L A K E
RESTORATION

THE ROLE OF BIOMANIPULATION

A one day seminar held in the Broads 18th March 1993

Organised by the National Rivers Authority and the Broads Authority

- Speakers abstracts & notes
- Record of final discussion

Broads Authority

NRA

National Rivers Authority

L A K E
RESTORATION

THE ROLE OF BIOMANIPULATION
A one day seminar held in the Broads 18th March 1993

Organised by the National Rivers Authority and the Broads Authority

- Speakers abstracts & notes
- Record of final discussion

National Rivers Authority
Kingfisher House
Goldhay Way
Orton Goldhay
Peterborough PE2 5ZR

Tel: (0733) 371811
Fax: (0733) 231840

Broads Authority
Thomas Harvey House
18 Colegate
Norwich NL3 1BQ

Tel: (0603) 610734
Fax: (0603) 765710

Statement of Use

This document contains abstracts of papers presented at a one day seminar held at the University of East Anglia 18 March 1993 on the Role of Biomanipulation, together with a summary of the discussion.

Additional Copies

Additional copies of this document may be obtained from the R & D Co-ordinator of the National Rivers Authority, Peterborough and from the Broads Authority, Norwich.

Programme

Chairman's Introduction

Mervyn Bramley, Head of R & D, National Rivers Authority, Waterside Drive, Aztec West, Almondsbury, Bristol BS12 4UD

The restoration of a diverse and sustainable habitat to a lake which has become degraded is a challenge both to the practitioner and to the researcher. Considerable experience has been gained over the past 15 years in lake restoration, yet the papers which are presented in this seminar clearly demonstrate that the potential for, and approach to, lake restoration through biomanipulation is site-specific to the ecosystem involved.

Nevertheless, the case studies and the descriptions of the underlying processes which are presented demonstrate that lake restoration must be approached in a systematic manner based on a sound understanding of the ecosystem at the site concerned. It is only by understanding the critical factors affecting the overall ecosystem that the steps to be taken in restoration can be planned.

While scientific knowledge is gained and applied on a site-specific basis, I am confident that the Broads Restoration will provide a major focus for the pooling of scientific knowledge and experience gained both from successful, and unsuccessful, biomanipulations carried out elsewhere. My own organisation - the National Rivers Authority - is looking both to a successful project in the Broads, and to the production through the project to a best practice guide which can provide advice to those responsible for the management of lakes elsewhere which are degraded through eutrophication and other causes.

Purpose and Strategy of Broads Restoration

Jane Madgwick, Broads Authority, 18 Colegate, Norwich NR3 1BQ

Introduction to Lake Restoration

Lakes are increasingly recognised as valuable natural resources. They occur where water is temporarily held up, either naturally or artificially in reservoirs. Their nature is usually influenced by a wide range of human activities in the catchment. It is widely recognised that lakes have many direct functions for people, such as water supply, irrigation, flood control and that they provide valuable wildlife habitats and recreational opportunities. Despite this, many of the lakes in the UK and elsewhere have been allowed to deteriorate in some way through human use.

There is now a growing commitment to manage degraded lakes, to rid them of nuisances such as blue green algae, loss of water clarity or deterioration of a fishery - often the symptoms of nutrient enrichment. In fact, eutrophication is the most widespread form of degradation of lakes, which has received the most public and scientific attention for the longest time. Mitigation and restoration efforts are beginning to be co-ordinated on an international scale through mechanisms such as the Ramsar Convention, IUCN and IWRB wetland programmes and a host of non-governmental wetland fora.

Restoration defined as the complete structural and functional return to a pre-disturbance state, is intuitively the most desirable option for a lake ecosystem. However, this is often not a realistic option due to unavoidable human influences in the catchment or climatological, biological or chemical changes in the lake environment. Lake restoration goals may therefore be only an approximation of the "original", pre-disturbance state. In addition, the wetland manager is increasingly required to attempt to cater for local, economic and recreation needs such as angling and boating, as well as the ecological restoration of lakes. In doing so, conflicts of interest usually arise and compromises in restoration management are the result. All of this means that it is important to have clear and realistic lake management objectives.

In many case studies, including that of the Norfolk Broads, there is poor information on the biology and limnology of the"pristine" lakes that occurred prior to nutrient enrichment caused by anthropogenic influences. The processes necessary to "rewind" to that former state are also largely unknown so that each lake restoration programme can be a journey of discovery. It is vital in these circumstances for advice and action on lake restoration to be based on an understanding of how the ecosystem works, otherwise it is easy to lose your way!

The Purpose and Strategy of Broads Restoration

In the Norfolk Broads, restoration of the aquatic life in the waterways and lakes is recognised as a clear priority for the Broads Authority. The rapid deterioration of water quality was a major reason for the political and public pressure that led to the establishment of a national park in the area. As well as the aesthetic, wildlife and fishery losses, it was realised that far greater resources would be needed to manage the navigation through increased dredging costs and severe bank erosion problems that had been exacerbated by the loss of the protective fringe of water plants.

The overall aim of the broads restoration programme is to re-establish a stable state where aquatic plants are dominant in the Broadland lakes and the margins of the river channels. The restoration projects are focusing on the development of techniques to restore large macrophyte beds since it is assumed that this will be the major trigger to the recovery of the whole ecosystem. The restoration programme also takes account of the recreation and navigation interests in the Broads. The most appropriate balance of these interests is agreed through detailed consideration and consultation with interested parties for each particular broad, taking account of its restoration potential and its context within the whole Broads system.

While the Broads Authority is charged with co-ordinating the restoration programme it can only do so in partnership with other agencies with overlapping responsibilities such as the National Rivers Authority, Anglian Water and English Nature and with the co-operation of fishing clubs, landowners and the boating public.

The partnership of the Broads Authority with the National Rivers Authority has been particularly fruitful in developing techniques to restore the broads. Neither organisation is a research establishment and the capacity to undertake fundamental research has been limited. Instead, the organisations have attempted to balance research and experimentation with the need to achieve restoration management. Small scale management trials, such as the use of 2 x 2 metre mesh cages to exclude fish, have progressed to whole lake experiments, for example at Cockshoot Broad where virtually all the fish have been removed by electrofishing over the past 3 years, in order to maintain clear water conditions. Investment in restoration management projects for some of the major broads, such as of Barton Broad (77 hectares) have been justified by the results of experimental management trials in small, isolated broads such as Cockshoot.

Discussion

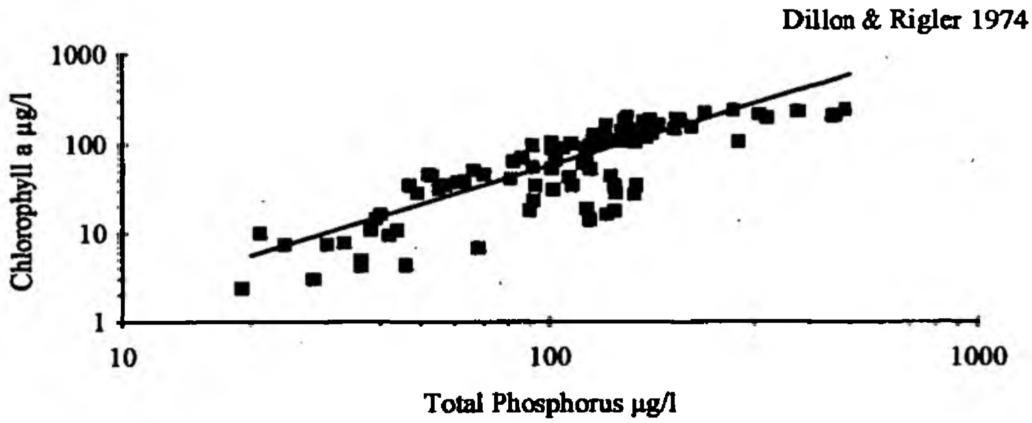
The Broads example illustrates an integrated approach to lake management achieved by close co-operation between key agencies and interest groups and backed up by research and experiment. Only modest successes can be claimed after around 15 years of work, but there has been steady progress in the development and application of restoration techniques. The programme has gained enourmous local public support and the Broads Authority and the National Rivers Authority have recently received an EC grant under the LIFE Fund to assist the very promising work being undertaken on bio-manipulation.

Why do we need to use Biomanipulation ?

Geoff Phillips, National Rivers Authority, Cobham Road, Ipswich IP3.

The Norfolk Broads are eutrophic and data collected over the last five years generally conform to published relationships between lake algal biomass and phosphorus.

Fig 1 Relationship between Mean Summer Chlorophyll & Total Phosphorus in the Norfolk Broads (1986-1992)



However despite a 90% reduction of the external phosphorus load to Barton Broad over the last 12 years no substantial reduction in algal biomass has been achieved.

One reason for this has been the continued availability of phosphorus from the sediment of these very shallow lakes. In Barton Broad this can be an order of magnitude higher than the external load. Two possible solutions exist. Sediment can be removed by suction dredging, or it may be possible to use direct dosing of the sediment with small amounts of ferric chloride to prevent phosphorus release. Both techniques are currently being investigated.

Grazing by larger cladoceran zooplankton *(Daphnia sp)* can markedly reduce phytoplankton populations and mean summer chlorophyll concentration of Barton Broad is negatively correlated with the abundance of *Daphnia hyalina*. Typically *D.*

hyalina is only abundant for a short period in the early summer due to subsequent predation by young fish, but in experimental ponds and small enclosures where fish have been removed grazing can generate clear water, resulting in the growth of submerged aquatic vegetation.

These small scale biomanipulation experiments have been scaled up to field trials at a number of sites. Cockshoot Broad was isolated from the River Bure and suction dredged, resulting in a large reduction in its fish population. Large *Daphnia* populations developed producing clear water, and subsequent management, to maintain low fish numbers, has enabled submerged aquatic vegetation to re-colonise the lake.

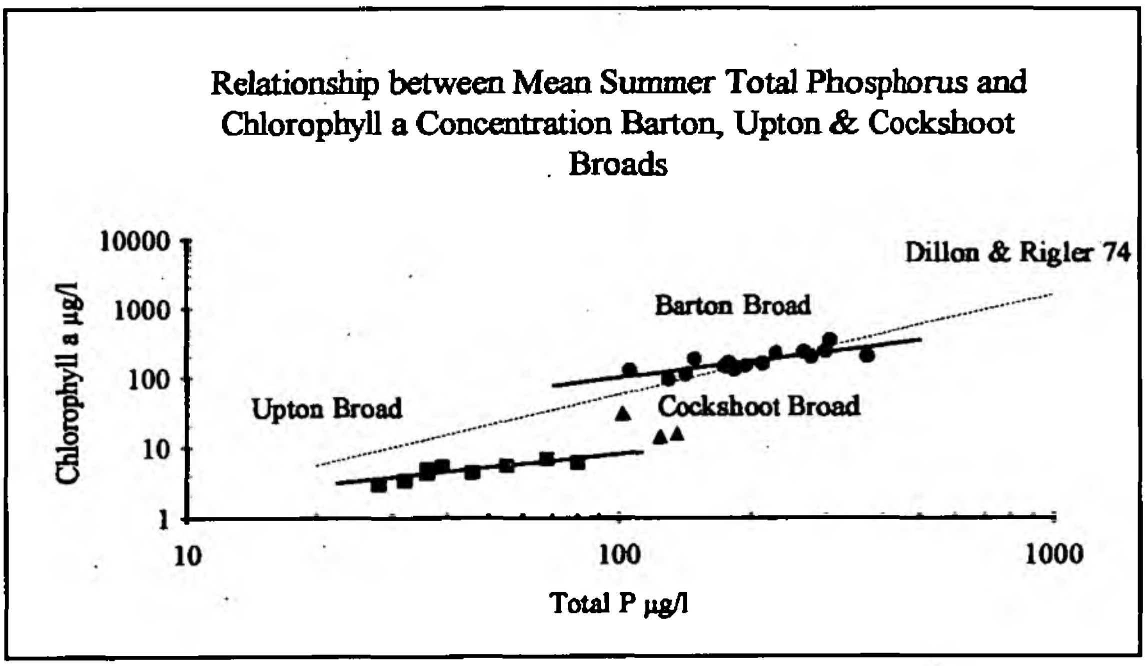
The Broads are however tidal waters and in many cases lake isolation is neither possible nor desirable. To overcome this, pilot experiments are underway to construct large (1-2 ha) fish exclosures, within which clear water can be produced and aquatic vegetation allowed to develop. Once established, it is envisaged that additional enclosures can be constructed until a sufficient proportion of the lake contains vegetation and the enclosures can be removed.

A recent review of the literature has shown that all successful biomanipulations in shallow lakes have involved an increased growth of aquatic vegetation and it is suggested that this vegetation is a critical factor in stabilising the new community. The re-establishment of vegetation is not proving easy in the Broads and experiments are now underway to investigate the importance of grazing by birds, particularly the Coot (*Fulica atra*).

There is now considerable evidence that shallow lakes will not respond to a reduction in phosphorus in a smooth continuous manner. During recovery the algal dominated state will tend to persist, due to numerous stabilising mechanisms within the lake food web. Biomanipulation can overcome this and if the relationship between algal biomass and phosphorus is examined in individual lakes, the effects of this can be seen. Upton Broad, a 'pristine' broad, falls below the Dillon & Rigler (1974)

prediction, while Barton Broad, a broad subject to reduced phosphorus load, remains above it. Cockshoot Broad has been biomanipulated and relative to its phosphorus concentration has a chlorophyll concentration similar to Upton Broad.
Biomanipulation however is unlikely to be possible if the algae involved are not edible, eg filamentous cyanobacteria. To overcome this, excess phosphorus loads need to be reduced.

Biomanipulation can create clear water, but there is evidence that fish removal can also effect the physical and chemical nature of the sediment by changing the extent of bioturbation. This could enhance phosphorus release, and in clear water this can enhance macroscopic benthic algal mats, which may be as detrimental to the growth of submerged aquatic vegetation as phytoplankton.



The restoration of the broads is now seen as a series of steps:

1 External nutrient control

2 Reduction of internal nutrients

3 Re-establishment of aquatic vegetation

4 Stabilisation and re-introduction of fish community.

The first of these steps is now in place and the remainder are now being investigated by the National Rivers Authority and the Broads Authority in a new research and management initiative, supported by the EC LIFE fund, with additional contributions from the Soap & Detergent Industry Association and English Nature)

Reference

Dillon, P.J. & Rigler, F.H. 1974. A test of a simple nutrient budget model predicting phosphorus concentration in lake water. J. Fish. Res. Bd. Can., 31 1771-1778

A 5 year field study of Food Competition between Fish and Wildfowl

N Giles, The Game Conservancy, Fordingbridge, Hampshire, SP6 1EF

Benthic invertebrate and submerged aquatic macrophyte biomass was monitored for five successive years (1986 - 1990) at a single sampling bay on each of two gravel pit lakes while fish stocks were experimentally manipulated. the fish communities of the lakes were sampled for dietary analysis in 1986 and 1987. In October 1987 the lakes were pumped down and the vast majority of bream, *Abramis brama* L., roach, *Rutilus rutilus* L., perch, *Perca fluviatilis* L., tench, *Tinca tinca* L. and pike *Esox lucius* L. longer than ca. 8 cm were seine-netted or electro-fished out (total biomass of fish removed = 7.46 tonnes). In the early spring of 1990 fish were restocked into the netted off sampling bays of the two study lakes.

Subsequent to the fish-removal (1988, 1989) the standing crops of dipteran larvae (mostly *Chironomidae*), gastropod molluscs, and submerged aquatic macrophytes increased substantially on both study lakes. These effects were reversed for both study lakes when fish were restocked in 1990. The diversity of the Main lake benthos invertebrate community increased, with *Sialis lutaria* L., and a range of amphipod and isopod crustacea, trichopteran larvae, ephemeropteran nymphs, and *Hirudinea* populations expanded in the de-fished habitat.

Tufted ducks, *Aythya fuligula* L. greatly increased their use of the lakes for brood-rearing subsequent to the fish-removal. Tufted duckling survival improved (by around 30%) compared with the period when fish were present in the lakes. The peak numbers of wintering mute swans, *Cyqnus olor* Gmelin 1789, coot, *Fulica atra* L. and gadwall, *Anas strepera* L. all increased sharply in the years following the fish removal.

Restoration by Fish Stock Reduction in the Netherlands

Marie-Louise Meijer & Eddie Lammens, RIZA, PO Box 17, 8200 AA Lelystad, The Netherlands

Since 1987 fish stock reduction has been applied as an additional method to improve the water transparency in the Netherlands. In 1987 experiments were started in small ponds (< 5 ha). In those cases the method was very successful. Large Daphnia appeared, the water became clear and macrophytes developed in abundance. In those ponds the water is still clear in 1993. During 5 years the transparency stayed high throughout the year, thereafter the transparency decreased in summer.

By 1993 fish stock reduction had been applied in 16 cases in the Netherlands. These can be divided into 6 success stories, 6 failures and 3 cases in which the water was only clear in the spring. The lakes with clear water are small, or the fish stock reduction has been very drastic (almost 100%). The largest lake with clear water the whole year around is 30 ha. Within 2 months of the fish stock reduction (75% reduction) it was colonized by Characeae and almost 60% of the lake is covered by this dense vegetation. The development of macrophytes seems to be essential to maintain clear water. It is not yet known what is the most important mechanism in achieving this stability. It might be reduction of resuspension of sediment, competition for nutrients, a refuge for the zooplankton, allelopathy or a combination of these possibilities. However in all successful cases no efficient planktivorous fish is present.

The failures are mainly caused by insufficient reduction of the fish stock. At least 75% of the original fish stock have to be removed in order to get clear water. Some of the lakes in which the method failed also had a high density of filamentous blue-green algae, which might have hindered the development of large *Daphnia*. In the lakes with a relatively short clear water phase (1-2 months) the transparency decreased in summer due to predation on *Daphnia* by 0+ fish or *Neomysis*. In those cases not enough macrophytes were present to keep the water clear.

The Use of Biomanipulation in Danish Lakes

Erik Jeppesen and Martin Søndergaard, National Environmental Research Institute, Vejlsøvej 25, P O Box 314, DK-8600 Silkeborg, Denmark

In eight Danish lakes fish manipulation by removal of planktivorous fish and/or stocking of piscivores (pike, perch and/or pike-perch) has been undertaken to speed up lake recovery following nutrient load reductions. In the least eutrophic of the lakes, Lake Væng, long-term improvement has been obtained following a 50% reduction of the planktivorous fish biomass. The lake shifted to a clearwater stage with extensive growth of submerged macrophytes and a high number of piscivores, and in addition the cyanobacteria (blue green algae) almost disappeared. In the most hypertrophic and green algal dominated Lake Søbygård, but short-term improvements took place following limited fish stock manipulation. At intermediate nutrient concentrations in the eutrophic, cyanobacterial dominated lakes, however, the response pattern deviated according to the method applied. The stocking of under-yearling pikes at high densities (1500 ha^{-1}) resulted in major short-term improvement in Lake Lyng, but at lower densities (250-2500 ha^{-1}) no changes were to be observed in neither Lake Lyng nor Lake Stigsholm. In the remaining four eutrophic lakes no or only minor changes were found following a 60-80% removal of the planktivorous fish biomass and the stocking of various piscivores.

On the basis of the above-mentioned results, data from surveys of 500 Danish lakes and large-enclosure experiments we propose to discuss the use of fish manipulation as a lake restoration tool. We suggest that in shallow lakes the success of biomanipulation depends on the abundance of submerged macrophytes, and even at comparatively low macrophyte densities (relative plant-filled volume: ~ 20%) major improvements may be expected.

Conclusions

For:	shallow lakes (mean depth <3m), not severely limited by nitrogen
If :	P-input is reduced below 0.5-2.0 gP m^2 y^{-1} or P-concentration is below 80-150 µg P l^{-1}.
Then:	A self perpetuating process may be initiated. • submerged macrophytes may be established • percentage of fish eating fish may increase progressively • cyanobacteria may be outcompeted • phosphorus concentration may decrease
Leading to:	Long-term Improvements
If :	P-input is larger than 0.5-2.0 gP m^2 y^{-1} or P-concentration is above 80-150 µg P l^{-1}

Then:	A temporary effect in some cases may be obtained
	• major effect in green algae/hypertrophic lakes
	• major effects if submerged plants appear in high density the probability increases with:
	  • decrease in lake size
	  • decrease in mean depth
	  • decrease in nitrogen input
	• major effect if under-yearling pike are stocked in high densities (>1000 h^{-1}) - either alone or in combination with removal of planktivores

Leading to:	Frequent fish manipulation is probably necessary to maintain an improved lake water quality

Biomanipulation - how do we make sure that it is appropriate?

Colin Reynolds, Institute of Freshwater Ecology, Windermere Laboratory, Far Sawrey, Ambleside, Cumbria LA22 0LP

The experiences gained in the application of biomanipulative techniques have certainly been varied. Whereas some attempts have been successful in achieving a desired and stable improvement in water quality, others have been partially successful in invoking a response at the higher trophic levels but not at the lower. Many have failed altogether. Analysis of the successful schemes does demonstrate a common involvement of large cladocera (*Daphnia*, especially; *Bosminids*, *Chydorids*, rotifers, even copepods will not do; some spectacular, but non-stable, results have involved ciliates), in water bodies that are both small and shallow or where open (pelagic) habitat is already encroached by, or planted up with, extensive stands of macrophytes.

These findings are tested against understanding of the trophic relationships in lakes, which is rather oversimplified to a functional producer - herbivore - planktivore - piscivore food chain. It is shown to matter a great deal what the dietary preferences of the predators are, what other predators are present, what are the alternative preys, and so on. It also matters critically to management that the generation times of the controlling species are usually much longer than those of the controlled. Food webs stabilize about their resources and only episodically are they structured by the cascade from the top-to-the bottom of the trophic pyramid.

This concept is reinforced by simple calculations of the biomass requirement at the highest trophic level for the containment of the intermediate trophic level to an abundance which crops the primary producing base to a desired abundance but without causing the ultimate starvation of the intermediate level.

The precedent of stabilising food chains is shown to invoke a stable population base of the algal grazers - the *Daphnia* - in the 'keystone' rôle. This can be done by providing a refuge from predation but which encourages a parallel heterotrophic food chain. Some macrophyte stands will fulfil these criteria and, provided they are sufficiently extensive, have shown to do so.

Mechanistically, the outcome matches the documented experiences of biomanipulations. Key features of successful adjustment are embodied into a checklist of criteria which, whilst not being a recipe for success or failure, are likely to be satisfied substantially in steady-state biomanipulations achieving permanent improvement in water quality.

(The full article has been accepted for publication in *Archiv für Hydrobiologie*.)

The Role of Biomanipulation in Lake Management, an Overview

Prof Brian Moss, Department of Environmental and Evolutionary Biology, University of Liverpool, Derby Building, Liverpool L69 3BX

Eutrophication is a system problem which in its milder, earlier stages disguises itself as a simple pollution problem. In these early stages it can be simply treated with algicides whether of copper, known organic substances, or the decomposition products of straw. It continues to be regarded as a simple pollution problem when it is possible to treat the causes of it by reducing the external nutrient loading. Sometimes this is successful, but increasingly, in severe cases, which include many lowland lakes, nutrient control is unsatisfactory or unsuccessful. This is because the increase in nutrient loading that has ultimately caused the problem has been proximately followed by a series of interacting, non-linear responses in the structure and functioning of the lake ecosystem, whose direction is not simply reversed when the external loading is reduced. In these cases also there have often been changes linked with the causes of the increased loading but distinct from it yet interactive in their effects on the system. Agriculture, for example, is a source of pesticides and herbicides as well as of nitrogen and phosphorus. It also entails management of catchment land which may alter water tables and stream flow. In all these instances a solely chemical engineering approach to eutrophication control is likely to be inadequate. Biological engineering, or biomanipulation will often be necessary.

For many lakes, a system approach to restoration of lakes from eutrophication will involve control of external nutrients as part of a programme of several different measures. For others, although theoretically desirable, nutrient control may be practicably impossible. The Municipal Wastewaters Directive requires only treatment works of a certain size to install nutrient removal treatment. Many are smaller yet strongly influence stream nutrient loads. Herds of stock may produce as much nutrient as a small village, yet are not able to be controlled. In some lakes, eutrophication may be driven by nitrogen from diffuse sources. It is not practicably possible to control these sources at reasonable cost. Internal loadings of nutrients from sediments enriched over long periods may confound external nutrient control.

In all these cases biomanipulation, in its widest sense of manipulation of the communities of the ecosystem, may be the only practicable way of restoring clear water, decreasing the incidence of algal blooms, or restoring macrophytes and the habitat they provide for fish, birds and other animals.

The number of lakes in the British Isles that suffer from severe eutrophication is likely to be very large. The problem is of concern to conservation bodies such as English Nature, National Park Boards and Authorities, County Wildlife Trusts, Local Authorities, from both amenity and public health points of view, water companies responsible for the provision of potable water, and angling bodies as well as the National Rivers Authority with its remit for maintenance and improvement of water quality. On the standard proposed by the DoE for the designation of eutrophicated waters or those likely to become eutrophicated, few water bodies in England and Wales could be excluded.

The level of information required to improve or restore severely eutrophicated lakes is considerable and there are wide gaps in our current knowledge. Biomanipulation often requires manipulation of fish communities but the traditional approach of research has been to separate fish ecology from the ecology of the rest of the system. Fisheries research has been essentially agricultural in approach and directed to issues of growth rate and its increase. Stocking policies have had the specific and narrow needs of anglers in mind. Freshwater ecological research has been more fundamental but equally reductionist. Despite the wide view of some of the pioneers of the subject, who treated limnology with a holistic approach and established perhaps the most genuinely environmental science, recent practitioners have more closely examined the trees but forgot that the forest was the important issue. We are thus in a position of needing to use biomanipulation but of not having a full enough knowledge to use it consistently and with predictable success.

Two examples will serve to illustrate the potential uses of biomanipulation, together with some of the uncertainties generated by the degree of our present knowledge. In one case, the Llandrindod Wells Lake, the Radnorshire District Council, faced with a turbid lake in which potentially toxic blooms occur, wishes to restore clear water and water lilies and other plants.

The problem, however, is that the eutrophication appears to be caused by internal generation of nutrients by common carp and exacerbated by a large stock of zooplanktivorous small bream, uncontrolled by any predators. The lake is fished by a club of specialist carp anglers. What replacement fish stock will satisfy both the Council and the Club? A better knowledge of the interaction of fish communities with the rest of the ecosystem would remove the uncertainty about exactly what should be done.

The second case concerns the Shrophsire-Cheshire Meres, an important group of lowland lakes, many of which are SSSI's. They fall into two groups both of which have suffered some eutrophication due to post-war intensification of agriculture. In the deeper group the algal crops are controlled by nitrogen rather than phosphorus because the local drift catchments are particularly phosphorus-rich. Nitrogen is not easy to control and hence any reduction in algal crop is likely to be feasible only through biomanipulation. Any alteration in fish stocks through plans by landowners, or fishing clubs leasing the waters, may exacerbate the situation, but the information is not yet available for sensible decisions on fisheries management, vis a vis conservation, to be made.

The second group of meres is shallow (<3m) and the phytoplankton is controlled by zooplankton grazing. The value of these lakes is in their macrophyte communities and these must be safeguarded. However, we do not know whether the macrophytes ultimately control the algae through the provision of refuges against fish predation for the crustacean grazers, or whether, because of past catastrophes such as winter or summer kills at low oxygen concentrations in these rather isolated lakes, the fish communities are abnormally low. Again, sensible management advice cannot be given in the absence of crucial information about the operation of these systems and how they would respond to changes in fish community.

There are other important potential uses for biomanipulation. Some reservoirs in south-east England are unusable in summer because of cyanophyte bloom problems. They have arable catchments and nutrient control is not easy. Often it can take the form only of addition of large quantities of precipitant chemicals. Can the husbandry of *Daphnia* be used to control these blooms? It seem likely that an established bloom can not be controlled.

But were fish stocks to be reduced sufficiently to allow the larger *Daphnia* species (those most susceptible to fish predation) to grow, it might be possible to intercept the development of a cyanophyte population at an early stage. There is a need for controlled laboratory experiments to elucidate this as well as large-scale trials on reservoirs. Again the problems of managing the water quality whilst maintaining a recreational fishery need to be solved by a greater knowledge of the integrated functioning of the system.

Overall, it is quite clear that food web management can be used to achieve desirable targets in water quality and ecosystem management. In deep lakes, where bottom up control of algal crops is usual, biomanipulation can give results when used continuously as a management measure. In shallow lakes such as the Norfolk Broads, it seems to be essential for restoration, because extreme eutrophication leads to complete changes in the state of the system and to production of alternative states, stable to high degrees of nutrient reduction. It is a cheap technique for all but large lakes and it merits much further consideration for the benefit of a range of organisations concerned with the state and management of lakes.

Where do we go from here? A Discussion.

Introduced by Geoff Phillips

In summary Geoff Phillips emphasised that biomanipulation was a useful technique that could be used successfully in certain situations. It was clear from present knowledge that it worked most effectively in shallow lakes and that in many cases it needed to be accompanied by steps to reduce nutrient availability. There was still much to learn and the work that was to be carried out under the EC LIFE programme by the NRA and the Broads Authority would help to translate scientific theory into restoration practice. Three questions remained to be answered:

1 Under what range of nutrient concentrations is Biomanipulation likely to work ?

2 Is it possible to biomanipulate cyanobacteria dominated lakes ? (linked to above)

3 How can it be made stable, particularly using aquatic vegetation.

Mervyn Bramley emphasised the need for research to be available to lake managers and announced that one of the outputs from the NRA/Broads Authority research programme would be a practical guide to lake managers. This would be produced in association with colleagues from the Netherlands and Denmark.

Questions from the audience to all of the speakers were then invited.

Q. ***Lord Cranbrook (Chairman of B.R.A.P.) asked about the effects motor boat activity had upon the turbidity of the broads.***

In reply, J. Madgwick explained that experiments have shown that the effects of motor boats are quite small in comparison to algae. Once the numbers of algae have been reduced motor boat activity may become more significant. The problem could then be reduced by the introduction of zoning measures and controlling the type of craft.

B. Moss pointed out that these questions had been raised previously and papers were written in the 1970's covering the question. It was found that within the broads there is little permanent stirring effect, whereas the rivers are a different story. Another effect, other than turbidity caused directly by sediment re-suspension, was explained by C. Reynolds. The disturbance of sediments by boat activity will also provide a means of supplying interstitial water to the overlying water and therefore will aid phosphorus release. Of course other mechanisms are also involved such as wind action, important in the shallow broads, and fish activity on the sediment surface. G. Phillips supported the importance of wind activity, due to the shallow nature of the broads, and also commented upon the importance of sediment stability for macrophyte establishment. He agreed that the activity of boats would have more effect within the river than the broads. However, although there were implications for phosphorus release, the river sediments are iron rich and therefore phosphorus could also be adsorbed. B. Moss followed by explaining that only the top 2-3 mm of sediment is actually affected by boats and therefore very little interstitial water is actually contributed.

Q. *P. Gowen (Friends of the Earth) asked about the effects of factors such as increased temperature and sunlight, due to climatic changes; the contribution of waste-tip leachates and the dissolving of aluminium by acid rain upon the Broads. Also as to whether the effects from such factors could be looked at in isolation ?*

B. Moss explained that, in reply to the comment upon the effects of acid rain, the area is highly chalky and therefore acid rain will have a negligible impact upon the roads. C. Reynolds also pointed out that it is important to look at the dominant mechanisms within the set of lakes under study. Ecosystems are very complex and the interactions can be compared to a bank of switches, most of which are on. It is the switches which are off which need investigation if any change is to be brought about.

Q. *M. George (B.R.A.P. member) asked whether it would be worthwhile removing the Cladophora from Pound End in much the same way as it had been cleared mechanically from Hickling Broad in the past.*

In answering, G. Phillips, suggested that the growth of the filamentous algae may well out compete the harvesting process. J. Madgwick also pointed out that the Cladophora attracted large numbers of birds to Pound End, which were effective at removing the filamentous algae. B. Moss explained that Cladophora will also take nutrients from the sediment rather than from the water.

Q. *A. Ferguson (N.R.A.) noted that the aim of the research is to return to a macrophyte dominated community, but asked as to whether an acceptable community had been identified and what the macrophyte species were likely to be in the Broads.*

G. Phillips explained that the aim was to return to the type of community described in records of the broads as previously existing. Most of the plant communities which have so far been restored are dominated by *Ceratophyllum*, and do not appear to be stable. J. Madgwick also pointed out that the broads do differ in their potential and that differing realistic aims for restoration will be required. A strategic approach is therefore needed. Within the countrywide context, B. Moss stated that the responsibility for deciding will lie with organisations managing the work, such as English Nature and the N.R.A.

Q. *C. Newbold (J.N.C.C.) asked about the possibility of early growing macrophytes having any control upon the algal populations, especially blue-greens.*

B. Moss wondered which species C. Newbold might have in mind. C. Newbold suggested *Ranunculus* species as a possibility. B. Moss explained that the number of early growing macrophytes are limited and that some algae will still grow before the plants become established in March. Also of importance is whether Cladocerans will remain in association with macrophyte debris and therefore be available to graze the early, developing colonies of cyanobacteria. G. Phillips reported that zooplankton populations do remain over the winter in some lakes and disappear in others.

Q. *M. Pearson (N.R.A.) commented that he has worked within Water Quality for the past 20 years and was very supportive of lake restoration programmes being put into operation. However, over 15 years have already been spent on R. & D. and he wanted to know how many more years would be required before management was introduced on a large scale.*

J. Madgwick explained that large scale management is already being carried out within Broadland. The introduction of management techniques has not waited for the research to provide all the answers. The broads deteriorated over decades and it is not unreasonable to expect it to take years before a stable system is restored. G. Phillips pointed out that a unity of views was being expressed at the meeting and that the techniques such as phosphorus stripping and biomanipulation were successful management techniques. The programme of research within Broadland has pushed back the frontiers of knowledge and it was now up to the N.R.A. to promote the methods and make use of the techniques in the UK. B. Moss compared the length of time spent answering the ecological questions to the greater amount of research needed to answer the question of cancer cells losing the ability to regulate growth.

Q. *M. Pearson (N.R.A.) also asked about the problems associated with changing the fish communities within lakes. He wondered who would make any decision over which community is to be introduced and how the decision would be reached.*

M. Perrow (ECON) explained that the eutrophic water biomass of fish is much reduced in comparison with what had previously existed. The problem is trying to convince the angler that by removing the existing fish, replacing existing species and changing the community structure, you will actually be improving the fisheries in the long term. J. Madgwick added that the fish removal is only a temporary step in the restoration process and that the anglers are potentially the biggest supporters of the water quality improvements. B. Moss pointed out that it is important to educate not only the angling community, but the general public, in order to minimise any opposition. The problem has been successfully overcome within Denmark and the Netherlands, where there has been the provision of public information. C. Reynolds pointed out that the decision will rest with public opinion.

Summary of Discussion

G. Phillips in summarising the points of discussion agreed with M. Pearson that the research has been progressing for a long time, but this was due to the fact that initially it was believed that nutrient control would work but just took time. It is important that other people do not have to go through the same learning process. The research has now shown that the steps needed for restoration are more complicated than at first thought. The research has led to a pioneering of the biomanipulation technique and the development of a strategy for restoration which other people are now able to use. The strategy can be summarised as follows:

1. Initial lowering of nutrient concentrations. Appropriate targets are still being ascertained, but they are likely to be in the range of 50-100 ugP l^{-1}.

2. Subsequent biomanipulation as a restoration tool, with the landowners permission and public support

3. The development of the knowledge necessary to re-establish aquatic vegetation and stabilise the new lake community.

This last step still needs development and the N.R.A. and other organisations need to continue to investigate lake restoration techniques.

Concluding Remarks

M. Bramley highlighted the importance of the European focus to ensure the continuing exchange of information and ideas. He hoped that other biomanipulation initiatives could be established in the in the UK and that these could be drawn together with the work in the Broads. There is great value in the drawing together of scientific information and it was important that a framework was provided both for the U.K. in particular and Europe in general enable generic aspects of current scientific knowledge and best site practice to be disseminated. The Broads initiative provided a focus through which this could be achieved.