for at larger sites, particularly those with variation in topography and associated water regimes.

In North America swamps dominated by cattail/bulrush, Typha spp., support a characteristic avifauna, and reed is usually considered an undesirable invasive species, especially in coastal wetlands on its north Atlantic coast (Section 9.4).

The primary considerations when managing swamps and fens will be the:

- annual water regime;
- desired proportions and locations of open water, swamp, and fen, and, where relevant, also of associated woodland, scrub, and grassland;
- desired vegetation structure of these different habitats.

These can be influenced by manipulating water levels and by vegetation removal through grazing, mowing, and burning, as described in the following sections.

8.8.1 Manipulating the annual water regime
Water levels in swamps and fens tend to be highest in winter or spring and then fall through late spring until autumn. Often, the rate of spring and summer drawdown is greater than desired, especially in small areas of swamp and fen surrounded by drained land. The rate that water levels fall during this period can be reduced using the methods described in Section 8.1 to:

- maintain high enough water levels to continue to support characteristic vegetation types;
- provide flooded swamp for breeding birds.

Water levels during spring to autumn (i.e. the growing season) will be important in influencing the successional stage of the vegetation and its associated fauna. If water levels are too low then areas will be invaded by drier-ground species, although the rate of succession can be slowed to some extent by vegetation removal (e.g. Fojt and Harding 1995). Maintaining water levels too high for the existing plant assemblage will reverse succession. In particular, introducing surface flooding during the growing season to formerly unflooded species-rich fen will result in its replacement by botanically species-poor swamp.

Maintaining surface flooding in reedbeds in spring and summer will provide wet reed of high value to some breeding bird species and allow fish to penetrate the margins of reedbeds abutting open water and thereby provide suitable feeding conditions for birds such as great bitterns (Gilbert et al. 2003). Prolonged flooding of reedbeds in summer probably also increases the invertebrate food supply for some nesting songbirds (Poulin et al. 2002), and also affects the availability of nest sites for birds that nest on or close to the ground. In reed-dominated and probably also other types of fen, though, submerging dry reedbed in summer will replace its characteristic and valuable terrestrial and semi-aquatic invertebrate fauna with more ubiquitous, aquatic species of far lower conservation value. Relatively few invertebrate species are characteristic of reed growing in shallow water (Kirby 1992b; Bedford and Powell 2005).

It is unlikely to be necessary to supplement winter water supply in swamps and fens. Hydrological management in reedbeds managed by winter cutting involves lowering water levels for a period during winter to allow access. This is quite different to a natural-water hydrological regime.
8.8.2 Manipulating the proportions of open water and swamp using periodic drawdowns and year-to-year fluctuations in water levels

Periodic drying out can be used to increase or decrease the proportion of swamp relative to open water. Emergent plants that form swamp and fen habitat have two methods of spreading: by vegetative growth of existing plants and by (p. 255) germination of seedlings on moist mud or, in the case of some species, in very shallow water. Emergent plants sometimes cease expanding vegetatively, or start dying back, due to herbivory by geese and other wildfowl and muskrats, *Ondatra zibethicus*, or through disease, erosion, or other environmental stresses. Maintaining consistently high water levels over many years has been implicated in regress of reedbeds (Van der Putten 1997). Where emergent vegetation has died back, its extent can be increased by lowering water levels in spring and summer to expose moist mud for seeds of emergent plants to germinate and establish on, in the same manner as described for moist-soil management (Section 8.4.1). Once seedlings have established, water levels can be raised in autumn, taking care not to completely cover and drown them. These plants will then spread through vegetative growth to re-form new expanses of swamp.

If the swamp has expanded more than desired, then the area can be dried out to allow the swamp to be cut, burnt, or grazed to reduce its extent. The area can then be re-flooded to recreate open water. Burning wetland vegetation creates more open ground than mowing, and so tends to result in more growth of ruderal vegetation during subsequent drawdowns (de Szalay and Resh 1997). Kostecke *et al.* (2005) found that the method of reducing the extent of bulrushes/cattails (burning, disking, or grazing) had little or no effect on subsequent invertebrate food supply for birds following re-flooding.

The mosaic of reedbed and open water in the wetlands in the Oostvaardersplassen in The Netherlands is maintained by a combination of fluctuating water levels and grazing by moulting greylag geese, *Anser anser*, which results in periodic expansion and regression of reed. During summers when water levels are high, geese graze back the edges of the reeds from the safety of adjacent water, reducing their extent. In summers when water levels are low, the reeds become surrounded by exposed mud. The moulting (and therefore flightless and vulnerable) geese are unwilling to walk on this
mud and so do not graze back the reeds in these years. Furthermore, the damp mud is colonized by reed and willow seedlings and by ruderal plants. When water levels rise again, they flood out the ruderal plants, making their seeds available to wintering wildfowl, create new areas of wet reedbed in the manner previously described, and drown any seedlings of willow that have not grown tall enough to protrude above the water's surface. This results in re-expansion of the reedbed (Ter Heerdt and Drost 1994).

Using periodic drawdowns to manipulate the relative proportions of open water and emergent vegetation will be impractical or unacceptable in many wetlands. It will risk temporary or permanent extinction of less-mobile invertebrates in isolated wetlands, where it is only possible to dry out all, or most, of the habitat. In these situations an alternative is to control succession by removing (p.256) vegetation and by lowering the surface of the ground relative to that of the water level.

When creating new wetlands, it is worthwhile designing them so they contain a number of separate hydrological units. This will allow periodic drying out of individual units as required, while maintaining suitable conditions for wetland species in others. The range of hydrological conditions within individual units can be further improved by increasing variation in topography within them.
Although contrived, creating different hydrological units will in many ways more closely mimic the natural fluctuations in water levels and other forms of disturbance that create diversity in larger, more natural wetlands.

**Fig. 8.10** Raising water levels to set back succession. Lake Hornborga in Västergötland, Sweden, is a formerly drained 3500-ha shallow lake that had become almost completely covered with dry reedbed and scrub by the mid-1960s.

An ambitious restoration project began in the early 1990s to restore the lake's importance for waterbirds by increasing the extent of open water by removing reedbed and scrub. The area of reedbed was reduced by 1200–1500 ha by a combination of burning and rotovating the reed using specially designed amphibious machines. Eight hundred hectares of wet scrub and woodland were removed and water levels raised by an average of 0.85 m. This has created shallow water where there was once reed.
8.8.3 Preventing or reversing succession by long-term raising of water levels

Raising water levels will set back succession across an entire hydrological unit, and can be a relatively easy method of setting back succession over a large area (Figure 8.10), providing this does not cause unwanted flooding of adjacent land. The disadvantage is that since most areas of swamp and fen are relatively flat, raising water levels high enough to set back succession in one area is likely to cause detrimental flooding of areas of drier fen within the same hydrological unit. This may be particularly damaging to its existing flora and, in particular, its invertebrate fauna. One option is to hydrologically isolate different areas.

On peat soils, the surface of the wetland may already be higher than areas of surrounding drained, oxidized peat. Where this is the case, the only way to maintain high water levels will be by surrounding the wetland with a buried impermeable membrane to reduce seepage losses of water into surrounding lower land. This is expensive, though.

Raising water levels by supplementing inputs from watercourses or from abstraction has the potential to change the chemistry of the water, particularly by introducing water with higher water levels and diluting the relative contribution of high-quality, base-rich ground water. In areas of spring-fed vegetation which are drying out due to reduction of spring flows, a better option is to carry out small-scale, sensitive lowering of the substrate to a level closer to the water table.
8.8.4 Lowering the substrate to set back succession and provide open water

There are a number of terms used to describe different types of excavation used to set back succession and create open water. Sod cutting refers to digging small areas to a shallow depth to provide very shallow water or unflooded ground with a high water table (Figure 8.11). These areas are also known as turf ponds. Bed-lowering refers to excavation or relatively large, slightly deeper areas, principally to provide open water that is relatively quickly re-colonized by swamp vegetation (Figure 8.12). Excavation of ditches is used to provide more permanent areas of open water and to maximize the length of swamp/open-water interface per volume of material excavated. The key decisions when digging turf ponds, (p.258)

sod cutting, and bed-lowering are the depth of excavation and extent of the area excavated. Many turf ponds created by past small-scale removal of peat for fuel now support highly valued assemblages of plants rare or absent from the adjacent drier un-lowered areas of fen (e.g. Giller and Wheeler 1986). Patchy, small-scale (between less than 1 m² and several square metres) turf stripping and sod cutting will

Fig. 8.11  Sod cutting and turf ponds. Small-scale, removal of the surface layers of peat, known as turf stripping or sod cutting, can be used to set back succession in bogs and fens and expose the buried seedbank.

This area had a thin layer of peat removed from it 20 years ago, and now supports shallow open water and very species-rich fen vegetation. The shallow pools created contain an exceptional dragonfly and damselfly fauna, including the stunning darter dragonfly, *Sympetrum piedmontani*, here on the north-western edge of its European range. Surrounding un-lowered areas are dominated by more species-poor stands of purple moor-grass
provide a mosaic of different hydrological conditions and increase small-scale variation vegetation. Providing high-water-level conditions through excavation, rather than raising water levels, has several advantages. If the fen has dried out significantly, then excavation will remove the surface layer of dried out, oxidized surface peat. These would otherwise release high levels of nutrients following raising of water levels and thereby result in the development of patchy scrub (Plateaux, Noord-Brabant, The Netherlands).

Small-scale peat cutting formerly maintained a mosaic of strips of land at different heights and supporting different successional stages. The name of this wetland, De Weerribben, is formed from the Dutch words weer, meaning turf pond, and ribben, meaning the narrow strips of land between the turf ponds on which the extracted land was laid out to dry. This traditional management maintained a mosaic of strips of open water, reedbed, and areas of wet woodland in higher, drier areas (De

Fig. 8.12 Large-scale bed-lowering. At this site, large-scale bed-lowering has been used to set back succession on areas formerly prevented from succeeding by small-scale peat extraction.
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Removing the surface peat will also expose any buried seedbank, which might contain propagules of plants not currently present in the vegetation. There is also evidence that re-vegetated turf ponds experience smaller fluctuations in water levels compared to the peat surface than to nearby unexcavated areas of the same altitude. This might be because the peat that has infilled the excavations is looser, and so contracts and expands as water levels rise and fall. These more stable water levels are thought to benefit the development of species-rich fen vegetation (Giller and Wheeler 1986).

Excavation to a lower level is usually carried out primarily to provide open water and wet swamp, especially reedbed, for birds. The ideal is to lower some areas to a shallow-enough depth that they become colonized by emergent vegetation, while also excavating deeper areas that remain as open water, thus increasing the extent of valuable open water/swamp edge. Leaving reed rhizomes in excavated areas will usually result in the rapid re-establishment of reed, unless the rhizomes are exposed to and damaged by frost during bed-lowering. Grazing, particularly by geese, can restrict or prevent re-growth of emergent vegetation in the open water of lowered areas. Removing all the organic matter and exposing the mineral substrate will provide a relatively infertile substrate. Providing that nutrient levels in the water are low (typically if the site is fed by high-quality ground water), then these lowered areas can provide suitable conditions for colonization by nutrient-poor aquatic vegetation of high conservation value.

When creating open water it is important to consider its suitability for fish. Making areas suitable for fish will benefit fish-eating birds such as herons and egrets, but reduce the suitability of these areas for breeding amphibians and invertebrates vulnerable to fish predation. Suitability for fish will be increased by:

- creating more permanent and deeper water, in which fish can survive during warm weather when shallow water becomes de-oxygenated and during cold weather when it freezes solid;
• connecting newly created areas to other deep water where fish can survive and from which they can re-colonize.

When creating linear ditches, the main considerations are their:
• depth;
• width;
• bank profile.

Blind-ended ditches, particularly those sheltered from the prevailing wind, tend to become more stagnant and therefore may have a different flora and fauna to those with more through-flow of water.

In general, the deeper and wider the ditch/dyke, the longer it takes to vegetate over with emergent vegetation. In the absence of further management (see next section) or grazing by wildfowl or wild mammals, emergent plants will in most cases eventually expand across even deep ditches in the form of floating hover. Wider ditches also have a smaller proportion of their area shaded by fringing emergent vegetation, and are thereby more suitable for growth of submerged plant species. Abundant submerged vegetation provides better habitat for invertebrates and wildfowl and probably also better conditions for fish. The value of ditches in providing open water/wet swamp edge can be enhanced by suitably profiling their margins (Figure 8.13).

(p.261)
Disposal of spoil following large-scale bed-lowering and ditch excavation can be a big practical constraint. Excavated material will reduce in volume as it dries out and decomposes. Leaving banks that protrude above the water in the middle of reedbeds and other swamps provides suitable habitat for water voles, which appear less susceptible to predation by introduced American mink in reedbeds compared to along other water channels (Carter and Bright 2003). Conversely, banks provide higher areas on which scrub can establish, which is undesirable where a principal aim of bed-lowering or ditch creation is to provide open water.

Fig. 8.13  Ditch/dike profiles through reedbeds and other swamps. Some of the most valuable areas in reedbeds and other swamps, especially for birds, are the margins of wet swamp and open water. This valuable edge habitat can be created and maintained on the margins of ditches, but only if they have a suitable profile.

Clearing out of ditches and depositing the spoil on their margins produces a steep slope with little wet swamp edge (a). The deposited ditch spoil prevents access by fish into the reedy margins, where they can be important prey for birds such as great bitterns.

A larger area of wet swamp can be created by excavating wide, sloping edges to the ditch/dike (b). Fish can enter the margins of the swamp if spoil is placed far back from the ditch/dike edge and if gaps are left in the spoil bank.
and open, wet swamp for wetland birds. Raised spoil banks might also provide access for mammalian predators that predate nests. Removing spoil from the site is expensive, though.

8.8.5 Long-term maintenance of open water

The basic principles of managing ditches in swamps and fens are largely similar to those in other habitats (Section 8.6), except that:

- because they are surrounded by tall emergent plants, the main objectives of management are usually wet swamp along their margins and open water in their centres;
- regular management is logistically more difficult, since margins are unlikely to be suitable for grazing and mechanical clearance in swamps and fens is more difficult.

There are two approaches: periodically scraping back and removing large quantities of floating swamp vegetation and accumulated silt using an excavator; and cutting encroaching emergent vegetation more frequently using amphibious machinery (see Figure 8.16). The practical difficulties of clearing out vegetation, and the fact that the area of marginal vegetation being cleared usually represents only a small proportion of the area of similar swamp, mean that management is rarely carried out on such a small scale and as sensitively as along ditches on more open habitats. As with excavation of open water, the material removed should be deposited away from the margins of open water (Figure 8.13).

8.8.6 Vegetation management: differences between mowing, burning, grazing, and non-intervention

Vegetation removal by mowing, burning, and grazing retards the rate of succession and loss of wet-fen plant species. However, maintaining both suitable hydrology and vegetation management is the only long-term solution for maintaining characteristic types of fen vegetation (e.g. Fojt and Harding 1995).

(p.263) Compared to non-intervention, removing vegetation by mowing, burning, or grazing:

- in most cases increases plant species richness by preventing dominance by one or a limited number of large swamp or fen plants;
• prevents the accumulation of litter, and thereby reduces the rate of increase in height of the substrate relative to the level of the water;
• prevents or reduces the rate of establishment of scrub, although the effects of grazing on this are quite variable.

Cutting and removal of vegetation and burning also reduces nutrients, thereby favouring less-competitive plant species. Grazing re-distributes nutrients. Differences between grazed, cut, and unmanaged wetland vegetation are shown in Figure 8.14.

The general differences between the effects mowing and removal of vegetation, burning and grazing on the structure, plant species composition, and invertebrate fauna of swamps and fens are similar to those in dry grasslands (Section 5.3). Although all these methods of vegetation removal tend to increase plant species richness by preventing dominance of bulky monocotyledons and forbs, they differ in their specific effects on plant species composition. In particular, grazing encourages lower-growing plants, especially smaller, tillering grasses (e.g. Stammel et al. 2003). Continual, heavy grazing converts swamps and fens to open water and wet grassland. Burning tends to remove more litter than mowing, thereby favouring plants that need to frequently re-establish by seed in gaps (Cowie et al. 1992; Kost and De Steven 2000). Repeated cutting converts tall fens into short, fen-meadow (Figure 8.14).

Both mowing and burning remove virtually all of the above-ground vegetation in a given area at the same time. This results in relatively uniform vegetation in areas cut or burnt at the same time. The sudden and catastrophic removal of vegetation is damaging in the short term for invertebrates, and possibly has longer-term, detrimental effects on less-mobile species, such as spiders (Decler 1990; Cattin et al. 2003). However, as when managing other habitats by mowing or burning, these negative effects can be minimized by only mowing or burning small areas at any one time (i.e. on rotation). This will also increase larger-scale vegetation diversity by produce a variety of different stages of re-growth. Neither mowing nor burning, though, provide the range of microhabitats for invertebrates produced by grazing, as described below.
Mowing was formerly widespread in parts of Europe to provide reed or sedge for thatching (Figure 8.15), litter, and marsh hay. Many areas of fen have often only survived because they have been managed to provide these products. (p.264)

(p.265)
Burning has been used more widely in North America (see review by Middleton et al. 2006). Harvesting of fen products has become uneconomic in most areas, making it difficult to sustain the frequency of mowing that created and maintained characteristic types of fen vegetation. Where this is the case, the challenge is to determine how infrequently fen can be mown to maintain its conservation value, and whether it can instead be maintained or increased through other (p.266)
low-cost means. These include larger-scale mechanical removal and low-cost grazing. Disposal of cut material can be difficult. Burning it for power generation offers opportunities in some areas.
Fig. 8.15  Mowing fen vegetation. Many characteristic and species-rich assemblages of plants have been created by periodic harvesting of fen vegetation. The flexible leaves of great fen-sedge, (a), are used to cap roofs of houses thatched with common reed, because reed stems are too brittle to bend over the ridge of the roof. Great fen-sedge is usually cut for thatch in summer on a 3–5-year rotation. In mixed fen this management favours great fen-sedge over reed.

(b) shows a calcareous flush containing species-rich sedge and vegetation dominated by marsh lousewort, *Pedicularis palustris*. This low, open community is maintained by annual mowing and removal of cut vegetation. In the absence of this management the smaller plants would be overtopped and shaded out by more bulky ones. Marsh lousewort is partially parasitic on the roots of other plants and so also helps maintain open vegetation (Market Weston and Thelnetham Fens, Suffolk, England).
Grazing removes vegetation more selectively than either mowing or burning, with the degree of selectivity varying with livestock type and grazing pressure. Thus, grazing favours unpalatable plants that are avoided by grazers, and those that are well able to tolerate repeated defoliation. Grazing therefore has the potential to create greater variety in vegetation structure. Furthermore, the distribution of livestock, and hence grazing pressure, is also heavily influenced by water levels.

Grazing also:

**Fig. 8.14** Effects of grazing, cutting, and non-intervention on wetland habitats. The floodplain of the River Prypyat in southern Belarus is considered the least modified in Europe. The vegetation in unmanaged areas is a mosaic of rank swamp, fen, and scrub (a), small areas of open water (b), and wet woodland (c). The main factors contributing to diversity of habitats and wildlife in the floodplain are variations in topography and seasonal and year-to-year variations in water levels. These prevent any one vegetation
• creates more bare and disturbed ground, especially at high stocking levels, and consequently ruderal vegetation than mowing or burning;
• provides a source of dung for invertebrates.

Wet peat is particularly easily poached by livestock. Concerns have been raised over damage to peat in fens by grazing. Heavy trampling can cause the soil to lose its structure, creating unconsolidated areas devoid of vegetation. Trampling also creates small-scale variations in topography. Creation of shallow, open water and wet mud by grazing, and associated growth of ruderal vegetation, benefits wintering, seed-eating wildfowl and breeding waders/meadow birds that feed in shallow water and muddy margins. Shallow water kept open by grazing and trampling can support abundant amphibians, particularly frogs. There is little information regarding the effects of grazing on invertebrates. Variation in vegetation composition and structure at medium grazing levels is likely to increase the range of niches available for invertebrates, especially compared to non-intervention, mowing, and burning. Bare mud, shallow, open water, and dung also provide additional niches for invertebrates, which are absent from areas managed by mowing, burning, or non-intervention. At low-to-medium grazing intensities, the effect of grazing should be to provide these additional niches, while still retaining even quite grazing-intolerant invertebrate species within patches of ungrazed or only lightly grazed vegetation (e.g. Ausden et al. 2005). Very high grazing levels run the risk of the loss of invertebrates associated with high levels of accumulated litter,
removal of nectar sources and food plants, and complete loss of areas of swamp and fen of importance for invertebrates.

**Mowing and burning**

Mowing is only practical when it is dry enough to allow access, when the water is frozen solid, or by using amphibious machinery (Figure 8.16). Burning is only practical in winter when the vegetation is no longer green. Any burning should be carried out using back-fires and taking suitable precautions as outlined in Section 5.6, including the cutting and dowsing with water of suitable firebreaks/fuel breaks.

Mowing to harvest fen products obviously involves removal of cut material. Mowing specifically for conservation also requires removal of cuttings to reduce litter accumulation and to prevent it from smothering re-growth. Cuttings are raked up and often burnt on site or otherwise removed. Piles of litter provide valuable habitat, though, particularly for over-wintering invertebrates, and mimic (p.268) accumulations of litter washed up by natural floods. It is worth retaining some piles of litter on areas of low botanical interest.

The effects of mowing and burning swamps and fens on plant species composition and structure will depend primarily on their:

- timing, particularly whether during the growing season or in winter;
- frequency.

Increasing the frequency of summer cutting increases plant species richness by further preventing small numbers of more vigorous plant species from out-competing a larger number of less-competitive species. In general, plant species richness in fens tends to decrease with increasing above-ground vegetation biomass (Wheeler and Giller 1982). A variety of characteristic assemblages of fen plants have been created and maintained by a combination of different mowing and water regimes. Fen and swamp should obviously not be cut during the bird breeding season.

In reed-dominated vegetation both burning and cutting in winter increase plant species richness and result in shorter, thicker and higher densities of live reed stems compared to non-intervention. Burning is more effective at reducing litter and also tends to result in higher flowering densities of reed (Gryseels 1989a; Cowie et al. 1992). This might be important for species that feed on their flowers and seeds. Experiments
have found little or no difference in the invertebrate fauna between cut and carefully winter burnt wet reedbeds (Ditlhogo et al. 1992). It is important not to burn in dry conditions in summer or autumn, though, when the fire will be hotter and burn deeper into the litter. This will probably be more damaging to invertebrates. Despite the results of this research, many site managers still consider burning more damaging to invertebrates than cutting. Areas of cattail-/bulrush-dominated swamp can be reduced by combinations of burning followed by disking or heavy grazing (e.g. Kostecke et al. 2004).

The effects of timing and frequency of cutting are fundamental to the management of reedbeds in Europe. Cutting to harvest dried reed stems for thatch is carried out in winter, after their lower leaves have dropped. This management perpetuates dominance by reed. Cutting reed in summer reduces the dominance of reed and creates a more species-rich mixture of it and other tall monocotyledons and forbs (e.g. Gryseels 1989b). Rotational summer mowing also favours great fen-sedge over reed (Figure 8.15), whereas annual or biennial summer mowing favours reed sweet-grass, Glyceria maxima, over reed. Cutting reed underwater in summer using a reciprocating mower prevents it from transferring oxygen down to its rhizomes. This can kill it and is a useful method of creating shallow, open water.

Cutting reed in winter usually requires lowering of water levels to allow access. This can compromise attempts to achieve suitable water levels for breeding birds in early spring.

Although cutting or burning in winter may be necessary to prevent, or reduce the rate of, succession in many in reedbeds, winter cutting also leaves areas open and unsuitable for nesting birds the following spring. In southern Europe, where re-growth of reed is rapid, winter reed cutting only reduces densities of early nesting, resident passerines (Poulin and Lefebvre 2002). In Northern Europe, where re-growth is slower, winter reed cutting also reduces densities of later-arriving migrant warblers (Graveland 1999). Winter cutting also eliminates moth larvae which overwinter in reed stems, and which are important prey for some reedbed songbirds. Studies have produced conflicting results regarding the effects
of winter reed cutting on total biomass of invertebrate prey of reedbed songbirds (Poulin and Lefebvre 2002; Schmidt et al. 2005a).

The frequency of winter reed cutting used to arrest succession varies between sites, but is typically once every 5–15 years. Commercial reed cutting for thatching takes place on a 1–2-year rotation, known as single or double wale, to provide high densities of strong, straight reed stems. Annual cutting of large areas of reedbed is detrimental to some nesting birds for the reasons just described, and is also damaging to its invertebrate fauna. Therefore, a compromise between the needs of commercial cutting and conservation is to cut only a proportion of the reedbed for thatching in any one year, carry this out on a 2-year rotation, and cut other areas on a longer rotation or not at all. Where there are limited resources for reed cutting, cutting should be concentrated on areas where it will provide the greatest benefits, such as in maintaining early-successional, wet reed and maximizing edge, while leaving larger areas of drier areas unmanaged or only infrequently cut. There is a variety of machinery that can be used to cut and remove reed and other vegetation at sites where commercial cutting is no longer economic, or desirable on account of its short rotation (Figure 8.16).

Grazing
Grazing of swamps and fens is only practical using cattle, water buffalo, and ponies. Sheep and goats are unsuitable for grazing very wet habitats, sheep being susceptible to foot-rot.

An initial consideration when considering swamps and tall-herb fens is the composition of habitats within the grazing unit. All livestock, even those considered particularly suited for use in wetlands, require access to dry ground to lie up on and woodland or scrub for shelter. Hence grazing units in wetlands need to also contain sufficient areas of these other habitats.

(p.270)
The effects of grazing wetlands can be difficult to predict, because of often large spatial variations in grazing pressure. The main factors to consider when setting up a grazing regime are the desired/likely:

**Fig. 8.16** Mechanised cutting and removal of common reed. Where smallscale mowing of fens for thatch and litter is no longer economic, larger-scale machines can be used to cut and remove vegetation to retard succession.

(a) The ‘Truxor’ is an amphibious machine that can be fitted with a variety of tools. These include a reedcutter unit for cutting common reed and other vegetation underwater, and a reedrake for collecting, transporting, and piling up cut vegetation.

(b) The Softrack is a tracked, low-groundpressure vehicle for use on soft and shallowly flooded ground. It cuts reed and other vegetation with a flail and blows the chopped material into a loading bin on its back.
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- proportions of open water, swamp, fen, and grassland vegetation created and maintained through grazing;
- dominant plant species and structure of the swamp and fen areas resulting from grazing and their associated fauna, particularly birdlife.

The main factors that will influence the overall effects of grazing are the:

- type of livestock;
- overall grazing pressure;
- timing of grazing, whether summer-only or year-round;
- spatial and year-round variation in water levels and how they influence the distribution of livestock.

Grazing pressure within a given area can be difficult to predict, particularly in mosaics of swamp, fen, open water, and grassland. It will vary in relation to the:

- relative preference for the particular type of vegetation relative to that elsewhere in the grazing unit;
- physical access to the particular area by livestock;
- experience of familiarity with the site of livestock;
- territorial behaviour of different groups of livestock.

The often patchy nature of grazing caused by differences in water levels during and between years can create abundant variation in vegetation composition and structure (Figure 8.17).

Livestock often, but not always, prefer grazing drier, grassy areas to entering water and grazing swamp and fen vegetation, although their grazing preferences vary according to the range and palatability of different types of vegetation in their grazing unit (e.g. Duncan and D’herbes 1982; Vulink et al. 2000; Menard et al. 2002). Where livestock prefer drier grassland, they tend to concentrate any grazing of swamp and fen in areas close to this dry ground. They often also concentrate grazing nearer areas of shade (in summer) and shelter. Livestock usually avoid entering stands of tall, dense fen vegetation. They can be encouraged to graze swamp and fen vegetation by cutting the vegetation first to provide areas
of short, succulent re-growth and by minimizing the quantity of alternative forage in drier areas.

The distribution of livestock and hence grazing intensities can be influenced by manipulating water levels to alter grazing regimes. Crossing points can be constructed over deep ditches that would otherwise prevent access to particular areas. Livestock are often initially wary of using these.

Livestock tend to increase the area over which they forage as they become more familiar with the site. Their grazing influences the vegetation, which in turn affects their grazing patterns. Hence the distribution of livestock and vegetation composition and structure often change substantially over a number of years. Ponies in extensive and naturalistic grazing systems often form strong, social groups, which also influence grazing patterns.

Grazing is often used to create and maintain mosaics of wet grassland and reedbed. There is, though, a danger of these mosaics not providing suitable habitat for either wet-grassland- or reedbed-specialist birds. The presence of small blocks and strips of reed can make areas unsuitable for open-grassland birds that (p.272)
prefer an unobstructed view, whereas small areas of reedbed will not be large enough to support reedbed-specialist birds either.

*Fig. 8.17* Extensive grazing and variable water levels. Many large wetlands are managed by a combination of variable water levels and extensive grazing which, in combination, can produce a dynamic mosaic of open water, wet grassland, and swamp (Parque Nacional de Doñana, Huelva, Spain).
**Type of livestock**

Basic differences in the effects of cattle and pony grazing on vegetation composition and structure are similar to on dry grasslands (Section 5.4.1). Cattle are less selective and at moderate grazing intensities produce more tussocky vegetation. At moderate grazing intensities ponies typically create mosaics of closely cropped lawns interspersed with largely avoided areas of tall swamp, fen, and other vegetation (Figure 8.18). Water buffalo are similar to cattle in their feeding habitats, but also create wallows. They are also better at swimming off across deep water and escaping.

Cattle and ponies have broadly similar food preferences in wetlands, although cattle eat a higher proportion of broad-leaved plants and are likely to survive less well than ponies in grassy habitats when food is limiting (e.g. Duncan and D’herbes 1982; Menard *et al.* 2002). Grazing and trampling by cattle and ponies in spring and summer reduces the extent of reed relative to most other tall monocotyledons such as sea club-rush/alkali bulrush, cattails/bulrushes, and reed sweet-grass (e.g. Duncan and D’herbes 1982; Kostecke *et al.* 2004; Ausden *et al.* 2005). In drier areas moderate to heavy grazing in summer by cattle or ponies results in the replacement of reed by grassland (e.g. Vulink *et al.* 2000). Year-round moderate and high levels of grazing and trampling by ponies also reduces the extent of sea club-rush/alkali bulrush relative to more open vegetation (e.g. Bassett 1980).

Positive attributes of breeds of cattle and ponies for use in wetlands are small size, which helps prevent them becoming stuck in mud, and tolerance of insect bites and internal parasites. A preference for entering water is desirable, unless the aim of grazing is to keep the vegetation on dry ground short and open, while retaining ungrazed, tall emergent vegetation in water. Livestock do not need to be particularly hardy if only used for summer grazing, since the quality of forage in complexes of grasslands and swamps/fens is usually high. More hardy breeds are required for year-round grazing due to the lower quality of forage and generally wetter and colder conditions in winter. Highland cattle (Figure 4.7) are good for year-round grazing of fens.

**Grazing pressure**
The overall grazing pressure heavily influences the structure and composition of the vegetation. When livestock first start grazing a patch of fen, they usually concentrate on grazing its margins, creating a border of trampled and grazed and (p. 274) often quite tussocky vegetation. Further grazing continues to reduce the abundance of the bulky, palatable emergents and tall forbs. Continued heavy grazing eventually converts the area to short grassland with or without taller, unpalatable plants. Often, the short grassland created by heavy grazing of fen vegetation retains short, heavily grazed tall emergent vegetation, which can re-grow and re-assume dominance if grazing pressure is reduced. (p.275) Swamps and fens are highly productive and can support relatively high grazing intensities in summer. However, since the aim of grazing is usually to only open up a

Fig. 8.18 Effects of pony grazing on swamp and fen vegetation. Grazing by Konik ponies has created a wide variety of vegetation types and structures in this one small (15 ha) grazing unit at...
proportion of the swamp and fen vegetation, while leaving much of it ungrazed or only lightly grazed, overall grazing intensities are usually lower than that which the habitat could potentially support. Grazing intensities of between 15 and 70 livestock unit days/ha per year are typically used for year-round grazing.

Minsmere, Suffolk, England. These include the following.

(a) Tussocks of common reed, sea club-rush/alkali bulrush, and grasses, created by patchy opening up of areas formerly dominated by swamp and fen vegetation.

(b) Heavily grazed, short, dry grassland alongside almost completely ungrazed, tall emergent vegetation in the shallow ditch to the right. The water in the ditch was only 2–10 cm deep when this photograph was taken (and not much deeper during most of the rest of the year), but the ponies still avoided grazing areas of it they could not reach from dry land.

(c) Complete eradication of areas of sea club-rush/alkali bulrush by grazing and trampling. The tall sea club-rush/alkali bulrush remains dominant within the grazing exclosure.

Moderate-to-high levels of livestock grazing prevent the establishment of swamp and fen vegetation. If the intention is to create mosaic of swamp, fen, and grassland that are subsequently maintained through grazing, it is important to first allow the areas of swamp and fen to establish before grazing is subsequently introduced to maintain this mosaic.

**Timing of grazing**

Plants vary in their relative palatability during the year and this influences the effects of grazing. Some tall emergents, such as reed and sea club-rush/alkali bulrush, are most heavily grazed and controlled by grazing in spring and early summer when they are more palatable. Cattle eat a higher proportion
of reed in summer than ponies. Ponies excavate and eat the rhizomes of reed more in winter than cattle (e.g. Vulink et al. 2000).

In winter livestock feed more on evergreen plants, particularly grasses on higher ground, evergreen sedges, and nutritious rhizomes. Ponies and cattle also eat bark during winter when other food is in short supply and this can kill scrub (e.g. Vulink et al. 2000). The reduction in suitable forage in winter can cause livestock to wander more widely in search of food and hence have quite a different spatial effect on the vegetation. High water levels in winter are also likely to reduce the area of habitat available to them and there will be an increased need for accessible dry ground. Poaching is also likely to be greater in winter when soils are wetter.

**Encouraging livestock to graze swamp and fen vegetation**

Livestock can be encouraged to graze swamp and fen vegetation by reducing the quantity of alternative forage in otherwise preferred areas, particularly on drier grassland which is often favoured by livestock over wet swamp. This can be achieved by only allowing access to a small area of dry grassland within the grazing unit and by reducing the quantity of forage on it. This can be done by, for example, using sheep to graze the grass in dry areas short, to force cattle within the grazing unit to seek food in wetter areas. Animal welfare considerations obviously need to be taken into consideration when deciding the trade-off (p.276) between providing too little food on the grassland to encourage animals to graze tall emergent vegetation, and maintaining them in suitable condition, particularly in winter.

Livestock can be encouraged to enter and graze swamp and fen vegetation by cutting it first to provide succulent regrowth. Cutting paths through areas of tall fen and even vehicle tracks through fen vegetation encourage livestock into new areas. Mineral licks can also be used to entice livestock into new parts of the fen.

**Modifying grazing patterns by manipulating water levels**

The general avoidance of submerged areas by livestock can be used to manipulate grazing patterns by controlling water levels. They can be raised to discourage access or lowered to encourage it. Livestock are often more reluctant to enter
water on peat, because it is soft and unstable, compared to firmer clays.

Large, seasonal drawdowns and between-year variations in water levels are a feature of many extensive, near-natural wetlands, such as those in Mediterranean climates which have relatively high rainfall and extensive flooding in winter, and then dry out during the hot summer. In dry years livestock enter and graze swamp and fen vegetation, thereby creating structural variation in it and increasing the length of its edge. Flooding of these areas during subsequent wetter years provides a diverse mixture of scattered swamp, interspersed with open water, and provides plenty of edge.

A particular combination of summer drawdown and summer grazing is used around the margins of shallow, reed-fringed margins, to create a feature known as a Blue-Border. This is considered the most productive zone of shallow, reed-fringed lakes for birds in parts of Northern Europe (Figure 8.19). It is a particularly simple and cheap form of management for providing a mixture of valuable wetland habitats in close proximity: deep, open water; ungrazed reedbed; shallow, open water; and wet and dry grassland. The fact that the method only relies on grazing animals entering shallow water in summer means that commercial livestock (usually cattle) can be used, rather than more specialist, hardy breeds. This method relies on a substantial drawdown, and is thus useful in wetlands where it is difficult to maintain high water levels throughout the spring and summer. Blue-Border management can also be designed into newly created wetlands. However, to maximize its benefits, the site needs to be designed to have a suitable topography in relation to the extent of drawdown (Figure 8.20). A disadvantage of Blue-Border management is that it does not provide dry reedbed, which is valuable for invertebrates. (p.277)
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(p.278)
Fig. 8.20 The width of the Blue-Border, and hence its value for birds in particular, is determined by the gradient of the shore and extent of the drawdown. For a given gradient, a small drawdown results in a narrow border, while a large drawdown allows livestock to eat all the reed.
Bogs

Vegetation growth and succession are slow in the acidic and wet conditions of pristine bogs. The only possible acceptable management is very light grazing, which can help to provide variation in vegetation structure and microhabitats. However, any grazing needs to be carried out sensitively. The slow-growing vegetation and surface layers of peat are fragile and easily damaged.

In practice there are few, if any, pristine bogs remaining in most areas. Many have been degraded through combinations of drainage, burning, and heavy grazing (overgrazing). Drying of the upper layers of peat results in oxidation and release of nutrients, making areas unsuitable for existing bog plants and allowing colonization by more competitive plants, including scrub. The artificial drainage may also cause erosion, while steep-sided drainage ditches can be dangerous for livestock and chicks that get trapped in them. Restorative management of degraded bogs involves:

- restoring a near-natural hydrology by blocking artificial drainage;
- removing any colonizing scrub.

Fig. 8.19  Blue-Border management. Allowing livestock to graze the margins of shallow, common reed-fringed lakes creates a ring of open water known as the Blue-Border (a and b). The photograph on the left shows how livestock have entered the shallow water and grazed back the reed to form, in this case, a relatively narrow Blue-Border. A more typical, wider Blue-Border is shown on the right. The Blue-Border contains grazing tolerant plants, such as low-growing grasses and sedges, and often an abundance of aquatic and marginal plants that would otherwise be shaded out by the tall reed (Lake Tåkern, Östergötland, Sweden).
The only long-term solution to maintaining the long-term value of bogs is to restore near-natural hydrology on a large-enough scale to restore active *Sphagnum* moss growth and peat formation. This will often require both blocking of artificial drainage on the bog itself, as well as raising water levels on surrounding land to maintain sufficiently high water levels on its periphery. Blocking of artificial drainage can be a large task where numerous, shallow drains (often known as grips) have been installed. There are a number of different methods used for blocking drainage, the optimal design at a particular site depending on the size of the drain and the availability of materials. Smaller drains can be blocked using solid dams constructed from:

- scoops of saturated peat and associated vegetation taken from the sides or bottom of existing drains and their margins (dried out and de-natured peat will not retain water);
- interlocking, plastic sheet-piling driven into the peat.

Smaller drains can also be partially blocked using bales of heather cut from adjacent areas. These help slow the flow of water, trap any sediment and increase vegetation growth within the drain. Shallow drains should become filled in with *Sphagnum* moss quite quickly following blocking. Larger drains will require more substantive dams, including those made of stronger, interlocking metal (p. 280) sheet piling driven deeply into the ground (Figure 8.21) or constructed from wood and stone. Care should obviously be taken to minimize damage to the peat when using heavy machinery. Dams should be installed so that their tops are slightly higher than the peat surface, to maintain the water level as close to
the peat surface as possible in winter, and within about 20 cm of it throughout the year. It is worth considering incorporating overflows or soakways to reduce water pressure on dams during periods of high flow and the risk of them failing.

8.10 Wet scrub
Wet scrub can be a valuable component of fens. It also occurs on the margins of watercourses, and includes valuable riparian scrub in otherwise arid areas. In fens, the presence of scrub will increase the total number of breeding bird species, mainly through addition of generalist scrub species.

Fig. 8.21 Blocking artificial drainage on bogs. The near-natural hydrology of bogs can be restored by blocking artificial drains using dams. Where these drains traverse sloping ground, series of stepped dams need to be installed at frequent intervals along their length to maintain water levels close to the peat surface.

A common method for blocking larger drains involves driving interlocking, metal sheet piling into the peat, as shown (a; Mondhuie, Highland, Scotland).

(b) Shows the characteristic shallow dome of a raised bog. This site is being restored by blocking artificial drains and removing scrub. The paler line from left to right across the centre of the photograph shows the more grassy vegetation that has established along the drier edges of one of the smaller drains (Ford Moss, Northumberland, England).
(e.g. Hanowski et al. 1999), but reduce it for specialist wetland birds. Scrub and trees, though, can provide important nest sites for colonial waterbirds such as herons, egrets, and ibises. Scattered scrub, with sheltered areas of fen among it, will be richer for invertebrates than large areas of scrub-free fen. Patches of scrub will also provide shade for grazing animals. Scrub will eventually succeed to wet woodland, which can itself be of high conservation value.

Scrub does not require any management to maintain it. As in drier habitats, there is the potential to diversify the age and structure of existing scrub by cutting small patches close to ground level (coppicing) and creating glades within it, to increase structural diversity and the length of edge. Mixtures of structurally diverse, coppiced, wet scrub and areas of herbaceous vegetation can contain extremely high densities of breeding songbirds (Wilson 1978).

The most common form of wet-scrub management is its removal to prevent it from out-competing more botanically rich vegetation (Figure 8.22), and to maintain open habitat for wetland birds. Removal of scrub and wet woodland can be viewed as long-term rotational management: allowing swamps and fens to succeed to scrub before setting back succession. Any decision to remove wet scrub needs to compare the benefits of doing so against the potential value of the wet woodland to which it will eventually succeed. Established scrub can be removed by:

- cutting and removal (usually requiring treatment of stumps with herbicide to prevent re-growth or grinding of the stump to at or below ground level);
- burning;
- clearing in winter when the ground is sufficiently frozen using a modified blade on a bulldozer (shearing).

Cutting and removal of scrub will usually require follow-up spraying of re-growth the first year. Grinding of stumps will be essential where the restored fen will be subsequently managed by mowing. Cutting scrub can be undertaken at any time (p.282)
of year outside of the bird breeding season, although wet conditions will usually make it impractical in winter. The key to successful restoration is being able to maintain high-enough water levels for maintenance of the re-instated swamp and fen vegetation following scrub removal. Minimizing ground damage, particularly on peat, is probably also important. Damage can be reduced by designing the pattern of machinery movement to reduce the number of passes and amount of turning, particularly in wetter areas. Turning causes considerably more damage than movement in a straight line. Where there are numerous blocks of scattered scrub it is best to move machinery back and forth along straight lines, rather than to and from Fig. 8.22 Large-scale, scrub removal. Fen vegetation can be restored by removing colonizing scrub. Scattered scrub and wet woodland, though, can be important habitats in their own right, and a balance needs to be struck between the desired proportions and distribution of these. The photograph shows fen vegetation in the third growing season following removal of dense willow scrub and alder carr; similar to that shown in the background of the photograph. There has been virtually no re-growth of scrub at this site. This is probably because annual winter flooding has prevented willow rooting from cut branches and establishing from seed (Upton and Woodbastwick Marshes, Norfolk, England).
Care should be taken to remove brash and to minimize creation of small hollows, since these can be hazardous to future mowing and to grazing animals. It is probably best to wait at least 2 years until above- and below-ground vegetation have established before any grazing is introduced.

The surface of the substrate can also be lowered to raise water levels relative to the ground surface and expose any buried seedbank, although this will be expensive and it may be difficult to dispose of the material removed.

8.11 Wet woodland
Wet woodlands support distinctive and valuable assemblages of birds, amphibians, and invertebrates in particular, but are rarely managed specifically for them.

Coppicing (Section 7.4.2) has been used in some wet woodlands. Small-scale, patchy coppicing of wet woodlands can help maintain a variety of different stages of tree regrowth and consequently variation in the openness of conditions within the understorey. Its benefits to wildlife are probably limited. Abandoned coppice will eventually become more structurally diverse as trees die and fall over.

The other type of management of wet woodlands is their use as greentree reservoirs. These are impounded areas of oak-dominated, forested wetlands managed for timber in the Mississippi and associated valleys in the USA, which are artificially flooded in winter to provide suitable habitat for ducks, such as mallard, Anas platyrhynchos, and wood ducks, Aix sponsa (e.g. Reinecke et al. 1989). The artificial flooding makes acorns and invertebrates accessible to these ducks. The pools left following artificial flooding also provide breeding areas for amphibians. This artificial winter flooding influences the structure of the woodland by maintaining an open understorey, with only seedlings and saplings able to survive prolonged periods of winter flooding being able to grow.

The only management required to maintain or enhance the conservation value of most wet woodlands is to maintain or restore their natural hydrology (Figure 8.23).

8.12 Wet grasslands
The general principles of vegetation removal on wet grasslands are similar to those of dry grasslands except that, unsurprisingly, there are no fire-prone types of very wet grassland. Hence, management by burning is rarely an option, although it is occasionally used in restoration management of damp grasslands.

The key difference is that much of the conservation interest of wet grassland is associated with moist ground and permanent and seasonal water bodies, including associated water-filled drainage ditches. Manipulation of hydrology is therefore key to managing wet grasslands for conservation. Two particularly ingenious forms of artificial flooding have been developed on wet grassland, which both inadvertently provided good habitats for wetland wildlife: water meadows and washlands (Figures 8.24 and 8.25).

Agriculturally unimproved wet meadows and pasture can support species-rich vegetation of high conservation value, which is dependent on continuation of a similar management

Fig. 8.23 Natural hydrology and tree regeneration in wet woodlands. The only management necessary to maintain the conservation value of forested wetlands, like this bald cypress, *Taxodium distichum*, swamp, is maintenance or restoration of natural flooding regimes. Fluctuations in water levels are particularly important in influencing tree regeneration. Like many wetland trees, bald cypresses require flood water to disperse their seed, and periods of low water levels so that seeds can germinate on mud exposed as the flood waters recede. However, if water levels then rise too highly they kill the young seedlings, which cannot survive submergence for more than a few days (Lake Fausse Pointe State Park, Louisiana, USA).
regime and lack of use of inorganic fertilizers, as in drier (p. 285) (p. 286)

Fig. 8.24 Water meadows. These are meadows which have calcareous spring or river water flowed over them in the early spring via an elaborate network of channels, in this case involving a raised watercourse (a). The water deposits nutrients and warms the soil, encouraging early spring grass growth. These water meadows support an impressive display of the rare meadow
grasslands. Agriculturally unimproved grasslands are rare in many lowland areas. Where they so occur a primary aim of management will be to maintain the existing botanical interest by maintaining similar cutting and grazing regimes and water-level regimes to those that created and formerly maintained them.
Many wet grasslands have been agriculturally improved. This greatly impoverishes their flora and fauna, as it does on dry grasslands (Section 5.9). Agricultural improvement has involved drainage, addition of inorganic fertilizer, addition of lime to raise the pH of acidic grasslands, and in some cases reseeding with (p.287) agriculturally productive grass species. Application of inorganic fertilizers will be especially damaging on wet grasslands where there is even greater potential for nitrates to leach into and raise nutrients levels in associated ditches and other water bodies. Although installing drainage in damp grasslands is often successful at increasing grass growth in spring, it can have an opposite effect later in the season, by reducing the quantity of water available for plant growth during drier periods of the year, even on ‘badly drained’ soils in the relatively wet south-west of

\( \text{Fig. 8.25} \) Washlands. These are artificial floodplains constructed to aid land drainage. They consist of a flat, embanked area lying between a river and artificial relief channel, or between two artificial relief channels, into which water is diverted and stored during periods of high flow.

The Ouse Washes in Norfolk and Cambridgeshire, England, was constructed in the seventeenth century to help drain the English Fens. Its winter floodwaters (a) provide habitat for large numbers of wildfowl. As floodwaters recede they expose grassland (b) used by breeding waders/meadow birds and wildfowl and which supports a valuable relic wetland flora and rich invertebrate assemblage.

Carefully designed, new washlands can both alleviate flooding and provide valuable wildlife habitat, although their benefits for wildlife will depend on their hydrological regime. In particular, flooding during the breeding season will disrupt nesting (e.g. Ratcliffe et al. 2005).

England (Tyson et al. 1992). From an agricultural perspective, though, grass growth in spring is often at a premium.

Any botanical interest of agriculturally improved grasslands is invariably restricted to their edges, especially to water-filled ditches and their margins, and to wetland and ruderal vegetation in areas of temporary flooding. Scattered scrub and trees will add to the wildlife interest of wet grasslands, particularly old willows that provide a continuity of decaying wood. However, their presence may be detrimental to some ground-nesting birds, particularly breeding waders/meadow birds. Trees and tall scrub will provide nest sites and look-out posts for crows and raptors which predate eggs and chicks (e.g. Green et al. 1990b). Enclosed fields will tend to be avoided by breeding and wintering waders/shorebirds and other waterbirds (Milsom et al. 1998, 2000).

Larger areas of wet grasslands are often of particular conservation value for their breeding and wintering waterfowl. The main breeding bird interest comprises breeding waders/meadow birds on the grassland itself and breeding waterfowl and swamp/fen songbirds along water-filled ditches and other areas of shallow water and swamp and fen vegetation. Common aims of wet grassland management are therefore to:

- provide suitable conditions for wintering wildfowl and other waterbirds;
- in central, Western, and Northern Europe provide suitable conditions for breeding waders/meadow birds (e.g. Ausden and Hirons 2002) and other waterbirds.
Suitable conditions for these birds can be created on agriculturally improved grassland of little or no existing botanical value. On agriculturally unimproved grassland raising water levels (as opposed to maintaining existing high water levels) has the potential to damage the existing botanical interest, especially if it involves introducing surface flooding during the growing season. Creating surface flooding during the spring and summer can also damage the invertebrate interest associated with areas of wet but unflooded peat. However, on most drained and agriculturally improved grasslands with little or no existing invertebrate or botanical interest, raising water levels and introducing patchy, (p. 288) surface flooding to benefit wetland birds should also provide additional habitat for wetland invertebrates and vegetation. Extensive flooding of grasslands will, not surprisingly, eradicate terrestrial small mammals (e.g. Jacob 2003). The main areas of wet grassland themselves tend to support few invertebrates of high conservation value. Most of the scarcer species are found in associated fen, swamp, open water, and marginal habitats, including saltmarsh vegetation on coastal grazing marshes, and habitats along associated water-filled drainage ditches and their margins (e.g. Drake 1998). Hence another method of maximizing the conservation value of wet grasslands is by sympathetically managing associated water-filled ditches for their plant, invertebrate, breeding waterbird, and other interest as described in Section 8.6.

Wet grasslands often lack suitable habitat for species of amphibians that require temporary pools for breeding. Ditch networks usually contain permanent water, while temporary winter flooding often dries out too early in spring for them to complete their larval life cycle. Additional pools for breeding amphibians can be created as shown in Figure 8.8.

8.12.1 Maintaining existing botanically rich swards
General principles of grazing and cutting to maintain the existing botanical interest of wet grasslands are the same as those described for dry grasslands in Section 5.3. Sheep, though, are unsuitable for grazing very wet conditions as in swamps and fens. As with drier grasslands, managing areas as agriculturally unimproved hay meadows will maintain their high plant species richness, but be damaging for invertebrates. The timing of cutting needs to be set back to minimize loss of nests and chicks of ground-nesting birds.
Other methods of minimizing loss of nests and chicks during mowing are described in Sections 5.5.4 and 8.12.3.

Grazing usually take place from spring to autumn (i.e. summer grazing), with winter grazing a less practical option, especially on very wet grasslands. Grazing regimes also need to take account of potential trampling of the nests of waders/meadow birds and other ground-nesting birds (Section 8.12.3).

Species-rich wet meadows are typically flooded for periods during the winter. Flooding by rivers deposits nutrient-rich sediment that can help maintain suitable nutrient levels for maintenance of species-rich grassland. Water-level management during the growing season should seek to maintain the hydrological regime, which created and maintained the characteristic vegetation type. Raising water levels to introduce surface flooding for significant periods during the growing season will be especially damaging to botanically rich swards, and result in their replacement with more species-poor aquatic and swamp vegetation and inundation grassland.

8.12.2 Providing suitable conditions for wintering wildfowl and other waterbirds

Wintering wildfowl and other waterbirds can be attracted to wet grasslands by providing extensive areas of shallow flooding (between a few centimetres and about 30 cm deep) and maintaining high water levels to increase the accessibility of larger soil invertebrates for them to feed on. Large, undisturbed areas of shallow water can provide important daytime roosts for dabbling ducks, which feed at night on areas often otherwise disturbed during daytime. High water levels will force earthworms closer to the soil surface where they are more accessible to birds and make the soil softer and easier for long-billed waders/shorebirds to probe. Most birds that feed on large soil invertebrates prefer relatively short (less than about 10 cm), open swards, presumably because it makes their prey easier to detect (e.g. Milsom et al. 1998). Wintering geese also prefer shorter, unflooded swards for feeding, typically between about 5 and 20 cm (Vickery and Gill 1999). Grasslands need to be appropriately grazed or cut in late summer and autumn to achieve these sward conditions in winter.
Flooding grassland in winter and spring encourages a range of plants that produce seed that ducks feed on during winter. These include perennial plants such as many sedges and rushes and prolific, seed-producing annuals that require bare ground for germination. Production of seeds from annual plants can be maximized using moist-soil management (Section 8.4.1). Re-flooding these areas in autumn and winter suspends these seeds and makes them available to dabbling ducks. Regular inundation also encourages some grass species favoured by herbivorous wildfowl, notably creeping bent, Agrostis stolonifera.

The prey available to birds as floodwaters recede depends on the origin of the floodwater. If the grassland is flooded by river water or overflow from another permanent water body, then fish and aquatic invertebrates will exploit the shallow floods but also become trapped in small pools as the floods recede. This provides an abundant, but temporary concentration of prey for fish-eating and invertebrate-eating waterbirds. If the flooding is created by rainwater lying on fields, with little or no connection to rivers or substantive water bodies, then it will lack fish and aquatic invertebrates. In both situations, though, receding floods will still, though, expose often bare or sparsely vegetated ground containing earthworms and other soil invertebrates that have survived the flooding.

8.12.3 Providing suitable conditions for breeding waders/meadow birds

Suitable conditions for breeding waders/meadow birds and other waterbirds can be created by:

- maintaining high water levels and shallow flooding in spring and early summer to provide suitable feeding conditions;
- maintaining a suitable sward height and structure for nesting and feeding waders/meadow birds by sward management during the previous summer/autumn and, where grass continues to grow throughout the year, also during the winter or early spring;
- minimizing loss of eggs and chicks during grazing and mowing.
Removal of trees and shrubs may be necessary to providing the open conditions preferred by breeding waders/meadow birds and to remove perches for avian egg and chick predators. This removes potentially valuable invertebrate habitat, though. An option is to pollard trees instead. This maintains their invertebrate interest and helps provide a continuity of decaying wood in their trunks, while preventing the trees from becoming tall enough to support nests of these species and reduces their suitability as look-out posts. Lime has been added to already agriculturally improved meadows in The Netherlands to raise soil pH with the aim of increasing earthworm biomass for breeding waders/meadow birds.

**Maintaining high water levels and shallow flooding**

There are two main ways of providing suitable hydrological conditions for feeding waders/meadow birds.

- The first is maintaining a high field water table to keep the upper soil wet and therefore soft enough for common snipe and black-tailed godwits, *Limosa limosa*, to probe for large soil invertebrates, mainly earthworms and leatherjackets, *Tipulidae*, in the soil.
- The second is providing shallow pools and their margins for waders/meadow birds, especially northern lapwings and common redshank, *Tringa totanus*, to feed on aquatic invertebrate and those in the damp, sparsely and unvegetated mud on their margins.
Maintaining large areas of soft, moist soil in which waders/meadow birds can continue to probe throughout their breeding season is only possible on permeable soils. Permeability varies with soil type and structure and is highest on well-structured peat. Water tables within fields on permeable soils are intimately linked to those on surrounding, water-filled ditches. On peat it is possible to maintain a high field water table throughout the breeding season by maintaining high water levels in surrounding ditches (Figure 8.26b), particularly if these ditches are closely spaced. This keeps the upper soil wet and therefore moist enough for common snipe, Gallinago gallinago, and black-tailed godwits to probe for food (Green 1988; Green et al. 1990a). On peat soils maintaining a water table within 20–30 cm of the soil surface is recommended for maintaining suitable conditions for breeding snipe (RSPB, EN & ITE 1997). Even on these soils, though, it is important to provide at least some shallow pools as well. The level of control over field water tables can be increased using shallow drains, often known as foot-drains or grips (Figure 8.27).

On less permeable soils, such as compacted soils, especially clays, it is not possible to maintain soft, moist upper soil over large areas of the field by maintaining high water levels in surrounding ditches (e.g. Armstrong and Rose 1999; Figures 8.26c and 8.26d). These soils are generally unsuitable for breeding common snipe and black-tailed godwits. Northern lapwings and common redshank are usually the commonest species and these feed on a variety of invertebrates taken from the sward, soil, and shallow water and its margins (Ausden et al. 2003). On these soils shallow, surface flooding is more important in providing suitable conditions for feeding waders/meadow birds, particularly towards the end of their breeding season (Milsom et al. 2000, 2002; Ausden et al. 2003; Smart et al. 2006). Flooding benefits these species by reducing sward height and providing shallow water and soft, muddy margins for them to feed on invertebrates. However, these breeding waders/meadow birds also feed on larger soil invertebrates during the early part of the breeding season, and winter flooding greatly decreases the abundance of these (Ausden et al. 2001). The ideal is therefore to contain a mosaic of short, unflooded grassland, winter flooded grassland and a succession of sequentially drying out shallow pools and open ditch edges present until the end of their breeding season.

Retention of shallow floods during the breeding season also provides feeding areas for breeding wildfowl, although more
densely vegetated ditches are usually more valuable for brood rearing.

Overall, it is best to maintain a suitable variety of hydrological conditions to help ensure there are always suitable feeding conditions present, and this will be easiest on areas with a varied topography. This also maximizes the range of conditions available for wetland invertebrates and plants (Figure 8.28). However, many grasslands are relatively flat. Raising or lowering water levels a small amount on these either floods or dries out large areas at the same time.

(p.292) It may also be impractical to raise water levels sufficiently due to lack of water or because raising water levels will flood adjoining farmland. Where this is the case, the only way of providing shallow-water and marginal habitat is by excavation. The maximum length of shallow water and muddy edge for quantity of material excavated is created by digging shallow, linear drains. These can also be used to feed water to low areas to maintain shallow flooding and damp soils. However, breeding waders/meadow birds seem to prefer feeding in shallow pools on grassland in preference to along linear drains. Nesting northern lapwings often nest close to the edges of isolated foot-drains, where they are sometimes subject to higher levels of predation than when nesting further away. This is probably
because mammalian predators such as red foxes follow these linear features when hunting. This might be less of a problem where there are high densities of foot-drains and more variation in their patterns. Creating foot-drains of different (p. 294)

**Fig. 8.26** Field water tables on permeable and impermeable soils in summer and winter. In winter, inputs of water on to the field through precipitation are greater than losses of water from it through evapotranspiration. The soil becomes saturated and there is a net movement of water out of the field and away into surrounding ditches (a). Surface ponding may occur, particularly on impermeable soils, such as poorly structured clays, because water only moves slowly away through the soil into surrounding ditches.

As the weather warms and plants start growing, then loss of water from the field through evapotranspiration begins to exceed inputs of water on to it through precipitation. On permeable soils such as well-structured peats, the water table within the field can be kept high in late spring and summer by maintaining high water levels in surrounding ditches. This allows water to flow back through the soil into the field and partially replace water lost through evapotranspiration (b). On impermeable soils there is less flow of water back through the soil from surrounding ditches to replace water lost through evapotranspiration in late spring and summer, and field water levels rapidly fall (c). The only way to maintain wet conditions on the surface of impermeable soils under these conditions is by flowing water over the field surface to create surface flooding (d).
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depths, including varying depths along their length, will again maximize the likelihood of their being some suitable areas of shallow water and freshly exposed mud being present whatever the height of overall water levels. The disadvantage of increasing densities and patterning of foot-drains is that it can make agricultural operations more difficult.

Providing suitable sward conditions

Moderate grazing by cattle is considered the best type of vegetation removal for creating suitable tussocky vegetation and patches of poached, bare ground (p.295)

![Foot-drains and grips. These are narrow, shallow drains, which were originally excavated at many sites to drain water off fields into surrounding ditches. Maintaining high water levels in surrounding ditches can be used to feed water back along these foot drains into the interior of fields. This helps maintain a high water table and the interior of the field moist and soft enough for breeding black-tailed godwits and common snipe to probe for earthworms and leatherjackets. Lowering water levels in surrounding ditches can be used to drain water out of the field to drain it for agricultural operations after the end of the breeding season.

This field is covered in closely spaced foot-drains. One can be seen stretching from the middle foreground to middle back of this picture, while the lines of cut grass mark the high ridges between individual foot-drains. This site supports high densities of breeding black-tailed godwits (De Pine, Freisland, The Netherlands).](image-url)
for breeding waders/meadow birds. This variation in structure should also support a more diverse invertebrate fauna than more uniform grassland. Different species of wader/meadow bird prefer different-lengthed swards. Northern lapwings prefer swards less than about 5 cm high for nesting and foraging, while common snipe, common redshank, and Eurasian curlews require taller swards (up to 25 cm) for concealing their nests in. All these species avoid unmanaged or only lightly grazed or irregularly cut vegetation with dense litter, with the possible exception of common snipe.

Fig. 8.28 Providing shallow water for breeding waders/meadow birds. Optimum conditions for breeding waders/meadow birds on clay and other mineral soils can be provided by creating a mosaic of shallow water, bare mud, and unflooded grassland. This is easiest to achieve by raising water levels on areas with existing variation in topography, such as unlevelled grazing marsh, which still retains its former saltmarsh channels (a). This coastal grazing marsh supports some of the highest combined densities of breeding northern lapwings and common redshank in the UK. The profile of flooded channels often flattens out over time and their margins can become steep and cliffed. Occasional reprofiling is sometimes needed to maintain their suitability (Elmley Marshes, Kent, England).
Grazing levels during summer and autumn will be important in determining sward conditions for breeding waders/ meadow birds the following spring, where there is little or no vegetation growth in winter. Additional winter grazing by livestock may be required where vegetation continues to grow through the winter and is not suppressed by winter flooding. Summer cattle grazing can be used to produce the desired tussocky structure combined with winter sheep grazing used to keep areas short. Winter cattle grazing can be used to provide light poaching to increase birds’ access to earthworms and leatherjackets.

Grassland that will be flooded in winter should be grazed relatively short. Flooding to a depth that covers the grass will suppress its growth and provide bare mud and sparsely vegetated ground for feeding waders/ meadow birds and other birds as water levels recede in spring. If grass protrudes above the floodwater it will continue to grow and, in the case of creeping bent, often the dominant grass in nutrient-rich, winter-flooded grasslands, produce a dense, floating mat. Flooding rank grass will leave behind a thick, dense mat of grass and thick layer of anoxic, decaying plant litter, containing few larger soil invertebrates and will be of limited value for feeding birds. Grazing by wintering, herbivorous wildfowl can be important in maintaining suitably short, open areas for feeding waders/ meadow birds the following spring.

A common issue when managing wet grasslands for breeding waders/ meadow birds is extensive, dense growth of rushes, especially on grazed, agriculturally improved grassland and former arable land. The presence of rushes will provide cover and produce seed for wintering wildfowl, but dense stands will make areas unsuitable for breeding waders/ meadow birds. On coastal grazing marshes sea club-rush/ alkali bulrush can form dense stands on the margins of shallow water. Again, small stands add diversity, provide valuable habitat for...
invertebrates, seed for wintering wildfowl, and cover for nesting wildfowl, but extensive areas make grasslands unsuitable for feeding waders/meadow birds.

Rushes and sea club-rush/alkali bulrush can be controlled to some extent by grazing in spring when their fresh growth is more palatable, but grazing is usually avoided or only carried out at low densities in spring to minimize trampling of birds’ nests (see next section). Other options for reducing the cover of rushes include heavy grazing using hardy livestock in winter when there is little alternative forage, repeated cutting ideally followed by grazing of re-growth and cutting followed by application of systemic/translocated herbicide to the re-growth. Sea club-rush/alkali bulrush can be controlled by cutting underwater, herbicide application, and heavy grazing, and will be further disadvantaged by low water levels in summer. On agriculturally improved swards where excessive growth of these species is an issue, occasional dry years should be taken\(^{(p.297)}\) advantage of and used to manage the vegetation as hard as possible to reduce their abundance.

**Minimizing trampling of birds’ nests by livestock**

The proportion of birds’ nests trampled vary according to the type of livestock and grazing pressure (Figure 8.29). There are three main approaches to reduce nest loss:

- excluding grazing from areas with nesting birds during the breeding season, but where necessary providing suitably open conditions for birds by heavily grazing adjacent fields without nesting birds;
- reducing grazing levels during the nesting season and accepting a low level of nest trampling;
- continuing grazing while protecting individual nests.
The benefits of reducing or excluding grazing during the nesting season have to be balanced against the potential disadvantages of allowing the sward to become too tall and dense for birds that require shorter, more open conditions. Grazing can be excluded from entire fields supporting high densities of nesting birds, or just from key areas of them using electric fencing. Nidifugous birds (those whose young leave the nest very soon after hatching) that require short swards can then take their chicks to feed in these more heavily grazed areas. Swards that have grown tall through exclusion of livestock during the nesting season can be difficult to return to their desired condition. Re-introducing livestock to tall swards tramples down much of the vegetation. This can form a matted layer of litter and live grass that smothers germination gaps and prevents access by birds to soil invertebrates. It can be difficult to remove this litter layer, or thatch, by grazing, although using combinations of cattle and sheep can be effective (Section 5.4.2). Power harrowing is a useful method for lifting up and dissipating thatch.

An alternative is to graze at low stocking densities during the nesting season. Some nests will be trampled, but hopefully the decrease in nest survival will be offset by increased chick survival due to the improved sward conditions provided by the grazing.

Nests of species that are easy to locate can be protected from trampling using nest protectors or nest exclosures. Nest protectors consist of raised metal grilles placed over the nest (e.g. Guldemond et al. 1993). There is concern that predators such as crows and red foxes might learn to associate the presence of the relatively conspicuous nest protectors with nests. Where this is a potential problem, nests can be protected from both trampling and larger predators using nest exclosures. These have a roof and sides constructed from plastic-coated steel bars. Incubating birds can enter through the gaps in their side but these are too narrow (p.298)
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(p.299) to allow access by larger predators such as gulls, crows, European badgers and red foxes. Exclosures have been found to increase nest survival of killdeers, *Charadrius vociferus*, northern lapwings, and common redshank, but to also *increase* predation rates on incubating common redshank. These sit tight on their nest and only fly off once a predator if very close. Nest exclosures probably impede their escape (Johnson and Oring 2002; Isaksson *et al.* 2007).

*Fig. 8.29* Nest trampling rates. Grazing animals trample birds’ nests. The rate of nest trampling depends on the type and density of livestock, and also varies between bird species.

The graph shows the estimated survival of nests of different wader species/ meadow birds in fields with homogenous vegetation grazed throughout the entire egg-laying and incubation period at a grazing pressure of one livestock unit per hectare (see *Fig. 5.8* and *Table 5.1* for an explanation of grazing units). It was calculated using daily nest survival rates from Beintema and Müskens (1987).

Adult dairy cattle trample a far lower proportion of nests per quantity of vegetation removed than sheep, mainly because it requires about 12 sheep (i.e. 12 times as many feet) to remove the same quantity of vegetation as one cow. Yearling cattle trample a far higher proportion of nests than adult dairy cattle, because they run about more. Northern lapwings and Eurasian oystercatchers, *Haematopus ostralegus*, suffer lower nest trampling rates than common redshank, probably largely because northern lapwings and Eurasian oystercatchers are able to successfully defend their nests against approaching livestock. Trampling rates increase with stocking levels. Trampling rates probably also vary to some extent according to the heterogeneity of the grassland. This might occur by birds preferentially nesting in vegetation subject to higher or lower grazing pressure than the rest of the field. Even if nests are only partially destroyed by trampling, predators often take the remainder of eggs. Otherwise,
Minimizing losses of birds’ nests and chicks during cutting

The most widely used method for minimizing loss of birds’ nests and chicks is delaying cutting until birds have finished breeding (e.g. Kruk et al. 1996). Alternative methods include:

- marking nests and mowing around them;
- using flags to deter birds with chicks from entering fields that are about to be mown; the flags are made out of bamboo canes with blue or white plastic bags attached to their tops (Kruk et al. 1997).

The pattern of mowing can also be altered to reduce chick loss (Figure 5.12).

Marking nests and mowing around them can only be used for species whose nests are easy to locate (e.g. Guldemond et al. 1993). Nests remaining in isolated patches of un-mown grassland might be particularly conspicuous and subject to high levels of predation. In The Netherlands strips of un-mown grassland are left in otherwise cut agriculturally managed fields to provide corridors for black-tailed godwit and other waders/meadow birds to safely move their broods to suitable un-mown grassland in nearby nature reserves. (p.300)