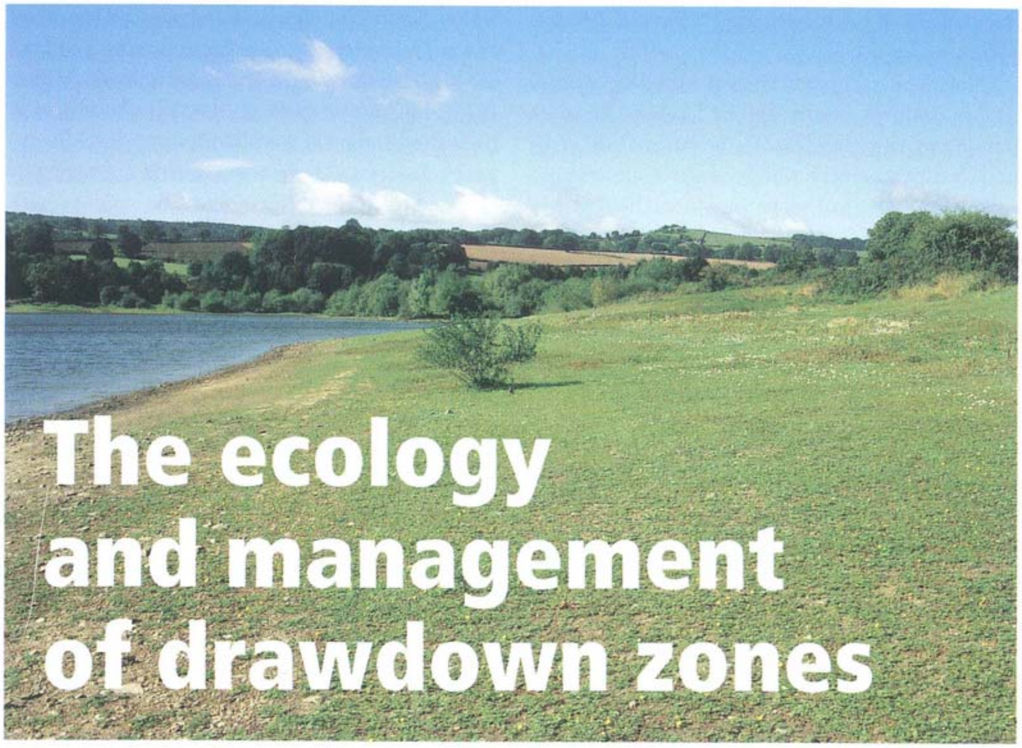

The ecology and management of drawdown zones

Carlos Abrahams

Shoreline zonation at Ogston Reservoir SSSI, Derbyshire. Carlos Abrahams

When water levels fall in lakes and reservoirs, previously submerged parts of the banks are exposed to the air. This causes a dramatic change in these locations from an aquatic to a terrestrial environment and has a major influence on the animal and plant life found there. This process is commonly termed drawdown, and the part of the shoreline that is exposed below the top water line is termed the eulittoral, inundation or drawdown zone.

Although water levels in all types of wetlands rise and fall on a seasonal, annual or long-term basis, drawdown has commonly been regarded as being of detriment to the nature-conservation value of waterbodies and has been blamed for the desiccation of habitats, destruction of wildlife, soil erosion and poor water quality. However, in recent years there has been increasing recognition that drawdown can produce conditions under which wildlife can thrive and vegetation can be revitalised, ensuring the persistence of valuable wetlands. It has even been suggested that the supposed fact that fluctuating water levels can be damaging is one of the 'most persistent myths' of wetland ecology (Biggs *et al.* 1994).

In most UK wetlands, water levels are at their highest in February-March and lowest in July-October. It is commonplace for small ponds to fall by up to 0.5m during the summer, while in larger lakes seasonal variations of about 1-2m are normal (Williams *et al.* 1998). In areas with permeable geology, groundwater-fed seasonal lakes such as the Irish turloughs can dry out completely in the summer, but then fill to a depth of 3-4m in the winter through groundwater recharging (Blackstock *et al.* 1993). In addition to these natural variations, management of reservoirs for water supply, flood storage or hydro-electric power can serve to exaggerate or limit water-level fluctuations. The most extreme examples appear in hydro-electric reservoirs, which can have drawdown measured in tens of metres, with as much as 80-100% drawdown every year (Fraisse *et al.* 1997). However, it is important to point out that this extreme fluctuation is not always the case in managed waterbodies, as water-level regulation, especially for supply and flood storage, may actually reduce the natural seasonal fluctuations of the waterbody (Wilcox & Meeker 1991).

Climate-change predictions for the UK indicate that in the near future there is likely to be more rain in the winter and less in the summer. In addition, hotter summers will heighten evapotranspiration from wetland systems. These changes will increase the incidence and magnitude of seasonal water-level changes in all types of wetland (Cannell *et al.* 1999). Increased drawdown is likely to have a great impact on shoreline ecosystems, especially in waters that are already shallow or seasonal. This trend is likely to present a number of threats and opportunities to shoreline conservation, and there is an urgent need for more research and guidance in this area.

Cyclical succession

The key feature determining the ecology of drawdown zones is the dynamic hydrologic regime, which dictates the chemical and physical character of wetland water, the resulting vegetation, and the use of wetlands by birds and other animals (Weller 1999). In contrast to the textbook hydrosere, with succession ending in woodland, water-level fluctuations produce a cycle of succession consisting of repeated disturbance, colonisation and growth stages. This starts with the exposure and drying of substrates during drawdown. This stage allows the breakdown of organic matter into available nutrients and increases the density of loose sediments, improving their value as a seed bed and to wildlife. However, in larger waterbodies, drawdown may also focus wave action on new parts of the shore, causing the removal of fine materials, so that shoreline substrates become characterised by coarse particle sizes and low organic-matter content.

Scentless Mayweed and Trifid Bur-marigold growing in the drawdown zone, Ogston Reservoir SSSI, Derbyshire. Carlos Abrahams

The exposure of previously submerged shores subjects aquatic plants to desiccation, frost, ultraviolet light and the effects of grazing. This often results in the death of these plants and the creation of open patches of habitat, which become available for colonisation and establishment by new individuals or species. Plant seeds may arrive from outside the patch by water, on the wind or on waterfowl, or there may be *in situ* sources such as rhizomes or the copious seedbanks that often develop in wetland areas. Drawdown provides the right substrate, moisture and temperature conditions for the seeds of wetland plants to germinate. This is particularly important for emergents such as Common Reed *Phragmites australis*, and for annuals including Trifid Bur-marigold *Bidens tripartita*, Marsh Cudweed *Gnaphalium uliginosum* and Celery-leaved Buttercup *Ranunculus sceleratus*.

Development of vegetation after drawdown tends to start with an initial pulse of recruitment from plants with early germination such as Lesser Bulrush *Typha angustifolia*, Water-cress *Rorippa nasturtium-aquaticum* and Great Willowherb *Epilobium hirsutum*. This provides these plants with a competitive advantage over other species, allowing extra time for them to develop through seedling and adult stages. In addition, a rapid growth rate enables space to be captured quickly by species such as Creeping Bent *Agrostis stolonifera*, Reed Canary-grass *Phalaris arundinacea* and Annual Meadow-grass *Poa annua*. For these reasons, annual or short-lived perennial species, with numerous mobile seeds that germinate and grow quickly, are most likely to secure an early place in the vegetation of drawdown communities. As the shoreline vegetation develops, competition starts to limit colonisation by new arrivals to those which have large, slowly germinating seeds and seedlings with a low growth rate, a strategy that allows plants to germinate in the shade of established vegetation. This development creates a succession in the vegetation structure towards longer-lived and taller competitive perennial herbs, shrubs and trees. However, this process is often checked by reflooding of the wetland, which completes the cycle back to an aquatic state.

The differences in life forms and strategies among plants will often produce a zonation of communities in waterbodies subject to regular drawdown. Near the top water line, wet-ground shrubs are found, together with creeping perennials and tussocky grasses. In contrast, lower slopes commonly have annual or facultative annual species present, their high growth rates and reproductive output aiding survival and colonisation in the less frequently exposed areas. Rosette or creeping plants are generally found lower down the slope or in more exposed areas, as they are able to withstand damage from flooding, wave action or desiccation (Wilson & Keddy 1988). The rate of water-level changes in a waterbody can affect this zonation process considerably. If water levels drop quickly, homogenous stands of vegetation are formed, as determined by the date of drawdown and substrate characteristics. However, when the water level falls more gradually, a sequence of vegetation zones can develop, with differentiated communities developing as the drawdown occurs (Backeus 1993; Hejny 1971).

Characteristic wildlife

The nature-conservation value of drawdown vegetation rests mainly in the character of its distinctive and resilient temporary communities. Over 85% of wetland species growing in ponds occur in the drawdown zone, and many are restricted to this area (Biggs *et al.* 1994). A variety of studies has recorded between 71 and 178 plant species in the drawdown zones of reservoirs (Duncan & Dalby 1960; Evans 1983; Spray 1980). Work by the author on Carsington Water and Ogston Reservoir SSSI, in Derbyshire, identified 71 species in total, with up to 18 species per m^2 recorded. This diversity compares well with that of other vegetation types, such as meadows and marshes, found on the same sites and appears to be produced by the fluctuating water levels which lead to the regular replenishment of seedbanks, the flooding of competitive plants, and the inclusion of species from both aquatic and terrestrial ecosystems (Naiman & Decamps 1990).

As natural wetlands have been lost to development, the nature-conservation importance of artificial waters such as reservoirs has increased. Open seasonal habitats are rapidly becoming less common in the countryside, and the drawdown zones of artificial sites, if managed appropriately, can provide important refuge habitats for specialised species and communities that are increasingly rare in the 'wild' (Gill 1977; Palmer & Newbold 1983; Williams *et al.* 1998). Examples of rarities to be found in drawdown areas include plants such as Six-stamened Waterwort

Pillwort growing on the shores of a natural pond in the New Forest, Hampshire. Bob Gibbons

Six-stamened Waterwort is a scarce annual of muddy lake shores.
Paul Sterry/Nature Photographers

Elatine hexandra, Thread Rush *Juncus filiformis*, Mudwort *Limosella aquatica*, Pillwort *Pilularia globulifera* and Shoreweed *Littorella uniflora* (Stewart *et al.* 1994). A number of rare bryophytes are also adapted for colonising bare mud, and hence benefit from drawdown in reservoirs and other waterbodies. These include species such as *Riccia cavernosa, Riccia subbifurca, Physcomitrium sphaericum, Physcomitrella patens* and *Ephemerum sessile*.

Vegetation and bare ground in eulittoral areas can provide valuable habitat for a range of animals, in particular invertebrate species and shoreline birds. A surprising number of macroinvertebrates appear to be adapted to fluctuating water levels and can cope with or even benefit from regular drawdown. The diverse and variable habitat mosaic in the drawdown zone provides conditions that the species can use during either the wet or the dry phases. In addition, some species make use of both phases, in synchronisation with their life cycle. The aquatic invertebrate communities are often characterised by mobile groups, such as microcrustaceans, beetles and waterboatmen, that are able to respond to changes in water levels by migrating into new littoral regions.

An alternative adaptation for species with low mobility and resistance to desiccation, such as mussels and snails, is to become dormant, sealing off the shell opening to prevent drying-out. Some crustaceans, such as the Fairy Shrimp *Chirocephalus diaphanus* and the Tadpole Shrimp *Triops cranciformis*, survive as eggs in the mud during drawdown. Even where there are adverse effects on unadapted aquatic species, recolonisation may be more rapid than expected. Studies have shown that recolonisation of a reflooded shoreline takes about three months, and, after recovery, the inundated zones can contain higher invertebrate numbers and biomass than they did before drawdown (Langford 1983).

During the dry phase, terrestrial invertebrates are able to make use of the exposed substrates. These include snails, spiders and ground beetles that live at the water margins. Some insects, including dragonflies such as Southern Hawker *Aeshna cyanea*, need bare mud for oviposition, and water beetle larvae crawl out to pupate above water level (Lott 1994).

Drawdown zones can provide important breeding and migratory habitat for a range of birds. Drawdown in spring or autumn attracts passage waders, such as Golden Plover *Pluvialis apricaria*, Redshank *Tringa totanus*, Oystercatcher *Haematopus ostralegus* and Common Sandpiper *Actitis hypoleucos*, to feed on the ready source of invertebrates present in the sediments, exposed shallows and bare ground. The same conditions in summer make good habitat for rearing ducklings. Reflooding over the winter releases drowned invertebrates and the copious seed produced by annual plants during the summer drawdown, providing food for wintering wildfowl such as Teal *Anas crecca* and Shoveler *A. clypeata*.

Drawdown may also have negative impacts on birds if it is carried out at the wrong time of year. Water-level fluctuations during the breeding season can strand or drown the floating nests of Coots *Fulica atra* and grebes or make those on islands vulnerable to predation. There can also be negative impacts on the food sources of diving ducks such as Tufted Duck *Aythya fuligula* and Goldeneye *Bucephala clangula* due to temporary reductions in freshwater snail populations.

Water-level control

The management of drawdown zones for nature conservation is extensively discussed elsewhere (Abrahams in press). In summary, there are four key factors that should be considered in the creation or management of drawdown zones. These are water-level control, substrate conditions, shoreline topography, and the practicalities of vegetation establishment.

The exposed mud of drawdown zones can attract migrant waders such as the Temmink's Stint (left) and Common Sandpiper (above).
Paul Sterry/Nature Photographers

Unlike many other important ecological criteria in a wetland system, the timing and magnitude of drawdown and flooding events can be manipulated to favour the germination and establishment of certain species and to inhibit the growth of others. Different durations of drawdown will favour different life histories, with one-year drawdowns promoting emergent perennials and longer periods allowing the development of woody species. The within-year timing of drawdown will also have a significant impact on species composition, with early drawdowns favouring seed production by emergents and germination by annuals, while late drawdowns can result in higher plant densities and greater species diversity.

Because of its effects on invertebrates, plants and substrate, drawdown can be used as an effective tool to manage fish stocks, and, if it is timed properly, specific groups of species can be targeted. Perch *Perca fluviatilis* and cyprinid fry densities can be regulated by water-level changes during the reproductive and early development stages. For fish feeding and spawning on a near-shore substrate, drawdown may reduce the population size, while creative water-level management can promote shoreline vegetation and hence raise insect populations and fish stocks (Merritt 1994; Zalewski *et al.* 1990).

Control of the frequency and timing of water-level manipulations can produce crucial habitat resources for birds at times that coincide with migration and other events in their annual cycles. The timing of flooding and drawdown can be utilised to establish emergents as bird breeding habitat or to promote seeding annuals to feed migrating or wintering waterfowl. Flooding of vegetation to a depth greater than normal may be carried out over the winter to kill off the existing plants. A small drawdown can be provided for spring waders and then stable conditions retained during the main nesting period. This is followed by a main drawdown in summer, in time for the autumn wader passage. The drying phase creates areas of bare mud and gives the seeds of food plants a chance to colonise. To prevent competitive perennials from inhibiting new growth, the area is subjected again to prolonged flooding, either during the autumn and winter or in the following spring, completing the annual cycle (Merritt 1994; Welling *et al.* 1988).

Rates of water-level change should generally be limited to less than 0.6-2m per month and annual ranges should not exceed 2-5m. Fluctuations greater than this on a regular basis may degrade the littoral biota, although annual communities will still colonise during the drawdown stage. In general, slower rates of drawdown produce better vegetation structure, allowing the development of a shoreline zonation with different stages of plant growth, while rapid drawdowns tend to result in

Wayott Reservoir in Lancashire. By controlling the frequency and degree of drawdown, viable wildlife habitats can be created.
David Woodfall/Woodfall Wild Images

wide homogenous areas with lower species diversity. To aid the appropriate management of drawdown and reflooding in reservoirs, Ecological Regulation Practices can be developed to integrate nature conservation and water-supply needs. These typically prescribe maximum rates of drawdown and restrict extreme fluctuations in water levels, while allowing smaller-scale variations within a defined main operating range.

Substrate conditions

Substrate character is one of the main factors determining the establishment and growth of plants on lake and reservoir shorelines. It is linked to wave action, which reduces the organic-matter content of the substrate and prevents plant growth by uprooting seedlings and damaging adult plants (Duncan & Dalby 1960). There are a number of actions that can be taken to reduce the potential for wave creation and to lessen the impacts of waves on shorelines. Placing the longest axis of the lake perpendicular to the wind will reduce fetch. Shelterbelts can be planted to reduce wind speed, and water depths can be reduced to decrease wave height (Andrews & Kinsman 1990). To prevent waves from reaching the shoreline, reefs can be built parallel to the shore, using timber 'branch-boxes', tyres, geoweb or stone rip-rap (Levine & Willard 1990). Another method is the use of geotextile 'sausages', which are filled with dredged material to produce a stable earth bund. In addition to this type of fixed barrier, the use of firmly anchored, floating timber booms can also dampen wave energy before it reaches the shore (Merritt 1994). Once wave-reduction measures have been put in place, substrate and vegetation can be further protected from erosion by materials such as biodegradable geotextiles or other meshes.

Slowing water movements close to the shore by such methods can promote the accumulation of fine sediments in areas intended for planting. Further measures to improve substrate characteristics could include ploughing, disking and fertiliser application. In nutrient-poor waterbodies, periodic drawdown in conjunction with fertiliser and liming treatments can increase seed production of annuals and cause an organic-matter base to be accumulated (Middleton 1995).

Shoreline topography

The development of shoreline topography needs to be carefully planned and implemented to create the right conditions for the desired wetland communities. In many schemes the drawdown zone is not considered in detail, and is therefore normally restricted to a narrow strip at the water's edge. It is better practice to make sure that the drawdown zone is extended to produce a large area of variable hydrology and high biological diversity. In designing new wetlands or managing existing ones, some key points for the topography of drawdown zones are the creation of hummocks and hollows or ridge-and-furrow, the development of shallow slopes and the bunding of bays or inlets.

Vegetation

Attempts to establish and improve the vegetation of drawdown zones have been rare in Europe and the UK. Work in the USA has, however, shown that methods for establishing tolerant vegetation on bare drawdown zones are a practical concept. The use of appropriate species and management techniques, tailored to the situation and used at the correct time of year, can create vegetation communities that will be able to survive, and benefit from, the environmental factors of flooding and exposure (Allen 1988; Allen & Klimas 1986; Fraisse *et al.* 1997).

To overcome problems with natural colonisation on lake and reservoir shorelines, plants can be established by artificial means. A range of species can be used to produce a varied vegetation composition, able to adapt to a variety of hydrological conditions. Annual plants such as Marsh Cudweed, bur-marigolds and Pale Persicaria *Persicaria lapathifolia* are able to persist in the drawdown zone by surviving flooded periods as seed and replacing themselves year after year. Vegetatively spreading herbaceous perennials, which colonise the bare zone as it becomes exposed every year, include species such as Couch *Elytrigia repens*, Silverweed *Potentilla anserina*, Creeping Bent and Reed Canary-grass (Hoffman *et al.* 1986; Little & Jones 1979).

Seeding of plants such as Creeping Bent and Reed Canary-grass has been carried out on mud banks and slopes of up to 45° together with fertiliser application, and has been most successful when undertaken in autumn and immediately after exposure of the substrate (Levine & Willard 1990). In sites subject to erosion, siltation or wave action, the use of transplants may be a more suitable method than seeding. For the planting of new stock, cuttings and root stocks collected in the previous winter can be planted out in April and May. A project on Lake Mead, in the United States, used a variety of species, including bulrush, club-rush *Scirpus*, Common Reed, willow *Salix* and poplar *Populus* (Croft *et al.* 1988). Local transplants, preferably from the same waterbody and water-depth range, should be used wherever possible, as these will be adapted to the conditions prevalent in the area. As an alternative to direct planting, species such as Sweet Flag *Acorus calamus*, Yellow Flag *Iris pseudacorus* and sedges *Carex* can be pre-grown in pallets with coir mat and secured with stakes and ropes to the substrate. In addition, rhizomes and tubers of some species, such as Wild Celery *Apium graveolens* and Fennel Pondweed *Potamogeton pectinatus*, can be established in mesh bags weighted with gravel.

Although woody species tend to be less successful in the drawdown zone than herbaceous species, adapted trees can be planted, even in areas where they would not otherwise colonise. Species such as Goat Willow *Salix caprea*, Alder *Alnus glutinosa* and hybrid Black Poplar *Populus nigra* are well adapted for growing low on the shoreline, with the trees located at or above the summer median water level. If possible, planting is best done a number of years before inundation, with mulching provided if drought is likely to be a problem. Once established, adapted tree species can probably survive prolonged periods of partial inundation, provided that they are unflooded for at least 60% of the growing season (Gill & Bradshaw 1971).

Conclusion

Contrary to much negative perception, the eulittoral environment is often less extreme than has been supposed, and drawdown habitats are clearly a valuable nature-conservation resource in many ponds, lakes and reservoirs. These transitional habitats can be incredibly rich and may provide amenity value, diversity to the waterbody and its surroundings, and habitats for a range of rare species. Because of their ecological significance and potential importance in a landscape, they merit special protection and management for their biodiversity.

Water-level dynamics, including extreme periodic drought, play a vital role in many ecosystems (Fredrickson & Reid 1990; Weller 1999). Research on a number of sites has shown that water-level fluctuations have not hampered the functioning of the ecosystem. In fact, after 50 years of winter drawdowns in one waterbody, the variety of plant species had increased, with some of the highest diversity being found in areas with most drawdown (Nichols 1975). In contrasting situations, misguided attempts to stabilise water levels have had adverse impacts on the vegetation and animal communities of wetlands (Kallemeyn *et al.* 1992; Weller 1999).

The advantages of vegetated drawdown zones deserve greater recognition and status in the overall planning and administration of reservoirs, especially as multiple-use concepts have become widely accepted. In some systems of reservoirs, recreational impacts are taken into account when planning the 'control-rule curves' that govern water-supply operations, and the same could also be done for conservation purposes (Gibbins & Acornley 2000; Hill 1993).

Wetland managers should consider the four key factors of water-level control, shoreline topography, substrate conditions, and any requirements for the introduction of vegetation. To achieve the greatest benefits, the potential influence of water-level fluctuations should be taken into account from the start of any wetland scheme. This should be the case whether the wetland is being developed for environmental or for economic reasons. The early integration of plans for drawdown and flooding in the process of site selection and design vastly improves the potential for sound biological management decisions. It can also potentially offer great benefits as an adaptation strategy for protecting nature-conservation and water-resource interests in the face of future threats from global climate change.

References

Abrahams, C (in press) Sustainable shorelines: the management and revegetation of drawdown zones. *Journal of Practical Ecology and Conservation*

Allen, H H 1988 Vegetating reservoir shorelines for erosion control. In *8th Annual International Symposium on Lake and Watershed Management. St Louis, MO. 15-18 November 1988.* North American Lake Management Society, Arlington, VA

Allen, H H, & Klimas, C V 1986 *Reservoir Shoreline Revegetation Guidelines. Technical Report No: E-86-13.* Army Engineer Waterways Experiment Station, Vicksburg, MS

Andrews, J, & Kinsman, D 1990 *Gravel Pit Restoration for Wildlife: A Practical Manual.* Royal Society for the Protection of Birds, Sandy

Backeus, I 1993 Ecotone versus ecocline – Vegetation zonation and dynamics around a small reservoir in Tanzania. *Journal of Biogeography* 20(2): 209-218

Biggs, J, Corfield, A, Walker, D, Whitfield, M, & Williams, P 1994 New Approaches to the Management of Ponds. *British Wildlife* 5: 273-287

Blackstock, T H, Duigan, C A, Stevens, D P, & Yeo, M J M 1993 Vegetation zonation and invertebrate fauna in Pant-y-llyn, an unusual seasonal lake in South Wales, UK. *Aquatic Conservation: Marine and Freshwater Ecosystems* 3: 253-268

Cannell, M G R, Palutikof, J P, & Sparks, T H (eds) 1999 *Indicators of Climate Change in the UK.* DETR, Wetherby

Croft, L K, Paulson, L J, & Huley, J S 1988 The Lake Mead cover enhancement project: Planting native vegetation creates new habitat. In *8th Annual International Symposium on Lake and Watershed Management. St Louis, MO. 15-18 November 1988.* North American Lake Management Society, Arlington, VA

Duncan, J E, & Dalby, M 1960 The vegetation of Swinsty and Fewston reservoirs 1957 to 1959. *The Naturalist* 3: 81-88

Evans, P A 1983 *Rutland Water Nature Reserve: Notes on the Vegetation of the Drawdown Zone.* Unpublished report

Fraisse, T, Muller, E, & Decamps, O 1997 Evaluation of spontaneous species for the revegetation of reservoir margins. *Ambio* 26(6): 375-381

Fredrickson, L H, & Reid, F A 1990 Impacts of hydrologic alteration on management of freshwater wetlands. In Sweeney, J M (ed), *Management of Dynamic Ecosystems.* North Central Section, The Wildlife Society, West Lafayette, Indiana

Gibbins, C N, & Acornley, R M 2000 Salmonid habitat modelling studies and their contribution to the development of an ecologically acceptable release policy for Kielder Reservoir, North-east England. *Regulated Rivers: Research & Management* 16(3): 203-224

Gill, C J 1977 Some aspects of the design and management of reservoir margins for multiple use. *Applied Biology* 2: 129-182

Gill, C J, & Bradshaw, A D 1971 The landscaping of reservoir margins. *Journal of the Institute of Landscape Architects* 95: 31-34

Hejny, S 1971 The dynamic characteristic of littoral vegetation with respect to changes of water level. *Hydrobiologia* 12: 71-85

Hill, A I 1993 The impact of reservoir drawdown on water-based recreation. In Currie, J C, & Pepper, A T (eds), *Water and the Environment.* Ellis Horwood, Chichester

Hoffman, G R, Klimas, C V, Shetron, S G, & Allen, H H 1986 *Environmental and Water Quality Operational Studies. Lakeshore Revegetation Studies at Lake Oahe, South Dakota. Report No: WES/TR/E-86-3.* Army Engineer Waterways Experiment Station, Vicksburg, MS

Kallemeyn, L W, Cohen, Y, & Radomski, P 1992 Rehabilitating the aquatic ecosystem of Rainy Lake and Namakan Reservoir by restoration of a more natural hydrologic regime. *Restoration Planning for the Rivers of the Mississippi River Ecosystem Symposium, Rapid City, SD, Sep 13-15:* 432-449

Langford, T E 1983 *Electricity Generation and the Ecology of Natural Waters.* Liverpool University Press, Liverpool

Levine, D A, & Willard, D E 1990 Regional analysis of fringe wetlands in the Midwest: creation and restoration. In Kusler, J A, & Kentula, M E (eds), *Wetland Creation and Restoration.* Island Press, Washington DC

Little, M G, & Jones, H R 1979 *The Uses of Herbaceous Vegetation in the Drawdown Zone of Reservoir Margins.* Water Research Centre

Lott, D 1994 *Survey of beetles at Saddington Reservoir.* Unpublished report: Leicestershire County Council

Merritt, A 1994 *Wetlands, Industry & Wildlife: A manual of principles and practices.* Wildfowl & Wetlands Trust, Slimbridge

Middleton, B A 1995 Seedbanks and Species Richness Potential of Coal Slurry Ponds Reclaimed as Wetlands. *Restoration Ecology* 3(4): 311-318

Naiman, R J, & Decamps, H (eds) 1990 *The Ecology and Management of Aquatic-Terrestrial Ecotones.* Unesco & Carnforth: Parthenon Publishing, Paris

Nichols, S A 1975 The impact of overwinter drawdown on the aquatic vegetation of the Chippewa Flowage, Wisconsin. *Wisconsin Academy of Sciences, Arts and Letters* 63: 176-186

Palmer, M, & Newbold, C 1983 *Wetland and Riparian Plants in Great Britain.* Nature Conservancy Council, Shrewsbury

Spray, M 1980 The botany of some Sheffield area reservoirs. *The Sorby Record* 18: 68-72

Stewart, A, Pearman, D A, & Preston, C D (eds) 1994 *Scarce Plants in Britain.* JNCC

Weller, M W 1999 *Wetland Birds: Habitat Resources and Conservation Implications.* Cambridge University Press, Cambridge

Welling, C H, Pederson, R L, & van der Valk, A G 1988 Recruitment from the seedbank and the development of zonation of emergent vegetation during a drawdown in a prairie wetland. *Journal of Ecology* 76: 483-496

Wilcox, D A, & Meeker, J E 1991 Disturbance effects on aquatic vegetation in regulated and unregulated lakes in Northern Minnesota. *Canadian Journal of Botany* 69(7): 1542-1551

Williams, P, Biggs, J, Barr, C J, Cummins, C P, Gillespie, M K, Rich, T C G, Baker, A, Baker, J, Beesley, J, Corfield, A, Dobson, D, Culling, A S, Fox, G, Howard, D C, Luursema, K, Rich, M, Samson, D, Scott, W A, White, R, & Whitfield, M 1998 *Lowland Pond Survey 1996.* DETR, London

Wilson, S D, & Keddy, P A 1988 Species richness, survivorship, and biomass accumulation along an environmental gradient. *Oikos* 53: 375-380

Zalewski, M, Frankiewicz, P, & Kalinowski, S 1990 The potential for biomanipulation using fry communities in a lowland reservoir: concordance between water quality and optimal recruitment. *Hydrobiologia* 200-201: 549-557

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