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Strategies for conservation management of lakes

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Abstract

This paper discusses how the use of nature conservation targets can influence the practice of the management and rehabilitation of shallow lakes. It suggests that managers need to identify realistic targets, based on a sound understanding of the nature and ecological processes operating in the lakes in question. The constraints on effective management towards ecological targets are identified in the context of the rehabilitation of shallow lakes from eutrophication. It is recognised that most commonly, nature conservation is one of several objectives in lake management. Using the Norfolk Broads case study, it identifies a range of ecological and human use influences that need to be assessed in order to form the basis of an integrated, sustainable approach to rehabilitation from the effects of eutrophication. The way in which nature conservation is taken account of through each stage in the planning of broads restoration projects is discussed, and the need for further specific advice for lake managers is indicated. This paper stresses the benefits of large scale experimental management, backed up by research and monitoring as a way of taking forward this applied science. The need for good communication with partner agencies and the local community when undertaking this management work, is also emphasised.

Introduction

The role of lakes as wildlife habitats and the goods and services they provide, such as water supply and recreational opportunities, have tended to be taken for granted. These standing open waters vary in size from tens of thousands of hectares, to ponds just a few metres across. They form an essential component of landscapes in every continent and from the tundra to the equator.

There is a growing international awareness that lakes, as for all types of wetlands, are more valuable in their natural, or slightly modified state than if drained or polluted and increased efforts are being made towards lake restoration and conservation. In their pristine state, most water bodies have nutrient poor water as a result of efficient natural systems for nutrient conservation. Rapid agricultural change and population growth in developed countries, particularly in the past century, has led to widespread eutrophication through the increased and continuous supply of nutrients to river and lake basins in the landscape. Hence eutrophication is now recognised as the most pervasive and extensive cause of lake degradation in Europe (European Commission, 1995). The symptoms and consequences of lake eutrophication have been widely reported elsewhere (e.g. Kling et al., 1995; Moss et al., 1996). In extreme cases, eutrophication results in a dramatic loss of biodiversity linked with the total loss of aquatic macrophytes.

The dominant argument for the conservation of wetlands for nature has historically been their role for supporting birdlife, particularly those on important waterfowl migration routes. The Ramsar Convention (1971) and the EC Wild Birds Directive (1979) aim to reverse the downward trend on an international basis. Through international commitments, measures are required to classify and protect sites and also to incorporate conservation measures in land-use policy. Site selection criteria are well developed now for all types of wetlands and include ‘representativeness’ and ‘rarity’ of wetland examples in biogeographical regions, the role a wetland plays in the ‘functioning’ of river basins or coastal systems, and the value in supporting human communities. Many lakes are part of these designated wetlands and in some countries in western Europe, notably in Denmark, Sweden and the Netherlands, considerable investment in lake restoration and rehabilitation is now in place. This is based on comprehensive national wetland strategies, recognising nature conservation as a major and sometimes primary use.

Sadly in the U.K., as is the case across Europe, lakes seem to have largely fallen through the net of historic nature conservation strategies. This is explained by the dominance of eutrophication as the agent of degradation and the requirement for control through the integrated management of water and land on a catchment basis, delivered by a multiplicity of organisations. Carvalho & Moss (1995) reported that of 90 SSSI lakes in England and Wales, more than three quarters showed 50% change over the last few decades, with only 4.4% remaining in a pristine condition. Many of those which showed the greatest change are considered oligotrophic or mesotrophic, such as those in the uplands of north-west England. The U.K. Biodiversity Action Plan (HMSO, 1995) recognises the historic enrichment of lakes and prioritises action through costed plans for remedial management of 50 mesotrophic lakes by 2010. It is clear that an ambitious programme of action will be needed to make progress with the restoration of degraded lakes (English Nature, 1997).

The European Commission Directives on urban waste water treatment (UWWTD) and nitrogen (Nitrates Directive), have a part to play in combating continued eutrophication, however many sites of high biodiversity significance fall outside the scope of this legislation. The UWWTD only applies to major urban sewage treatment works with population equivalents of over 10 000 and, therefore, will fail to address the nutrient supplies of the most valuable lakes in the U.K., most of which are in rural areas. In the U.K. the Nitrates Directive has only been used to safeguard the quality of drinking water and not, as the Directive allows, to reduce nutrient loading for environmental reasons. Furthermore, the major contribution to eutrophication from nutrients applied to arable farmland is becoming more apparent (Royal Society, 1983; Foy et al., 1995; Johnes, 1996).

There are important policy and strategic planning issues to resolve, and considerable investment to be made if the U.K. commitment to sustainable development and biodiversity are to be fulfilled sufficiently and consistently for the water environment (U.K. Round Table on Sustainable Development, 1997). The U.K. Biodiversity Action Plan endorses the development of a strategy for the control of eutrophication and nutrient standards appropriate for mesotrophic lakes, the latter in association with water quality objectives. Ultimately, it is envisaged that countries within the European Union will define and monitor the ecological of lakes using a standard approach, linked to a common set of environmental objectives (European Commission, 1997). Clearly, the basis on which the ecological status of lakes is assessed in future, will have a profound effect on the ability of relevant agencies to justify regulatory, mitigation or restoration measures.

Attempts have been made to relate physical and chemical parameters to biological communities (e.g. Palmer et al., 1992) but these are incomplete studies. It is apparent, not surprisingly, that a large number of interlinking ecological factors operate, especially in shallow lakes, to make only general guidance possible on which plant and animal communities are likely to be associated with lakes of different environmental conditions. Added to this is the fact that monitoring information is fairly patchy, except in a few ‘hotspots’ like the Broads and the Lake District, where there has been a long history of interest. Another constraint is the fact that the basic biology and ecological requirements of rare and scarce aquatic species are poorly understood. Some fundamental research is therefore required before appropriate actions can be proposed and justified to secure and enhance particular species populations. All of these constraints make national target setting, using biodiversity standards, an imprecise activity.

Significantly, it has been proposed by the Environment Agency to set lake management targets according to the potential for restoration, based on an assessment of the physical and chemical variables (including nutrient loading) that would be associated with no increase in the current population and a less intensive, pre-war agriculture in the catchment. This ‘reference’ approach would, for example, draw attention to a small absolute change but extreme proportionate change in the nutrient status of a naturally highly infertile lake. It seems to offer a robust basis for prioritising actions for the conservation and restoration of lakes.

The Norfolk and Suffolk Broads

Over the last 20 years, work has been underway in the Broads wetlands in eastern England to determine ways of restoring the ecological richness and natural beauty of around 40 shallow lakes, (broads) which originated as peat diggings (see Figure 1, and Moss,

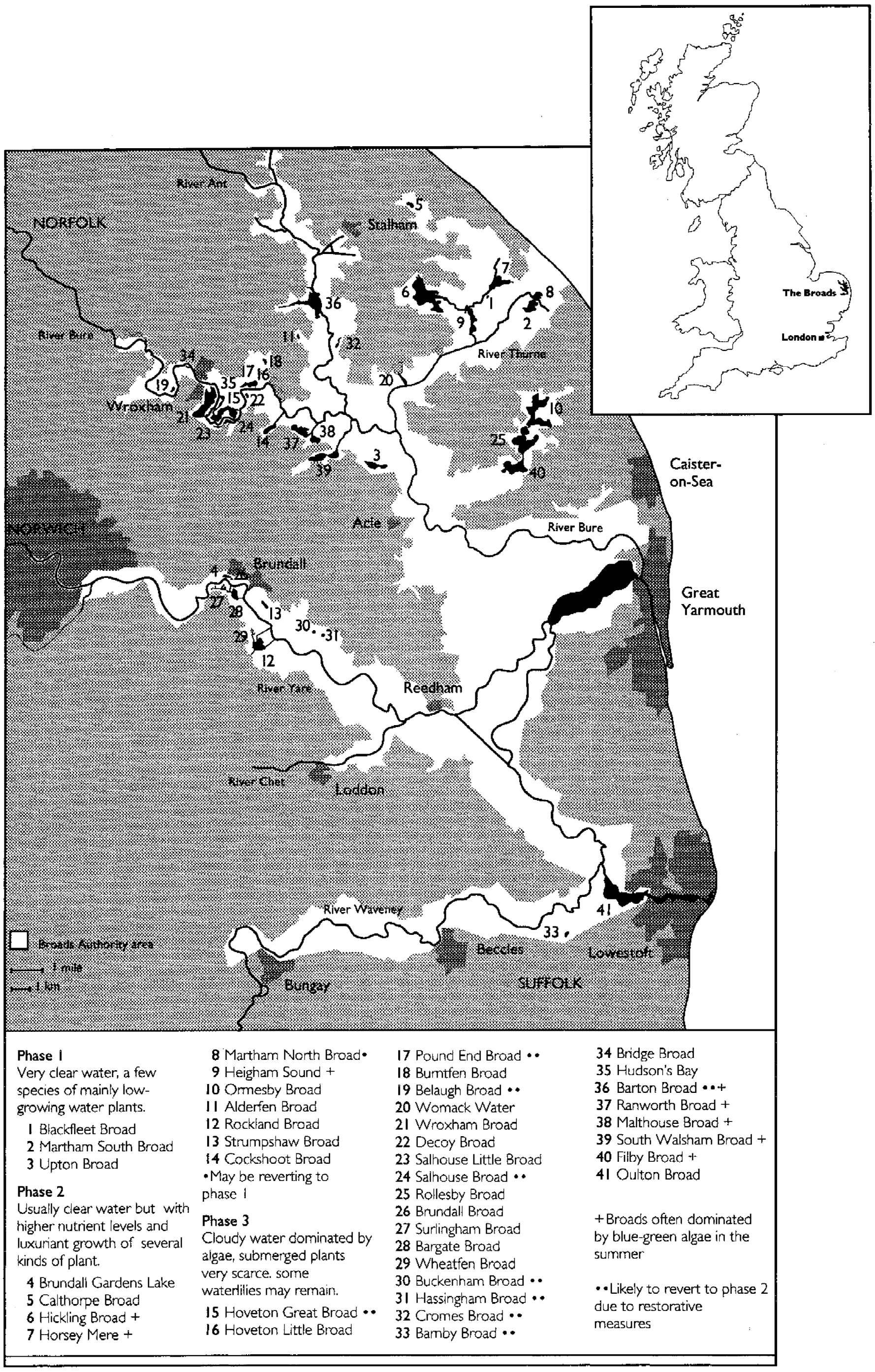

Figure 1. Location of the Broads wetland and individual Broads, grouped according to their ecological condition.

1989; George, 1992; Madgwick & Phillips, 1996 for overview). An initial awareness of the problems was heightened by a report of the then Nature Conservancy (Nature Conservancy, 1965) which drew attention to the catastrophic loss of water plants, decline of the fishery, increased pea-soup algal blooms and erosion of the reedswamp margins of rivers and lakes. These very visible changes in a popular holiday destination led to a strong commitment from a number of agencies to identify and implement practical solutions.

The establishment of a Broads Authority, with responsibilities for coordination of policies and actions for the whole area, enabled an integrated approach to the problem. The aims and working policies are embodied in the Broads Plan (Broads Authority, 1997) and the Environment Agency Catchment Plan for the area (NRA, 1995). The policies and actions relevant to eutrophication control, have been based on the results of a developing programme of research and experimental management. This work was made possible by the cooperation and joint investment of a number of agencies and universities, most recently coordinated by the Broads Authority and Environment Agency and assisted by the E. U. 'Life' Environment Programme. The development of the Broads research investigations have been summarised by Phillips et al. elsewhere in this publication and the recent work is detailed in Madgwick & Phillips (1996). The rest of this paper will consider the strategy for restoring the broads as a case study, showing how practical actions for nature conservation have been proposed, and how they are influenced by environmental constraints and multifunctional uses.

Reasons for broads restoration

Before setting out the influences and constraints on the broads restoration strategy, it is necessary to consider the reasons why a restoration policy has been promoted. Firstly, it is not acceptable to do nothing. Without further action, degradation will continue and further reduce the natural resources and recreational potential. Delay in taking action is only likely to increase the difficulty and cost. Secondly, if restoration actions are successful, there will be tangible benefits in terms of a more attractive and diverse environment, which will benefit local people and visitors alike, for example through an improved quality of recreation and lower costs of maintaining the navigation through dredging. Lastly, there are a number of national and international government commitments, which agencies such as the Broads Authority, English Nature and the Environment Agency are obliged to fulfill, such as the U.K. Biodiversity Action Plan and EC Directives mentioned above.

Broads restoration aims

The accepted aim is to restore the rivers and broads to 'a good ecological condition' which will support stable populations of plant and animal life (Broads Authority, 1997). Stability in this sense is meant to mean that the lake is able to buffer itself though internal biological and chemical mechanisms against external influences, which would tend to cause it to switch back to an algal-dominated state. It also implies that once 'restored', it will require minimal management to maintain its integrity and quality.

Nature conservation priorities

Since the early days of research and experimentation on water quality improvement in the Broads, the nature conservation case has been considerably strengthened. Around 20% of the wetland area is recognised as being of international importance for nature conservation, including 15 of the 41 broads, the majority of which are nature reserves. The Broads Natural Area Profile, which assessed the natural resources of Broadland in a national context, drew attention to a number of nationally rare and threatened species limited to Broads (Holve, 1996). The designations in themselves, however, are an unreliable guide to the nature conservation value of individual broads or of their restoration potential, since many were designated as part of a wider wetland complex where other natural features have higher importance.

Ecological targets

Biodiversity and environmental targets and standards, based on pre-eutrophication conditions in the Broads, are not considered appropriate and hence, strictly speaking, the aim is for rehabilitation to an improved state rather than for restoration. True restoration would be frustrated by an incomplete knowledge of the historical nature of the Broad, an acceptance that catchment influences on water quality and water resources can be reduced but not reversed, and that fairly intensive recreational use of many Broads is likely to continue in the medium term. Instead, it has been necessary to develop a vision based on what might be possible and sustainable in the future.

It has become increasingly apparent through research and monitoring work in the Broads and elsewhere that fairly dense beds of submerged macrophytes and a well developed littoral margin are prerequisites to the stability of macrophyte dominated lakes, which also support a diverse assemblage of invertebrates and fish (Timms & Moss, 1984; Perrow et al., 1999). Basic ecological theory suggests that biological diversity is likely to increase with a more complex biological structure within the lake. A well-developed littoral margin, floating and submerged plants together with variation in sediment type, depth and profile would maximise the habitat heterogeneity. Survey and monitoring work on macro-invertebrates (Jackson, 1997) and fish populations in Broads across the full range of ecological conditions (Perrow, 1991; Perrow & Jowitt, 1997), have confirmed this relationship between diversity and structure.

The pursuit of increased overall diversity has to be tempered to some extent by the need to promote conditions appropriate to rare habitats or species. In the Broads, an ideal goal is thought to be the restoration of extensive charophyte beds. This is justified by the previous domination of the broads by charophytes, as proven by reference to sediment cores (Moss, 1988), and the current national rarity of these species assemblages (HMSO, 1995; Holve, 1996). Particular species recovery targets for rare species, such as holly-leaved naiad (*Najas marina*), will be directed to suitable broads and possibly newly excavated peat diggings where the potential for recolonisation is the greatest.

Apart from the direct nature conservation benefits associated with achieving a near pristine condition in Broads, there would be less conflicts with recreational boating due to the low growing nature of charophytes. In Broads which are navigable, restoration attempts could be unpopular unless charophyte dominance is achieved. This is because if tall, dense growth of water plants is achieved instead, there will be disruption to boating and consequent high costs of weedcutting.

Steps in restoration

The research and experimental management work in the Broads has established four essential steps in the restoration process. These are explained by Phillips et al. (1999) and in Madgwick & Phillips (1996). They are in summary:

1. Reduction in external and internal nutrient loading.
2. Biomanipulation to create clear water conditions in the summer.
3. Re-establishment of macrophytes.
4. Stabilisation of the lake ecosystem, including the re-establishment of appropriate fish populations.

Whilst the implementation of a stepwise programme of restoration can be justified based on this simple theoretical framework, the implementation of such a programme is likely to more or less be successful in a particular Broad, depending on a number of catchment and site specific issues. These have been outlined for the Broads Authority in a position statement document (Madgwick, 1996) and are discussed below with reference to their influence on management targets and conservation strategies.

Control of catchment nutrients

The majority of broads are small and distant from the rivers and mainly receive nutrients from the agricultural catchment area. The nutrient inputs to some of these lakes can be significant, as at Alderfen Broad (Moss et al., 1990), and a choice has to be made concerning diversion of nutrient-rich inflows or use of other measures to reduce the nutrient status of the incoming water. As evidence is growing for the importance of water exchange in these moderately eutrophic lakes, there is a growing case for finding means of minimising or intercepting nutrients in supply waters to these broads.

A localised and short-term management option for nutrient control is to isolate some of the broads from the river system by creating an artificial barrier. This was achieved at Cockshoot Broad in 1981, as an early experiment (see case study in Moss et al., 1996). However, due to public navigation rights and a desire to retain the historical landscape and hydrological continuity between rivers, Broads and the surrounding wetland, there is now a general presumption by the Broads Authority and English Nature against using isolation as a management technique (Holve, 1996). There is also increasing evidence from the Broads monitoring data that water exchange or ‘flushing’ of Broads is important to prevent recycling of nutrients (Pitt et al., 1997).

Since a recovery of aquatic life is desirable ultimately for the whole rivers and broads system, and not just for broads that are naturally or artificially isolated from the rivers, a phased programme of investment for phosphorus reduction has been negotiated between interested parties.

The main source of catchment phosphorus into the northern (Bure, Ant and Thurne) rivers and broads was shown to be from 15 key sewage treatment works (with population equivalents >100). Control of the nutrient inputs to the rivers and connected Broads from major sewage treatment works is ultimately limited by the ability of Anglian Water to invest in phosphate removal plant and its continued maintenance.

At first, this investment was supplemented by the Broads Authority in an experimental phase in the 1980s but more recently, Anglian Water has been able to pass on the costs to its customers. This in turn is limited by OFWAT (the government-appointed water regulator) and the Department of the Environment, who have to agree to any expenditure outside that required by statute. The Environment Agency regulate non-statutory objectives through a consent procedure, agreed with Anglian Water and the Broads Authority. The 1mg l^{-1} total phosphorus standard for the final effluent from 8 sewage treatment works in the northern part of the Broads, was set as an agreed target which is thought to be achievable and reasonable, taking into account of the background diffuse inputs from the catchment and internal loading from rivers and Broads. This negotiation process was considerably assisted in the Broads by the use of demonstration projects which have shown what results may be possible as a result of restorative measures following nutrient reduction.

Although there is no doubt that a phased programme of investment in phosphorus reduction at sewage treatment works is needed, there is recent evidence in the Bure catchment that agricultural inputs of phosphates from arable land and the contribution of a large number of small point source private sewage treatment works, are becoming significant in terms of nutrient loading (Johnes, 1996). Further regulatory mechanisms may be needed to control these diffuse inputs. For agricultural sources this would need to include reductions in application of fertilisers or poultry litter to arable land in certain areas. In time, this kind of measure could be made a condition of continued agricultural subsidies through agri-environment reforms. The use of buffer strips or created wetlands may also be necessary to intercept run off that carries particulate phosphorus (Haycock et al., 1997).

The fundamental objective of phosphorus reduction measures in the Broads has been to achieve nutrient levels in broads that are in the range for a switch to a macrophyte dominated condition to be achievable through biomanipulation. However, from a nature conservation point of view, the greater the reduction in nutrient supply to lakes the better. At the lowest end, with lake water quality below about 50 μg l^{-1} total phosphorus, a return to charophyte-dominated systems may be achievable and conservation value in terms of the diversity of water plants and the stability of the lake is likely to decrease with increasing nutrient levels (Moss et al., 1996; Hosper, 1997).

Control of internal nutrient loading

Sediment release of phosphates and the control of internal nutrient loading through suction dredging and dosing with iron salts have been investigated in broads through experimental management (Pitt et al., 1996). Iron dosing trials have not justified large scale application but may have a role in broads that remain unconnected to the main river system. In many broads, suction dredging has proved necessary to establish 1–2 metres of water depth and it is currently the only means of reducing the available sediment nutrient supply. Unfortunately, monitoring data on the effectiveness of suction-dredging in the Broads is limited (see Phillips et al., 1999).

One problem with suction dredging concerns the decision about what depth of sediment to remove, and to what extent a nutrient target can be proposed. Analysis of a number of sediment cores in Barton Broad revealed a generalised cut-off point with increased depth in cores from each sector of the broad, beneath which nutrient levels declined dramatically, although there was considerable local variation, presumably influenced by sedimentation patterns and the influence of boat traffic (Figure 2). The final specification in this case incorporated depth requirements for various types of boats (Holzer et al., 1997).

Recent investigations concerning the factors affecting macrophyte recovery (Schutten et al., 1997), conclude that sediment instability is a key factor and in lakes with soft, peaty sediments, seedlings may not survive long as they are so easily uprooted, for example by birds, water or sediment movement. Experience in dredging down to the solid peat in the Broads and in lake Geerplas in the Netherlands has shown that a fluid sediment can reform in one or two years with similar phosphorus release characteristics as before dredging (Pitt et al., 1996). Monitoring of the current large scale dredging project in Barton Broad will help to increase understanding of these effects. It will be necessary to define more precisely the chemical and physical parameters that can serve as management targets for suction dredging, taking into account objectives for nutrient control alongside those for macrophyte recovery and use of the lake.

The main practical constraint of suction dredging, apart from cost, is the local availability of suitable

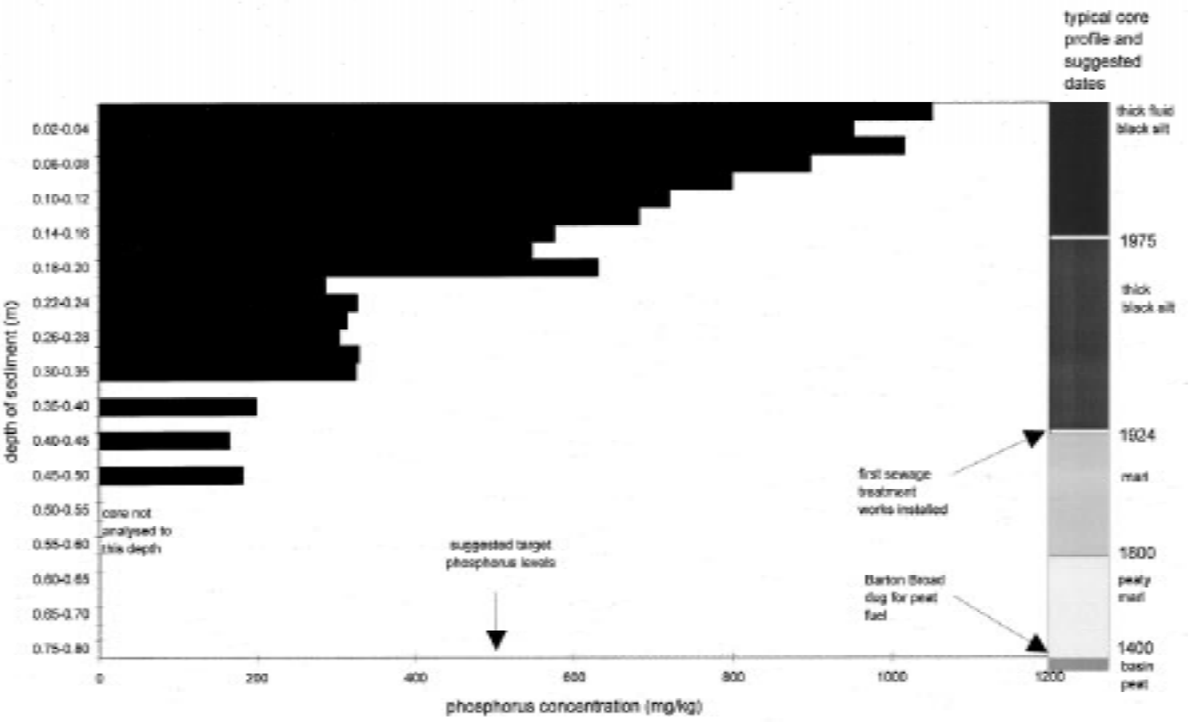

Figure 2. Phosphorus concentration profile in a sediment core from Barton Broads, and its relationship to visible layers, which reflect the history of human influences on the lake.

spoil disposal sites. Use of agricultural land is preferable to wetland of nature conservation importance but this brings further constraints on site preparation and handling of soils (see Barton Broad case study in Moss et al., 1996).

Biomanipulation

'Biomanipulation' or the near complete removal of zooplanktivorous fish to enhance the effects of grazing Cladocera, has been practised in a number of small broads over the last 7 years (Perrow, 1994), and has most recently been successfully applied as a sole restoration technique for one of the largest broads, Ormesby Broad (54 ha), where nutrient levels are moderately low with the mean around 50 μg l^{-1} total phosphorus (see case study in Moss et al., 1996). A range of practical fish removal techniques have been developed to take account of the physical characteristics of different broads and the nature and seasonal behaviour of fish stocks (Holzer et al., 1997).

In the Broads, the obvious practical constraint is the connection of many of the major broads to the river system and hence the need to create temporary, fish barriers to isolate whole or part of each lake. The ability to achieve this is often frustrated by navigation objections and design difficulties for the barriers which need to be able to withstand a tidal regime, allow water exchange, while preventing the passage of fish fry and spawn and resist clogging with epiphytic algae. Sometimes it is also necessary to build in a means for boat passage (Moss et al., 1996; Holzer et al., 1997). Another obvious practical consideration is the use of the lake for angling purposes. The retention of tench (*Tinca tinca*) and pike (*Esox lucius*) in biomanipulated broads has at least enabled some angling to continue in the short term. As successful examples of biomanipulation become available, where the need for fish removal declines and ceases as at Cockshoot Broad (Perrow, 1997), it has become easier to convince passionate angling groups of the future benefits of biomanipulation for the quality of the fishery and hence their sport.

Despite the technical problems, trials in the Broads have shown that even small fish free areas in broads can sustain clear water and water plants over a number of years. Further work is required to establish whether a lake can be restored by the progressive use of exclosures in bays. If this is a practical solution, it will be necessary to establish what proportion of the waterspace should be targeted for biomanipulation to achieve macrophyte dominance.

Re-establishment of macrophytes

In non-biomanipulated broads, the shading effect of dense algal blooms is likely to be the dominant constraint on aquatic macrophyte growth and survival. Even in clear water broads, following biomanipulation, the recovery of macrophytes has been fairly slow and erratic. In several broads it has been observed that many seedlings develop in the first spring clear water period but they have disappeared by the end of the summer, even though the water remains clear. Recently, considerable attention has been given to investigate potential limiting factors for macrophyte recovery (Schutten et al., 1997). A comparative study of a range of environmental variables associated with a limited number of plant species was carried out in 30 shallow lakes in the Netherlands and the U.K. A number of physical and chemical attributes of the sediment, that this survey highlighted as having a strong influence on water plant presence, were further tested in the laboratory. This work has suggested that the instability of peaty sediments in the Broads may be the key limiting factor on seedling survival. Further research and use of modeling will help managers to identify target species or guilds of plants for different lakes or parts of lakes according, for example, to local conditions of wind fetch and sediment variability. Experimentation with ways of treating and stabilising loose sediments in peaty lakes like the Broads, will assist the identification of realistic management techniques to secure water plant recovery.

Grazing by water birds is often cited as an important influence on macrophyte composition and in some situations it is suggested that grazing pressure is such that it may prevent or severely delay the recovery of macrophytes in shallow lakes (Van Donk, 1997). Some detailed survey and experimental work in the Broads showed that losses to grazing birds were negligible in the summer growing period in comparison to potential growth rates (Perrow et al., 1997). However, year to year variations in plant communities may well be determined in part by late summer and autumn grazing.

Further development of models is needed to assist managers in using the data available on existing conditions at a given lake, to predict the likely success of macrophyte recovery and to determine what, if any, mitigation measures might be necessary. It will also be important to carry out autecological research on rare macrophyte species or local, native species that are thought to play a central or 'keystone' role in the plant recovery process. This type of ecological information would greatly add to the ability for managers to determine and prioritise actions in particular lakes and for nature conservation targets to be incorporated into wider lake restoration strategies.

Stabilisation of the lake system

The presence of submerged vegetation and benthic diatoms act as 'buffering mechanisms' to reduce the susceptibility of sediment to wind-induced resuspension, compete with phytoplankton for nutrients and provide refuges for grazing zooplankton (Hosper, 1997). This is more achievable in small lakes (<30 hectares) (Hosper, 1997). The effectiveness of 'top down' control exerted by piscivores, which helps stabilise lake systems is also known to be dependent on the presence of substantial areas of macrophyte beds of varying density, interspersed by patches of water (Grimm & Backx, 1990; Walker, 1994; Perrow & Jowitt, 1997).

Despite good agreement amongst limnologists and fisheries scientists on these general preconditions for lake stability, there is relatively little specific information available for managers, for example concerning the target proportion of submerged macrophyte beds for zooplankton refuge effects to be effective from year to year. Apart from the percentage cover of aquatic macrophytes, targets for the volume, structure and pattern of cover of aquatic and littoral plants may be appropriate. This in turn may influence where biomanipulation works are prioritised within the lake and the scale and type of measures which will be needed for water plant introductions or protection from bird grazing.

Preliminary results from Cockshoot Broad and Ormesby Broad suggest that fish communities can respond fairly rapidly to the presence of submerged macrophyte beds and that diversification of the fish community and a tendency to pike dominance will occur without the need for restocking (Perrow, 1997). However, there is uncertainty about the stability of these lake situations and there is a desire to establish appropriate targets for fish population composition and structure for the range of shallow lake types (Moss et al., 1996). In the Broads, a precautionary approach has been taken in monitoring zooplanktivore populations during the restoration process and continuing to

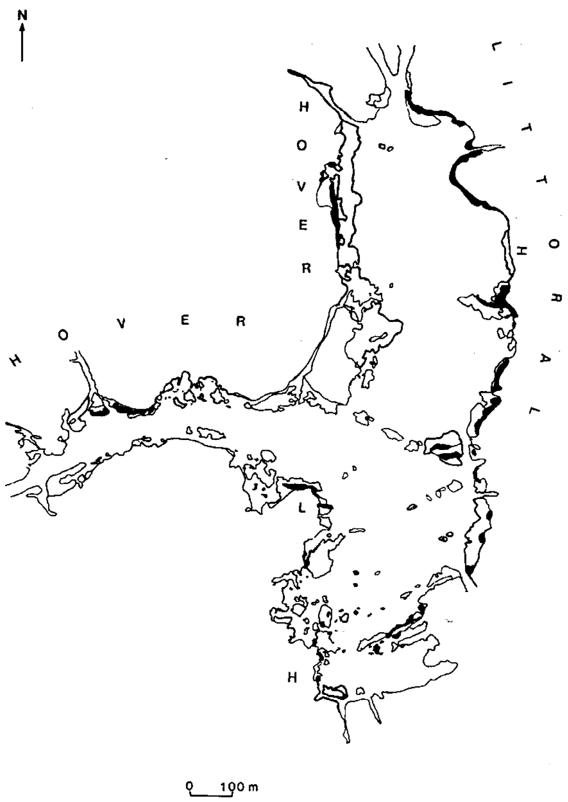

Figure 3. The distribution of hover and littoral growth forms of reedswamp in Barton Broad, showing areas lost to open water (unshaded) between 1946–1977 (from Crook et al., 1983).

keep them low through small scale fish removal operations, until submerged macrophyte beds are seen to occur across the Broad for several years. However, some fairly arbitrary decisions on fish manipulations have needed to be made from year to year. For example, when macrophytes are present, but variable in cover from year to year, it is difficult to know whether it is cost-effective to further reduce the adult bream (*Abramis brama*) population to minimise the predation pressure of young fish in the spring and summer. More information on the habitat requirements for perch (*Perca fluviatilis*), would enable management to encourage this species to play an important piscivore role in a 'restored' lake situation.

The presence of a well developed littoral margin around the lake and a high proportion of reedswamp edge to open water, is thought to be crucial in enabling pike dominance to be re-established quickly vegetation (Jeppeson, pers. comm.; Hosper, 1997). Aerial photographs from the 1930s to the 1950s show a large proportion of the Broad basins covered by floating reedswamp (hover), interspersed with open water. A detailed study of the reedswamp regression revealed that virtually all of this floating hover was lost by the mid 1970s (Crook et al., 1983) and that littoral vegetation was confined to the firmer edges of Broads (see Figures 3 and 6). This floating reedswamp habitat is likely to have played a key role in determining the predator/prey interactions in the fish community and providing sheltered bays for aquatic macrophytes. Hence, restoration of substantial areas of reedswamp may prove to be necessary prior to, or in association with, biomanipulation in many Broads. This, in any case is a desirable objective from a nature conservation point of view, since reedswamp is a valuable transition habitat in terms of plant communities (George, 1992), a wide range of macroinvertebrates (Jackson, 1997) and nationally scarce birds, such as the bittern (*Botaurus stellaris*), (Holve, 1996).

Finally, stabilisation of a macrophyte dominated lake following biomanipulation, may depend on further nutrient controls. This is another important area for future research because most of the lake restoration projects of this kind in western Europe have occurred in the last decade and it is too soon to draw any conclusions. However, there is some evidence that plant communities in the Broads associated with intermediate nutrient levels (around 50–100 μg l^{-1} total phosphorus), typically including tall, leafy plants such as *Ceratophyllum demersum*, *Potamogeton* spp. and *Elodea* spp, are relatively unstable and may show considerable shifts or cycles in plant abundance and composition, due to weather-induced events and other de-stabilising influences. Conversely, charophyte-dominated lake communities which are always associated with low nutrient conditions ($<$50 μg l^{-1} total phosphorus) tend to be relatively stable in terms of the composition and abundance of macrophytes from year to year (Kennison et al., 1998).

Other influences on the success of broads restoration

Apart from the practical constraints, environmental influences and uncertainties mentioned above, which are likely to face most managers of shallow, eutrophic lakes, there are some particular water management issues in the Broads which impose another layer of complexity on decision-making and planning. These are associated with the tidal nature of the Broads waterway system.

Summer freshwater river flow may be a critical factor influencing the success of restoration attempts.

Greater flows reduce algal development by decreasing retention times in Broads connected to the rivers. This reduces the chances of dominance by blue-green algae (in particular *Oscillatoria* blooms) and limits nutrient recycling (Phillips, pers. comm.; Hosper, 1997). Apart from the recreational problems, blue-green algae may cause toxicity to zooplankton grazers. Reduced summer flows can also increase the chance of entry of predators of zooplankton, such as Neomysis integer, which can interrupt the restoration process. Such an event was recorded at Cockshoot Broad in 1992 resulting in cloudy water and poor growth that summer (Moss et al., 1996), although macrophyte recovery accelerated in the following years (Dunsford, 1996). There is also an increased risk of introduction of other toxic algal populations associated with more brackish conditions, such as *Prymnesium parvum*, which can cause dramatic changes in fish communities.

The degree of water exchange is known to influence the type and amount of algae that are produced in broads (see Phillips et al., 1999). The characteristics of those Broads close to the river, at the head of the system, are likely to be the most affected by any future reduction to river flow, which could be caused by increased abstraction and the effects of climate change. Those lowest down the river valley are most influenced by the tidal regime, saline intrusion and nutrient inputs from downstream. Broads connected to the middle reaches of the rivers by long, narrow channels have the longest residence times and hence provide the most stable environment, where blue-green bacterial populations are favoured.

The implication of these water management issues is that broads which are isolated from the river, and those which receive a regular throughput of freshwater, and are furthest from the estuary, are likely to be a safer bet for restoration to clear, freshwater Broads. A case has been made to quantify the river flow requirements that would satisfy Broads restoration objectives for the northern broads system, through hydrological modeling. This would be part of a bigger project to determine an integrated water management strategy for the area (Harper, 1997).

Classification of Broads according to management need

It is possible to group Broads according to their position in the Broads waterway system, the likely influence of river flow and saline intrusion, degree of isolation and ecological condition. An early classification system for the Broads identified three phases of ecological condition, related to a nutrient gradient (Broads Authority, 1987). This linear model was later adapted to reflect the notion of 'alternative stable states' (see Figure 4; Broads Authority, 1997). Recently, a water plant classification system has been derived from a long-term macrophyte monitoring dataset (Kennison et al., 1998). A summary matrix (Figure 5) shows a grouping of broads into three categories, according to the plant and animal communities that are thought to be achievable as a result of restoration management and their relationship to total phosphorus concentrations. The recreational implications of the three alternative scenarios are indicated. The influence of the position of broads in relation to the river system (and hence to tidal effects and salinity) and the degree of current navigational use are also shown. This classification of broads according to restoration potential, taking account of a multiplicity of constraints, will help to inform the Broads restoration strategy and individual site management plans.

Future prospects for Broads restoration

There is uncertainty over the ability of agencies to meet the ultimate target of restoring the whole rivers and broads system. It will require continued large-scale investment in phosphorus removal facilities at all significant sewage treatment works. All parties are committed to this approach in the Broads Plan, 1997. As this progresses, other catchment inputs from agriculture and a large number of septic tanks and private sewage works become more significant. It is only justifiable to tackle these types of sources as part of an integrated, catchment approach will make a significant difference to the water quality and aquatic life of the rivers and broads. New approaches to water quality regulation will be required, along with a joint commitment for investment from the water companies, Environment Agency and Ministry of Agriculture (MAFF). Until the minimisation of nutrient and pesticide losses from agricultural land becomes mandatory, through agri-environment reforms, any schemes to intercept nutrient and particulate run-off from farmland will also require the voluntary cooperation of landowners.

In the medium-term, some temporary restrictions on navigation will be required in the Broads to enable isolation of lakes for biomanipulation purposes. In the longer-term, considerable changes to the intensity and type of boating may be justified in certain Broads and

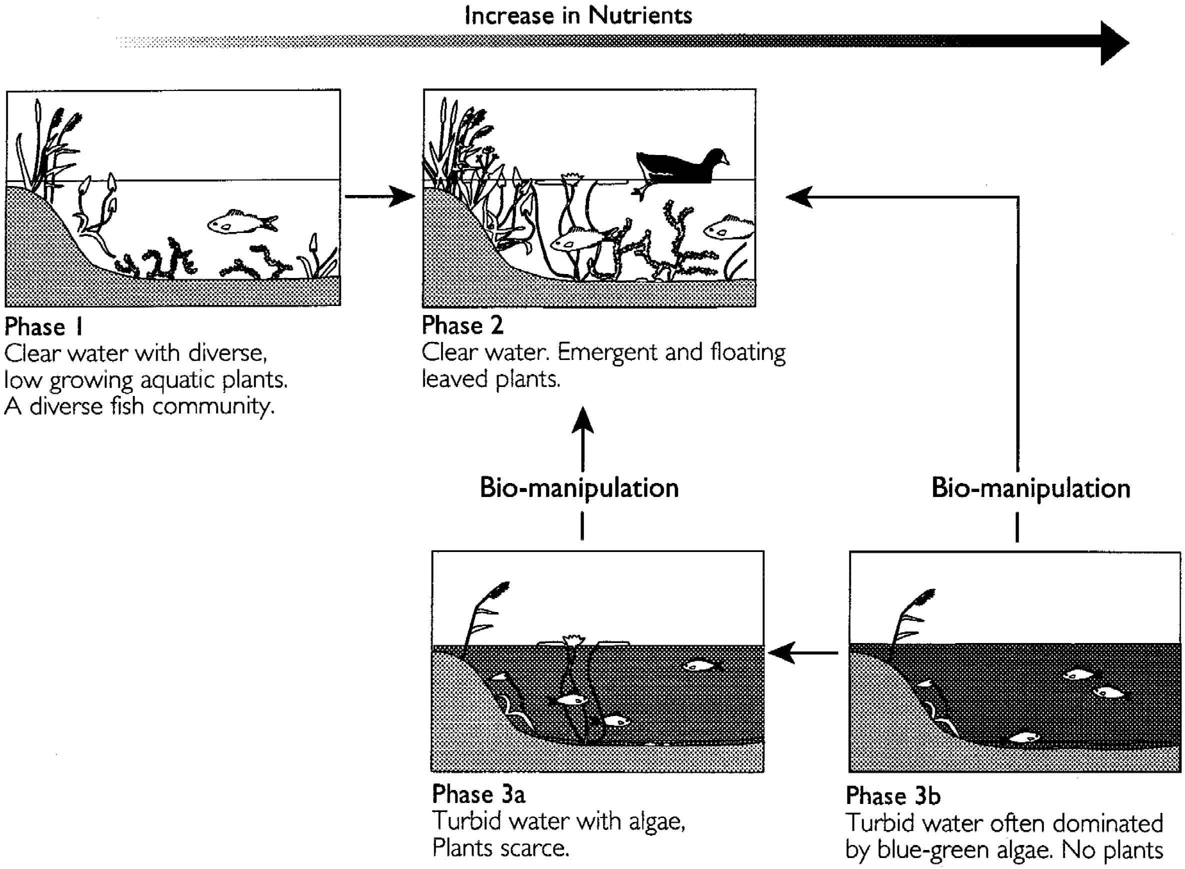

Figure 4. The alternative stable states model for dominance by aquatic plants or phytoplankton in shallow lakes at moderate nutrient levels (50–100 $\mu g\, l^{-1}$ total phosphorus), showing biomanipulation as a 'reverse switch'.

in the rivers themselves. Due to the connectedness of the rivers with the major broads, the rivers would almost certainly need to be rehabilitated to support a diverse fish community (Harper, 1997).

The future prospects for the restoration of the whole rivers and Broads system is likely to also depend on regional and local water resource management. Future trends in agricultural irrigation, population growth and settlement patterns, tourism strategies etc. may place significant and conflicting demands on these resources. The ecological scenarios related to different river flow conditions will need to be fully evaluated. Some broads at the lower end of the river system may inevitably become brackish in the long term due to climate change. For others, some local or strategic changes in water abstraction may be needed to ensure that past restoration efforts are safeguarded and that future freshwater restoration efforts are underpinned. As the legislative mechanisms for such changes are currently unavailable, any water resource obstacles of this kind could prove to be significant.

In the short-term, experimental management will need to continue to focus on small, isolated broads where nutrient reduction has been achieved, and boating and angling influences are small or absent. The outcome of this work is being applied to major broads restoration projects in an integrated manner, accepting that investigatory work is proceeding in tandem with restorative actions.

A bold restoration project has been started at Barton Broad, the largest broad to have suffered from severe eutrophication (see Figure 6). The 67 ha broad straddles the top end of the River Ant, where sufficient phosphorus reduction in the river has now been secured at the sewage treatment works upstream. Since the 1970s, this lake has been almost devoid of aquatic macrophytes and it is dominated by algal blooms in the summer months as a result of high total phos-

(BMT = Broads macrophyte type) References: [1]Kennison et al (1998), [2]Jackson, 1997, [3]Stansfield et al, 1997, [4]Perrow et al, 1997, [5]Phillips et al, in this volume

Achievable plant communities	Other ecological targets	Associated nutrient status	Key 'symptoms' of restored state	Recreational implications	Broads where target applies (__ means target achieved)	Nature reserve & SSSI	Category of broads according to ease of ecological restoration	Tidal #	/Public navigation ~
Charophytes (*Chara* spp) or *Najas marina* dominant (BMT1)[1] Extensive, diverse littoral margin	Diverse macro-invertebrate assemblages[2] Large-bodied Cladocera present throughout plant growing season[3] Pike (*Esox lucius*) and tench (*Tinca tinca*) dominant in fish community[4]	Total P ≤ 50µg/1	• clear water throughout the summer • low risk of blue-green algal blooms • plant community relatively constant - only small perturbations	• high quality pike angling • little conflict with sailing as low growing plants	Martham N Broad	*	Isolated broads where mainly diffuse agricultural inputs of nutrients or/ broads at top of river system where there are no major point sources of nutrients or/ where benefits of P stripping at sewage treatment works realised and bio-manipulation is a practical option	#	
					Martham S Broad	*			
					Hickling Broad	*		#	~
					Horsey Mere	*		#	~
					Heigham Sound	*		#	
					Blackfleet Broad	*			
					Brundall Garden				
					Upton Broad	*			
					Calthorpe Broad	*			
					Ormesby Broad				
					Ormesby Little Broad				
					Rollesby Broad				
					Filby Broad				
					Cockshoot Broad	*			
					Alderfen Broad	*			
					Strumpshaw Broad	*			
					Belaugh Broad			#	
					Decoy Broad	*			
					Crome's Broad	*			
					Barnby Broad	*			
					Burntfen Broad				
Significant proportion of lake with dense beds of tall leafy submerged plants including, for example, *Potamogeton* spp, *Zanichellia palustris*, Elodea spp; charophytes and *Najas* occur locally (BMT2a)[1] Intact, extensive, diverse littoral margins	Diverse macro-invertebrate assemblages[2] Large bodied Cladocera abundant in plant beds during plant growing season[3] Diverse fish community of cyprinids, percids and pike[4]	Total P 50-100µg/1	• clear water sustained through plant growing season at least in areas of dense plant beds • blue-green algal blooms uncommon • plant and fish communities may show some temporary shifts or cycles due to weather-induced events	• temporary conflicts with boating due to need for bio-manipulation, weedcutting may be needed outside main navigation channels • variety of angling opportunities	Rockland Broad		Tidal broads where further investment in nutrient reduction is needed and/or where bio-manipulation will be problematic due to navigation and/or tidal influences	#	~
					Hoveton Great Broad	*		#	
					Hudsons Bay	*		#	
					Hoveton Little Broad			#	~
					Pound End			#	
					Salhouse Little Broad			#	~
					Barton Broad	*		#	~
					Ranworth Broad	*		#	
					Bargate Broad			#	~
					Surlingham Broad	*		#	~
					Wheatfen Broad	*		#	
					Buckenham Broad			#	
					Hassingham Broad			#	
					S Walsham Inner Broad			#	~
Nuphar lutea and *Nymphaea alba* ant lake margins, other submerged plants scarce (BMT2b)[1] Intact littoral margins	Improved macro-invertebrate and fish communities, associated with margins[2,4]	Total P >100µg/l	• turbid water except at margins • water plants restricted to margins • higher risk of blue-green algae	• weed-free water depth for sailing • some angling opportunities	Wroxham Broad		Tidal broads where navigational use is probably a dominant constraint but where restoration of marginal macrophyte communities may be possible	#	~
					Salhouse Broad			#	~
					Bridge Broad			#	~
					Malthouse Broad			#	~
					S Walsham Broad			#	~
					Oulton Broad			#	~

Figure 5. Suggested ecological targets for broads grouped according to the ease of ecological restoration, determined by the influences of nutrient sources, geographic posiiton, tidal action and recreational use.

Figure 6. Barton Broad in 1997, the site of a major lake restoration project involves suction dredging, biomanipulation and the regeneration of reedswamp margins, following successful reduction of phosphorus inputs from Stalham sewage treatment works, just upstream.

phorus concentrations, maintained by internal loading. The restoration project will test the whole range of restoration techniques which have been developed in smaller scale experiments and in particular, the effectiveness of suction dredging in permanently removing a major nutrient supply (see case study in Moss et al., 1996). Further nutrient export modeling work will be carried out to investigate the significance of diffuse and small, point-source inputs and depending on the hydrological pathways, some further control measures may be required.

Following suction dredging of the whole lake, a start can be made on biomanipulation activities in some large bays (Figure 6). A greater understanding of the fish populations and their use of the river, broad and surrounding wetland in different seasons, is a prerequisite to planning biomanipulation measures for the whole broad. It may be concluded that a more holistic approach to fish management may be possible and worthwhile, taking into account the whole area affected by fish migration. In the same way, the restoration of flooded marshlands around the Friesland lakes has been proposed to provide optimal nursery areas for pike and hence to help stabilise macrophyte dominated conditions (Grimm, 1994).

Major lake management projects such as this, offer a real opportunity to increase understanding of lake ecology through associated research and monitoring work.

Conclusions

This paper has argued that nature conservation strategies need to operate at various levels. Although the setting of conservation targets can be helpful in directing and prioritising actions, it suggested that ecological targets may need be adjusted as our understanding of what is possible and sustainable increases. There are still gaps in the theoretical framework for shallow lake restoration as well as technical problems to overcome, but this is a fast developing field. It is noted that most progress in developing management techniques has been made through the combination of focused research projects in tandem with large-scale field experiments, against a background of long-term monitoring. The joint programme managed by the Broads Authority and the Environment Agency in the Broads has proved very productive in this respect over the last decade.

Effective conservation and restoration of a representative network of shallow lakes in Europe and in each country will depend on the adoption of a workable, common lake classification system. The use of a 'reference' approach as proposed by Johnes et al. (1994) would enable ecosystem standards to be defined which would reflect appropriate lake conditions for their natural catchments and allow meaningful comparisons of lake condition through time and space. An integrated catchment approach to water management is another pre-requisite to effective lake conservation. Procedures are being formalised to assist this process in the European Union through the proposed Water Framework Directive.

At a more local level, nature conservation priorities need to be considered alongside other uses of the lake or group of lakes in order that common management goals can be agreed between the various stakeholders. The management options will largely depend on a number of factors which influence the ecological potential, such as nutrient loading, morphometry, sediment type, type of recreational use and bird grazing pressure.

As research and experimental management work progresses, more specific advice will become available to managers, for example concerning fish predator/prey targets and the optimal reedswamp edge to lake area ratio. An increased use of multi-lake studies and models is envisaged to analyse complex lake interactions and derive appropriate ecological targets for lake managers. Thus, as the information base grows, the risks, costs and benefits of lake management measures and ecological restoration will become clearer. However, this is not an inevitable process and it will depend on researchers and lake managers working ever more closely.

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