Lake Restoration Strategy
for The Broads

May 2008

Broads Authority
The Broads - a member of the National Park family

Contents

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Front cover photo: Hoveton Little Broad and Pound End by Mike Page

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1 Foreword

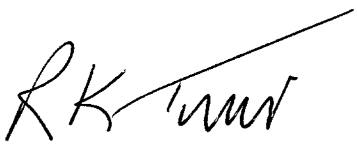
The Broads Plan 2004 has laid down a comprehensive and long-term management strategy for Broadland. The Broads system is the UK's largest and most visited lowland wetland and it poses a complex set of management challenges across both the scientific and socio-economic and political domains. These challenges are made even more severe by the threats posed by climate change, the influence of which will be felt first and foremost in the East Anglian and wider Eastern region coastal and catchment areas.

There seems little doubt that the rate of environmental change will continue to escalate as climate change and other pressures (population growth, urbanisation, etc.) build. Given this context, the strategic goal encompassed within the 2004 Plan, to maintain and enhance the quality of lakes over time by working on a catchment scale and with all relevant partner agencies and organisations, is ambitious but feasible. In order to continue to generate the necessary and sufficient resources for the required management actions new forms of organisation need to be articulated at the local and national political levels. The so-called ecosystem services approach (i.e. the benefits people obtain from ecosystems such as wetlands and others) has a key role to play in this dialogue. The Broads provide a number of ecosystem services – provision of water flow, water quality, recreation and amenity, biodiversity, etc. – which are of significant economic value. Better management and conservation of the ecosystems and the linked navigation will result in economic wealth creation and livelihood protection. These economic arguments can supplement the more traditional cases put forward for protected area status based on scientific knowledge and ethical propositions.

The challenges to be addressed are formidable, while major ecosystem restoration successes have been achieved in a number of Broads, so far these have been achieved largely through the development of direct intervention actions, e.g. reduction of point source phosphorus pollution and sediment pumping. Further lake restoration advances will require a more holistic, catchment-wide, approach that encompasses diffuse pollution reduction and climate change impacts adaptation. The Broads Authority can only achieve such objectives through more effective partnership working. It has already made progress in this direction with the establishment of the Broads Water Quality partnership.

Climate change is likely to lead to an increased threat of saline water intrusion, marine inundation and fluvial flooding, biodiversity changes and losses, and increased rates of sedimentation. Unfortunately, the science of shallow lakes still contains a number of gaps and uncertainties, among which is a less than adequate knowledge of threshold effects which can cause a shift from one quality state to another in a relatively short period of time.

The response strategy set out in the following report has been designed to fit an approach which seeks to adaptively manage waterbodies within a more naturally functioning flood plain over a long time horizon (50 to 80 years). It is further conditioned by compliance with existing legislation such as the Water Framework Directive. It has twin dimensions in that it is targeted, i.e. focused on the protection and enhancement of those existing good quality sites that have the greatest chance of retaining freshwater habitat over the long term. But it also seeks to uniformly prevent, as far as is feasible, any further deterioration of any of the existing waterbodies. In short, it aims to combine efficiency, effectiveness and prudence principles.



Kerry Turner, Chairman of the Broads Authority

Acknowledgments

The Broads Authority is grateful to all those who commented upon the text and for provision of information. Particularly the Steering Group members in no particular order: Clive Doarkes and Stewart Clarke (Natural England), Lisa Turner and Geoff Phillips (Environment Agency), Martin Perrow (ECON ecological consultant), Tony Davy (UEA), Tony Stapleton, John Sharpe and Kerry Turner. Also many thanks to Tiziana Luisetti for the ecosystems services approach report and David James for data from the STEAM model.

Much of the strategy has built upon the research, knowledge and understanding gained over the last 30 years of study and practical experimentation and management of The Broads and could not have been pulled together without this foundation to work from.

Additionally, discussions and information exchange with a number of individuals including David Whiles, Jenny Johnson and Amanda Elliot of the Environment Agency, Kevin March of Broadland Environmental Services Ltd and Rick Southwood of Natural England have been helpful to gain further national and local information alike.

Thanks also go to all the attendees of the 2006 lake restoration workshop which kick-started the development of this strategy.

2 Headline findings

1 The value of natural assets in The Broads in terms of visitor revenue, drinking water and carbon storing are £320 million, £17 million and between £50 - 240 thousand per year.

2 Lake restoration achieves successful outcomes for wildlife and people - our extensive reviews show that the step-wise approach, tackling nutrient load externally, then internally, followed by biomanipulation and stabilisation, is working.

3 The Broads catchment has challenges of large-scale complex diffuse sources, such as agriculture and properties without mains sewage – the 'Broads Water Quality Partnership' provides a focus for the actions required to deliver the Lake Restoration Strategy and its Action Plan.

4 The lake restoration reviews and Sediment Management Strategy (2007) prove that in-lake restoration is a powerful and necessary tool to achieving Water Framework Directive (WFD) targets in The Broads.

5 Prioritising the best broads, in terms of the greatest recovery potential and the safest locations, ensures that investment is secured for the long term against increasing risk of saline water intrusion and marine inundation.

6 This spatial response strategy provides for future investment in freshwater lakes in the context of a changing climate, with cyclical reviews to incorporate new evidence and adapt to change.

7 Using this prioritised approach, investment scenarios demonstrate that additional annual budgets of £350,000 are required to achieve WFD targets by the third river basin cycle in 2027.

8 This local strategic plan will link to the national Water Framework Directive's River Basin Management Plan to provide coordinated delivery of: required projects, policy change and incentives both non-financial and financial.

9 Combined with the Action Plan, this strategy provides a clear direction for the Broads Authority and partners to invest in The Broads, as well as providing a model strategic approach for other lake areas.

3 Executive summary

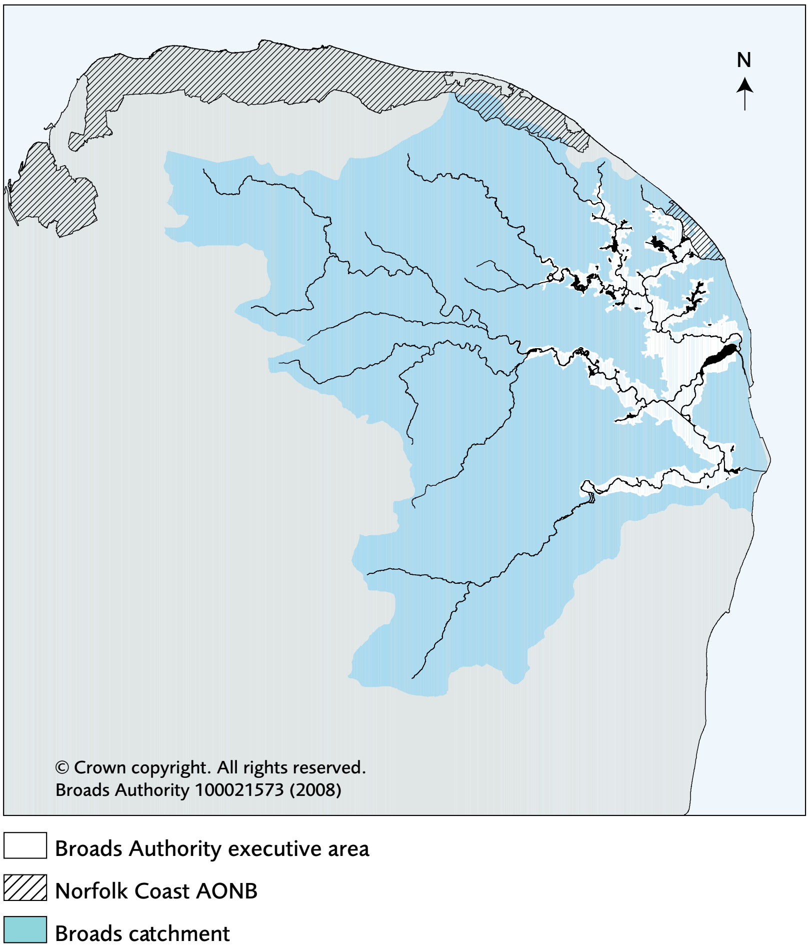
This strategy was written by the Broads Authority, with contributions from the Steering Group (Environment Agency, Natural England, ECON ecological consultancy, UEA). It prioritises the requirements for further lake restoration to improve the water quality and ecology in the Broads against the main impacts of climate change: risk of saline incursion and coastal breach. In addition it provides investment scenarios for restoration actions.

The strategy is divided into three sections; the first provides **clarity** on the current issues, status and targets under the existing legislation. The degradation of The Broads ecology was dramatic and well documented. The recovery has been slow, sometimes faltering, yet is still an immense achievement. This strategy celebrates the achievements of working in partnership for 30 years to make the water environment a better place for all to enjoy.

The second part of the strategy reviews the effectiveness of Broads Authority lake restoration projects, delivered over the last 20 years, as well as looking forward to the next five years of lake restoration. The broads selected for restoration are done so within a long time horizon (50 to 80 years), using existing knowledge of current and future pressures on the security of freshwater broads. Additional criteria are used for prioritising the five-year **Action** Plan of projects, which will flow from this strategy.

Finally the strategy summarises the **challenges** and next steps for achieving large-scale restoration of broads for wildlife. Pressures from increased population combined with the changing climate set the context for this strategy and its adaptive management approach. This includes recognising, for the first time, the economic value of Broads lakes, using an 'Ecosystem Services' approach to aid investment and recognise the benefits of restoring high quality natural ecosystems.

Map 1 Broads river catchment



4 Guiding principles

A set of principles has been developed and used to guide the adoption of appropriate targets and actions to facilitate the achievement of a high quality aquatic environment.

Ecological Principles

1 To achieve low nutrients, minimal contaminants and native wildlife.

2 To capture and deliver sufficient freshwater flow.

3 To connect a diverse landscape of habitats and create protective buffers along river corridors.

Project Delivery Principles

4 To protect and enhance the existing good quality sites that have the greatest chance of retaining freshwater habitat in the long term.

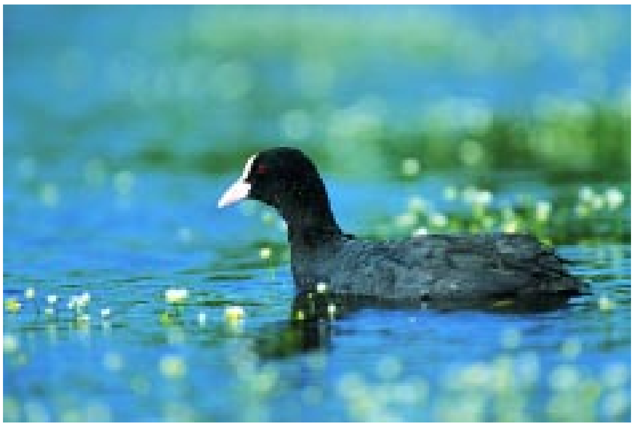
5 To prevent any deterioration of lakes as required by the Water Framework Directive.

6 To work with partners in both small and large-scale catchment projects.

7 To build in the wider societal values of natural assets, for example recognising the value of clean water for water users such as boaters and water companies.

These principles will support:

- Development of resilience of habitats and species to adapt to climate change or invasive species.
- Protection and enhancement of biodiversity across the wetland and adjacent habitats.
- Delivery of ecosystem services.



5 Introduction

Why restore broads?

The Broads is the UK's largest and most visited lowland wetland, offering people a mosaic of habitats where they can interact with nature. The rivers and lakes provide a significant visitor attraction with over 50% of the tourism income generated by people having water-based holidays (Tourism Industry Study (2001), using the Cambridge Model). These visitors value a quality water environment (BA visitor survey 2006) and rely upon organisations such as the Broads Authority and Environment Agency to provide this.

Outside these narrow river corridors the increasing population of Norfolk and Suffolk and changes in agriculture have put pressure on the water environment decreasing the biodiversity since the 1950s. These pressures include increased nutrient discharged into the rivers via the sewers combined with intensification of agriculture. These factors are the main causes of eutrophication, where algae take up excess nutrients, turning the water green and leading to a loss of submerged vegetation and reduced biodiversity.

In addition these changes were exacerbated by boat wash arising from increased recreational boat traffic as The Broads became a popular destination enjoyed by thousands of locals and visitors each year, which resulted in higher levels of bank erosion.

This loss of aquatic life is a pattern replicated in most lowland rivers in England and considerable investment has been targeted at lowering nutrient input from sewage treatment works. This has improved water quality dramatically, with 90% decrease in total phosphorus recorded in the water of the River Ant since the late 1970s. This first chapter of the recovery story shows that improvements in the water environment are effective, realistic and achievable.

Major ecosystem restoration successes have been achieved at Barton, Ormesby, Alderfen, Buckenham, Crome's and Cockshoot Broads. These successes have all led to developing water plant communities in locations at relatively low risk of climate change. In addition to wildlife benefits there have been enhanced opportunities for visitors to these sites including deeper water for sailing, provision of boardwalks and canoe trails. Over the past 20 years numerous other broads have begun to be restored with nutrient, sediment or fish removal, (See Appendix 5, History of Lake Restoration).

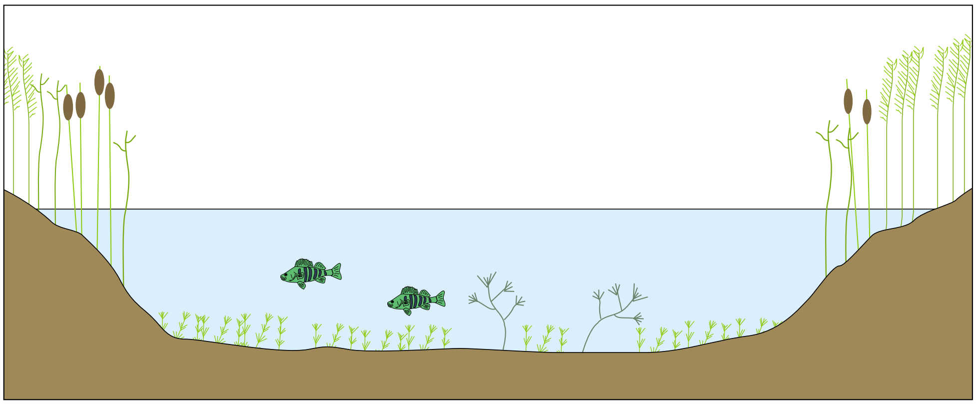
The lake and river restoration work is not yet complete; most waterbodies, despite showing improvement, still have a high nutrient status. This continues to result in turbid waters with blue-green algal growth and an absence of water plants and associated invertebrates, fish and wild birds. Since lowering the polluting nutrient inputs from waste-water treatment works, almost 30 years ago, the ecological response has mainly been a decrease in algae characterised by a change from water to surface sediment dwelling species.

This slow and limited response of Broads waterbodies demonstrates that there is continued requirement for nutrient control to ensure that ecological recovery becomes self-sustaining, with minimal restoration. The isolated broads that have had in-lake restoration actions, such as biomanipulation or sediment removal, have shown a more rapid recovery and serve as a demonstration of how the majority of the broads may respond to further catchment nutrient controls.

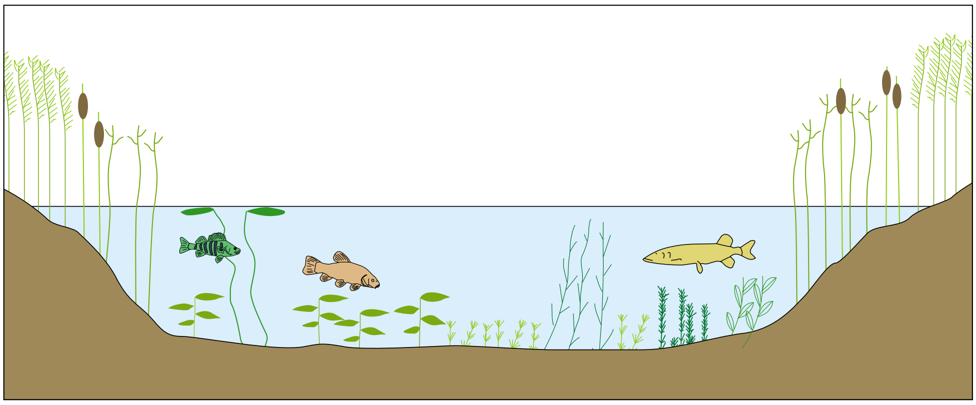
Building in adaptation to climate change will ensure The Broads wetland and its lakes are more resilient to cope with increasing sea levels and different rainfall and temperature patterns. New challenges of connecting wetland ecosystems (i.e. connecting waterways and fens) require further Broads investment, extensive consultation and improved communiccation with local communities to ensure wildlife and people can adapt and coexist. The challenge of recognising the social, economic and environmental benefits provided by natural ecosystems is required to ensure that sufficient resources are invested to protect and enhance ecosystems and ensure that outcomes are not compromised.

It is important that ecological thresholds and functions of aquatic ecosystems are understood, for example those that cause a shift between the phases shown in Figure 1 which are key to effective management. Phases two and three are found currently in the Broads, whereas phase one is only recorded in books and the historic sediment record. The factors for change are well documented. However the thresholds that cause a shift from one state to another are less understood.

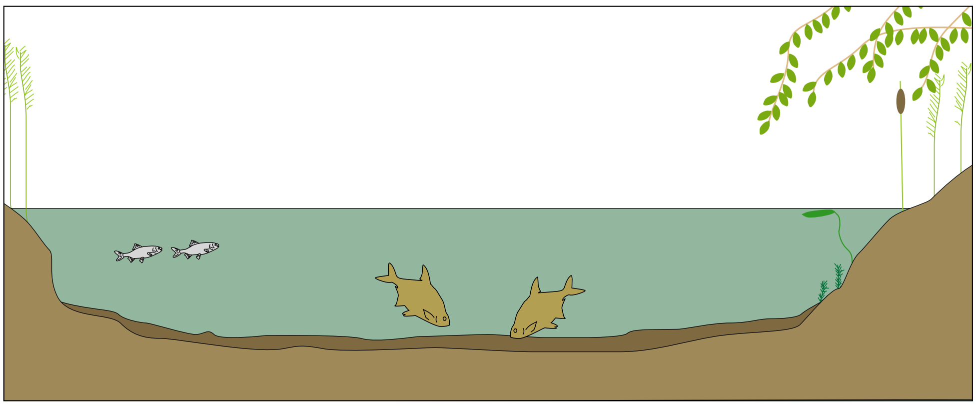
Figure 1 Ecological phases in a broad



Phase 1 - low nutrient, clear water, carpets of stoneworts and other pondweeds, mixed fish population



Phase 2 - medium nutrient, clear water, mix of abundant submerged and floating vegetation, mixed fish population



Phase 3 - high nutrient, murky water, few or no water plants, mainly small roach and bream

Why do we need a Lake Restoration Strategy?

The Broads Plan 2004 (the statutory management plan for the Broads area as required by the 1988 Norfolk and Suffolk Broads Act) identifies the need to maintain and enhance degraded lakes to safeguard the interests of future generations and to do this by working on a catchment scale with local partners and with national support.

This Lake Restoration Strategy builds on a lake workshop held in 2006 that assessed restoration techniques and undertook a gap-analysis to identify further research and restoration needs. Following this Natural England, the Broads Authority and the Environment Agency undertook an assessment of lake Public Service Agreement (PSA) target status and projects required to achieve this in the short term.

This strategy provides ecological targets that are evidence-based and appropriate for the future rather than providing a return to past pristine conditions. These targets shape the actions required to improve the water environment for wildlife where they are technically possible and in the case of non-designated sites not disproportionately costly to society. In addition to assessing the costs of actions to improve the water environment this strategy will begin to explore the wider societal benefits of a better environment.

Adoption of a long-term strategic approach provides a framework for prioritised resource allocation as well as setting out a business case for increased resources. This locally agreed strategy will sit alongside the Water Framework Directive Anglian River Basin Management Plan, providing a focus for Broads catchment.

The Lake Restoration Strategy aims to celebrate the beginnings of the recovery of The Broads ecology, whilst recognising that more time and significant investment is required for The Broads water ecosystem to achieve its potential as the UK's premier series of lowland lakes.

Strategy Steering Group

The development of the strategy has been steered by a group composed of Broads Authority members, managers, practitioners and academics, working together for a period of one year. This group has clarified the issues, targets and current condition, developed criteria for prioritising broads and lake restoration actions, as well as consulting on the work to recognise the value of The Broads' natural resources to people.

Aim and Objectives

Aim

To provide a framework for the sustainable long-term management and restoration of lakes and rivers within The Broads in terms of achieving ecological quality targets within this internationally important wetland.

Objectives

- Deliver Water Framework Directive (WFD) (2000/60/EC), and Protected Site (Public Service Agreement (PSA) for SSSIs and Favourable Conservation Status for Natura 2000 sites) targets for waterbodies in The Broads through working partnerships.
- Prioritise resources appropriately through a risk based approach to ensure waterbody targets are met, as well as protecting and enhancing existing good quality sites.
- Identify ecosystem services delivered by lake restoration projects.
- Review and synthesise data in a concise usable format to ensure decision making is supported by a research-led approach.
- Assess the cost effectiveness of lake restoration actions.

Strategy Approach

The approach taken to formulate this strategy, the targets and actions required to deliver them at the national and site level. A dual approach was taken.

Approach 1: National

This first approach focuses on gaining clarity on national level guidance in terms of the targets for water environment within a context of the governing legislation. Broads targets need to be in harmony with national targets, linking with WFD and designated site targets. This included consideration of national and regional work streams such as the Significant Water Management Issues (SWMI) as identified as part of the WFD, the developing River Basin Management Plans and the preliminary Cost Effectiveness Analysis for proposed WFD measures.

Approach 2: Local

The second approach considers lake restoration actions at the site level appropriate to the characteristics of the sites and the local catchment. This approach leads to strategic site level decisions for The Broads based on local restoration knowledge. It includes refining national to area-based targets and focusing on local actions which will feedback into the Anglian River Basin Plan.

Strategy Timescale

The strategy will produce an action plan to be updated annually and will be reviewed every 5 years, the next review due in 2013.

The strategy focuses on managing waterbodies within a more naturally functioning flood plain[1] of extensive connected habitats, accommodating the longer-term impacts of climate change, social and economic influences over the next 50-80 years, in line with the Broads Plan objectives and as set out in the Natural England Climate Change Adaptation Plan.

This longer-term timescale includes consideration of actions to lessen the impact of sediment and nutrient input from headwaters (Whitehead, 2006) as well as saline incursion. Potential actions for the latter include provision of fish refuges and creating new waterbodies within the upper river corridor, as well as reconnecting fens to waterways to provide corridors for aquatic life.

The strategy adopts an adaptive approach, assessing current condition, existing pressures, then risk before setting the objectives and actions required and monitoring the impact of these actions on the current condition. So, the process can adapt to changes in the lakes, their pressures, and our knowledge and targets over the five-year strategy time frame, (Figure 2).

Whilst this strategy clearly recognises the potential risks associated with climate change and sea level rise it is important that the strategy does not prejudice future decisions and retains a position that can benefit from flood defence as well as being realistic towards adaptation at the appropriate point in the future.

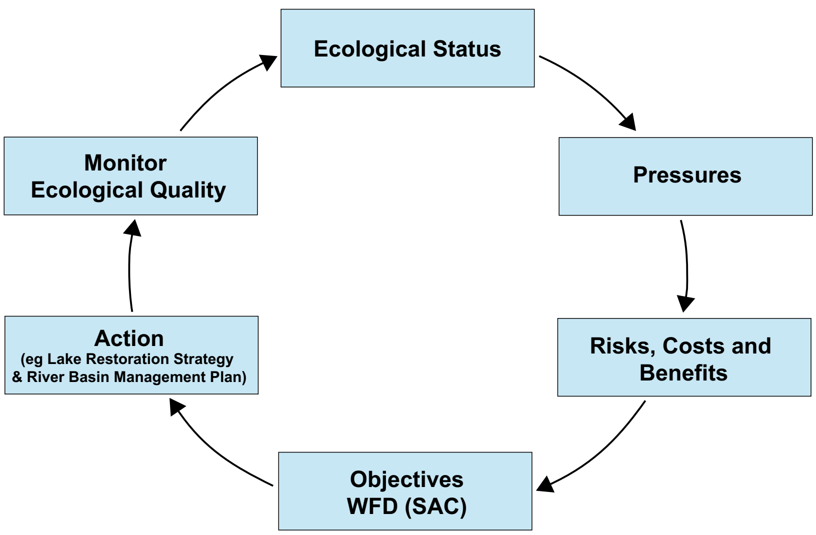
Lake Restoration Framework

This strategy nests with other Broads Strategies with a future aim to integrate these into a Rivers and Broads Strategy (Figure 3). Developed by partners, local and national experts the Lake Restoration Strategy has been handed over to the Water Quality Partnership for delivery, monitoring and reporting. The Partnership includes key organisations involved in improving water environment, which set the local framework for action.

The framework opposite (Figure 4) has been developed to take account of all the requirements for decision making for lake restoration, to deliver conservation objectives and to manage user requirements whilst ensuring cost-effective management of the Broads.

Environment Agency monitoring is central to this strategy, alongside research and review of project achievements. Other drivers such as legislation and catchment management links are also recognised.

Figure 2 Adaptive approach to target setting and delivery of actions



[1] Flood plains provide natural flood protection for communities with additional benefits of recharge of ground waters as well as providing habitat for fish and wildlife.

Figure 3 **Context of the Lake Restoration Strategy**

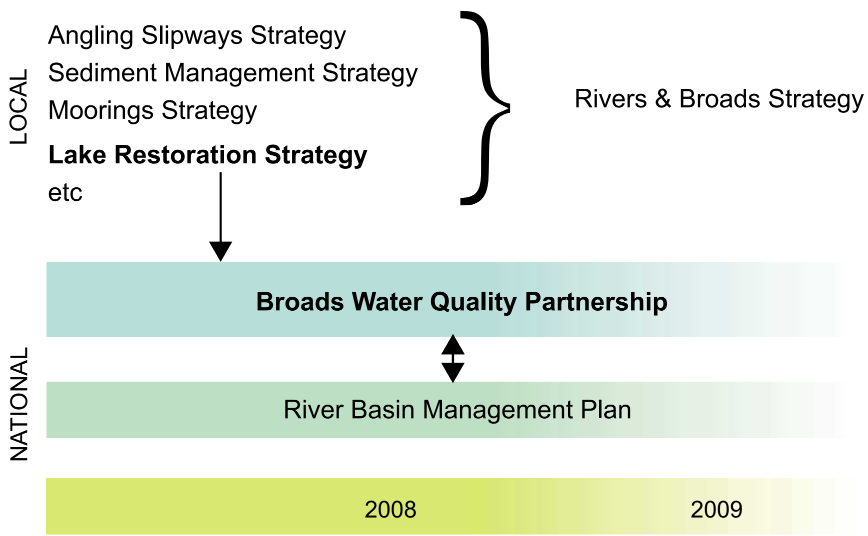
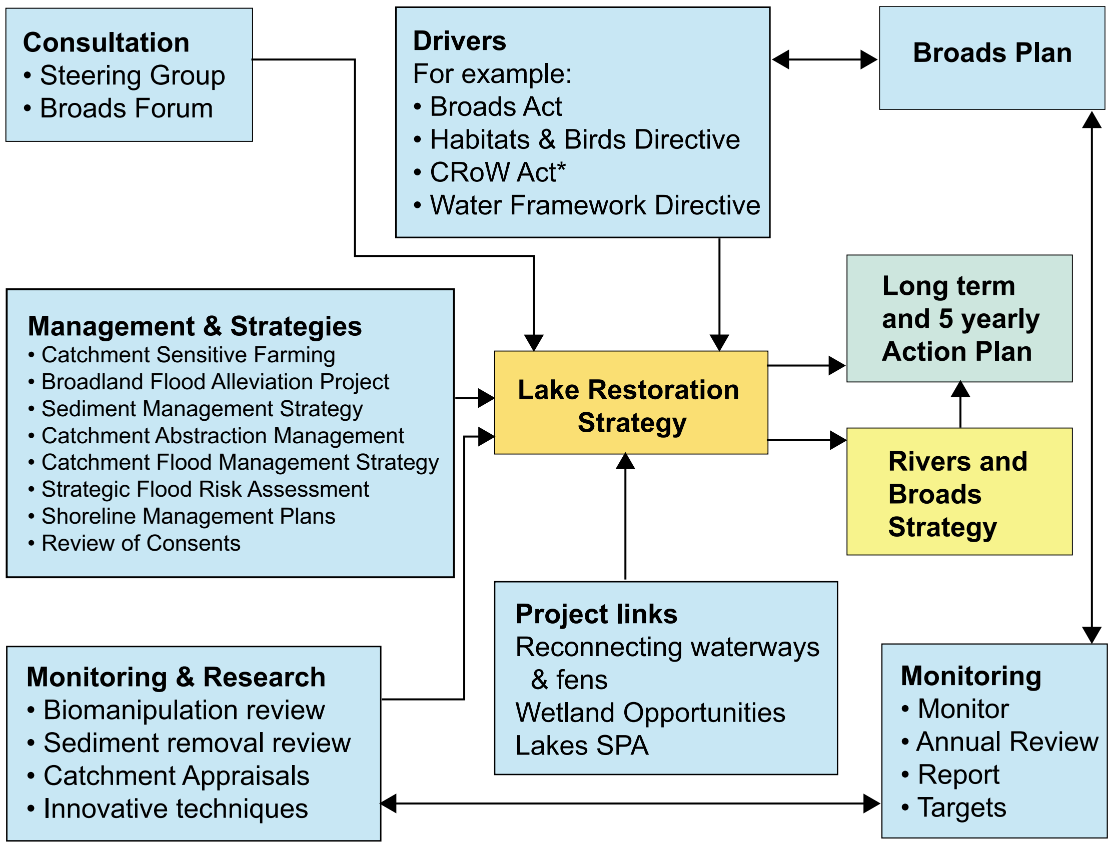


Figure 4 **Framework for the Lake Restoration Strategy**



*CRoW Act, section 28 places a duty on all public bodies to enhance the special interests of SSSIs

6 Summary of issues affecting lakes

Issues affecting the achievement of ecological targets for waterbodies in The Broads have been grouped under the following headings to help link similar issues or issues that have similar root causes or solutions:

Table 1 Significant water management issues for The Broads
Issues that increase the risk of not achieving targets after implementation of all ongoing actions

Issue groupings	Detailed issues
Diffuse pollution from rural areas and internal sediment release	Nitrates, phosphorus and sediment ochre
Diffuse pollution from urban areas and transport	Nitrates, phosphorus, contaminants and sediment
Point source pollution	Nitrates, phosphorus, contaminants and sediment
Flow problems	Abstraction and other artificial flow pressures, physical modifications
Alien species	Native wildlife, flow problems, ecosystem function
Physical modifications	Abstraction and other artificial flow pressures, physical modifications (e.g. dredging, weedcutting, flood defence, urban structures, channel neglect), ochre
Saline incursion and coastal breach	Salt water, nitrates, phosphorus and sediment ochre

Adapted from Anglian Region Significant Water Management Issues document, EA.

For further details of these issues that are affecting broads see Appendix 1.

Sea flood water near Reedham, November 2007

7 Targets

The quality of rivers and lakes is currently measured by three main targets. These are applicable to certain waterbodies (Table 2).

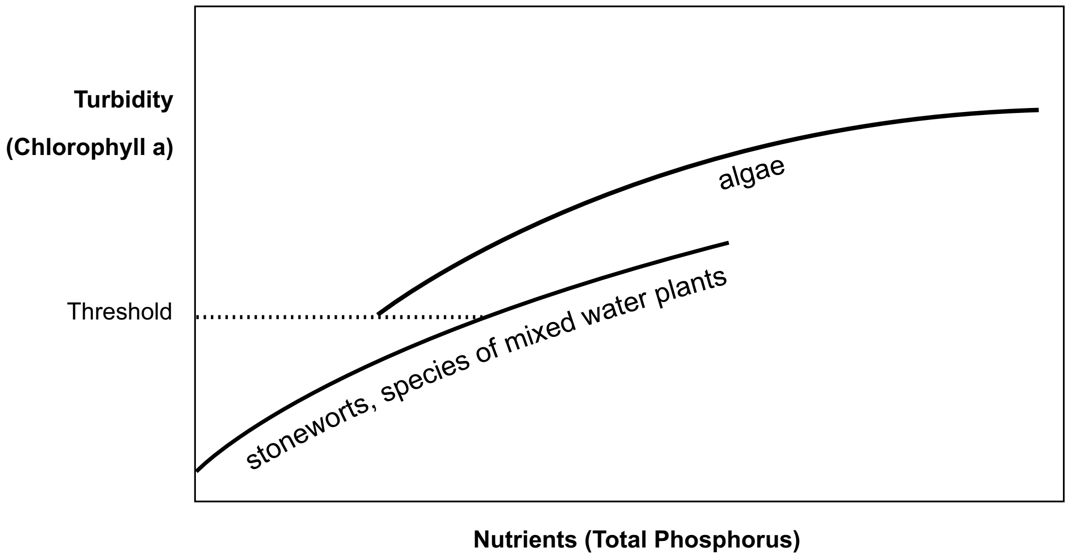
It is possible for high alkalinity shallow lakes to have a macrophyte dominated state over a wide range of phosphorus concentrations (Figure 5). However, 30 years of Broads research, supported by European studies, show that the lower the nutrient concentration the higher the probability of achieving a stable, clear, water plant dominated aquatic ecosystem.

Both WFD and Special Area of Conservation (SAC) objectives focus on achieving biological as well as chemical targets which, when combined describe the ecological status. WFD adopts SAC targets for these designated sites. In setting these targets it is critical that the hydrological links between Broads rivers and lakes are recognised, as a less stringent upstream river target will potentially compromise the achievement of a stringent downstream lake target.

Table 2 Targets for waterbodies in The Broads

Directive/Driver	Target	Applicable to
Water Framework Directive	Good Ecological Status/Potential by 2015	>50ha (SACs/SPAs >5ha)
Habitats and Species Directive	Achieve and maintain feature targets by 2015 as WFD	Natura 2000 sites: SACs and SPAs
Government's Public Service Agreements	95% of area in favourable or recovering condition by 2010	SSSIs

Figure 5 Alternative stable states



Source: Adapted from Scheffer, M. 1998
Ecology of Shallow Lakes

Water Framework Directive (WFD) waterbodies

The WFD designates the majority of rivers and lakes as Heavily Modified[1] within the Broads area. This means that Good Ecological Potential (the biological value achieved by taking identified mitigation measures[2]) will be the target; this can be equivalent to Good Ecological Status.

The indicative Environment Agency Good/Moderate class boundary values in the Broads are 25µg/l for chlorophyll a (which represents the amount of algae present) and 75µg/l for total phosphorus. There will be further targets developed for water plants, fish and invertebrates in lakes and rivers; however these are not currently available. In the first River Basin Management Plan, lakes over 50 ha (e.g. Fritton Lake and Barton) or over 5 ha and within a Site of Special Scientific Interest (SSSI) (e.g. Upton and Decoy) will be reported. Within the Broads several of these lakes will not be reported in the first round due to data discrepancies. These include Alderfen and Bargate Broads, both within an SSSI.

Many of the rivers in the Broads (Yare to Norwich, Bure to Hoveton and Thurne to Martham Ferry) have been designated as transitional and coastal waters (TrAC)[3]. These rivers are being monitored. However the impact of this designation on the targets for these rivers and their adjacent broads is currently unclear.

Special Areas of Conservation (SAC) waterbodies

A single threshold of 50µg/l phosphorus has been adopted by Natural England and the Environment Agency for SAC broads, since this promotes ecological protection and improvement at this threshold and reduces the potential for inconsistency in target setting between sites.

There is a chance that some lakes might require a more stringent target (somewhere between 35 and 50µg/l). If there is clear local evidence that this is the case, for example an existing biological impact, a more stringent target should be adopted.

This strategy supports seven broads having a target of 35µg/l for the following reasons:

- Broads data shows that several SAC lakes support macrophyte populations only when phosphorus concentrations are 35µg/l or below. Indeed when these concentrations are exceeded the macrophyte populations have been shown to become unstable and at risk. These broads are Hickling, Horsey and Heigham Sound.
- Another small set of broads (Martham North and South, Upton and possibly Blackfleet Broads, although there is little data from Blackfleet) have over the past 26 years had phosphorus concentrations less than 35µg/l with associated important macrophyte populations. Again this evidence is sufficient to put forward a target of 35µg/l for adoption.
- A further broad, Ormesby, supports good macrophyte populations, including stoneworts; however the phosphorus concentration regularly exceeds 50µg/l. At this level there is a high risk of switching back to turbid conditions if the conditions changed, resulting in loss of macrophytes. There is a continued requirement for management intervention in Ormesby to ensure this does not happen.

The only exception to the 35 or 50µg/l is Hardley Flood, which has a phosphorus target of 100µg/l, due to its position in the lower river reaches and occasional inundation of saline water. In the future targets for other broads within the lower reaches may need review as climate change impacts become more apparent.

Overall Targets for The Broads

The standard of 50µg/l total phosphorus is appropriate for all broads for the following reasons:

- Extensive data shows that below 50µg/l broads show a biological response to lower nutrient conditions, i.e. their algal communities significantly shift, moving away from blue-green algae, and the macrophyte communities begin to grow in the clearer water.
- Water plants and associated wildlife are usually only found where total phosphorus is less than 50µg/l.
- Most broads are within designated sites (around 75% of the area and over 62% of broads).

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[1] Artificial & Heavily Modified Waters are designated where:
a) changes to the hydromorphological characteristics necessary for achieving good ecological status would have significant adverse effects on:
1) the wider environment; 2) navigation, including port facilities, or recreation; 3) activities for the purposes of which water is stored, such as drinking water supply, power generation or irrigation; 4) water regulation, flood protection, land drainage or 5) equally important sustainable human development activities.

b) the beneficial objectives served by the artificial or modified waterbody characteristics of the waterbody cannot for reasons of technical feasibility or disproportionate costs, reasonably be achieved by other means which are a significantly better environmental option.

[2] Mitigation measures will not include those that have a significant impact on use, or deliver only slight improvement.

[3] TRaC waters are generally defined as tidal estuaries and coastal waters.

- Most of the non-designated broads are not considered by WFD's first river basin cycle, so have no specific objectives to improve water quality.
- Most broads are highly influenced by the quality of the main rivers, thus the actions undertaken to improve river quality for the designated sites will also apply to many of the broads without additional investment.

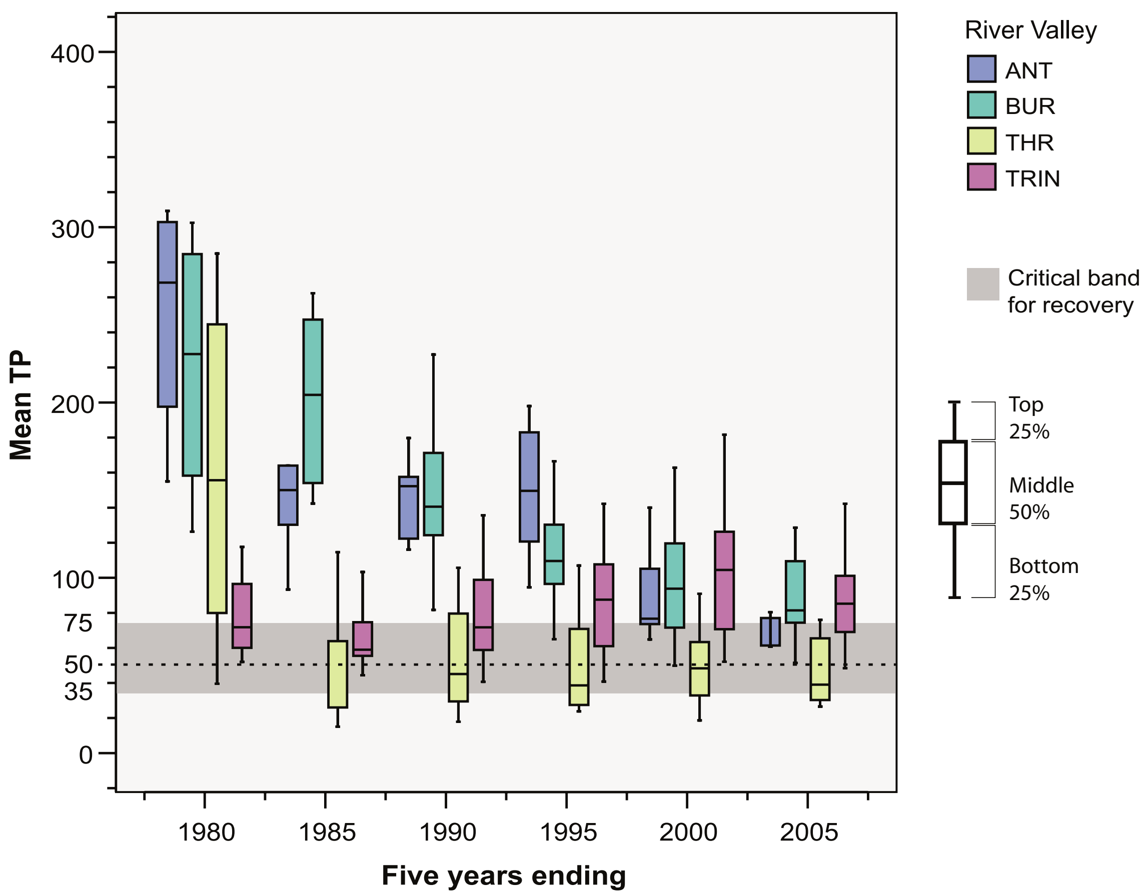
In addition to setting a 50µg/l total phosphorus target for broads, this strategy sets a 'critical band for lake recovery' from 75 to 35µg/l. The upper value of 75µg/l is the point at which the probability of achieving the objectives of the strategy starts to increase and 35µg/l is a point at which there would be high certainty of delivering the strategy objectives.

Figure 6 shows that the Ant and Thurne and some Bure broads are already within the upper end of the critical band. Achieving the lower end of this critical band remains a long-term aspiration. Currently only two broads (Upton, Martham) achieve 35µg/l, with the exception of Hickling in 1999. It will take several years and more restoration effort, both on a catchment scale and in-lake scale to achieve this in other broads.

The ecological targets for broads also need to be developed. These will include targets for aquatic plants, fish and invertebrates and will be incorporated into this strategy when nationally available.

This strategy acknowledges that, within this intensively farmed and populated catchment, achievement of ecological recovery goals for all broads may not be possible via catchment nutrient controls alone. Shallow lakes in The Broads require nutrient control actions to move into the critical band and towards the 50µg/l target, which should begin ecological recovery. It will be this ecological recovery that then supports the required change from a turbid to a stable clear water state by providing mechanisms for retaining phosphorus within the lake, limiting algal growth and thus creating clear water.

Figure 6 Total phosphorus concentrations over five year periods for the broads in the main river valleys and the critical band for recovery



Source: Environment Agency

8 Past and current condition

Past condition

Past conditions included crystal clear waters with diversity of submerged plants providing habitats for predatory fish. Remarkably The Broads still has a few isolated sites where water plants have remained whilst in most of the UK they have either been lost or undergone a transition toward more nutrient tolerant species.

Palaeolimnology, or the study of the history of a lake in regard to its ecology, aims to answer questions about what successful lake restoration could look like, what species occurred in the lake before it was polluted and what have been the changes and the possible causes.

Evidence comes from historical records gleaned from the notebooks of Victorian botanists as well as studying dated sediment cores (Ayres, in press), which contain the preserved fossil remains of water plants called 'plant macrofossils'. These historic resources provide information on the plant species to begin to reconstruct long-term changes in underwater vegetation. Some of the step-like changes recorded in The Broads include loss of meadows of *charophytes* (commonly known as stoneworts) that occurred before the 1900s. From 1900 to around the 1950s or 60s, several changes can be noted. In almost all cases, a decline of stonewort species and increases in water lilies, water soldier, millfoils and several pondweeds. In this phase diversity may have been at its highest. Finally, from around the 1960s onwards, in many sites, a dramatic reduction in the number of plant species present and in some cases a complete loss of submerged vegetation. However there are variations across sites and the story is complex.

Characteristics of broads

The broads are very shallow, between 0.5 m to 3 m depth and with the calcareous catchment geology are 'very high alkalinity'[1] as classified by the WFD. The size of the broads ranges from less than one hectare to the largest at 130 hectares. Most are freshwater with conductivities of 252-1000 micro Siemens per centimetre (μScm^{-1}) with the exception of the Upper Thurne broads, which are brackish at conductivities ranging from 1800-3000 μScm^{-1}.

Current condition - water quality

Over the past 25 years the northern rivers (Ant, Bure and Thurne) have shown a decrease in total phosphorus as a result of point source phosphorus control of treated effluent in the case of the Ant and Bure, and the loss of a large gull roost in the Thurne (Figure 6). The Trinity Broads however show no real change in phosphorus, demonstrating that a reduction is easier where the starting concentrations are high.

'Gathering water-lilies' by the Victorian photographer P. H. Emerson

[1] >125 mg/l calcium carbonate ($CaCO_3$), with some just over and others exceeding 200 mg/l $CaCO_3$.

The Trinity Broads

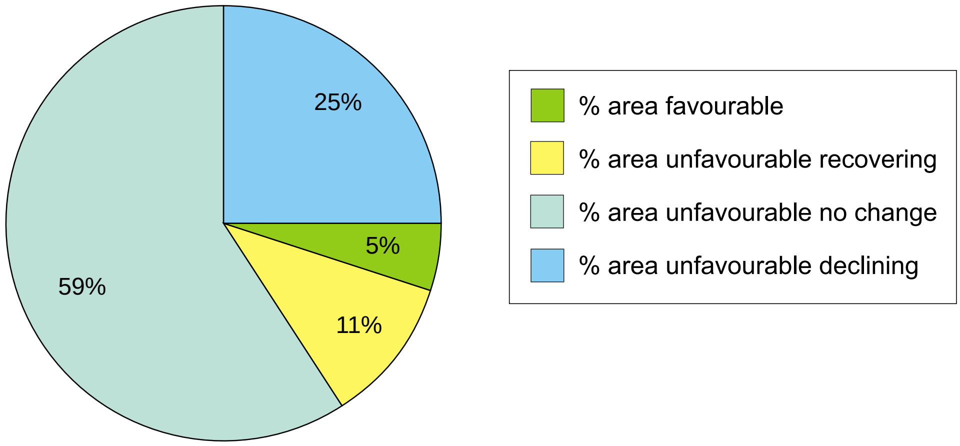
In recent years the Yare and Waveney have also responded to lower phosphorus load from sewage treatment works, although higher phosphorus concentrations remain in these rivers compared to the northern broads, due to more recent investment in nutrient removal from sewage treatment works and the large impact of Whitlingham STW. As nutrient levels decrease the algae as measured by their pigments (chlorophyll a) decreases.

Although there is a statistically significant relationship between phosphorus and algal growth, this relationship is sometimes not straightforward and alternative states of water clarity (Figure 5) can exist at different nutrient concentrations. For example the more unusual conditions of clear water and high nutrient tends to be only maintained where fish populations are low, such as in isolated lakes that have experienced fish kills or within biomanipulated lakes. The algae in these lakes, rather than being controlled by nutrient levels (bottom up control) are controlled by grazing by zooplankton (top down control).

Assessment for Public Service Agreement, undertaken by Natural England and the Broads Authority shows that currently only 16% of the area of SSSI fresh waterbodies in the Broads (around 13, mainly smaller, broads) have been evaluated as being in a favourable or recovering ecological condition based on ecological condition and restoration actions put in place. Of the remaining broads 25% of the area (or 23 broads) fall in the 'unfavourable no change' category. Only two waterbodies are assessed as 'unfavourable declining', although this makes up 25% of the total waterbody area. The relatively large size of Hickling (128 ha) and its assessment as 'unfavourable declining' leads to the large proportion of the area in this final category. The individual assessment of waterbodies is detailed in Appendix 1.

Hickling Broad

Figure 7 Condition assessment of the open waterbody area within SSSIs in The Broads



In addition to algae and phosphorus it is also important to consider other chemical aspects of the water quality in the lakes and the wider Broads catchments. The General Quality Assessment (GQA) is the Environment Agency's method for providing an accurate and consistent measure of the status of water quality and changes in the state over time. It consists of separate windows – the chemical GQA, biological GQA and nutrient GQA.

The chemical GQA is based on measurements that detect the most common types of pollution: biological oxygen demand (BOD) and ammonia, which are mainly derived from sewage works or agriculture. Ammonia is toxic to fish and aquatic life and elevated BOD can strip dissolved oxygen from the water, thus concentrations of these need to be kept low. Another parameter monitored is dissolved oxygen which again is necessary in adequate concentrations for aquatic life to thrive. For reporting purposes rivers are broken down into stretches and each stretch of river is allocated a grade from A to F, with A indicating good quality and F very poor.

A summary of the 2006 General Quality Assessment of Broad rivers (the whole catchment of the Yare, Wensum, Waveney, Bure, Ant, Thurne) is given in Table 3. This includes the stretches of river that run through the riverine broads on the Bure, Ant and Thurne. The table shows the length of river in each grade by determinand as well as the overall grade. The grade assigned to each river stretch is determined by the worst determinand.

Table 3 Total lengths (km) of Broads rivers assigned to each chemical GQA grade by determinand

	Ammonia	BOD	Dissolved Oxygen	Overall grade
A	480.8	417.3	55.5	50
B	66.2	115.2	240	236.5
C	5.5	20	144	153
D	0	0	64	64
E	0	0	49	49
F	0	0	0	0
	552.5	552.5	552.5	552.5

Table 4 Total lengths of Broads rivers (km) assigned to each of the nutrient GQA grades

GQA grade	Phosphate (km)	Nitrate (km)
1	21	0
2	136	36
3	87	61.5
4	157	285
5	127	106
6	24.5	64

The A and B grades correspond to 'very good' and 'good' water quality. For ammonia and BOD, 99% and 96%, respectively, of the river lengths are A and B grades indicating that water quality, with respect to organic pollution, is good. However, only 51.8% of river length is classed as A or B for dissolved oxygen. This is due to natural influences in the watercourses rather than pollution issues. This is supported by the fact that the biological GQA shows that 91.6% of the Broads river stretches achieve A or B grades indicating that the biological health of the rivers is good and not affected by low dissolved oxygen levels.

The results of the 2006 nutrient GQA are shown in Table 4.

The phosphate grades are fairly evenly spread across grades 2 to 5, with some river stretches even achieving grade 1. In contrast to this the majority of the river stretches fall into nitrate grades 4 to 6, with none achieving grade 1. The wide range of phosphate grades, including a number of stretches achieving the lower concentration grades, reflects the widespread phosphate stripping of sewage effluents discharging into The Broads rivers.

Three lakes, Barton Broad, Hickling Broad and Rollesby Broad are designated as stretches under the Freshwater Fish Directive. The directive sets a number of physical and chemical standards, including dissolved oxygen and ammonia levels. In 2006 all three lakes were compliant with the standards.

Current condition - invertebrates

Zooplankton have been monitored by the Environment Agency (EA) in key broads over the past 25 years. Zooplankton are an important component of The Broads ecosystem, they graze on algae and have the ability to filter the water within the lakes several times a day. They are key indicators of predation pressure from fish and other invertebrates, as well as habitat structure and associated refuge provision.

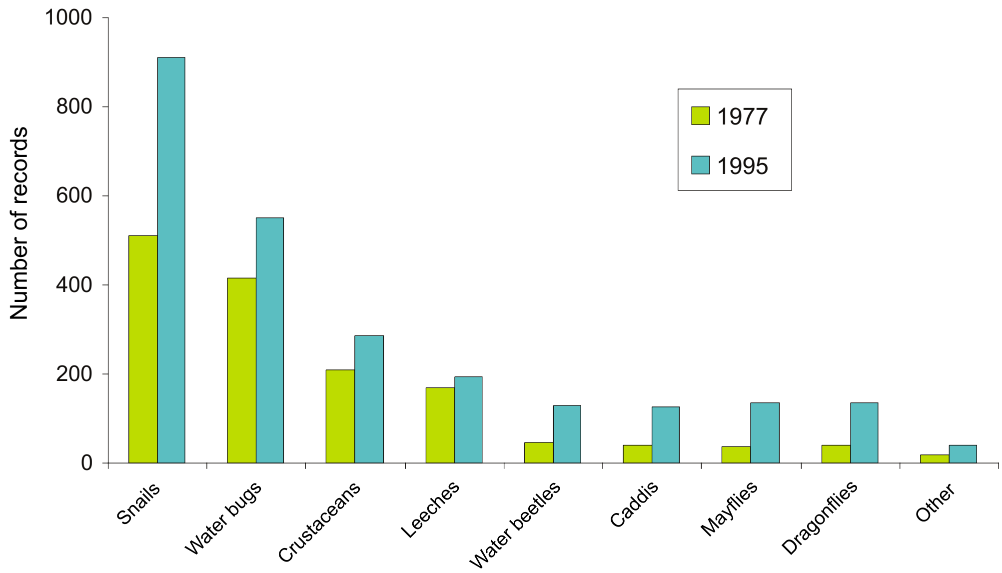
Benthic invertebrates (that live on vegetation or the river bed) are also recorded by the Environment Agency, at a network of river locations in The Broads area. Most of these monitoring locations are in The Broads headwaters outside the executive area.

The Wheatfen Partnership has undertaken freshwater mollusc surveys (including zebra mussels and depressed river mussels) as well as undertaking surveys of the non-native asian clam, which has been shown to be expanding in range (Muller, PhD thesis).

Invertebrates inhabiting the lake edge habitat (littoral margin) were studied by Jackson (2003). By comparing 1977 and 1995 populations he showed a marked improvement in species richness in around 20 broads over this time (Figure 8).

Jackson's work concluded that the overall number of species were 143% higher in 1995, with the main increase recorded in the river connected broads of the Yare and

Figure 8 Number of records of macroinvertebrates from major groups, 1977 and 1995



Source: Jackson (2003)

Bure. Isolated broads that had been subject to restoration also showed significant improvements. Jackson suggested that these changes were due to improved water quality, with species such as red-eyed damselfly, ramshorn snail and anglers curse (a mayfly) benefiting, and of particular interest, large numbers of water stick insect not found in the 1977 survey. However, despite these improvements The Broads are capable of supporting more species of invertebrates, for example well managed grazing marsh dykes can contain two or three times as many invertebrate species as found in the 1995 survey.

Current condition - submerged aquatic plants

Submerged aquatic plants are probably the best indicators of ecological health of shallow lakes. The Broads Authority has surveyed and reported on water plants for the past 24 years (since 1983), using standard methodology (Kennison *et al* 1988).

Before this survey existing surveys were done on an ad hoc basis without standard methodology. During the early 1900s the survey shows the few good populations of plants were present in smaller isolated broads (e.g. Flixton,

Table 5 Scores for broads surveyed in 2006

Blue text indicates estimated condition or surveys from other years (based on Broads Authority annual water plant survey data, methodology from Rivers and Broads Strategy, Kelly, 2003)

LOW ABUNDANCE		HIGH ABUNDANCE	
Low diversity	**High diversity**	**Low diversity**	**High diversity**
4	**3**	**2**	**1**
Bridge Wroxham Burntfen Salhouse Great Hoveton Great Decoy Hoveton Little Pound End Ranworth Rockland Bargate Fritton Lake Barnby Filby Irstead Holmes Burntfen Devils Hole (no data) Malthouse (2002) Little (2005) Ranworth Flood (no data) Snape's Water (no data) Womack Water (no data) Hardley Flood (no data) Surlingham (no data) Brundall Inner (no data) South Walsham (no data) Oulton (no data)	Rollesby Ormesby Little Lily Hickling Barton	Whitlingham Little Wheatfen Hassingham Belaugh Upton Little Upton Great Alderfen Heigham Sound Blackfleet Hudson's Bay (2007) Salhouse Little (1998) Calthorpe (NE) Sprat's (2004) Wheatfen (2006) Norton's (2004) Woolner's Carr (no data) Round (no data) Sotshole (no data) Brundall lakes (UCL)	Crome's Cockshoot Whitlingham Great Strumpshaw Buckenham Flixton Decoy Ormesby Martham North Martham South Blackfleet Mautby Decoy (2007) Catfield (2004)

Buckenham, Hassingham and Upton), which are not directly connected to the main rivers. Water plant status is generally poor in river-connected sites (e.g. Rockland and Hoveton Great).

The status of water plant is described here in terms of the abundance and number of species. Abundance dictates the structure and available refuge within the broad and shapes the populations of other aquatic organisms, such as fish and invertebrates. The number of species, or diversity, is important for providing different types of habitat and resilience to environmental change.

The Broads Authority data shows that most of the broads have poor plant populations (i.e. low abundance and diversity). These sites are often directly connected to the river, such as the Bure (e.g. Wroxham) and Yare (e.g. Rockland).

Low abundance means the broad has anything from an odd plant fragment up to a few stands of plants, usually around the margins. High abundance equates to a large proportion of the broad covered with submerged vegetation which may be low or high growing. Low and high diversity is represented by below or above seven species.

Broads that have a high diversity but low abundance have in this survey generally been subject to restoration action (such as Catfield and Barton) or have never completely lost their macrophytes (Trinity and Hickling); whereas broads with high abundance and low species diversity are generally indicative of good water clarity. The final macrophyte category generally represents the good quality broads (i.e. high macrophyte abundance and diversity) that are isolated from the main river network (Mautby Decoy) and have been subject to restoration programmes (Ormesby, Strumpshaw and Cockshoot).

As water plants continue to recover in the broads so the potential for exchange of plant material between sites increases assisting with natural recovery. This has certainly been occurring in Barton with colonisation of plant material from the River Ant to the broad. It is possible the recent expansion of the range of the rare holly-leaved naiad (*Najas marina*) to Alderfen, Trinity and Barton Broads is a result of movement of seeds via wildfowl.

The Broads Authority river survey has shown an increase in submerged plant abundance in all The Broads rivers over the past three years. This increase is mainly within the upper reaches of The Broads Authority area, where the volume of boat traffic is less.

Current condition - Fish

There are eight main species of fish within The Broads. These are roach (*Rutilus rutilus*), common bream (*Abramis brama*), rudd (*Scardinius erythrophthalmus*) and tench (*Tinca tinca*) (the cyprinids or 'carps and their allies'), perch (*Perca fluviatilis*) and ruffe (*Gymnocephalus cernuus*) (percids), northern pike (*Esox lucius*) and the european eel (*Anguilla anguilla*). The latter was formerly very common but is now in decline. Several less common but widely distributed species include gudgeon (*Gobio gobio*), noted especially in Fritton Lake and the River Ant by Environment Agency surveys, and three-spined (*Gasterosteus aculeatus*) and ten-spined sticklebacks (*Pungitius pungitius*), which are present throughout the margins of The Broads. Carp (*Cyprinus carpio*) have a more restricted distribution including the Trinity Broads. Non-native but naturalised carp and occasional records of wels (*Siluris glanis*) and North American *Ictalurus sp.* catfish relate to illegal introduction, which is to be actively discouraged.

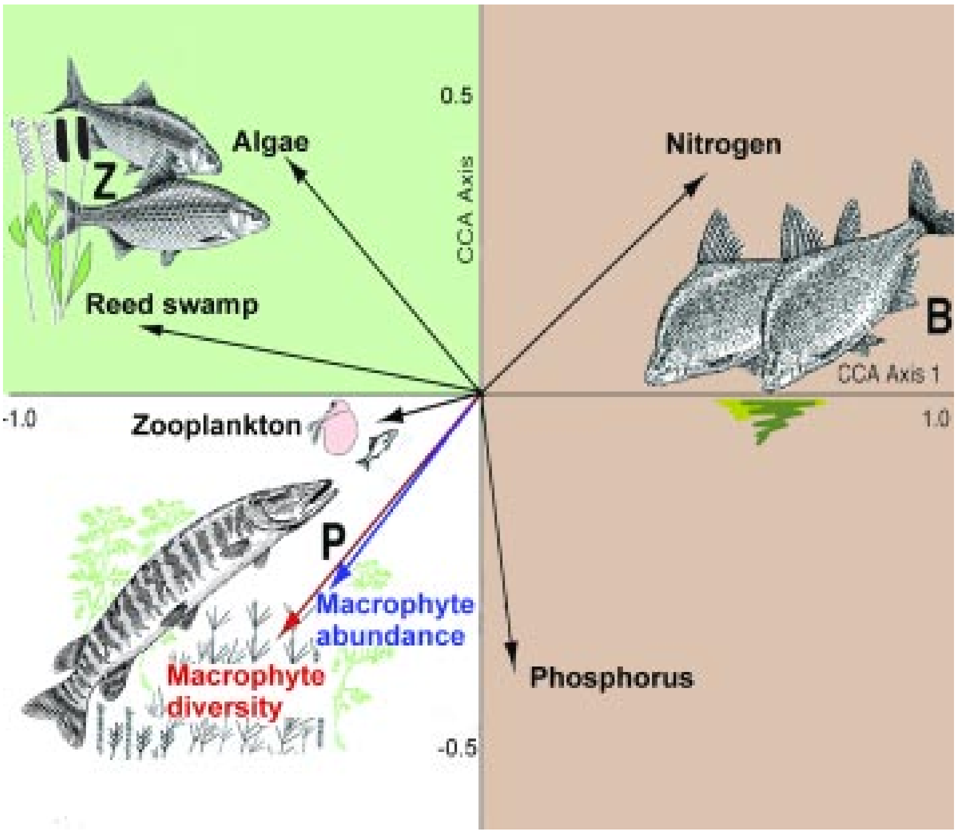
In the more saline broads and the lower sections of the main tidal rivers (Yare, Bure and Waveney), flounder

(Continued on page 27)

White water lily leaf, Upton Great Broad, 2007

Rigid hornwort, Alderfen Broad, 2007

Figure 9 **Relationships between the fish and environmental variables**



Notes to Figure 9. This figure shows a canonical correspondence analysis (CCA) plot of the relationships between the biomass of piscivorous, benthivorous and zooplanktivorous guilds of fish and selected important environmental variables including submerged plants abundance, number of species of macrophyte, littoral margin width, density of zooplankton in open water, amount of algae measured by chlorophyll-a concentration and concentrations of total phosphorus and nitrogen (nitrate) in 28 shallow lakes in eastern England, including many broads.

The direction and length and arrows for different variables represent their relative position within the variance of the dataset, most of which is explained by axis 1. The different fish guilds, especially benthivorous fish, are clearly separated from each other in lakes characterised by different environmental variables. Thus, piscivorous fish such as pike occurred in clear lakes characterised by more species of macrophytes conferring high cover. Zooplanktivorous fish such as roach occurred in phytoplankton-dominated (green with reduced water transparency), but otherwise similar lakes with good littoral margins. Benthivorous fish such as bream and carp tended to dominate the fish biomass of turbid (often brown) lakes with few or no plants at all and with higher concentrations of nitrates. As all lakes would best be described as eutrophic, total phosphorus was not limiting and of no importance in explaining any relationships between fish and other environmental variables.

Overall, both piscivorous and zooplanktivorous fish appear to be coupled to the 'pelagic' chain of top-down interactions between piscivorous fish→zooplanktivorous fish→ zooplankton→phytoplankton→water transparency→ submerged plants. Benthivorous fish on the other hand were linked to a 'benthic' chain of interactions, the most important effect of which was thought to be the physical uprooting of plants by large fish feeding amongst the sediments.

Data and interpretation from Zambrano et al *(2006) funded by NERC awards to Dr Carl Sayer (University College London), with line drawings of fish and other animals and plants from Natural England and the Broads Authority.*

(*Platichthys flesus*), smelt (*Osmerus eperlanus*) and even bass (*Dicentrarchus labrax*) are present. The latter have been found as far up the system as Hickling Broad in EA surveys. Occasional sea trout (*Salmo trutta*) running off the North Norfolk coast reach the River Wensum in Norwich, reminiscent of the run of atlantic salmon (*Salmo salar*) known from the river before the 16th Century. Burbot (*Lota lota*) became extinct as recently as the late 1960s and is now a focus of potential re-introduction in other parts of the UK.

Fish community structure, the abundance, biomass and age structure of the different species populations as well as their distribution are influenced by a variety of environmental factors. The most significant of these are probably habitat resources (the nature of the littoral margin and the abundance of submerged vegetation being especially important), salinity and interactions between species, including competition and predation. Other factors such as water temperature, light and the diurnal cycle influence behaviour and key life events (e.g. energetics, migration, spawning etc).

Large-scale seasonal movements (in some cases possibly tens of kms) is a key aspect of some species populations (Jordan & Wortley 1985). Fish such as roach abandon the open broads to aggregate in sheltered locations in the rivers such as boatyards. Even in isolated lake systems, roach may aggregate in huge densities of several hundred per m^2 in connecting sheltered dykes and drainage channels (e.g. the Muck Fleet in the Trinity system). Similarly, in connected systems, fish such as bream and pike may undertake spawning movements to preferred, 'traditional' areas offering optimal spawning habitat conditions.

As well as being influenced by their surroundings, fish play a critical role within the food web within the shallow lakes of The Broads, which may lead to deleterious changes in habitat conditions. Key impacts are 1) the selective predation of large-bodied zooplankton (e.g. *Daphnia* spp.) (which otherwise may have grazed on edible phytoplankton) by species such as (young) roach, 2) promotion of nutrient release and cycling by large benthic feeding (benthivorous) fish such as bream and 3) disturbance and uprooting of submerged vegetation, again by large benthivorous fish. Biomanipulation relies on the release of these suppressive effects to promote better water quality and encourage growth of submerged vegetation.

Recent research by Zambrano *et al* (2006) in shallow lakes in the area, including several broads, showed benthivorous fish form a distinct community in turbid lakes with no vegetation (Figure 9 and 10). In keeping with this, large adult common bream dominate the fish biomass of the open broads, although young roach are typically the most abundant fish in numerical terms (e.g. 79% in Wroxham Broad and 95% in Barton Broad - EA 2005). In these favoured turbid conditions, bream exhibit higher than national average growth rates in most years (typically 104-126%, EA 1996-2005) with much of the population in excess of 12 and reaching over 20 years of age. Recruitment of young fish is often poor, perhaps constrained by competition with roach, which typically show below average growth (78-87%, EA 2004-2005) with fish only reaching 7 years of age. Older fish require prey resources often associated with plants, such as molluscs.

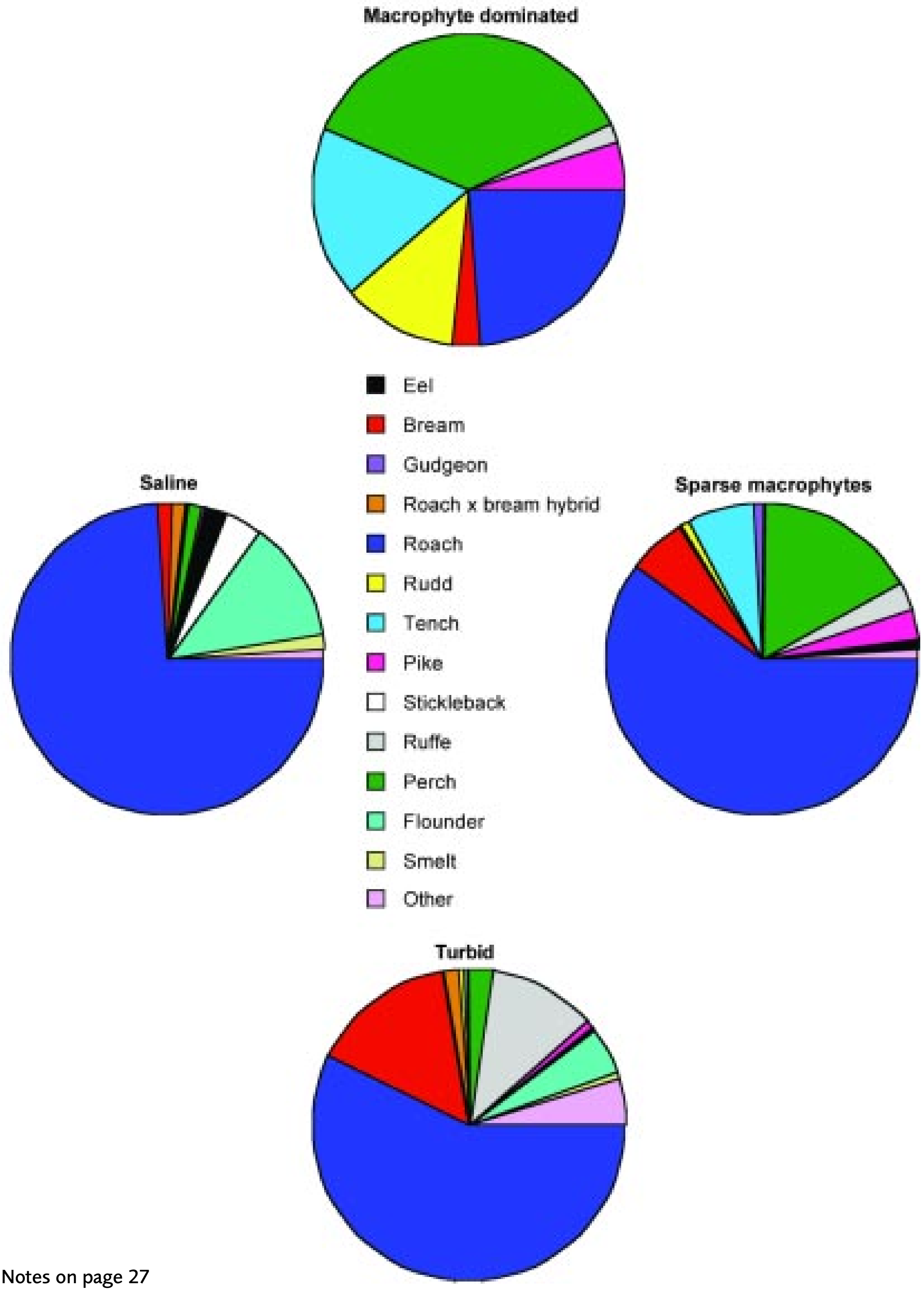
Although the exact boundaries of any relationship between fish biomass and macrophyte cover remain difficult to define, a general rule of thumb appears to be that a broad is unlikely to support good populations of plants with more than around 100 kg ha^{-1} of benthivorous fish. Similarly, in open water with no refuges, >0.2 ind. m-2 of zooplanktivorous fish may exert a negative effect on zooplankton, although in the presence of submerged plants, the density may have to be much higher (> 1ind. m-2) to exert the same effect (Perrow *et al* 1999).

Pike

Notes to Figures 10A and 10B on pages 28 and 29
Mean relative composition (%) by A) number and B) biomass of different fish species in broads that contain dense macrophytes (*n*=5) and sparse macrophytes (*n*=5), that are turbid with no macrophytes (*n*=8) and are saline (*n*=4). The numerical proportion of roach, rudd, tench, perch, ruffe, pike and flounder are all significantly ($p<0.05$) different between categories. For biomass, significant differences are restricted to roach, tench, pike and flounder (Perrow *et al* 1999b).

Data from selected Environment Agency (National Rivers Authority) fisheries surveys and surveys conducted for the Broads Authority.

Figure 10A **Relative number of fish in broads with dense and sparse macrophytes, turbid or saline**



Notes on page 27

Figure 10B **Relative biomass of fish in broads with dense and sparse macrophytes, turbid or saline**

Notes on page 27

Current thinking suggests biomanipulation may be better targeted towards benthivorous rather than zooplanktivorous fish. This has been reinforced by observations that where large bream have effectively been eliminated there appears to have been a more favourable response in water quality, recovery of submerged macrophytes and the fish community (see Review of Biomanipulation Appendix 4).

Although fish communities are predicted to respond clearly to restoration, with species such as rudd, tench, perch and pike increasing with macrophyte cover (Figure 9), this has proved to be much more variable in practice. The exception is the return of rudd to a number of sites (e.g. Ormesby and Alderfen) and some recruitment events amongst the tench population, although it can take decades for slow-growing tench to form large populations. The size of the initial population and subsequent recruitment success as well as the development of habitat conditions and other species may all play a role. Monitoring of un-manipulated sites such as Upton Great Broad has shown how even species adapted to plant-dominated conditions such as pike, may suffer from 'fish-kill', most likely through the absorption of oxygen at night by plants. This in turn could be an important regulator of the plant-dominated state.

Whilst pike are intuitively a key predator of other fish, there is little evidence that natural populations (as opposed to artificially stocked populations) can really help stabilise the plant-dominated state through predation of other fish species. Cannibalism of small pike by larger ones, poorly understood vagaries of recruitment (despite specific research efforts by the EA) and a propensity to fish-kill may limit populations even in otherwise suitable conditions. In the open broads, pike tend to be restricted to the littoral margin, where they may form a large part of the fish biomass of this zone (e.g. 79% in Wroxham Broad and 60% in Barton Broad, EA 2001).

Perch, which can be an open-water chasing predator geared to the capture of small fish, has also proved to be sensitive to water quality and habitat conditions. Large populations with a range of age classes have yet to be obtained in restored lakes, although there are signs of improvement in some rivers from angling catches. It has also proved difficult to stock perch (e.g. at Alderfen) to trigger population development. With future global warming, it remains debateable whether the very shallow waters of many broads, prone to low oxygen concentrations, can again support large and stable perch populations as they once appeared to do.

In summary, the nature of the fish community and the individual species populations within it is a key consideration in lake restoration, with manipulation of fish (removal of undesirable components and retention of beneficial or neutral species) being a powerful restoration tool. The subsequent development of fish communities during restoration is critical to how a lake responds to restoration and further management (e.g. additional targeted removal or ongoing manipulation of spawning success) is often required. In simple terms, the long generation time of many fish species and variable recruitment patterns mean that it may take a long time (a decade or more) for an appropriate community to develop naturally without specific management (stocking and manipulation).

Current condition - invasive non-native species

Invasive non-native species (plants in particular) are thought to be one of the greatest threats to our native wildlife. The problems they cause are very significant and cost millions of pounds to put right.

Invasive non-native species have the ability to establish themselves and spread, out-competing natives and taking over new environments. Most non-native species do not cause a problem in the wider environment, and some are considered beneficial. However, a small number become invasive and endanger native biodiversity and possibly result in impacts on human interest, for example by causing financial losses or public health issues. The fresh and brackish invasive species that are known in the Broads are listed in Table 6. Other species are likely to enter and become a problem in The Broads in the future; however due to uncertainty these have not been listed.

The Norfolk Non-native Species Management Initiative aims to develop a coordinated approach to partnership working in freshwater and their transitional habitats of Norfolk. The aim is to provide a programme of rapid action, surveillance, research, data exchange and awareness raising across the county.

Floating pennywort, River Bure, 2007

Table 6 Occurrence and density of invasive non-native species[1] in The Broads

Group	Species	Occurrence and density	Risk	Action
Mammals	Mink	Present in all river valleys. Mink Management Project ongoing	Significant threat to water vole population	Mink Management Project
Birds	Feral geese	Widespread in the Broads, often several hundred in flocks	Damage to reed margins	Egg pricking, encourage shooting where possible
Molluscs	Asian clam	All middle reaches of rivers at high-low density, not recorded in broads to date Have found them in Rockland and Wheatfen channels	Blocking water intakes, competition with native mussels, other inverte-brates and fish benefit by clearing water	Minimise spread into surrounding watercourses
	Zebra mussel	All middle reaches of rivers and broads where substrates are suitable at low density	As above	Minimise spread into surrounding watercourses
Crustacean	Crayfish (non-native)	Turkish crayfish widespread in Waveney, this population has carried crayfish plague (2007) Signals and natives in headwaters	Transmission of plague, burrowing into banks, uprooting water plants	Record presence, minimise spread of plague via awareness raising
Fish	Carp	Occasionally recorded in broads, not considered to be a problem currently	Uprooting of water plants	Continue stocking ban in flood plain and monitor fish populations in The Broads
Aquatic plants - submerged	Australian swamp stonecrop	In flood plain fens, several grazing marsh dykes, Whitlingham Little, Lound ponds and several village ponds	Significant risk of smothering small waterbodies and competing with native plants	Chemical and mechanical removal or filling in of waterbody. Eradication difficult in small waters and impossible in large connected waters
	Floating pennywort	4 occurrences recorded in the Executive Area (2003-07), including presence in three locations in River Bure despite control in grazing marsh dykes	Significant risk of smothering waterbodies, competing with native plants and reducing river width and flow	Mechanical removal mainly or filling in of waterbody Eradication as for Australian swamp stonecrop
	Parrots feather	Occasional ponds and ditches around Broads area	Significant risk of smothering ponds	Mechanical removal and chemical control possible
Aquatic plants - emergent and marginal	Japanese knotweed (Schedule 9 W&C Act)	Rare patches	Significant risk of spread, out competing bank vegetation	Control difficult, repeat cutting & burning of dried material followed by herbicide spraying of re-growth
	Himalayan Balsam	Scattered throughout Broads, particularly in Bure and Yare valleys	Significant risk of spread, out competing bank vegetation	Minimise spread, hand pulling prior to seed setting effective after 3 years continuous removal
	Giant Hogweed (Schedule 9 W&C Act)	Distributed throughout The Broads	Dominates native vegetation in marginal habitats	Mechanical removal and herbicide spraying
Aquatic plants - floating	Water fern	Noted in Ant and Bure valleys, low density.	Rapid growth, rapidly shade out areas	

[1] Invasive non-native species - a species that does not naturally occur in a specific area and whose introduction and proliferation does or is likely to cause economic or environmental harm or harm to human health.

9 Probability of not achieving targets

Water Framework Directive (WFD) waterbodies

In their current condition the Environment Agency has determined that the combined risk of broads (lake waterbodies) not achieving their WFD objectives, as a result of various pressures (such as nutrient input, water flows) used in Article 5 Reporting is 64% at high risk of not achieving objectives, 29% at moderate risk and only 7% at low risk.

In addition the second River Basin Cycle assessments for rivers show the following risks: all rivers are at high risk of diffuse sediment inputs; there is no significant risk from point phosphorus for the rivers themselves; pesticide risk is moderate for all rivers and high in the Bure; and finally the Waveney and Yare rivers in particular have a high risk of failing as a result of nitrate levels.

Special Areas of Conservation (SAC) waterbodies

There is a high risk that Public Service Agreement (PSA) targets for SSSI waterbodies in The Broads will not be achieved by 2010, with only 16% of this area being in a favourable or recovering ecological condition. This condition, assessed by Natural England and informed by the Broads Authority annual macrophyte survey and Environment Agency water quality data demonstrated that around 70% of the area of open water SSSIs was without any significant populations of aquatic plants.

The Broads Authority was given an additional Defra grant significantly during 2006-08 to help bring lakes to favourable condition. As restoration costs are large the projects focused on small lakes, of around less than 5 ha, so overall these did not contribute towards the area-based PSA target. However most of these broads are isolated from the main rivers, thus once restoration is complete the broads should be resilient to further change and the investment secured in the longer term.

Water lilies

10 Review of lake restoration techniques

River and lake restoration measures require review to ensure that they are both fit for purpose and provide a cost effective response to tackling water issues. It is beyond the scope of this strategy to report on the numerous Broads relevant reviews and evaluations. However, as part of this strategy the in-lake broad restoration techniques of sediment removal and biomanipulation have been undertaken.

The full sediment removal and biomanipulation review reports are in Appendices 3 and 4. These reports concluded that these restoration techniques are effective in their aims and that in the context of ongoing water quality issues in terms of nutrient and sediment input from climate change and population growth impacts they require scaling up to achieve WFD objectives.

In tandem with reviewing existing restoration techniques, new techniques are continually evolving as pressures change and understanding of the issue increases. These new techniques are included in the action plan.

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Mud pumping at Little Broad, Burgh Common

11 Prioritisation and action plan

Prioritisation criteria for waterbodies

A two-stage prioritisation has been used. The first stage focuses on prioritisation of lakes, whereby broads are divided into designated (i.e. whose with a conservation designation) and non-designated waterbodies, with designated sites having the greater priority. Broads are then scored 1-4 based on 'risk of impact from saline incursion' (based on the Broads hydrological model and 2006-07 saline incursion data), and 'probability of success' (a combination of timescale to achieve target and current ecological status, based on water plant population). See Table 7 for scoring criteria.

These scores are added together and broads categorised into six priority areas, Low, Medium and High priority, each with a success probability status and a risk status. The results are shown on a matrix for visual and comparative purposes in Figures 11 and 12.

Within these categories, broads are sorted based on size category (<5 ha, 5-50 ha, >50 ha). Broads that have access from land or water or have been subject to in-lake restoration are highlighted by the bold or italic text respectively in Figures 11 and 12. Total phosphorus concentration of the water data is available in the prioritisation database; however this is not known for each broad so has not been used within the prioritisation criteria (Appendix 2).

Prioritisation aims to identify broads where restoration to WFD targets is likely to be achievable at relatively low risk, forming the basis of the High priority list. Medium and Low categories represent broads of poorer current ecological condition and thus longer timescale for achieving any improvement.

Restoration investments in the 'long-term risk' broads need to take account of the uncertainty of maintaining freshwater in the long-term. Current coastal defence policies aim to protect freshwater habitats for up to 50 years; however saline incursion is likely to increase in frequency in lower river reach broads unless investment in washlands or other water control structures is considered.

However, restoration investment should target not only the less risky, quick wins, which are often small lakes (e.g. Upton Great Broad), mostly in good condition. Investment also needs to target broads which are low risk sites requiring greater investment (e.g. Barton Broad). In addition it is also appropriate to invest in broads where the management can improve ecosystem resilience, such as connected wetlands, even though in the long term (50-80 years) there is a greater risk of more frequent saline incursion.

In summary, this approach provides a guide to prioritising investment in restoration in accordance with the probability of success and the risk of retaining freshwater habitats in the long-term.

Visitors at Barton Broad

Table 7 Prioritisation and sorting criteria

PRIORITISATION CRITERIA	SCORE	COMMENT	EVIDENCE
Risk of impact from saline incursion and coastal breach			
Risk of impact from saline incursion			
No risk	4	Protected by flood defence structures and distance from salt tides	BESL hydrological model, tidal surge salinity data
Low	3	Resilient to saline incursion (e.g. u/s of Horning)	
Medium	2	Middle reaches	
High	1	Increasingly impacted by saline incursion	
Risk of impact from coastal breach			
		Secure within 50 years	
		Less secure within 50 years - broad automatically goes into long-term risk category	
Probability of success			
Timescale to achieve target		The combined risk of not achieving waterbody targets for ecological condition given the existing measures in place and the ease of the restoration	WFD & SSSI assessments, influence of and control of main river water and size of catchment
Target achieved	5	No action required	
Short timescale	4	In-lake	In-lake actions only e.g. sediment removal or biomanipulation
Medium timescale	3	Small catchment (+/- in-lake)	Inflow from small catchment area is resulting in excessive nutrient loading
Medium-long timescale	2	Large catchment and in-lake	Broad has large influence from main river resulting in excess nutrient loading and requires in-lake restoration
Long timescale	1	Large catchment	Broad has large influence from main river resulting in excess nutrient loading
Water plants			BA water plant survey, 2006/7 or most up to date
	4	High abundance, high diversity	
	3	High abundance, low diversity	
	2	Low abundance, high diversity	
	1	Low abundance, low diversity	
SORTING CRITERIA	**SCORE**	**COMMENT**	**EVIDENCE**
Size	3	> 50 ha	OS 1:250,000
	2	5 - 50 ha	
	1	< 5 ha	
Total phosphorus	4	< 0.035	Mean TP mgl^{-1} from 2006 or most recent data, EA data
	3	0.035 - 0.05	
	2	0.05 - 0.075	
	1	> 0.075	
Access	3	Both water and land recreation	
	2	Water or land recreation	
	1	No recreation	

Figure 11 Prioritisation matrix for directing investment for restoring designated broads

Risk of saline incursion or coastal breach ↓ / Probability of Success →	High		Low
Low	***Ormesby Broad*** ** *Upton Great* * ***Alderfen Broad*** * *Catfield Broad* ***Crome's Broad*** *Buckenham Broad* Upton Little Broad **Sprat's Water** Round Water **Woolner's Carr** *Hassingham Broad* *Strumpshaw Broad* ***Little Broad*** Irstead Holmes *Barnby Broad* **HIGH**	***Barton Broad*** *** ***Filby Broad*** ** ***Ormesby Little Broad*** ** ***Hoveton Great Broad*** ** ***Rollesby Broad*** ** **Decoy Broad** * ***Lily Broad*** ** Hudson's Bay **MEDIUM**	Reedham Water Ranworth Flood **LOW**
High	*Calthorpe Broad* **HIGH** Long-term risk	***Cockshoot Broad*** * **Wheatfen Broad & channels** **Hickling Broad** *** **Horsey Mere** * **Heigham Sound** * Martham North Broad **Martham South Broad** Blackfleet Broad **MEDIUM** Long-term risk	**Ranworth Broad** ** **Hardley Flood** ** **Rockland Broad** ** **Bargate Broad** * **Surlingham Broad** **LOW** Long-term risk

* < 5ha, **5-50ha, ***>50ha

Broads with land or water access are **bold** to indicate the importance of recreation and economy for these sites. Broads in *italics* have received restoration investment.

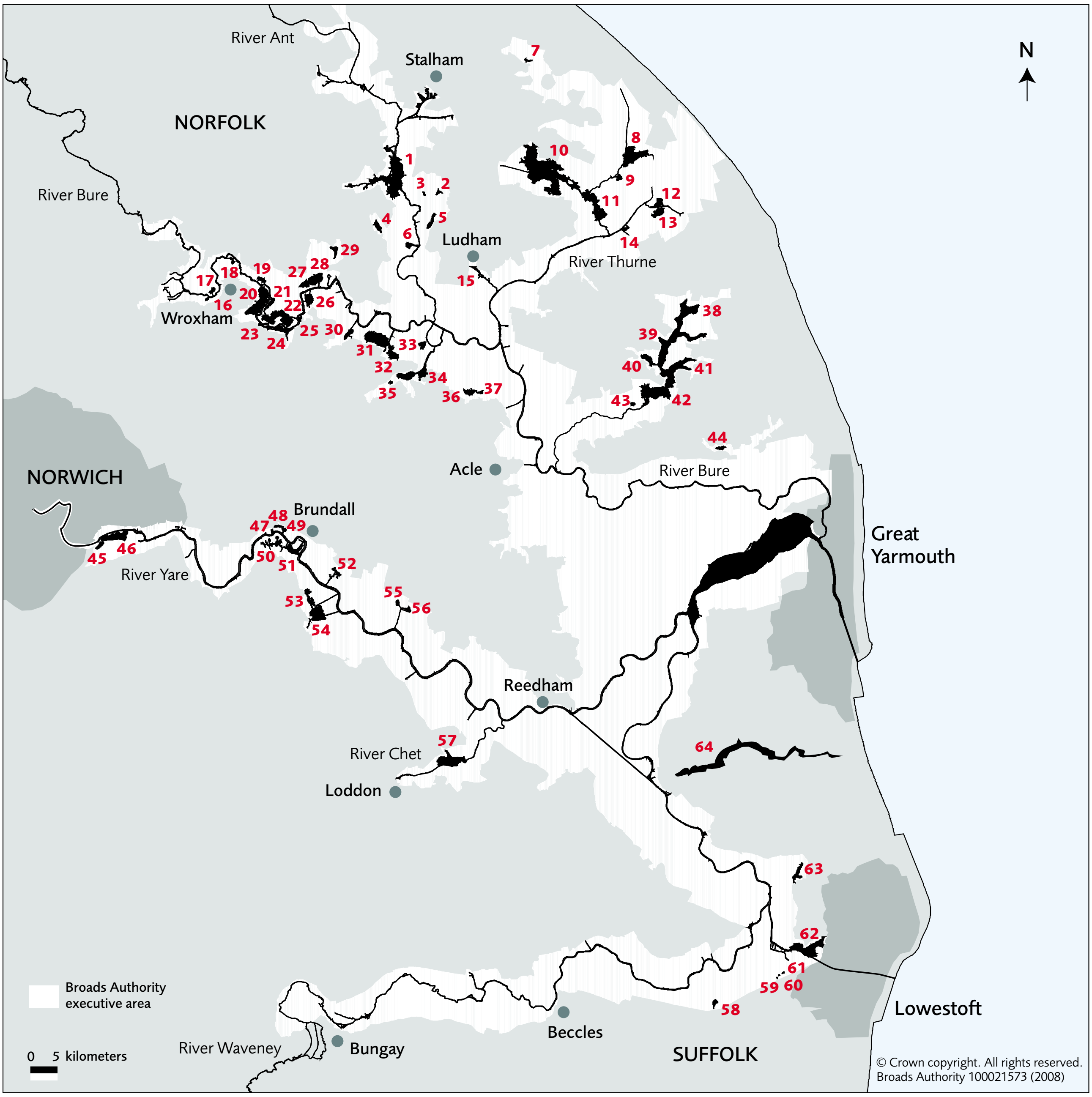
Figure 12 Prioritisation matrix for directing investment for restoring non-designated broads

Risk of saline incursion or coastal breach ↓ / Probability of Success →	High		Low
Low	**Whitlingham Great Broad** ** Flixton Decoy * Mautby Decoy **Whitlingham Little Broad** Sotshole Broad **HIGH**	**Fritton Lake** *** **Wroxham Broad** ** Burntfen Broad **Salhouse Broad** ** Snape's Water Norton's Broad *Belaugh Broad* **Bridge Broad** Salhouse Little Broad **MEDIUM**	Devil's Hole **LOW**
High	**HIGH** Long-term risk	Brundall Gardens Lake **MEDIUM** Long-term risk	***Hoveton Little Broad*** ** **Malthouse Broad** ** **Oulton Broad** ** **South Walsham Broad** ** *Pound End* **Womack Water** Brundall Inner Broad **LOW** Long-term risk

* < 5ha, **5-50ha, ***>50ha

Broads with land or water access are **bold** to indicate the importance of recreation and economy for these sites. Broads in *italics* have received restoration investment.

Map 2 Location of broads and other permanent bodies of water



1 Barton Broad
2 Catfield Broad
3 Irstead Holmes
4 Alderfen Broad
5 Crome's Broad
6 Reedham Water
7 Calthorpe Broad
8 Horsey Mere
9 Blackfleet Broad
10 Hickling Broad
11 Heigham Sound
12 Martham North
13 Martham South
14 Martham Pits
15 Womack Water
16 Norton's Broad
17 Belaugh Broad
18 Bridge Broad
19 Snape's Water
20 Wroxham Broad
21 Hudson's Bay
22 Hoveton Gt Broad
23 Salhouse Little Broad
24 Salhouse Broad
25 Devil's Hole
26 Decoy Broad
27 Pound End
28 Hoveton Little Broad
29 Burntfen Broad
30 Cockshoot Broad
31 Ranworth Broad
32 Malthouse Broad
33 Ranworth Flood
34 S. Walsham Broad
35 Sotshole Broad
36 Upton Gt Broad
37 Upton Little Broad
38 Ormesby Broad
39 Rollesby Broad
40 Lily Broad
41 Ormesby Little Broad
42 Filby Broad
43 Little Broad
44 Mautby Decoy
45 Whitlingham Little Broad
46 Whitlingham Great Broad
47 Brundall Outer Broad
48 Brundall Gardens Lake
49 Brundall Inner Broad
50 Surlingham Broad
51 Bargate Broad
52 Strumpshaw Broad
53 Wheatfen Broad & channels
54 Rockland Broad
55 Buckenham Broad
56 Hassingham Broad
57 Hardley Flood
58 Barnby Broad
59 Woolner's Carr
60 Round Water
61 Sprat's Water
62 Oulton Broad
63 Flixton Decoy
64 Fritton Lake

12 Investment scenarios

Looking back over the costs of previous broad restoration projects over the past 20 years, the high costs of restoring degraded broads means that it is more cost-effective to target the less degraded sites as well as being more effective in terms of successful outcomes.

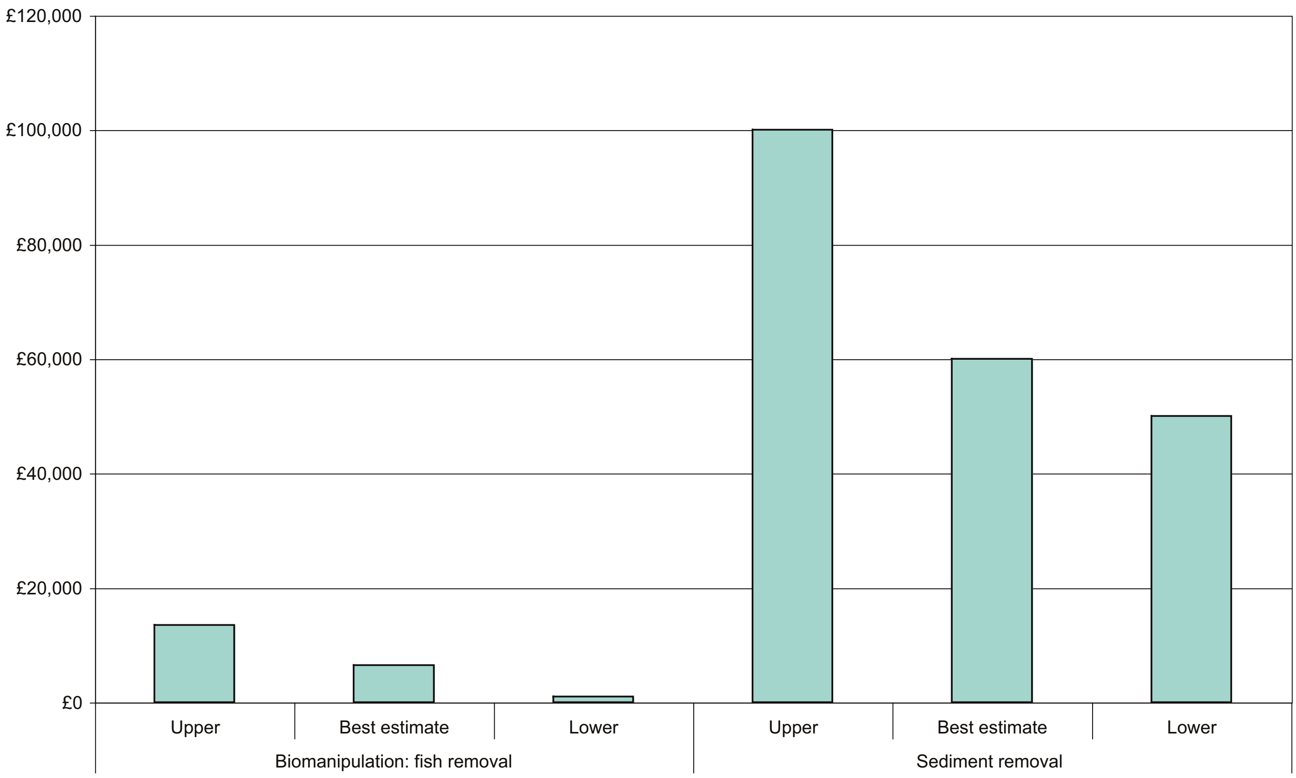
These investment scenarios focus on two in-lake restoration techniques, sediment removal and biomanipulation. The reviews of these techniques (see Appendices 3 and 4) concluded that these proven restoration techniques require scaling up to achieve lake restoration targets.

The costs of sediment removal to achieve nature conservation goals are £5,865,000, as set out in the Sediment Management Strategy (2007). The Lake Restoration Strategy Action Plan updates these figures, based on further feasibility studies. The overall cost of biomanipulation for the following broads is £611,508 (Short to medium-term: Hoveton Great, Cockshoot, Burntfen, Ormesby and Barton; longer-term: Hoveton Little, Rollesby, Ormesby Little, Lily, Filby). Figures for biomanipulation costs are based on Broads Authority information and the most appropriate methods. It should be noted that owner agreements and full feasibility are required for each broad.

The following investment scenarios have been considered, with the objective of achieving sediment removal required for lake restoration. For this purpose the following assumptions have been made:

- Annual budget figures are assumed to increase in line with cost increases.
- The need for sediment removal in lakes to achieve nature conservation aims remains the same as it is now.
- Cost of sediment removal, using the best estimate at £60,000ha^{-1}.

Figure 13 Costs of biomanipulation and sediment removal per hectare



Source: Broads Authority data

Figure 14 Scenarios of sediment removal based on annual budgets of £10,000, £100,000, £250,000 and £500,000

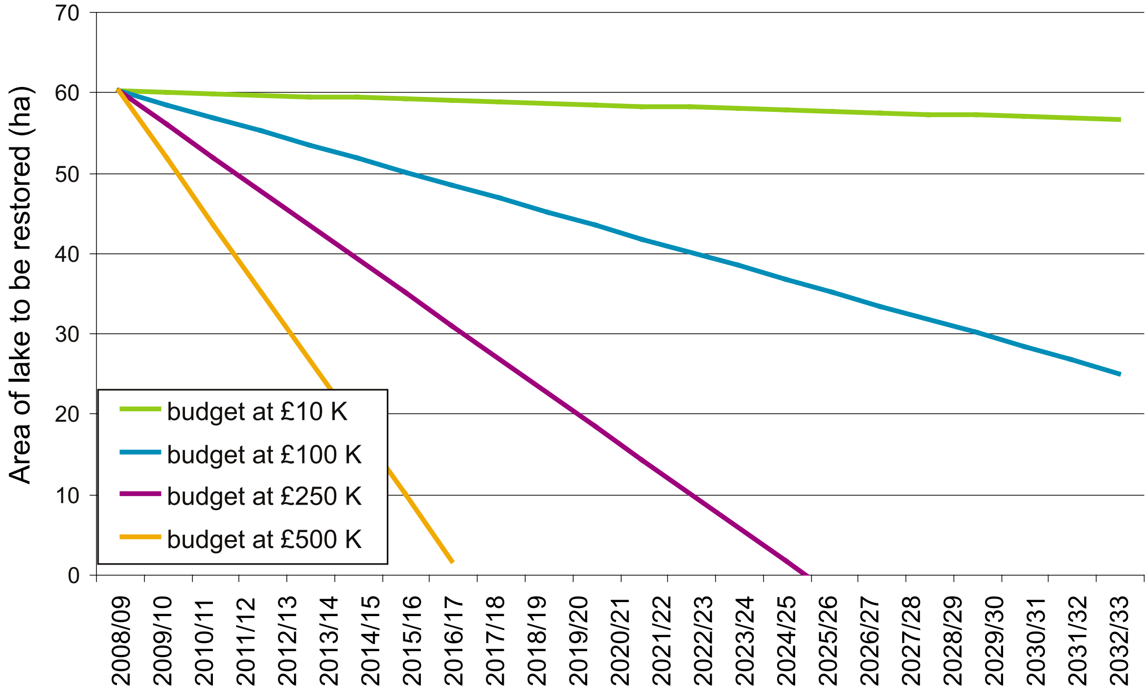


Figure 15 Scenarios of biomanipulation based on annual budgets of £10,000, £100,000, £250,000 and £500,000

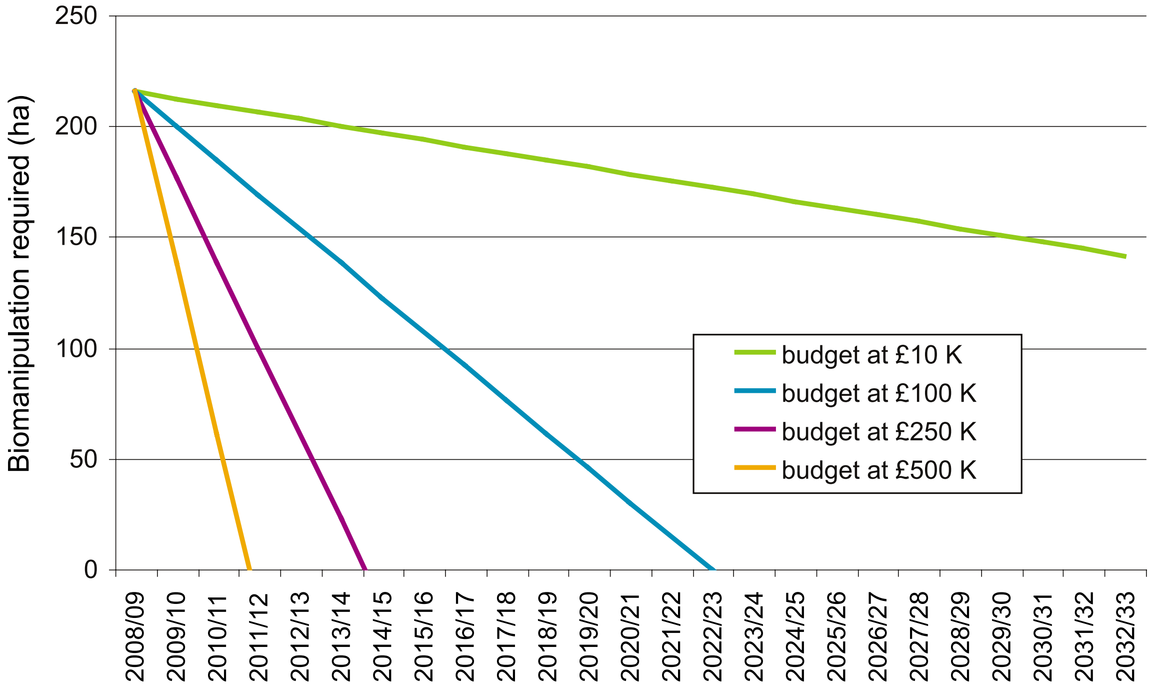


Table 8 Investment scenarios and years by which lakes will be restored based on annual budget scenarios

Scenario		**Hectares restored**		**Years by which lakes will be restored based on annual budget scenarios for:**		
	Budget	Sediment removal	Biomanip-ulation	Sediment removal	Biomanip-ulation	
1	£10 K*	0.2	3.08	2368	2079	Equivalent to 2007/08 waterways conservation budget for routine sediment removal
2	£100 K	1.7	15.4	2044	2023	Equivalent to annual additional Defra fund 2005 - 2008
3	£250 K	4.2	38.5	2024	2015	Equivalent to annual additional Defra fund 2008 - 2011 for all waterways conservation projects
4	£500 K	8.3	77.1	2017	2012	Equivalent to total annual additional Defra fund 2008 - 2011

* £20 K for biomanipulation

Note: These investment scenarios of £500K require consideration of the capacity to deliver

The analysis above shows that existing core budgets of £20,000 for biomanipulation and £10,000 for sediment removal make little progress towards achieving WFD targets. In terms of the six-yearly River Basin Management Plan cycles, these actions would be achieved by the 12th or 60th River Basin Cycle, respectively, without additional funding.

These figures confirm that investment in excess of core budgets is required to deliver WFD targets and an annual budget of £350,000 (£100,000 for biomanipulation and £250,000 for sediment removal) is required to achieve WFD targets by 2027, or the third River Basin Cycle.


Water soldiers


White water lilies

13 Programme of actions for The Broads catchment and lakes

Whilst the objectives for most broads are not being achieved, restoration schemes on a lake-by-lake and catchment scale are required.

The prioritisation process outlined in Section 11 for individual broads will form the overall ranking of projects on a site-by-site basis. In conjunction with the site prioritisation, a prioritisation of actions (or restoration projects) will be made depending on their cost effectiveness, capacity, relevance and synergies with other projects. This prioritisation process is explained in the Action Plan.

The actions required to address the issues identified for the Broads catchment are detailed in the separate Action Plan document.

Bladderwort and swans on Strumpshaw Broad

14 Value of natural ecosystem resources

The Broads, as the UK's largest lowland wetland, is visited by over six million people a year. It also provides a home for around 6,000 households and a livelihood, directly and indirectly, for thousands of people. But the semi-natural characteristics of The Broads present a complex set of management challenges. The dynamic nature of the environmental changes that the area experiences is likely to be affected by the impact of climate change and continuing socio-economic pressures.

The costs of management are counterbalanced by the range of benefits that The Broads provides to society including: recreation opportunities, biodiversity, water-related services and others. The ecosystem services approach report (Appendix 6) sets out an analytical framework for assessing the value to society provided by a sustainable management regime. This 'ecosystem services approach' is being adopted in order to provide a more quantified evidence base for future management activities. Although only a desk-based study, enough data has been compiled to offer good evidence in favour of the proposition that continued and enhanced management of The Broads ecosystems and linked navigation, and the services they provide will result in increased wealth creation and livelihood protection for local people.

It is useful to divide ecosystem services (i.e. aspects of ecosystems utilised actively or passively to produce human well-being) into intermediate services, final services and benefits. The focus in this report is on the benefits that people receive from the ecosystem and in particular on the financial and economic value of the benefits. Two key groups of benefits can be identified in The Broads context: existing and potential benefits. The former are: biodiversity conservation, land and water-based recreation and water supply for households, agriculture and industry (linked to intermediate services such as water provision and regulation, nutrient cycling and soil formation and final services such as habitat provision and water flows). The potential benefits include carbon storage, flood protection and biofuel supply (linked to a set of services).

A valuation of the set of benefits is constrained by a lack of comprehensive financial and economic data. However a range of valuation methods have been utilised in order to provide as full a valuation as is practicable. But the use of different valuation methods across the benefits categories means that aggregation is not technically possible. Nevertheless, the analysis does indicate that substantial financial flows and economic benefits are provided by The Broads. The visitors to The Broads, for example, generate some £320 million per year, which has a significant economic multiplier effect in the area. The value of drinking water, the flow of which is sustained by The Broads system, is at least £17 million which is the price paid by the consumer population. The value of the environmental damages avoided through the storing of carbon in The Broads marshes is between £50,000 and £240,000 per year. When questioned in a survey, a random sample of people said that they were willing to pay up to nearly £100 per household per year to conserve The Broads environment.

While these valuation estimates are only indicative, together they represent a strong case in favour of continued conservation and management expenditure. This financial/economic evidence should not, however, be seen as an alternative to reasoning based on science and/or moral propositions. Rather, the ecosystem services concept and approach, and the estimated monetary benefits it can generate, provides a useful additional argument, alongside scientific and moral reasoning, for continued protected area investments.

15 Next steps and challenges

The considerable ongoing and emerging challenges to restoring broads within this populated and agricultural coastal catchment are wide ranging. The following challenges and next steps combine the required efficiency, effectiveness and prudence principles:

1. Seek opportunities to create and enhance freshwater broads within wetland ecosystems both within upstream parts of The Broads and outside the area, as well as developing resilience in all existing waterbodies to prevent deterioration.
2. Use carbon budgeting alongside existing decision-making tools across sectors when considering long-term and ongoing restoration investments.
3. Continue to recognise and minimise the impacts of agricultural and population change, with possible intensification of agricultural production and potential increased demand for biofuels.
4. Identify and manage the smaller sources of nutrient and other pollution inputs, such as that from those properties not connected to the mains sewer and find mechanisms to ensure that polluters recognise and pay for ecological harm.
5. Campaign for better incentives for farmers to attain ecologically relevant[1] lower nitrogen, phosphorus and pesticide inputs, whilst retaining agricultural competitiveness in global markets.
6. Influence policy outside the Broads Authority area by partnership working with the Environment Agency and the National Trust, and by supporting local River Care groups. Working with water companies and district planning authorities to ensure that infrastructure and development protect water resources and water quality as well as, providing protection from non-native species. A Broads Authority advisory area could play a role.
7. Work in each valley with locals and water users to make issues and solutions relevant, identifying the benefits of restored broads to people and the nation.
8. Work with partners to find societal and economic funding justification for continuing to understand and safeguard broads and their historical archive for the future.

[1] Nitrate Vulnerable Zone regulations need to fully address the input of agricultural nitrogen and its impact on ecological status of waterbodies.

16 Glossary

Adaptation - adjustment (of habitats or species) to environmental conditions

Benthivore/ous - term to describe fish that eat invertebrates and plants that occur in the sediment

Carbon storage - forests and soils store carbon. Factors including soil and water quality, climate and types of trees will determine the amounts of carbon stored. Soil disturbance is also a strong factor in the loss of carbon into the atmosphere (carbon flux - when carbon is released from where it is stored). Each year billions of tonnes of carbon is released into the atmosphere through deforestation, soil management and the use of fossil fuels. The majority of this carbon dioxide is removed from the atmosphere by plants or the ocean, but a significant portion remains airborne.

Charophyte (Stonewort) - submerged lower plants, structurally complex class of algae

Competent Authorities - such as the Broads Authority, Natural England or Internal Drainage Broads

Conductivity - a measure of how well fresh or sea water conducts electricity. Conductivity increases with increasing salinity, and is thus used to measure salinity indirectly.

Defra - Department of Environment Food and Rural Affairs

Diffuse pollution - sediment or contaminants originating from a variety of small-scale locations

GQA - General Quality Assessment, used by the Environment Agency to report on the chemical and biological status of waters

Macrofossil - preserved remains of plants and animals occurring in the sediment

Macrophyte - aquatic (or water) plants (not including algae)

Natura 2000 - an EU ecological network of protected sites which represent areas of the highest value for natural habitats and species

Pelagic - refers to organisms that live in the water rather than in the bottom sediment (which are described as benthic)

Piscivore/ous - term to describe fish that eat other fish

Public Service Agreement (PSA) - government targets to achieve 95% of the area of SSSIs to be in favourable or recovering condition by 2010

Phytoplankton - microscopic algae that generally float in the water

SAC - Special Area of Conservation (see Natura 2000)

SSSI - Site of Special Scientific Interest

Stonewort - see *charophyte*

Water Framework Directive (WFD) - EU legislation that integrates water management through river basin planning

Zooplanktive/ous - term to describe fish that eat small crustaceans (*Daphnia*) in the water

Zooplankton - small crustaceans (or water fleas) that live in the water and graze on algae

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Canoeing on Whitlingham Little Broad

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