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A Review of Lake Shoreline Restoration Techniques

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Contents

Executive summary

- Lake shorelines are a diverse range of habitats which form the transition between terrestrial and open water. These habitats perform essential functions for lake ecosystems and contribute to the healthy functioning of physical, chemical and biological processes in lakes, when in good condition. The role of shorelines is often overlooked and their habitats can be subject to significant pressure both from land use change on the terrestrial side and impacts of human activities on in-lake ecosystems, such as eutrophication. As a result, it is likely that many lake shorelines are not in a good condition and their potential to contribute to halting biodiversity decline and improving the natural functioning of lake ecosystems more widely is currently unmet.
- Lake shoreline restoration, as a field, has received significantly less attention than that of restoration of lake water quality and river restoration (which usually includes both the channel and riparian habitats). Knowledge of lake shoreline restoration techniques and their successful application is largely limited to individual studies. The aim of this project is to collate available information on shoreline restoration methods that could facilitate the recovery of shoreline habitats and natural processes.
- An evidence review was carried out using a variety of sources. We reviewed studies in the published and grey literature, carried out an online survey of experts in the field and undertook structured interviews with practitioners and experts.(see Appendix 1 & 2) Information gained from these sources was categorised into a number of restoration techniques and key information summarised on the effectiveness of measures for biodiversity and ecosystem functioning, the application of techniques, cost-effectiveness, long-term maintenance, ease of deployment or construction, other impacts or considerations needed for application, climate change resilience and knowledge gaps. In addition, case studies of the applications of different techniques were identified and summarised.
- Techniques covered in this review include reedbed, fen and swamp creation/ restoration, removal of riparian/ scrub woodland, water level management, artificial floating islands, soft engineering, coarse woody debris, recreational access restrictions and reducing the impact of animals.

- A wide range of techniques have been identified that address a range of pressures on lake shorelines, however, available evidence on the application and effectiveness of specific techniques varies substantially. More evidence is available on the creation/ restoration of reedbeds and soft engineering approaches, than for impacts and remediation of drainage – especially of adjoining shoreline wetlands, or the management of recreational access, for example.
- Our review found that investment in good initial design work was essential for the long-term effectiveness of measures. This includes a thorough understanding of site-specific issues and identifying and adequately addressing wider system pressures such as eutrophication prior to carrying out interventions at the shoreline. Adopting best-practice approaches and decision support frameworks from experience in river restoration could benefit the field. Wider skills and information sharing between practitioners could also improve restoration outcomes. The design and use of adequate monitoring strategies is considered essential, although in many examples this has not been undertaken to identify how measures work and their long-term effectiveness.
- Note that this project links to a related project commissioned by Natural England on the loss of lake wetland habitats.

1 Introduction

Lake shorelines, encompassing the aquatic and riparian transition between open water and terrestrial land, represent an important mosaic of habitats contributing to the healthy functioning of lake ecosystems. Shoreline habitats are important for physical, chemical and biological aspects of lake functioning when in good condition, by, for example, dissipating energy from waves during storm events, regulating nutrient release and cycling in the water and providing important habitat for feeding and breeding for invertebrate, amphibian, fish and bird species at different phases of their lifecycles.

At the interface of terrestrial and aquatic habitats, lake shorelines are frequently subject to intense pressure from human activity and can be impacted by modifications that degrade their natural functioning. This can affect the biodiversity of a site and other ecosystem services provided by the lake, such as carbon storage, recreational and cultural value and clean water provision. Loss of function can also be associated with a loss of resilience to other pressures such as increased storm intensity occurring due to climate change, potentially leading to a negative feedback loop destabilising lake shoreline habitats further. The potential benefits that more natural shorelines offer to the healthy functioning of lakes, allied to the likely extent of shoreline modifications, suggests that in many cases improved functioning may be possible where nature-based shoreline restoration techniques are applied.

Currently, knowledge of lake shoreline restoration techniques and their successful application is limited largely to individual studies and a synthesis on this topic is lacking. The aim of this project is to collate available information on shoreline restoration methods that could facilitate the recovery of shoreline habitats and natural processes. To fulfil this aim, we have carried out an evidence review to address the following objectives:

1. Research and describe the range of shoreline restoration techniques that could be applied to English lakes;

2. Systematically evaluate the effectiveness of the different techniques, both from a lake functioning, and biodiversity perspective, including in-lake and lake edge species;

3. Provide information on application of techniques (this can include links to existing

available guidance), the sustainability of techniques and their longevity and requirements for maintenance, and, if readily available, information on costs per shoreline length or area of habitat;

4. Describe and review any monitoring that has, is, or could be done to evaluate their effectiveness in the long-term;

5. Suggest any novel techniques for shoreline restoration now and in the future, especially considering likely impacts of climate change (e.g., increased winter rainfall / summer storminess in some areas using the latest UK Climate Impacts Programme (UKCIP) projections);

6. Suggest any future trialling of techniques required - including potential locations, if appropriate;

7. Evaluate gaps in knowledge and where further evidence would be most beneficial.

This report details the findings of the evidence review and is structured into three sections. Firstly, the methodology sets out an overview of the evidence review process in terms of the literature search and expert survey. Secondly the main results section presents the details of the restoration techniques, organised around the following headings: reedbed, swamp and fen creation/restoration, removal of riparian scrub/woodland, water level management, artificial floating islands, soft engineering (replacements for hard engineering), coarse woody debris, recreational access restriction, reducing the impact of animals – fencing, reducing the impact of animals – population controls and monitoring. The final conclusions and recommendations section then summarises the key findings from the review and provides recommendations for further work.

2 Methodology

2.1 Introduction

This section provides an overview of the approaches taken to carry out the evidence review. Firstly, it details the criteria used to carry out the searches in the literature review and the number of studies obtained through different approaches to gathering data. Secondly, it summarises the key questions used as part of the expert survey, providing an overview of the results and details of the practitioner interviews carried out.

2.2 Literature review

A literature review was undertaken to collate and synthesise all the readily available evidence in the published and unpublished literature on the topic of lake shoreline restoration. The aim of this evidence review was to use it to:

- Identify the range of shoreline restoration techniques or other appropriate measures, including novel techniques;
- Evaluate the effectiveness of the techniques from lake functioning and biodiversity perspective;
- Provide information on application of techniques;
- Identify monitoring that has or could be used to evaluate effectiveness;
- Identify knowledge gaps for shoreline restoration techniques.

This review followed the code of best practice established by Collins et al. (2015). Given time constraints, a quick scoping review was undertaken rather than a full systematic review. Relevant literature were identified using two web-based sources of information, Web of Science (WoS) and Google Scholar. Priority was given to UK case studies but international literature from similar temperate climatic zones was also consulted.

Evidence was gathered using WoS literature searches conducted in January 2022. The following search terms were used and covered the period 2000 to 2021:

(lake OR loch* OR "standing water" OR pond* OR reservoir* OR lough* OR wetland*) AND (England OR Scotland OR Wales OR UK OR "Europe" OR ''USA'') AND (shoreline* OR littoral) AND (restore OR restoration*)*

This initial search yielded 68 'hits' but many referred to coastal wetlands, with only a small sub-set of possibly useful references directly related to lake shoreline restoration. Nevertheless. these 'coastal wetlands' 'hits' had to be checked for relevance, as in the USA, lake shorelines, particularly in larger lakes, are often referred to as 'coastal wetlands'. A further WoS search conducted without any geographical restrictions and omitting 'wetland*' in the search string produced a total of 340 'hits' and added a small number of potentially useful peer-reviewed references, mainly of Dutch or German provenance.

A further literature search was carried out using Google Scholar and the search term "lake shoreline restoration" for the period 2000-2021 to check for any peer-reviewed articles not found on WoS and any relevant unpublished literature that would not have been listed by WoS. This yielded 17,400 results, although the vast majority of which were not directly relevant to this study on lake shoreline restoration with many covering other types of lake restoration, e.g. nutrient loading control. However, some additional relevant peer-reviewed papers and reports published in the 'grey literature' were found, particularly in relation to lake shoreline restoration work that has been carried out in the Great Lakes area in Canada/USA.

These references found in the above literature searches were supplemented by information gleaned from the following sources: citations within these publications; our own knowledge of relevant published and unpublished reports; and additional information provided by Natural England staff and other stakeholders.

Evidence from the literature review was compiled and summarised in an Excel spreadsheet and linked to the accompanying location map for UK sites that provides a framework for addressing the questions outlined above. More details about lakes **highlighted** in the text below are featured in the spreadsheet.

2.3 Expert Survey

To complement the literature survey detailed above, a survey of lake restoration experts was carried out to gain additional information on specific techniques and is provided in Appendices 1 and 2. The survey included questions on the following topic areas:

- Familiarity with techniques;
- Effectiveness of techniques when applied or considered for application;
- Ease of deployment and construction;
- Long-term sustainability and maintenance;
- Cost-effectiveness;
- Wider consideration for the application of shoreline restoration techniques;
- Alternative techniques for hard engineering, wetland restoration, bank erosion or improving biodiversity in artificial waterbodies;
- Novel techniques for restoration.

The survey was carried out using the online platform, Jisc Online Surveys (https://www.onlinesurveys.ac.uk/) and the link to the survey circulated to a list of known lake shoreline restoration experts and practitioners identified by the UKCEH project team and Natural England. In addition, we publicised the survey via social media and distributed it to an international group of lake restoration experts, the SIL working group on lake restoration. These different groups comprised experts from academia, conservation charities, water companies, conservation agencies and environmental engineering companies active in lake shoreline restoration. The survey was open from 1st February to 16th February 2022 and 12 responses were received during that period. A summary of the survey results is provided in Appendix 2 and supplementary information included under specific techniques and in the conclusions and recommendation sections.

In addition to the online survey, 14 interviews were carried out with experts to gain additional insight into specific case studies of restoration projects or the application of specific techniques. This information was used to supplement the findings of the literature review and is summarised in the results and conclusions sections.

3 Shoreline Restoration Techniques

3.1 Introduction

This section of the report provides an overview of lake shoreline restoration techniques identified as part of the review process. Table 1 provides an overview of the techniques covered and the pressure(s) that they are designed to address. They include reedbed, swamp and fen creation/restoration, where previously lost or new areas of reedbed, swamp and fen habitat are created, removal of riparian scrub/ woodland to improve the light climate of littoral and shoreline areas for aquatic plant species, water level management to improve natural hydrological function, use of artificial floating islands to improve biodiversity where there is little space for shoreline habitat, the replacement of hard engineered lake edges by softer engineering options improving biodiversity and reducing bank erosion, the introduction of coarse woody debris to increase shoreline habitat complexity, restricting access to shoreline habitats to reduce human disturbance and reducing the impact of animals on shorelines through fencing or population control.

These techniques relate specifically to improving habitats and functioning along lake shorelines, however, it should be noted that these measures may provide additional benefits to the wider lake and that the implementation of these techniques needs consideration in the context of the functioning of the whole lake and its catchment in order to maximise the benefit of investments in restoration measures and the long-term sustained recovery of the lake ecosystem.

For example, water quality issues such as nutrient enrichment can pose a pervasive impact on the biodiversity and natural functioning of lakes and lake shorelines, affecting the balance between macrophytes and algae, altering species composition within primary producer communities and altering the growth and morphology of individual species. Reducing external nutrient sources through catchment management is likely to be an important component of lake restoration activity, where catchment nutrients are identified as a problem and should be used in conjunction with, and usually prior to, shoreline restoration measures in order to ensure that investments in improving the lake are likely to be effective and sustained. In addition to the catchment, the lake itself may also act as a source of nutrients or sediment, via internal loading or resuspension of enriched bed sediment material. Improving conditions for the colonisation of bed sediments by macrophyte species can provide a positive feedback in controlling sediment nutrient release.

Table 1 Summary of lake shoreline pressures and the shoreline restoration techniques which can be used to target them

	Technique							
Pressure	Reedbed, swamp & fen creation/restoration	Removal of riparian/ scrub woodland	Water level management	Artificial floating islands	Soft engineering	Coarse woody debris	Recreational access restrictions	Reducing the impact of animals
Shoreline vegetation disturbance	X	X		X			X	
Man-made structures/ hard engineering					X			
Water level changes – drainage or impoundment			X					
Substrate modification					X	X		
Recreational access							X	
Overgrazing								X
Water quality	X			X			X[1]	

[1] Recreational use of lakes may be an issue for water quality, however in the context of lake shoreline restoration which was the focus of this study, we did not come across direct evidence of these effects.

3.2 Reedbed, swamp and fen creation/restoration

Description

The aim of this measure is to create or restore fringing reedbeds, swamp or fen, usually consisting of common reed (*Phragmites australis*) in areas where pre-existing habitats have declined or been lost. The examples provided below, predominantly, consider reedbed creation or restoration in the context of *Phragmites* reed, however, edge restoration can include a wider diversity of species, such as *Typha* spp. or mixed species fen turfs. These losses have occurred due to a range of pressures, such as: human development in the shoreline/littoral zone, natural plant succession, boating activity causing shore erosion (through wave wash from boat bow waves, launching boats etc.), changes in water levels, nutrient enrichment, farm animal/wildfowl grazing and climate change.

Effectiveness

Whilst reedbed restoration or creation for specific biodiversity objectives such as habitat creation for certain bird species has proven effective (e.g., RSPB 2014), the use of this technique as a lake shoreline restoration measure is less well evaluated. Effectiveness of reedbed creation and restoration along lake shores is often difficult to judge objectively as often very little monitoring following the restoration is carried out other than anecdotal reports or basic visual inspections of whether reeds have established. Based on discussions with practitioners, reed establishment and spread beyond initial planting can be very good where the environmental conditions are appropriate, e.g., wetness of the site, correct water depth, nutrient levels are acceptable and pressure from grazing by water birds can be contained through fencing. For some projects existing monitoring schemes at the sites, for example, annual macrophyte surveys in **Duck Broad** and repeat aerial surveys using drones at **Hickling Broad on the Norfolk Broads** have shown an increase in diversity of species and extent of reedbed. Regular Wetland Bird Surveys (WeBS), other bird, amphibian and camera trap surveys carried out by volunteers at **Bodenham Lake (Herefordshire)** (https://www.herefordshirewt.org/luggwetlandgem), have shown an increase in wading birds, warbler species, toads and otter activity. A lack of budget to carry out these assessments was frequently cited as the reason why this work was either not carried out or formally written up and shared more widely.

Application

A range of different approaches to reedbed creation and restoration have been undertaken and these vary in their complexity depending on the site context, project aims and available budget. These range from requirements for large engineering works using floating excavators and sediment pumps at **Hickling** and **Hoveton Great Broad (both Norfolk)** (CANAPE: Hickling 2 - Return of the 20 tonne excavators, Interreg VB North Sea Region Programme) to simpler manual approaches using plug plants, fencing and brash bundles at some sites around **Windermere (Cumbria)** (https://scrt.co.uk/what-we-do/habitat-improvement/reedbed-restoration/).
Discussions with a number of the interviewees revealed that a range of different options are available for reedbed creation, including the translocation of rhizomes, use of nursery grown plug plants, reed laying, reed cuttings and seeding areas. They also indicated that effectiveness for reed establishment varies depending on the method used, with generally more established plants doing better than seed (e.g., seed establishment trialled at **Abberton Reservoir**), but this approach also requires more work, particularly if undertaken manually, such as rhizome translocation (e.g., as trialled at **Windermere** and **Bodenham Lake**). The choice of method must also consider site-specific issues such as the presence of a suitable donor reedbed, area required for restoration, likely grazing pressure and project budget. Fencing off areas to exclude grazers was universally recommended by interviewees to enable good reed establishment. Fencing needed to consider accessibility of the site from all sides and potential for reuse as reedbed grows. Long-term maintenance required at sites depends a lot on the purpose of the project. Initially, this could involve periodic checking to ensure plants establish and infilling where there are gaps, then over the long-term this would involve movement or removal of fencing, and if there were particular conservation objectives for specific species, active reedbed management to prevent succession of or shading of trees and reed cutting and removal or grazing. At **Piper Marsh (Yorkshire)**, more extensive reedbed management using an excavator to lower the lake bed and remove rhizomes was carried out to reduce reed encroachment into open water areas to ‘reset’ reed extent after 30 years of development.

Project costs can vary substantially depending on the scheme, the size of area and technical requirements for the restoration. Projects undertaken in the Norfolk Broads, which involved extensive engineering works to dredge sediment and create bunds, have costs ranging from £100 000s to £1.6million, where the reedbed creation work is a very small proportion of the total budget. Relatively simple schemes involving volunteer labour, locally sourced coppiced materials and reedbed plug plants are, in contrast, much cheaper £5,000 to £10,000.

Other considerations for reedbed creation or restoration can be significant and require time and a budget to carry them out. These include understanding and agreeing activity with land owners, the requirements for necessary consents or permits including planning permission if a large structure is required, Flood Defence Consents on main rivers from the Environment Agency or local authority or Internal Drainage Board on ordinary water courses. There is a need to consider potential drainage issues with adjacent land, particularly if land drains are likely to be affected. Consultation with the local community is recommended where public access may be affected and rights of navigation impacted. The footprint of a reedbed restoration is again scheme dependent, but can be substantial for larger schemes or where capacity is being provided for water level change. Hydrological changes are likely to be minimal from the increasing presence of reedbed alone, although these should be considered where creation also involves sediment removal or shoreline re-profiling over large areas. Indeed, consideration of the hydrology of a site is essential to ensure the success of the scheme, illustrated by the work of the RSPB at **Lakenheath Fen (Suffolk)** (Sills and Hiron, 2011). According to the RSPB, a “natural” water regime cycle with a drawdown in late summer may be better for reedbeds than one with stable deep water that increases the exposure of reeds to the negative effects of litter accumulation (RSPB, 2014). The RSPB suggest that the ideal annual water regime may well be one with deeper winter water (*c.* 50-100 cm with the reeds) which then drops to a lower summer level (*c.* 5-30 cm), although allowing fluctuations within this range should be beneficial to wildlife.

Climate change resilience

Older case studies have rarely considered resilience to the impacts of climate change in their design, but more recent work at **Abberton Reservoir (Essex),** and **Bodenham Lake**, which was combined with shoreline re-profiling, has considered water level changes and allowing space for reedbeds to occupy larger gradients in wetness allowing for recolonization due to drowning from drier areas or drought from wet areas.

Knowledge gaps

- Quantitative effectiveness of measures for biodiversity;
- In lake shore areas where public access and/ or wave action is high, a better understanding of the ability of roots and rhizomes to establish in gravel as opposed to soft sediment substrates, including the impact of gravel compaction would be useful;
- The impact of climate change on species range and invasive species, including different thermal tolerances, growth rates and invasive species competition.

European examples

In a 1995 study of seven central European case study lakes **(Germany: Havel lakes, Lake Constance-Untersee, Lake Constance-Obersee; Switzerland: Lake Zurich, Lake Biel, Lake Neuchâtel and Lake Geneva)** a range of restoration measures adopted to try and reverse lake shoreline deterioration and associated reedbed decline were assessed (Ostendorp et al., 1995). Most of the restoration measures in these case studies focussed on controlling mechanical damage and bank erosion (rather than eutrophication) in threatened sections of shoreline. These measures included the following: use of fences to protect reedbeds, refilling of substrates, brushwood fascines constructions to dissipate wave action; reduction in nutrient exports from reeds by winter mowing; and supplementary measures such as planting reeds, restricting public access to lake shorelines. The shoreline restoration options selected depended on the main factor(s) responsible for deterioration; what degree of 'naturalness' that was aimed to achieve, technical possibilities and what amount of money was available for the restoration measures to be adopted. Ostendorp et al. (1995) concluded it would need further fundamental research and longer-term surveillance to determine the success of these various measures in achieving shoreline restoration aims. At the time of publication, the scientific rationale behind such lake restoration works was considered weak. Subsequently, Lorenz et al. (2015) postulated that for lowland lakes in northern Germany a reedbed belt width of 27-32 m was needed to protect shorelines from ship-induced wave action. However, Ostendorp et al. (2020) also demonstrated that dense reedbed belts were not necessarily a suitable shoreline restoration option in wind-exposed shorelines, such as occur in **Lake Constance**, where such wetland habitats were not naturally occurring.

English examples

A high-profile example of this restoration technique being applied in England is at **Windermere (Cumbria)** where in total, between 1900 and 2012, there was an estimated 81% loss of reedbeds (Rushworth and Codesal, 2013). The ‘Restore the Shore’ project was planned to create/restore reedbeds in 800 m^2 in four separate areas across the lake by getting volunteers to plant young reeds to facilitate the rehabilitation of reedbeds and swamp habitats coupled with the installation of fences and wave barriers to protect existing reedbeds. The aim of the work was to enhance biodiversity and natural functioning of the lake and improve water quality in Windermere by acting as a treatment system for pollutants in lake. Effectiveness of the measures for biodiversity and natural functioning have not been formally quantified, the evaluation report for the wider Windermere Reflections project cited the outputs of the work as over 10,000 m^2 protection for juvenile reedbed, which also included the removal of overhanging trees, construction of 400 fascines and planting of reed rhizomes and installation of 2.2 km of fences (Clarke and Anteric, 2014). The approximate cost of the project was £45,000 including cash and in-kind contributions (Learning for Lakes). Restore the shore project: https://scrt.co.uk/what-we-do/habitat-improvement/reedbed-restoration/

In the Norfolk Broads the Broads Authority have developed what they regard as a novel and innovative design solution to re-creating reedbeds by using sediment dredged from neighbouring channels (to increase depth of navigable channel and reduce sediment disturbance). This has a dual benefit in that dredging helps maintain a navigable channel and the dredged sediment is re-used to re-create reedbed swamps in adjacent areas of Broads where they existed historically. This restoration technique has the advantage that this use of dredged sediment negates need for it to be removed and sent to landfill, bringing cost savings as well as being more environmentally sound.

A pilot project in **Upton Little Broad (Norfolk)** was used to develop and test these innovative methods for dredging and use of dredged sediment in Broads (Coulet and Hunter, 2014).

In the example of **Hoveton Great Broad (Norfolk),** a project led by Natural England, sediment was dug from the bed of the broad by diggers on rafts, which was then pumped into geo-textile bags to create artificial banks. More sediment was added behind banks which was then used as new land for reedbeds and other marginal plants to colonise. Translocated fen turfs were taken from a nearby nature reserve to kick start the marginal plant habitat growth laid on top of newly created banks. This was a large-scale restoration measure requiring the use of a mechanical excavator with work carried put in two phases with 55,000 m^3 of sediment by excavator (https://hovetongreatbroad.org.uk/science/sediment-removal/). It is thought likely that these restoration measures will improve biodiversity and water quality in the broad although there were concerns that the gains from sediment removal for improving lake nutrient cycling may be short-lived after two to three years. Post-restoration monitoring has been carried out at this site, but has not been written up at the time of this report, although indications are that the translocations have been very successful, with vegetation becoming established on the banks (Ruth Hall, *pers comm.*).

In **Hickling Broad (Norfolk)**, a similar dredging scheme to re-create reedbeds has been planned. Here sediment was to be dredged (target to remove 46, 600 m^3 of sediment) from the navigable channel and used to fill constructed lagoons that will then be used to plant a reedbed fitted with goose guards to minimise grazing pressure from geese. Sediment was to be pumped into geo-textile bags to create artificial banks with more sediment added behind banks that would be used as new land for reedbeds and other marginal plants to colonise.

In Barton Broad (Norfolk), another novel reedbed restoration technique has been tried: the installation of floating reed islands to try and help replace lost hover reed swamp, although it is unclear how effective this restoration measure has been (Broads Authority. From darkness to light: the restoration of Barton Broad).

In Fleet Pond (Hampshire) the lake was dredged using floating pontoons and long-range excavators to create a series of islands and reedbed extensions containing organic-rich sediment. New reedbeds were established using several techniques: reed 'turf' translocation, placing of planted coir rolls and protection of new vegetation using wire mesh and woody debris. Early indications, post-restoration measures, was that there was an improvement in both water quality and habitat conditions (Johns

Associates, 2017). Reeds have successfully established on some of the floating islands and additional areas of reed were created on the pond edges (as mitigation for loss of areas elsewhere on the site), although on the islands some unwanted scrub, such as willow has developed in places and some repair to the islands is required. Future management includes proposals for rotational cutting, and further reed plug planting using reed-stems sourced from within the site. Note this is part of an ongoing project by Hart District Council, implementing and trialling various lake restoration techniques at the site, now being implemented using Countryside Stewardship funding and monitoring of the site continues.

At **Piper Marsh (Yorkshire)**, part of the Potteric Carr Nature Reserve, reedbed re-profiling was carried out in 2021 to lower the lake bed, re-profile some islands and reduce the extent of reed growth, improving areas of open water and habitat for breeding birds including ducks and geese and improve feeding and loafing areas for ducks. Work was carried out by local contractor with extensive experience in doing wetland conservation management and this enabled the costs to be minimised, being £6,500 for the ground works. Main focus for biodiversity is on bird populations and it is hoped that breeding bird surveys carried out every five years will capture improvements in their habitat. Long-term maintenance of this type is likely to be needed again in 20 years, although the feasibility of using livestock grazing as a reedbed control measure is being investigated.

Additional resources

Bringing Reedbeds to Life:

https://ww2.rspb.org.uk/Images/bringing_reedbeds_to_life_tcm9-385799.pdf

3.3 Removal of riparian scrub/woodland

Description

Aim of this restoration technique is to remove the shading effect of riparian scrub or tree encroachment preventing fringing lake wetlands from developing or being maintained.

Effectiveness

Based on evidence from the literature review, riparian scrub control appears to be effective in improving the light climate along lake shorelines and allowing wetland and littoral vegetation communities to re-establish increasing the biodiversity of the site, although recovery times can differ between species and take a number of years for emergent plants **(Cockshoot Broad, Norfolk)** (Kelly and Southwood, 2006)**.** However, it is also clear that the method of control needs to be carefully considered to prevent adverse consequences from machinery used **(Lake Neuchâtel, Switzerland)** and the risk of invasive species establishment following scrub removal **(Cropston Reservoir, Leicestershire)**, which might both have unintended effects on the biodiversity and functioning of the site.

Application

The technique is relatively simple to undertake using mechanical methods, such as mowing machines or chainsaws, depending on the type of vegetation removal required. Manual removal using hand tools was also common practice for groups with access to volunteer work parties according to interviewees. No quantitative information on costs was available for this technique, however, over half of the survey respondents graded it as having medium to high cost-effectiveness. As is clear in the examples below, ongoing maintenance through mowing, grazing or tree removal would be required to prevent the scrub returning as part of natural successional processes. The intensity of this activity will be site-specific and depend on the scheme objectives. Other considerations for this technique, based on discussions with interviewees, relate to potential public perceptions of tree removal and alterations to the visual landscape. Hydrological impacts are considered to be minimal.

Alternative approaches to this type of management could involve the use of more natural 'ecosystem engineers' such as the Eurasian beaver (*Castor fiber*). These animals could have the potential to impact riparian scrub and woody areas along lake shores, but no specific studies on this were found in this context. There is ongoing work investigating the potential role of beavers in a wide range of habitat restoration projects (e.g., Brazier et al. 2021; Law et al. 2017) and, therefore, this approach is not considered in detail here.

Climate change resilience

This measure doesn't explicitly consider increased resilience to climate change effects.

Knowledge gaps

None identified by literature review or expert survey.

European examples

In **Lake Neuchâtel (Switzerland)** a long-running study from 1984-1985 to 2000 looked at the effects of winter mowing of vegetation within a calcareous lake shore fen (Gusewell and Le Nedic, 2004) on plant succession. The aim of this mowing was to preserve the diversity of vegetation types by preventing organic matter accumulation and shrub encroachment, and reverse the trend towards a decline of aquatic plant species and gradual terrestrialisation of the semi-aquatic plant communities. However, although the mowing slowed the trend towards terrestrialisation, it did not stop it. Mowing increased species richness. Without mowing species richness remained constant. One noteworthy conclusion from this study was that considerable soil damage was caused by the mowing machine, which contributed more to the effects of management on species composition than the periodic removal of plant biomass. In **Lake Constance (central Europe)** winter mowing of reeds to help with eutrophication (by removing nutrients from reeds) failed (Ostendorp et al., 1995).

English examples

Number of English examples where this approach to stop or reverse the loss of riparian and littoral vegetation has been adopted.

In **Cockshoot Broad (Norfolk)** this involved the removal of overhanging alder (*Alnus glutinosa*) and grey sallow (*Salix cinerea*) carr woodland from a 10 m strip around 1500 m of the broad (75% of perimeter). The trees were cut with chainsaw and stumps of trees not near edge of lake treated with glyphosate (Kelly and Southwood, 2006). Riparian plants quickly recovered, followed by emergent plants although lesser bulrush

(*Typha angustifolia*) and common reed (*Phragmites australis*) took longer (two to three years) to re-establish in open water around the broad edges. Kelly and Southwood (2006) concluded the removal of trees from edge of Cockshoot Broad was a simple and cost-effective method for improving the condition of the littoral zone.

Seven Trent Water have employed, predominantly, willow scrub clearance work to reduce shading and stop encroachment onto the shoreline of **Cropston Reservoir (Leicestershire)** with the aim of encouraging the recovery of Site of Special Scientific Interest (SSSI) notified shoreline plant species to, at least, unfavourable recovering site condition status. Where scrub clearance has occurred so far, post-restoration botanical surveys have confirmed an increase in species of conservation interest in the drawdown zone plant communities. Seven Trent Water aim to complete the removal of scrub from remainder of reservoir perimeter along with Himalayan Balsam control and on-going control of any willow re-emergence. This approach is considered to be a relatively easy, low maintenance lake shoreline restoration measure although there are concerns that they may create favourable conditions that increase risk of non-native invasive plant species becoming established.

Similar control restoration measures to remove willow scrub from the drawdown zone are also planned for **Blackbrook Reservoir (Leicestershire)** by Seven Trent Water. They are also exploring options to discourage the establishment of the non-native invasive plant species New Zealand pigmyweed (*Crassula helmsii*), which is dominating fine sediments on parts of the reservoir shoreline. One control option is looking at the re-introduction of gravels and coarse sediments, possibly, by scraping away fine sediments deposited on upper shore regions to expose underlying gravels, although it is unclear what impact this might have on the plant propagule bank contained therein.

In **Colemere (Shropshire)** shading of the mere from expansion of the woodland up to the edge of the mere, is thought to have contributed to the almost complete eradication of the marginal vegetation, whether emergent, floating or submerged. It is hoped that the proposed small-scale restoration measure involving tree clearance work along 5-10 m strips along bays of the northern shoreline of the mere will promote the survival of population of glacial relict species, the least water-Lily (*Nuphar pumila*), although it is not known yet how effective this restoration measure will be in the long-term.

In **Little Hawes Water (Lancashire)**, as part of a range of lake shoreline restoration measures aimed at restoring the natural hydrology and area of associated alkaline fen community, the removal of a beech plantation and secondary woodland, (along with a boardwalk and relocation of a visitor access route) was undertaken by Natural England. Cattle grazing was also allowed in the fen pastures and grassland adjacent to the lake to improve habitat condition and prevent scrub re-growth.

The restoration of the marl bank grassland on the eastern shoreline, has been very successful with recovery of characteristic species. The extensive grazing here and elsewhere on the shoreline of the lake with red-poll cattle is also maintaining greater diversity in the transition from the reed and willow at the lake edge into the adjacent terrestrial habitats (National Nature Reserve (NNR) manager*, pers comm*.).

In **Summer Leys (Northamptonshire)**, vegetation management of established willow and hawthorn on Hawthorn island was undertaken in 2021 to re-create more open habitat suitable for nesting sites for breeding waders and overwintering water birds – the primary interest features for the project. On Gull island, re-profiling of the site to reduce the height of the island and encourage bare and open habitat through winter flooding of the island was also carried out. Material removed from the high point was re-distributed offshore to increase the area of shallow water available as wading and water bird feeding habitat. Access to the work site was challenging and involved the construction of a submerged causeway to allow mechanical machinery access to the site. Construction work needed to be sensitive to existing wildlife on site and be carried out at a time of low water levels in summer. Woody material had to be removed from site for disposal due to limited options within the reserve. Logistical challenges contributed significantly to the cost, which was £90,000 for the scrub clearance and £10,000 for the island re-profiling. Although it is hoped that ongoing maintenance will be reduced as access to the islands is now easier for mechanical rotavators and mowers. Since the restoration measure was only recently carried out, there is currently no information on the effectiveness of the measure.

3.4 Water level management

Description

Artificial drainage of land surrounding lakes is a pervasive pressure on lakes and can have a detrimental impact on lake wetland, riparian and littoral plant communities. Restoration of impacted sites involves management of water levels. Potential techniques to raise water levels can include blocking drainage ditches, building raised structures to retain water and removing dams upstream from lake wetlands. Such restoration measures are designed to increase the amount of water retained in the lake wetlands, supporting the recovery of emergent vegetation, thereby, increasing the potential for wetland habitat recovery or restoring seasonality to water level fluctuation. In addition, the re-naturalisation of lake inflows may also benefit water quality in the lake by promoting the deposition of sediment and nutrients in riparian areas before they enter the water body.

Effectiveness

Very little information on the effectiveness of these techniques in the UK were found during the literature searches or from the expert survey. It was the technique which scored lowest in terms of familiarity and none of the survey respondents had used the technique for lake shoreline restoration. Discussions with Iain Diack, the wetlands specialist at Natural England, suggested that measures to increase water levels or reinstate more natural fluctuations could be beneficial to shoreline vegetation communities, particularly through extending available areas suitable for colonisation and increasing the extent of the shoreline zone. Taylor et al. (2021) summarise the global peer-reviewed literature for evidence to assess the effectiveness on vegetation of raising water levels to restore/create freshwater marshes from other land uses, although this evidence pertains mostly to wetlands in river catchments in the USA, rather than to lakes *per se*. Although difficult to draw any definite conclusions on the effects of raising water levels on restoring both diversity and abundance of the studied vegetation communities, based on studies that were not all directly comparable or of equal value, Taylor et al. (2021) did indicate that, on the whole, actively managing water levels is likely beneficial for freshwater marshes.

Application

The installation of water control devices requires specialist design and installation to ensure that the desired water level regime can be achieved. Practical implementation on the ground can be relatively simple, if measures involve the blocking of ditches and raising outflows or more complex where water level infrastructure has to be retained. The intended effect of the measure is to impact on the hydrology of the site, with a likely increase in water levels, impacting both inflows and outflows. As a result, consultation with the Environment Agency and Flood Defence Consents are likely to be required. However, ideally, the blockage of drainage drains will involve raising water levels so that the natural hydrology is restored without the recourse to introducing artificial structures that need maintenance.

Climate change resilience

Restoring more natural water level regimes is considered to be an important climate change adaptation strategy for lakes (Natural England and RSPB, 2019), providing increased resilience to shorelines through habitat availability and connectivity.

Knowledge gaps

- Relatively little literature available on the application or effectiveness of this type of restoration measure in the UK. The measures involved are straightforward but inadequate monitoring means that it isn’t possible to track changes, identify how the shoreline recovers and how the measure works;
- Understanding the potential benefit for flood flows in re-naturalising hydrological functions of meres, basin peatland and basin lakes at the headwaters of catchments and the increase in water storage provided by these systems functioning more naturally.

English examples

In the **Little Hawes Water (Lancashire)** basin drainage in the past, through the removal of a rock ridge, has led to a lowering of water levels, which coupled with a transition to a drier plant assemblage, is likely to have affected the coverage of its fringing wetlands. Thus, in Natural England’s Little Hawes Water restoration project one of the aims is to restore towards natural hydrological function in the basin to increase the area of open water in the marl tarn and associated alkaline fen community.

The plan is to install a sluice and boards to block a main drain to raise the water levels gradually. This approach has been driven by some concern in the local community about the proposed changes due to potential effects on the hydrology of surrounding land. Extensive, but unpublished, monitoring has been carried out on baseline vegetation and hydroecological characterisation of the system, with additional transects of water level monitors installed to measure the change in water level.

At **Quoisley Meres (Cheshire)** an artificial outflow to a seepage lake, which wouldn’t naturally have an outflow, was partially blocked. This increased the area of open water and sedge swamp habitat by rewetting the peat across the basin area around the meres, providing a much larger wetland habitat than under the drained system, providing more habitat for a rare wetland snail. The project was undertaken 10 years ago and is considered a success, although no published evidence is available. This project highlighted that it is important to consider the likely changes in habitat across a site prior to implementing the measure as some types of habitat may be lost in their original location but could be reinstated elsewhere with initial scheme planning.

Artificial deepening of outflows is a common pressure on many lakes, at **Bomere Pool, Crose Mere** and **Sweat Mere (Shropshire)**, deepened outflows were raised using peat and plastic piling (**Bomere**) and timber dams (**Crose Mere** and **Sweat Mere**), which raised the water level. Water abstraction was also stopped at Bomere and the combined measures have led to an increase in *Typha angustifolia* swamp spreading towards the shore, based on repeated photograph surveys. Extensive pre-intervention work was carried out at this site to justify the need for the work, with modelling of abstraction pressure used to illustrate the extent of shoreline habitat loss. Common standards monitoring was not adequate to detect the effects, as a shoreline transect based approach would be needed to monitor change quantitatively. A lack of resource was highlighted as an issue with respect to understanding the long-term changes at the site. At **Crose Mere** and **Sweat Mere**, the site was instrumented with water level loggers in the lake and surrounding peatland and transects of vegetation communities were monitored. These demonstrated clear evidence of change, with improvement in the extent of the classic zonation of wetland communities. A reduction in grazing pressure on the landward side of these waterbodies has also led to an improvement in the area of *T. angustifolia* swamp. However, there were some concerns from adjacent landowners over the effects of rewetting on the drainage of their land due to the peatland rewetting.

In **Loe Pool** (also known as The Loe) **(Cornwall)** there has been a loss of lake marginal habitat due to flood prevention measures at Helston (River Cober). Thus, the Environment Agency in their **Loe Pool** water level management plan aim to restore a more natural seasonal water level regime (water levels were inverted with summer levels higher than winter levels) (Environment Agency, 2016). The proposal was to manage the inlet structure by the installation of two new water control devices. By managing water levels it was hoped to create an extra 22.4 ha of additional wetland habitat within the margins of **Loe Pool** and allow the upper willow carr to receive a higher water table than is currently experienced in the winter months and lower in the summer.

These restoration measures described above are planned to be enacted at the time of writing, so the success in achieving the desired outcome of altered water levels and associated benefits to lake marginal habitats is as yet unknown.

3.5 Artificial floating islands

Description

Artificial floating islands (AFIs) are structures that are designed to attach to the hard-engineered sides of artificial waterbodies or float offshore creating new habitat. They are usually formed of an artificial substrate that is designed to be buoyant and then planted with a diversity of aquatic plant species, the composition of which varies depending on the project objectives. Growth of the aquatic plants and the colonisation of roots by biofilms contributes to the buoyancy and water purification potential of the features. Artificial floating islands are particularly prevalent in Japan. In the UK there are examples of where these man-made structures (often made with recycled plastic materials) have been installed in artificial standing waters to improve both water quality and biodiversity, in some cases to replace the lost littoral habitat where water level fluctuations are large.

Effectiveness

Formal assessment for biodiversity enhancement of these measures is very limited. Nakamura and Mueller (2012) reviewed the performance of artificial floating islands as a restoration tool in standing waters globally. They stated that artificial floating islands have four main functions; habitat enhancement, improved landscape features, shoreline erosion protection and water purification. In their review Nakamura and Mueller (2012) concluded that water quality enhancement was the most important benefit from these man-made structures, especially in Asia where their installation over large surface areas (10 to 30%) of lakes and reservoirs helps to mitigate the effects of eutrophication. Nakamura and Mueller (2012) claimed that the shade from artificial floating islands helps to decrease phytoplankton, their vegetation helps in nitrogen reduction and the turbidity associated with shoreline erosion is reduced. In a study of the capacity of plant uptake to remove nutrients by floating treatment wetlands Keizer-Vlek et al. (2014) found that plant uptake by yellow flag (*Iris pseudacorus*) represented 74% of total nitrogen and 60% of total phosphorus removed from floating treatments wetlands trialled in mesocosms over a three-month experiment. Other advantages of artificial floating islands are that they float and can adapt to water level fluctuation and so are resilient to climate extremes, they are of aesthetic value and can provide safe, inaccessible refuges for nesting birds and habitats for other biota such as fish and invertebrates (Keizer-Vlek et al., 2014). Anecdotal reports based on responses from interviewees suggest that they do indeed provide nesting habitat for wetland birds and nursery habitat for small fish, where plant roots create a new biome containing algal biofilms, zooplankton grazers and fish. It is suggested that they can provide a significant biodiversity enhancement in artificial standing waterbodies, where there is no habitat or space available on the edge for natural vegetation establishment.

Application

An advantage of the artificial floating islands examples below is that they appear to be relatively quick and cost-effective to install and have been deployed in a number of UK sites (see below for examples). For example, BioHaven® floating islands have been sold as a 2 x 1m modular units that can be configured as required including as linear features or with holes in the middle to create protected open water areas. These plastic units are planted via pre-vegetated coir pallets including a mix of species with selected types to suit the objectives of the project, although consideration needs to be given to ensure effective root growth, with *Carex* preferred over *Typha* or *Phragmites* species. The modular nature of this design results in cost scaling according to the area required. Individual BioHaven® modules are around £244, plant pallets for that area are £61, anchor points £35, with two required per module and fencing £9.60 per linear metre. Design and installation costs are then added on top. Deployment of islands can be via fixings to artificial walls or deployment offshore and anchoring via anchor plates attached to the island. A small boat and outboard motor are required to tow the feature into position and anchor chains at three points attached using a single chain that splits to give three to four anchor weights for each attachment point. These need arranging to prevent the island twisting on the corners or where they are needed according to the design. Fencing off vegetation for the first two years of deployment is recommended to prevent grazing by water birds. Although floating islands are relatively easy to install, the distributor of the BioHaven® suggested that careful design of the deployment for the specific site is essential to ensure a successful installation, this is particularly relevant when considering water level fluctuations in artificial water bodies and the energy environment of the site. Installation is not suitable in high flow, strong currents or where large waves are likely. In general, the technique is considered to be low maintenance, although checking and removal of fencing will be required as plants establish and installation infrastructure such as anchor points need checking around once per year. Our interviewee suggested that most problems occur within the first six months of a scheme such as issues with over-grazing, plant establishment and movement of anchors.

Such artificial floating islands can also offer the potential to deliver quick and easy beneficial results and can be managed and maintained by volunteer groups and charities. However, there is still need for some longer-term monitoring of sites where artificial floating islands have been installed to assess success or not of this restoration measures in achieving their stated purpose of improving water quality and biodiversity.

Based on discussions during the expert survey, other requirements for the installation of artificial floating islands can include planning permission, though this varies from council to council and flood risk activity permits may be needed from the Environment Agency, if being installed on a main river. There were felt to be no issues with public access or landscapes as they are usually perceived as having a positive impact when installed in an artificial environment. However, consultation with anglers is recommended to ensure that positions are compatible with fishing activity. Islands rest on the water surface, therefore, impacts on hydrology are minimised, as they are floating structures. Wider impacts on the lake are more likely where coverage of the water surface is more extensive, although there are few studies which have quantified these effects directly, impacts would likely include changes to the light climate of the water column and alteration to the mixing energy received by the lake from wind.

Climate change resilience

The design of artificial floating island schemes can take account of likely water level changes resulting from climate change impacts, making them relatively resilient to these fluctuations. Issues may arise if water bodies dry out and plant roots come into contact with bed sediments, which could result in drowning when water levels rise. This makes them unsuitable for waterbodies or locations where this type of contact is likely to occur. Increased storm intensity may prove to be a problem, if wave, flow or currents become too large for the structures and additional energy dissipation measures may be needed to protect the islands.

Knowledge gaps

- Quantitative information on the effectiveness of islands for biodiversity objectives, particularly in relation to the sub-surface communities such as zooplankton and fish;
- The role of floating islands in carbon sequestration via peat formation as vegetation dies back and builds up;
- Wider impacts on the whole lake system with increasing coverage of AFIs.

English examples

Brooklands Lake (Sussex) (https://five-rivers.com/case-study/brooklands-lake-restoration/) and **Serpentine Lake (London)** (https://www.salixrw.com/solution/floating-island-benefits-wildlife) artificial floating islands have been planted with native wetland plants to facilitate the development of wetland habitats with, hopefully, knock-on biodiversity benefits although the evidence for long-term impacts of establishment of artificial floating islands is currently unclear. Another English example of where artificial floating islands have been installed is the **Reading Gateway (Berkshire)** (a lake surrounded by a new residential development), in order to try and improve biodiversity and water treatment. As the site cannot accommodate a natural wetland, 160 m^2 of floating island was anchored in the lake, built based on a modular grid buoyant structure with a high surface area matrix engineered for long-term wetland plant establishment. Pre-established wetland plants grown on coir were placed directly on planting matrix (Frog Environmental BioHaven brochure.pdf.).

3.6 Soft engineering (replacements for hard engineering)

Description

A range of shoreline restoration measures have been adopted to improve bankside vegetation and find alternatives to hard engineering. The underlying pressure for these measures is frequently the problem of shoreline erosion caused by increased wave exposure on the lake-ward side of the shore resulting from human activities, such as boat traffic and storm disturbance and also because riparian vegetation communities are impacted by excessive grazing, access or development pressure, reducing shoreline resilience to withstand waves. The impacts of erosion on biodiversity and natural functioning in lakes may be particularly acute where human shoreline development decouples littoral zone from the riparian zone and alters the structure and trophic basis of littoral food webs, primarily through a reduction in littoral habitat diversity (Brauns et al., 2011). Soft engineering alternatives, vary in scope depending on the specific issues at a site but frequently include some element of shoreline re-profiling to much gentler gradients compared to the hard structure once the hard engineering measure is removed, enabling the reconnection of riparian and littoral habitats. In addition to re-profiling, the use of stake palisades, silt curtains, Nicospan and vegetated gabions or geotextile sediment-filled tubes have been used to dissipate wave energy and allow littoral and wetland vegetation to establish behind the structure. Erosion control measures from river restoration work may also be relevant in this context, particularly considering measures for green bank protection, where understanding the underlying cause of the erosion issue and type of erosion is essential prior to selecting the appropriate restoration measure(s) (River Restoration Centre, 2020). In this context, there is a continuum of restoration techniques that may be deployed individually or in combination from purely green infrastructure measures, such as vegetation planting and willow spilling bank protection, to green-grey measures which incorporate elements of green infrastructure with hard engineering, such as vegetated gabions or riprap, to purely grey hard engineered measures, such as rock mattresses or geotextile that may be used alongside softer green measures under situations where erosion may be severe and there is high risk to people or assets (Roca et al., 2017).

Effectiveness

There are some published studies looking at the effectiveness of these measures for biodiversity in lakes, although these measures are often combined with wider habitat creation, so separating effects between different scheme elements isn't possible. As with the other measures covered in this report, systematic evidence on the effectiveness of these measures on improving biodiversity and natural functioning is limited to specific examples. The re-profiling and wetland habitat creation work at **Abberton Reservoir, (Essex)** has had a positive impact on populations of breeding wetland birds and birds associated with reedbeds and piscivory, benefiting this Special Protection Area (SPA) and Ramsar site. In addition to increase emergent reed species, submerged macrophyte habitat and cover has improved at the site with indirect evidence for fish population increases via bird populations. The use of sediment dredging to re-create a lake edge and reedbed at **Duck Broad, (Norfolk)** resulted in enhanced growth and diversity of aquatic plant species, including stoneworts, based on evidence from annual macrophyte surveys. However, it is unclear whether this was due to reducing the fetch at the site, and consequent reduction in sediment resuspension, or isolating it from the nearby river, reducing flow and nutrient inputs.

Application

Application of techniques varies depending on the scheme. Detailed information is available on re-profiling and shoreline stabilisation methods from the examples in North America. Roca et al. (2017) also provide more information on green and grey-green infrastructure, which spans a gradient from softer engineering and greater emphasis on working with natural processes, to approaches combining softer engineering with conventional hard engineering techniques, in the context of river restoration projects with many transferable concepts applicable to lake shorelines (see below). Roca et al. (2017) outline the use of a decision-support framework when investigating the use of restoration measures to address specific pressures and impacts (Figure 1). This includes a two-stage options appraisal, firstly at the business case level, where all options including no intervention or management only options are considered alongside restoration measures and the technical level where the design of measures and use of specific products are considered.

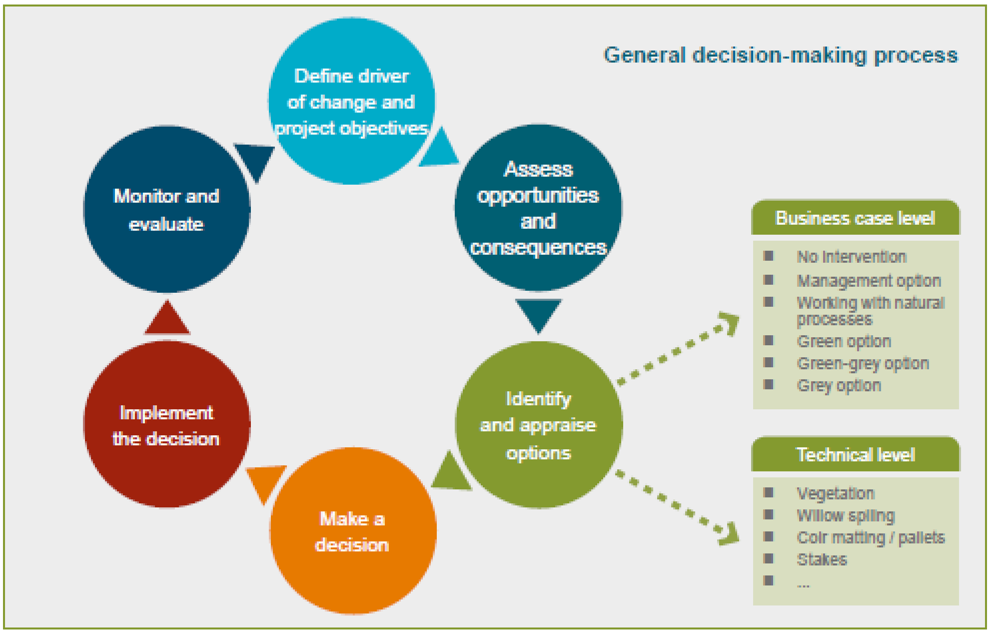

Figure 1 Decision support framework to consider options for restoration measures from Roca et al. (2017).

At lake sites, discussions with interviewees suggested that key considerations for re-profiling should include:

- The intended new profile, aiming for 1:3 or 1:4 slope at minimum and ideally 1:20 where there is space;
- When designing the scheme it is important to consider the wave energy at the site using design tools to inform whether just planting, or stabilisation or wave protection barriers are needed;
- Materials used for wave protection ranged from brushwood bundles and coir logs to large trees and multiple size grades of rock depending on the position and exposure to wave energy;
- Use of native or local provenance vegetation either through plug plants, seeds or transplanting rhizomes depending on the area being restored and budget;
- The type of plants used again varied depending on the scheme with shrub-type plants favoured due to root structure and erosion prevention in the North American examples, whilst reedbeds or tree planting advocated at other sites;
- Fencing was universally recommended for at least the first year after planting to allow good vegetation establishment without grazing by livestock or birds.

Individual techniques which span the green infrastructure, green-grey infrastructure and grey infrastructure (soft to harder engineered techniques) are generally designed to cope with differing levels of mechanical energy and site slopes. From a river perspective, Roca et al. (2017) suggest the following measures in order of their maximum permissible flow velocity: stakes (live), coir rolls, faggots/ fascines/ brushwood, aquatic vegetation, coir matting/ pallets, bankside vegetation, willow spilling, woody material, vegetated reinforced earth, vegetated rip-rap, geo cell systems, geotextile, rock rolls, vegetated rock rolls, vegetated concrete blocks, vegetated reinforced mattresses and vegetated gabions. They stress that information on velocity tolerance is relatively limited and clearly considered in the context of rivers here. Velocity tolerance of green infrastructure measures will also likely vary over time as vegetation becomes established, suggesting that additional temporary measures could be undertaken to ensure establishment is successful for specific sites. The measure chosen also depends on the intended purpose and for erosion control, these are characterised as bank protection measures, slope toe protection measures and bank and toe protection measures (Table 2) (Roca et al., 2017; River Restoration Centre, 2020). The identification of specific measures or combination of measures should be undertaken as part of the wider options appraisals described above.

Table 2 Summary of bank erosion protection measures used in river restoration projects based on Roca et al. (2017) and River Restoration Centre (2020)

Type of protection	**Infrastructure type**	**Restoration measure**	**Indicative cost[2]**
Bank protection	Green infrastructure	Bankside vegetation	£185 per square metre
		Stakes	£25 per metre
		Willow spilling	£100 per metre
		Coir matting/ pallets	£32 per metre
	Green-Grey infrastructure	Vegetated concrete blocks	
		Geo cell systems	
		Vegetated reinforced earth	

[2] Provided by Salix and Roca et al. 2017

		Vegetated reinforced mattresses	
Slope toe protection	Green infrastructure	Aquatic vegetation	£185 per square metre
	Green-Grey infrastructure	Vegetated rock rolls	
	Grey infrastructure	Rock rolls	£28 per metre
		Aquarock bag	£250 per 2 tonne bag
Bank and toe protection	Green infrastructure	Coir rolls	£32 per metre
		Faggots/ fascines/ brushwood	£105 per metre
		Woody material including root wads	£145 per metre
	Green-Grey infrastructure	Vegetated gabions	
		Vegetated riprap	
	Grey infrastructure	Geotextile	

The costs of schemes in lakes again varies depending on the site, context and size of area being restored. In North America, cost examples from interviewees ranged from $5,000 - $10,000 for simple re-profile and re-vegetation projects, whilst those requiring greater erosion control and stabilisation materials were typically between $15,000 - $25,000, with 36 – 38 plug plants available for around $80 suitable for covering a 15 m x 3 m wide area. At **Delta Lakes (Carmarthenshire)**, simple bank re-profiling and the installation of plain and pre-planted coir rolls to address bank erosion and create water vole habitat cost ~£10,000. Erosion control measures at **iPort (Yorkshire)**, which involved remediation of severe bank erosion in a flooded gravel pit and a combination of hard and softer measures, cost in the region of £200,000, although better forward planning during the transition from gravel extraction to flooding the site would have reduced this cost significantly. The larger scale and more complex projects, where sediment dredging or large scale engineering works were carried out alongside re-profiling, costs ranged from £1.5 million for **Hickling Broad** works to £80 million for the whole reservoir reconfiguration project at **Abberton Reservoir**. These costs also reflect, in part, the complexity of the restoration task, with relatively simple approaches requiring only small-scale excavators operated from the shore for re-profiling work and manual planting, up to work on floating platforms using specialised machinery. Long-term maintenance was, generally, considered to be low by the interviewees, with some inspection requirements needed to check structures, such as gabions if used, and plant establishment and removal of fencing once the grazing risk was lower.

Other considerations of these types of measures include the need for a sufficient riparian or littoral footprint, if extending into the lake, to allow for the creation of a suitably shallow slope. These projects may facilitate greater public access, which could require additional management, see the example from **Lake Constance**, below. In the case of **Abberton Reservoir**, additional footpaths and visitor viewing opportunities were created as part of the scheme to deliver additional recreational benefits. Works may require flood risk activity permits, therefore, consultation with the Environment Agency and local councils are recommended. Water levels may be increased by this type of work, as was the intended objective at **Abberton Reservoir**, but this depends on the size and scale of the activity, and was considered to be minimal for the other examples discussed. Increased water levels may have implications for drainage of adjacent land and, therefore liaison with landowners and development of mitigation measures may be required.

Climate change resilience

Where footprints allow, the design of schemes has the potential to take account of potential impacts of climate change through providing a more naturally graded shoreline that vegetation can colonise, allowing for recolonization of habitats disturbed by floods or droughts. At **Abberton Reservoir**, in a similar way to **Bodenham Lake**, this was achieved through having wetter and drier areas of emergent reedbed.

Knowledge gaps

- Prediction of potential water quality and greenhouse gas emissions impacts of re-wetting large areas of former farm land in terms of sediment and nutrient mobilisation;

- Impacts of invasive species colonising new niches created by shoreline re-creation;
- For large schemes where sensitive species may be present, create more refuge areas in advance of main restoration activities;
- Impacts of waves and boat generated waves, such as the wake from boats on small lakes;
- Revisiting sites installed previously to assess extent of vegetation establishment and spread beyond original scheme to understand what has worked well, what hasn't and why measures fail;
- Knowledge sharing across practitioners to share design expertise and installation experience, learn from others mistakes and try implementing measures.

Global examples

In North America there has been a particular focus on preventing bank erosion in lakes – mostly to preventing lake shore property owners from 'sea walling' their properties and encouraging the use of more natural methods instead. For example, **in New York State** a guide to best practice in shoreline stabilisation techniques that favours the use of "soft" or natural shoreline protection methods over "hard" or structural methods. This guide is aimed at landowners and provides detailed advice and information on various shoreline stabilization methods (Department of Environmental Conservation, 2010). In **Lake Michigan**, the Michigan Natural Shoreline Partnership has developed guidance on natural shoreline methods, i.e. bio-engineering methods to control lake shoreline erosion (https://www.mishorelinepartnership.org/) and there are other similar websites such as the Living Shorelines Academy (https://livingshorelinesacademy.org/index.php/learn) that promote 'living shorelines for property owners' and gives advice on 'designing, construction and permitting of living shorelines'. In **Lake Champlain (Canada/USA),** the Shoreline Stabilization Handbook for Lake Champlain and Other inland Lakes (Northwest Regional Planning Commission, 2004) the pros and cons of various shoreline erosion control methods are described and compared in detail: non-structural and preventative; structural; bioengineering and; biotechnical. It describes in tabular form each listed erosion control method where it works, where it doesn't work, neighbouring impacts, ease of deployment, cost, monitoring and maintenance, where and who it can be installed by, advantages and disadvantages.

In **Lake Constance (central Europe),** the wide presence of retaining walls along its shores has resulted in increased near-bottom current velocities, higher bed-load transport rates, coarsening of surface sediments resulting in a decline in the abundance and diversity of the freshwater biota (Ostendorp et al., 2020). Here a formerly armoured shore section was restored by a lake-ward orientated submerged wedge-shaped cobble embankment in front of the former retaining wall on the assumption that biotic communities would achieve a more 'natural' composition. Ostendorp et al. (2020) compared this restored shore against an armoured shore with a retaining wall and a pristine section of shore. This comparative study found that the artificial embankment shore restoration measures managed to re-establish ecological conditions comparable to those found in pristine shores in **Lake Constance**. Although the artificial embankment created positive effects in the sub-littoral zone *c.* 3-5 m wide there were also possible negative ecological impacts of the restoration measure by also creating a terrestrial zone > 10 m wide, a habitat not typical of lake shores and facilitating increased use of a newly created beach by the public. These negative impacts were considered by Ostendorp et al. (2020) to potentially be more important than positive impacts of the shoreline restoration measure.

Brauns et al. (2011) in a study of **three German lakes**, recommended preserving the structural integrity of lake littoral zones by restoration measures such as the deployment of coarse woody debris (see below) and reed and root habitats (see above), as cost-efficient measures to improve degraded lakeshores. They suggested replacing erosion control structures such as retaining walls with stake palisades in front of lakeshores plus increasing littoral habitat diversity by restoring reedbeds and planting native riparian trees behind stake palisades to provide a supply of coarse woody debris and submerged root habitats. Where retaining walls couldn’t be replaced, Brauns et al. (2011) suggested establishing reed stands to help protect the upper littoral zone from the negative erosional impacts of activities such as boating. However, Ostendorp et al. (2020) noted that in wind-exposed shores, for example in **Lake Constance,** dense reedbed belts and coarse woody debris would not represent an appropriate restoration method for shore sections with retaining walls, as reedbeds and deposits of driftwood were not typical for exposed pristine shores.

English examples

In **Abberton Reservoir (Essex)** most of the concrete edge in the reservoir was removed and the shoreline re-profiled to produce an improved 'natural' marginal habitat. Large-scale construction activity (taking over four years) involved the creation of a new shallow habitat (plus the creation of water retaining bunds and lagoons) with the aim of providing larger areas of shallow water (0-1 m depth). This shoreline re-profiling improved the habitat for submerged vegetation to flourish with a significant proportion of water birds (particularly dabbling ducks and waders) now concentrated in the new, more natural edge habitats (Wallis et al., 2019). These_restoration measures had the additional benefit of increasing the water storage capacity in the reservoir and provides greater resilience against climate change (Wallis et al., 2019).

In the **Norfolk Broads** there are a number of sites where alternatives to hard engineered shoreline piling solutions have been trialled, primarily to protect the edges of broads from the deleterious effects of wave erosion causing the re-suspension of sediments and the uprooting of macrophytes. A range of environment protection structures have been employed including silt curtains (acting as wave barriers), Nicospan (pre-fabricated double weave revetment fabric) with posts, planted metal/gabion structures and geotextile tube structures (holding dredged sediment) in a number of locations: **Barton Broad, Duck Broad, Hickling Broad, Bridge Broad, Salhouse Broad** and **Rockland Broad**. These environmental protection structures are held in place with chains, floats and weights, and some are protected by goose guards fitted to stakes to reduce grazing pressure by waterfowl. The aim of the measures is to give some bankside protection from wave exposure and, hopefully, promote the establishment of emergent macrophytes (assuming nutrient concentrations are under control and there is historical evidence of greater shoreline complexity). These type of shoreline restoration measures should also potentially helped by reducing the gradient of the bank-water interface (Philips et al., 2015). According to the Broads Authority, these environment protection barriers have also helped provide new marginal habitats to improve biodiversity plus at sites where dredged sediment was used in environmental protection barriers they have improved water depth in the broad navigable channels (Broads Authority: Environmental Protection Info Sheet, see Appendix 3 below). In the example of **Salhouse Broad**, grab dredging was used to dredge sediment from the River Bure and the sediment used to create a spit in **Salhouse Broad** and planted with reeds. 7,000 m^2 of reedbed was created with a diverse range of other species. The whole restoration project cost the Broads Authority £250,000 in 2012-13 to dredge 12,000 m^3 of sediment (https://www.broads-authority.gov.uk/looking-after/projects/prisma). Although the Broads Authority regularly check condition of the environmental protection barriers at this and other Broads sites where similar restoration measures have been installed, it is unclear as to the long-term success of these environmental protection barriers. At **Duck Broad,** a novel restoration technique was used that was first employed in Afghanistan by the British Army to build barricades. **Duck Broad** was selected as a site by the Broads Authority to take part in a PRISMA pilot project to improve sediment management methods. (https://www.broads-authority.gov.uk/looking-after/projects/prisma). At this site an alternative soft engineering approach (compared with a more traditional hard engineered one) was used to create a new lake edge that separated **Duck Broad** from the main river channel. Here fabric-lined steel mesh baskets (gabions) were filled with rocks and sediment dredged (by suction) out of **Heigham Broad (Norfolk)** and joined together to make perimeter of a 1 ha spit of land and planted with common reed and reedmace. The use of a suction dredger limited the environmental impact of the dredging operations with the dredged sediment treated in lagoons. This novel restoration approach reportedly resulted in improved water quality, clearer water and increased macrophyte growth in the re-profiled area - a possible reflection of more sheltered conditions? An additional benefit of this restoration scheme was it increased the navigable depth in **Heigham Broad.** In total, this restoration scheme cost the Broads Authority, in 2010-14, £355,000 to dredge 15,000 m^3 of sediment.

In **Malham Tarn (North Yorkshire)** past raising of water levels has led to increased contact between the peat cliff edge at Tarn Moss and water in the lake causing erosion of peat into the lake leading to an artificially cut cliff edge of Tarn Moss. At more 'natural' water level conditions a more gradual sloping margin between the bog and the lake would be expected. To address this bank erosion problem wood log piling and wave breaks have been installed over the last decade or so by the eroding edge of the lake next to Tarn Moss. These log pilings are probably limiting the erosion but are not considered sustainable as a long-term restoration measure. Some logs have been lost from the protective structure and the site is still suffering from significant peat erosion and the constant loss of water from bog to lake, causing drying of peat back into bog and preventing recovery of affected bits of the bog. Probably the only long-term solution to stopping the erosion of peat from Tarn Moss will be to restore natural water levels in the lake through a gradual drawdown to enable littoral habitats to migrate, although it may be difficult to re-establish the natural transition zone between bog and lake without direct intervention (Ruth Hall, *pers comm.*).

In **Delta Lakes (Carmarthenshire)**, bank erosion problems caused by a combination of wave action and excessive mowing were addressed through the use of shoreline re-profiling with a mechanical digger and the installation of coir rolls in 1 m water depth to break wave energy and provide colonisation substrate for a range of pre-planted local provenance marginal plant species, with re-profiled material used as backfill behind. This measure was intended to provide better habitat for water voles and improve the appearance of the lake edge. Accompanying the measure was a reduction in mowing within the riparian zone adjacent to the shore. Anecdotal reports suggest the vegetation has established well under anti-grazing netting and has spread along the targeted areas.

At **iPort (Yorkshire)**, severe erosion problems developed along several shorelines in response to flooding the ex-gravel pit site without adequate pre-intervention scheme design and re-profiling activity. In response to the erosion issues, which threatened to encroach on neighbouring land and be a risk to infrastructure, the remediation at the site used a combination of hard landscaping around culverts and a combination of hard measures such as rock rolls and mattresses and soft measures including planted coir mats and rolls at lower risk sites. The objectives for the project were purely focussed on erosion prevention, with no consideration of allowing for some natural erosion processes or some bare shorelines to enhance biodiversity. Vegetation planted was mostly composed of *Phragmites* sp., *Typha* sp., *Carex* sp. and *Juncus* sp. and no reference was given to the use of local species or those associated with the nearby SSSI wetland.

Additional resources

Roca et al. (2017). Green approaches in river engineering https://eprints.hrwallingford.com/1250/1/Green_approaches_in_river_engineering.pdf

River Restoration Centre (2020). Green bank protection. Manual of River Restoration Techniques: https://www.therrc.co.uk/sites/default/files/general/MOT/Decision_support/ds4_v2.pdf

3.7 Coarse woody debris

Description

Coarse woody debris in temperate littoral zones can provide a relatively stable habitat in many lakes with wooded/forested shorelines (Czarnecka, 2016). Thus, when the resource of coarse woody debris is depleted, following shoreline development, it can result in the disruption of normal lake functioning.

Effectiveness

There is very little evidence for the effectiveness of the introduction of coarse woody debris in lake shorelines. Respondents to the expert survey graded it as highly effective for improving lake functioning. There was a mixed response from interviewees over its effectiveness as an erosion control measure over the long-term. Czarnecka (2016) noted that although artificially restoring lost coarse woody debris stocks in lakes could bring about positive changes in the littoral biota some studies have indicated ambiguous effects on littoral species, suggesting a better understanding of the role of coarse woody debris is needed for their successful deployment in lake restoration schemes.

Application

Relatively little information was available on the application of coarse woody debris in a lake context. However, the examples below suggest it is a relatively simple, low-cost and low-maintenance measure that can be used to stabilise shorelines and introduce more habitat complexity to a site. The expert survey respondents had mixed views on the ease of deployment, but it scored highly on long-term sustainability and maintenance requirements and nearly two-thirds scored it has being highly or moderately cost-effective.

Climate change resilience

The measure is likely to be relatively resilient to drought impacts, although increased storminess may require additional maintenance or more frequent replacement of smaller features and improved securement of wood where it needs to be retained on the shore area.

Knowledge gaps

- Need to understand effectiveness and impacts on littoral communities.

Global examples

Brauns et al. (2011), from a study in **three German lakes**, recommended preserving the structural integrity of lake littoral zones by restoration measures such as the deployment of coarse woody debris (as well as associated reed and root habitats) as cost-efficient measures to improve degraded lakeshores. They suggested that planting native riparian trees behind stake palisades could provide a supply of coarse woody debris as well as a submerged rooting habitat. Lorenz et al. (2017) also suggested that near natural shorelines could also be potentially be improved by developing the habitat structure, e.g., by the provision of higher proportions of dead wood at shorelines.

English examples

The Salix website details a range of bioengineering techniques such as, brushwood faggots that could be used to artificially stabilise lake banks and artificial islands (https://www.salixrw.com/solution-category/reservoirs-lakes-shorelines/). They are presented as relatively low-maintenance/straightforward lake shoreline restoration measures. However, there appears to be scant evidence of the long-term success of woody debris/faggots deployment as a lake shoreline restoration measure.

At **Littlesea (Dorset)**, the National Trust used brushwood fences, close to the shore as experimental wave barriers – and whilst not designed for the purposes of introducing woody debris, the deployment technique is another example of introducing more ‘natural’ wood structures into a shallow lake.

3.8 Recreational access restriction

Description

This lake shoreline restoration measure is designed to relieve pressures from recreational visitors, e.g., from shoreline disturbance and littering, on the shoreline environment by reducing or preventing public access to lake shorelines, particularly at sensitive locations.

Effectiveness

There is very little evidence for the effectiveness of limiting recreational access to lake shorelines, although it is presumed that it is likely to have a positive effect on both biodiversity and natural functioning.

Application

Little information was available on the application of this type of restoration measure in a lake context, although the few examples below suggest it is a relatively simple, low-cost measure that can be used to minimise shoreline disturbance at a site.

Climate change resilience

This measure doesn't explicitly consider increased resilience to climate change effects.

Knowledge gaps

- Need to understand effectiveness of measures to limit or stop recreational access to lake shorelines.

English examples

Hatchet Pond (Hampshire) is a 6.7 ha shallow lake and part of the New Forest SSSI/ Special Area of Conservation (SAC). One large pond dominates with a surrounding fringe of species rich mire and wet heath mosaic. Heavy and increasing visitor pressure, have left much of the bank closest to the car park bare and compacted. Erosion of the lake shoreline has occurred, leading to increased siltation of the lake and damage to shoreline communities, especially in proximity to the car park (and associated recreational pressures from bird feeding, dogs swimming in the lake etc.). Relocation of visitor car parking is anticipated in 2022 to help minimise these impacts, evaluation of the effectiveness of this measure was, therefore, not currently available.

NB more information at [Hatchet Pond restoration | Forestry England]

At **Hawes Water (Lancashire**) the-existing boardwalk was replaced and the path re-routed to move visitor access away from the lake shoreline along the line of the existing Public Rights of Way.

In **Hatchmere (Cheshire**), the Cheshire Wildlife Trust banned public swimming at the site because of issues around littering and damage to the shoreline, particularly around the publically accessible east shore (Glen Cooper, *pers comm*.).

At **Heath Lake (Berkshire)** tree removal to reduce shading of the shoreline submerged macrophyte community has been used to create a natural barrier to prevent the general public and dogs accessing the lake where vegetation communities are being re-established. The effectiveness of this measure is unknown.

3.9 Reducing the impact of animals - fencing

Description

It is now common practice in UK for reedbed restoration schemes to have grazing exclusion zones as an integral component to protect newly planted reedbeds from grazing pressure from wildfowl and/or wild or farm animals. Other techniques covered in this report involving the use of emergent vegetation also advocate the use of fencing whilst vegetation establishes (see also sections on Reedbed, swamp and fen creation/restoration, Artificial floating islands and Soft engineering (replacements for hard engineering)). Grazing exclusion usually involves the use of fencing configured to prevent access to young plants. Frequently used in conjunction with other restoration activity, fencing can also be used alone to allow the regeneration of existing habitats by removing the grazing pressure. However, it is also recognised that appropriate grazing regimes, including appropriate density, livestock and timing of grazing can be a sustainable way to manage habitat, create greater habitat diversity and prevent succession.

Effectiveness

Anecdotal evidence from the expert survey and interviews suggests that fencing is considered highly effective in improving lake functioning and biodiversity through enabling the establishment of more natural vegetation communities. It is often considered to be key to the successful application of other restoration techniques. In addition, a review of a number of studies by Taylor et al. (2021) suggest that there is some published evidence for increased plant density and biomass in fenced areas and increased survival rates 12 – 18 months after planting.

Application

Approaches to fencing vary depending on the specific project. In reedbeds, fencing often involves the use of moveable narrow exclosures to deter water fowl from landing within the site and for some planting schemes it may involve fencing that vegetation grows through. These types of fencing are usually temporary measures to enable establishment of plants and then they can be removed or moved within the site to allow the spread of plants into wider areas. Different types of fencing are used depending on the setting, with specific mesh sizes and gauges of fence sold to target geese, deer or livestock. It is considered to be a highly cost-effective (£100s - £1000s) and simple measure to promote shoreline recovery and aid restoration activity, although maintenance and checks on effectiveness may be needed at the early stages of a project to ensure that grazers are being excluded. Landownership and access need considering for this technique, particularly where there are access requirements for stock watering or public access to shores for recreation. Footprint requirements will vary depending on the design of the restoration scheme and the area of the exclosure, but the fence itself will take up very little space.

Climate change resilience

Fencing can enable vegetation communities to re-grow and increase diversity and complexity of habitats of lake shorelines. Increased storminess may pose a risk to increased damage of fencing measures, whilst water level fluctuations due to flood or drought could render the exclosure less effective if the habitat enclosed is isolated. This may necessitate more frequent checks to ensure the position of fencing is having the desired effect.

Knowledge gaps

- None identified.

UK examples

In the **Norfolk Broads** goose guards are installed (fitted to stakes) in order to minimise grazing pressure from geese and other wildfowl on newly planted reedbeds, e.g., **Hickling Broad**, **Salhouse Broad.**

In **Bodenham Lake (Herefordshire)** reeds planted in re-profiled areas to create a reedbed have been fenced off to protect them from grazing wildfowl and sheep.

In **Delta Lakes (Carmarthenshire)**, coir rolls pre-planted with reeds and other marginal wetland plants, had protective netting placed over coir rolls for first year or so to protect young marginal plants from grazing by wildfowl. These grazing exclusion methods are cost-effective, low maintenance restoration measures that allow reedbeds to get well established after planting and have been shown to be successful (see Appendix 4 below Delta Lakes Llanelli Shoreline habitat enhancement summary).

3.10 Reducing the impact of animals – population controls

Description

Measures to control the impact of animal populations on lake shorelines include reducing livestock numbers, culling or interference in the life cycle of wild herbivores such as birds and deer and the removal of benthivorous fish species, such as common carp and bream. The principle aim is to reduce the grazing, trampling and compaction pressure on shorelines that can result in the loss of particular species or whole vegetation communities and increase the likelihood for shoreline erosion or sediment re-suspension, where plants are lost from below the water line.

Effectiveness

Amongst the experts interviewed in this project, most measures to promote shoreline restoration involved the complete exclusion of livestock over the initial period of restoration and vegetation establishment. On certain habitats, particularly reedbeds, longer-term management of the habitat and the prevention of scrub or tree growth included the use of grazing animals such as cattle or ponies at low densities to prevent negative consequences associated with scrub or tree growth. A review by Middleton et al. (2006) found that excluding grazing entirely from fen habitats reduced the number of plant species and the biodiversity benefits of grazing strongly depended on the intensity. In general, low to moderate grazing levels enabled the maintenance or increase of biodiversity in nutrient-rich fens. However, stock levels aimed at avoiding the negative impacts of trampling may not be sufficient to maintain biodiversity and additional management action may be required. Tanner (1992) also concluded that whilst heavy grazing of shorelines is detrimental to vegetation, low density grazing offered benefits for increasing the diversity of habitats (NB also note the example cited above for **Little Hawes Water**).

Culling programmes for native herbivores, particularly water fowl and deer, were discussed with the restoration experts surveyed for this project. The general opinion was that at individual sites, these measures were not very effective for reducing grazing pressure due to the territorial range of the animals covering large areas relative to the individual sites where restoration work was carried out. Vermaat et al. (2016) also reported that muskrat grazing of reedbeds in Dutch lakes was unaffected by a culling programme, but reedbed re-establishment was effective in areas of fenced exclosures. Culling of water birds to control populations is a controversial topic and no direct evidence was found of the effect of this measure on lake shoreline plant communities. However, a study conducted by Bakker et al. (2018), which carried out management of the greylag goose (*Anser anser*) through chasing away the animals and removing nests and eggs, resulted in a large reduction in goose numbers and increased stem density and height in *Phragmites australis* reeds. Literature searches did not find evidence analysing the impact of deer on lake shorelines, although the impact of deer on other terrestrial habitats, is well documented e.g., deer culling used to reduce population density on heather moorland, combined with localised winter feeding was found to be beneficial to the cover and height of heather plants (Welch et al., 2006).

The presence of bottom-feeding or benthivorous fish can have a damaging effect on lake shoreline vegetation communities through reductions in light climate due to sediment and nutrient resuspension favouring dominance by planktonic algae, and through direct grazing pressure on, or uprooting of aquatic plants. In addition, the presence of large populations of planktivorous fish can reduce populations of zooplankton grazers that control planktonic algal populations, resulting in more algal growth, and a subsequent reduction in macrophytes. In some cases, fish additions may be beneficial to increase the biomass of piscivorous fish species such as pike. These ‘bio-manipulations’ are aimed at addressing excessive planktivory and benthivory, to promote the recovery of shallow lakes from a turbid-water to a clear-water state. Although this is unlikely to be sustained without an adequate reduction in nutrient concentrations, that usually accompanies the issue of imbalances in the lake food-web.

Removal of benthivorous fish species such as the common carp (*Cyprinus carpio*) has been found to have positive effects on macrophyte communities, with increased vegetation density following a reduction in fish density (Bajer and Sorensen, 2015). Thresholds for carp biomass influencing ecosystem processes in lakes have been reported from as little as 5 kg/ha (Weber and Brown 2009). Studies from the Netherlands suggest stocking densities need to be <50 kg/ha of both benthivorous and planktivorous fish in order to achieve a shift from turbid to clear water state (Hosper and Jagtman, 1990).

Application

Whilst livestock reduction is a relatively simple technique, considerations around land ownership and management need to be considered before implementation. Fish community management, sometimes involving removal, in contrast, will vary in cost (£100s to low £1000s), may be more labour intensive, depending on the effort needed to reduce animal populations and the requirement for repeated intervention if the overall cause of the damaging population size is not addressed.

Changes to restore more natural fish communities and abundances usually involves the use of electrofishing and netting to manage initial fish stocks, usually relocating fish to other sites, with follow-up netting often needed to address recruitment or illicit restocking. Relocation (and potentially culling) of some fish species may also be considered as controversial, particularly with certain stakeholder groups, such as animal rights and angling groups and, therefore, considerations around engagement with these communities will be necessary. Relatively little detail was found on how any culling measures are implemented, given the lack of studies directly focussed on this measure. Licenses for fish removal will also be needed the Environment Agency.

Climate change resilience

This measure is unlikely to impacted by climate change effects increasing storminess or drought, but increased air and water temperatures may favour survival and breeding of invasive, introduced and nuisance species.

Knowledge gaps

- Limited information on optimum stocking densities of terrestrial grazing animals to promote diverse lake shoreline vegetation communities;
- No direct evidence for the effectiveness of culling on shoreline vegetation.

Global Examples

Goose management through scaring and removal of nests and eggs was carried out at **Lake Terra Nova** and **Lake Waterleidingplas (Netherlands)** (Bakker et al., 2018). In addition, fencing to create goose exclosures was also carried out. Both approaches improved reedbed growth, with the reduction in overall grazing through scaring increasing reed stem density and height across fenced and unfenced experimental plots. The use of scaring was felt to be time-consuming and potentially costly.

Bajer and Sorenson (2015) provide an example of carp removal from **Lake Susan (Minnesota, USA)**, where stocking densities reduced from 300 kg/ha to 40 kg/ha leading to an increase in aquatic plant density and improved light climate, although there were no detectable effects on summer algal biomass and phosphorus concentrations.

UK Examples

Biomanipulation of fish communities of **Llandrindod Wells Lake (Powys)** through the removal of carp, bream and perch enabled large submerged plant communities to become established (Moss et al., 2002). However, the success of this measure was not sustained owing to concern about excessive growth of introduced plants, which were generic highly invasive forms that did not account for the site-specific conditions of the lake. Pressure from angling interests and the lack of an agreed restoration target for the lake, focussed on amenity and conservation status, resulted in subsequent management measures including the use of herbicides and carp stocking that returned the lake to a turbid state (Moss et al., 2002).

A number of examples of biomanipulation of fish communities have been carried out on several of the **Norfolk Broads** at **Cockshoot Broad**, **Pound End**, and **Ormesby Broad** to try and generate clear water conditions and improve macrophyte cover and diversity (Phillips et al., 2015). Success in increasing macrophyte cover occurred at all sites, at least over the short-term, whilst increases in macrophyte diversity were more variable. Key to the effectiveness of the measure was ensuring that low fish densities could be maintained and that other factors influencing the stability of macrophyte dominance, such as nutrient conditions, were also adequately addressed (Phillips et al., 2015). Biomanipulation is being demonstrated at **Hatchmere** and **Betley Mere (Staffordshire)**, and scheduled as part of the whole lake restoration of **Hoveton Great Broad (Norfolk)**.

Additional resources

Phillips, G., Bennion, H., Perrow, M. R., Sayer, C. D., Spears, B. M. and Willby, N. (2015). *A review of lake restoration practices and their performance in the Broads National Park 1980-2013*. Report for Broads Authority Norwich and Natural England.

https://www.broads-authority.gov.uk/__data/assets/pdf_file/0025/205855/Broads-Lake-Review.pdf

3.11 Monitoring

In general, very limited monitoring information is available to assess effectiveness of the restoration measures detailed in sections 3.2 - 3.10. Where monitoring is carried out, it is usually only for relatively short time periods following an intervention (< five years and, typically, one to two years) and, therefore, long-term success is rarely quantified. There also appears to be a bias in what techniques have been monitored, resulting in some measures having no information on their effectiveness. The result is that the effectiveness of lake shoreline restoration techniques for biodiversity and natural functioning benefits are not well quantified, which restricts the evidence base available for justifying the use of these approaches in future work. In addition, the lack of reporting on what works or doesn't in restoration means that it is more difficult to learn from the experiences of existing schemes and apply best practice in future work.

Some monitoring activity was carried out as part of some of the case studies identified above. This can be divided into three categories, ordered to reflect the likely utility of the approach for drawing conclusions on the effectiveness of the measure: i) targeted quantitative monitoring; ii) general quantitative monitoring; and iii) targeted qualitative monitoring. Examples of these approaches are provided below along with some suggestions for monitoring scheme designs to improve our ability to quantify the effectiveness of measures.

Targeted quantitative monitoring

Use of repeat photographic surveys via aerial approaches, a technique being used on the Norfolk Broads, enables a quantitative estimate of reed establishment to be made. Comparison of scale defined photographs over time at similar times of year enables the change in area of reedbed to be assessed in a 'before and after' approach. However, it should be noted that changes observed 'after' an intervention may not necessarily be causally linked to the restoration measure, as other factors such as weather variations and extremes can also change over time and interfere with the result. The addition of a control site to this monitoring approach would help to mitigate against other factors influencing change at the site and allow for more accurate assessment of change due to the intervention. In addition, use of remote sensing techniques has also been carried out to assess the health of reeds (Tóth, 2018).

Fenced exclosures to limit grazing have been assessed through the comparison over time of control grazed plots versus exclosures. Vermaat et al. (2016) and Bakker et al. (2018) both quantified the benefits of exclosures in this way and Taylor et al. (2021) reviewed the effectiveness of these measures in the published literature, although studies were typically limited in length (one to two years post-exclosure). Assessment of changes to hard engineered lake edges by Ostendorp et al. (2020) in **Lake Constance (central Europe)** was also structured around a quantitative comparison of restored areas with hard engineered control sites in the lake to assess the change in function across different biological elements and whether restoration shifted the communities to resemble more pristine locations.

Very little systematic monitoring of the biodiversity benefits of artificial floating islands has been carried out to date. There is a lot more evidence for their effectiveness in water purification, particularly in the context of quantifying nutrient and pollutant removal in effluent treatment wetlands, reviewed by Dodkins and Mendzil (2014).

General quantitative monitoring

A frequent monitoring tool used to assess changes in response to restoration measures was that of site condition monitoring, particularly of macropyhtes. Repeated botanical surveys have been used at **Cockshoot Broad** and **Cropston Reservoir** to assess the recovery of the riparian and littoral plant communities and identify potential issues with invasive species. Use of regular surveillance monitoring of macrophyte communities detected the change in plant diversity following the work at **Duck Broad.** This approach may be suitable at other sites where restoration activities are planned but budgets for specific monitoring are not available. In the large **Abberton Reservoir** restoration scheme, the five-year management plan developed a strategy to monitor waterfowl, breeding birds, reptiles, bats, great crested newts, macrophytes, zooplankton, algae, bird nest and ringing data, covering the before, during and after restoration periods. This has now ended but ongoing waterfowl surveys continue at the site carried out by volunteers. Use of volunteer labour in addition to paid workers to carry out monitoring activities at sites was common, particularly regarding surveys of water birds such as the BTO WeBS and Breeding Birds Surveys (BBS) and bird ringing.

Targeted qualitative monitoring

The approach of anecdotal assessment of restoration measures was the most common measure used to assess success identified in the interviews with experts. This could involve the use of repeat photography at fixed stations, in a semi-quantitative assessment or the revisiting of the site to assess vegetation establishment. This latter approach was frequently used in conjunction with the need to carry out maintenance or checks on the works, such as fence removal, fence relocation and checks on the integrity of introduced structures.

Designing a monitoring scheme

A number of the examples above do provide useful guidance on how a monitoring scheme could be designed to help assess the effectiveness of restoration measures. In restoration science, Before-After-Control-Impact (BACI) studies are viewed as the best practice approach in enabling a quantitative assessment of the effectiveness of measures (Conquest, 2000). In the scheme design, it is also important to identify the objective of the restoration work (in SMART terms) and what specifically needs to be measured in order to enable assessment of the target for restoration and quantify the success of the measure in achieving it.

The most effective assessments of schemes identified above included some elements of the use of replicated control and impact sites where measures are either carried out or not and repeated surveys of those sites over time to look at change. Less common in most studies, is any long-term monitoring (> five years) either prior to a restoration measure being carried out, to establish the baseline conditions or subsequent monitoring of sustained or long-term effectiveness of measures. It also became apparent when discussing monitoring in the interviews that where data has been collected it usually isn’t available beyond individuals directly involved and there was a lack of resources to write-up or share this information.

4 Conclusions and recommendations

4.1 Conclusions

This report has provided an overview of the effectiveness and application of lake shoreline restoration techniques. The work carried out an evidence review combining literature searches with an expert survey and interviews with practitioners to examine the evidence around lake shoreline restoration in the UK and internationally. The objectives of the project were:

1. Research and describe the range of shoreline restoration techniques that could be applied to English lakes;

2. Systematically evaluate the effectiveness of the different techniques, both from a lake functioning, and biodiversity perspective, including in-lake and lake edge species;

3. Provide information on application of techniques (this can include links to existing available guidance), the sustainability of techniques and their longevity and requirements for maintenance, and, if readily available, information on costs per shoreline length or area of habitat;

4. Describe and review any monitoring that has, is, or could be done to evaluate their effectiveness in the long-term;

5. Suggest any novel techniques for shoreline restoration now and in the future, especially considering likely impacts of climate change (e.g., increased winter rainfall / summer storminess in some areas using the latest UKCIP projections);

6. Suggest any future trialling of techniques required - including potential locations, if appropriate;

7. Evaluate gaps in knowledge and where further evidence would be most beneficial.

As part of the evidence review, we have largely addressed objectives one to four and objective seven. Although it must be acknowledged that limited information found for some techniques restricted our ability to fully ‘answer’ the objectives. Relatively little information was found on identifying novel techniques (objective five) or where trialling of techniques is required (objective six) and additional work may be required here.

Drawing together the findings from this review there are a number of key conclusions that can be made about lake shoreline restoration:

Range of techniques and applications

The evidence review identified a wide range of techniques and case studies of lake shoreline restoration being carried out in the UK, central Europe and North America. They cover techniques that address a range of the key pressures on lake shorelines, however, it is clear from the review that there is more evidence of shoreline restoration techniques being used to address certain pressures. In particular, reedbed creation and restoration has much more information on application and effectiveness than measures designed to address drainage or abstraction pressures. A focus on specific pressures was also somewhat geographically aligned, with most focus from North American examples being around replacing hard engineering ‘sea walls’ for erosion control on shorelines which have been developed for private housing.

Importance of good design

Discussions during the practitioner interviews identified the importance of good initial design work in the successful choice and implementation of measures. This is needed to take into account the site-specific context of the work and the likely challenges surrounding appropriate application of techniques. Experience from North America focussed on erosion control, emphasised the need to consider the wave energy of the environment utilising specific tools to quantify and design the measure. Best-practice in river restoration techniques also provides additional generic guidance in this area, particularly the principles of the decision support framework set out by Roca et al. (2017) to address bank erosion issues.

Access to information

As part of the process of the review, it became clear that despite a range of activities being undertaken in the area, very little information on lake shoreline restoration techniques, their application and effectiveness was available in the published literature. Discussions with practitioners, repeatedly highlighted the interest in a better understanding of what shoreline restoration activities were being undertaken by other organisations. Skills sharing and understanding the practical implementation of techniques was highlighted in an interview with a North American practitioner as a knowledge gap that deserved more attention.

Lack of monitoring for effectiveness

A common theme across all the techniques covered was the lack of published and peer-reviewed evidence for the effectiveness of measures, particularly over the longer term. Ogdahi and Steinman (2014) noted that despite the ever-growing proliferation of aquatic habitat restoration schemes worldwide, including ones to restore lake shorelines, few evaluate the longer-term ecological outcomes of such restoration efforts. For example, Hartig et al. (2011) in a survey of the ecological effectiveness of 38 soft shoreline (both rivers and lakes) engineering projects in the Detroit River-western Lake Erie catchment found that only six schemes had some quantitative assessment of ecological effectiveness, while the remaining projects had only qualitative assessment through visual inspections. These findings are in line with our experience during the review, most assessments, if made were qualitative in nature and, typically, only carried out for a few years post implementation.

The evaluation and documentation of restoration of freshwater habitats is considered critical for guiding adaptive management, demonstrating benefits to funding agencies and the general public, as well as improving the collective knowledge base of restoration techniques and monitoring strategies (Palmer et al., 2007). In one case study, examining the response of the aquatic macrophyte community to a $10 million project to restore the wetlands and stabilise the southern shoreline in Muskegon Lake, Michigan in the Great Lakes region, Ogdahl and Steinman (2014), found that even four years of sampling was still too short a timeline to properly assess the ecological response to the lake shoreline restoration measures. However, Isley et al. (2018) did assess that over a period of twenty years the total economic value generated by the Muskegon Lake restoration programme was nearly six times the initial lake restoration spending outlay. Responses from interviewees suggested that often the reason for a lack of monitoring or the continuation of monitoring over longer time periods was the lack of budget, either for any monitoring activity or for activity beyond the implementation phase of the restoration work. In some examples, routine surveillance monitoring or monitoring activities undertaken by volunteers had allowed for some continuity in monitoring over a longer period of time, but frequently these data were not reported in this context owing to a lack of resources.

4.2 Recommendations

Based on the wider conclusions of the evidence review, this report has identified the following recommendations:

- Improved skills and information sharing between practitioners. Making information on techniques, how to apply them and their effectiveness in different settings more widely available could assist in improved restoration outcomes. Learning lessons from existing projects across different organisations would provide the opportunity to create a more evidenced-based approach to the use of lake shoreline restoration;
- There is a need for an improved approach to monitoring and assessment of the effectiveness of techniques over the long term, including quantitative assessments within a statistically robust scientific design using before – after – control – impact assessment (BACI) approaches. This will require additional resource but is considered important in order to support the evidence base for the application of restoration techniques; monitoring should ideally include social and economic impacts as well as environmental impacts;
- Evidence for the creation/restoration of reedbeds and for many soft engineering techniques is relatively well established, particularly in a qualitative way. Key gaps in our knowledge and published evidence on lake shoreline restoration measures and where there may be scope to develop novel techniques are considered to be:
    - evidence to demonstrate the effectiveness of water level management on, and especially restoration of natural hydrology in wetlands adjacent to lake shorelines. There are many examples but very little published information on the potential for a relatively simple measure to enhance biodiversity and natural functioning;
    - evidence for the biodiversity and natural functioning benefits of artificial floating islands. Although there is some published data to demonstrate water quality benefits, over relatively short time periods, a better understanding is needed of how these measures can contribute to habitat provision for aquatic species;

    - the role of coarse woody debris as an effective and potentially low-cost restoration measure, this technique is well established in river restoration projects, but there is very little evidence of effectiveness as a measure for lake shorelines;
    - effective methods to manage recreational pressure on lakes and especially their shorelines and balance providing access with conservation and restoration objectives;
    - the impact of livestock and wild fowl grazing on lakeshore wetland habitats, including critical levels of stocking for specific wetland habitats and the effects of historical management on the resilience of the system;
    - a wider understanding of how the structure of in-lake plant communities contribute to the recovery and restoration of lake shorelines. Evidence from Barton Broad suggests that particular species such as *Schoenoplectus* may contribute to the structural integrity of macrophyte beds enabling diverse communities to be maintained in areas of higher physical forcing from wave action (Madgwick et al., 2011).
- Many of the techniques identified above would benefit from trialling in a UK context, under conditions where the scheme design permits a more robust assessment of the effectiveness of the measure to be undertaken. For example, by using Before-After-Control-Impact (BACI) type approaches with multiple years of data.

5 Acknowledgements

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6 Additional Resources

General

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Reedbed creation/ restoration

Bringing Reedbeds to Life:

https://ww2.rspb.org.uk/Images/bringing_reedbeds_to_life_tcm9-385799.pdf

South Cumbria Rivers Trust Reedbed Restoration:

https://scrt.co.uk/what-we-do/habitat-improvement/reedbed-restoration/

Soft engineering (replacements for hard engineering)

Michigan Natural Shoreline Partnership guidance on bio-engineering methods to control lake shoreline erosion (https://www.mishorelinepartnership.org/)

Living Shorelines Academy (https://livingshorelinesacademy.org/index.php/learn) promotes ‘living shorelines for property owners’ and gives advice on ‘designing, construction and permitting of living shorelines’

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8 Appendices

Appendix 1 Expert survey

Lake Shoreline Restoration Expert Survey revised

Page 1: Introduction

UK Centre for Ecology & Hydrology

This survey is being carried out by the UK Centre for Ecology & Hydrology as part of a review of lake shoreline restoration techniques for Natural England. The aim of the project is to carry out a systematic evaluation of existing and novel techniques that have or could be used to restore or improve shoreline habitats for both artificial and natural lakes. The collation of this information will be used to inform plans for the future recovery of shoreline habitats and natural processes that could lead to improvements in the condition of lakes. The focus of this work is to improve lake shoreline biodiversity and natural functioning, which includes wetland functioning and lake functioning. In this survey, we are interested in collating your views and expertise on the topic of shoreline pressures and restoration techniques that we can use to inform the wider review.

The data collected as part of this survey will only be used at an aggregated level, based on the categories used in section four, where appropriate. We are not collecting personal data as part of the survey, but if you are willing to be contacted to discuss your responses in more detail, via a follow-up conversation, we will store your contact details on a secure sever and only use them for the purposes of this project. These details will be deleted following the completion of the project.

1 / 14

Page 2: Knowledge of lake shoreline pressures and restoration measures

1. Please identify your familiarity with the following lake shoreline restoration techniques (1= never heard of it, 5 = know a lot about it)

Please don't select more than 1 answer(s) per row.

	1	2	3	4	5	Don't know
Coarse woody debris						
Floating islands						
Tree/ scrub management to enhance or reduce shading						
Fencing or exclosures for grazing						
Fencing or exclosures to limit access						
Reed bed/ fen restoration in the riparian zone (e.g. using dredged sediment, coir rolls pre-planted with reeds)						
Reedbed restoration in open water						

2 / 14

Artificial embankments (e.g. log piling/ revetments, willow fascines/ bundles)	☐	☐	☐	☐	☐	☐
Shoreline reprofiling	☐	☐	☐	☐	☐	☐
Offshore structures to dissipate wave energy	☐	☐	☐	☐	☐	☐
Shoreline structures to dissipate wave energy	☐	☐	☐	☐	☐	☐
Drain blocking/ rewetting	☐	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐	☐

If you selected 'Other', please specify. Any additional comments

3. Where you have used, considered using or reviewed them, please rate how effective you think these techniques have been for improving lake functioning, the associated biodiversity of the lake and its shorelines (1 = poor effectiveness, 5 = highly effective)

Please don't select more than 1 answer(s) per row.

	1	2	3	4	5	Don't know	Haven't used this technique
Coarse woody debris	☐	☐	☐	☐	☐	☐	☐
Floating islands	☐	☐	☐	☐	☐	☐	☐
Tree/ scrub management to enhance or reduce shading	☐	☐	☐	☐	☐	☐	☐
Fencing or exclosures for grazing	☐	☐	☐	☐	☐	☐	☐
Fencing or exclosures to limit access	☐	☐	☐	☐	☐	☐	☐
Reed bed/ fen restoration in the riparian zone (e.g. using dredged sediment, coir rolls pre-planted with reeds)	☐	☐	☐	☐	☐	☐	☐
Reedbed restoration in open water	☐	☐	☐	☐	☐	☐	☐

4 / 14

Artificial embankments (e.g. log piling/ revetments, willow fascines/ bundles)	☐	☐	☐	☐	☐	☐	☐
Shoreline reprofiling	☐	☐	☐	☐	☐	☐	☐
Offshore structures to dissipate wave energy	☐	☐	☐	☐	☐	☐	☐
Shoreline structures to dissipate wave energy	☐	☐	☐	☐	☐	☐	☐
Drain blocking/ rewetting	☐	☐	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐	☐	☐

Comments

4. Ease of deployment and construction (Score)

Please don't select more than 1 answer(s) per row.

	Low	Medium	High	Don't know
Coarse woody debris	☐	☐	☐	☐
Floating islands	☐	☐	☐	☐
Tree/ scrub management to enhance or reduce shading	☐	☐	☐	☐
Fencing or exclosures for grazing	☐	☐	☐	☐
Fencing or exclosures to limit access	☐	☐	☐	☐
Reed bed/ fen restoration in the riparian zone (e.g. using dredged sediment, coir rolls pre-planted with reeds)	☐	☐	☐	☐
Reedbed restoration in open water	☐	☐	☐	☐
Artificial embankments (e.g. log piling/ revetments, willow fascines/ bundles)	☐	☐	☐	☐
Shoreline reprofiling	☐	☐	☐	☐
Offshore structures to dissipate wave energy	☐	☐	☐	☐
Shoreline structures to dissipate wave energy	☐	☐	☐	☐
Drain blocking/ rewetting	☐	☐	☐	☐
Other	☐	☐	☐	☐

5. Long-term sustainability/ maintenance (Score)

Please don't select more than 1 answer(s) per row.

	Low	Medium	High	Don't know
Coarse woody debris	☐	☐	☐	☐

6 / 14

Floating islands	☐	☐	☐	☐
Tree/ scrub management to enhance or reduce shading	☐	☐	☐	☐
Fencing or exclosures for grazing	☐	☐	☐	☐
Fencing or exclosures to limit access	☐	☐	☐	☐
Reed bed/ fen restoration in the riparian zone (e.g. using dredged sediment, coir rolls pre-planted with reeds)	☐	☐	☐	☐
Reedbed restoration in open water	☐	☐	☐	☐
Artificial embankments (e.g. log piling/ revetments, willow fascines/ bundles)	☐	☐	☐	☐
Shoreline reprofiling	☐	☐	☐	☐
Offshore structures to dissipate wave energy	☐	☐	☐	☐
Shoreline structures to dissipate wave energy	☐	☐	☐	☐
Drain blocking/ rewetting	☐	☐	☐	☐
Other	☐	☐	☐	☐

6. Cost effectiveness (Score)

Please don't select more than 1 answer(s) per row.

	Low	Medium	High	Don't know
Coarse woody debris	☐	☐	☐	☐
Floating islands	☐	☐	☐	☐

7 / 14

Tree/ scrub management to enhance or reduce shading	☐	☐	☐	☐
Fencing or exclosures for grazing	☐	☐	☐	☐
Fencing or exclosures to limit access	☐	☐	☐	☐
Reed bed/ fen restoration in the riparian zone (e.g. using dredged sediment, coir rolls pre-planted with reeds)	☐	☐	☐	☐
Reedbed restoration in open water	☐	☐	☐	☐
Artificial embankments (e.g. log piling/ revetments, willow fascines/ bundles)	☐	☐	☐	☐
Shoreline reprofiling	☐	☐	☐	☐
Offshore structures to dissipate wave energy	☐	☐	☐	☐
Shoreline structures to dissipate wave energy	☐	☐	☐	☐
Drain blocking/ rewetting	☐	☐	☐	☐
Other	☐	☐	☐	☐

7. Comment on cost effectiveness (e.g. costs per unit area or factors that influence cost like need for access by specialist machinery). *Please specify the technique(s) this applies to.*

8. Are there other considerations needed for these measures (e.g. Legal implications or constraints, risk of introducing invasive species, landscape impacts, other benefits beyond

8 / 14

biodiversity). *Please specify the technique(s) this applies to.*

9. Are there alternative techniques that could be used as replacements for hard engineering, wetland restoration, bank erosion or for improving biodiversity in artificial waterbodies? (Please specify)

Page 3: Novel techniques for shoreline restoration

10. Are you aware of any novel lake (or analogous) shoreline or lake wetland restoration techniques that we should include in our review? Please provide links to sources of information, if appropriate.

Page 4: About you

11. What type of organisation do you work in? Please tick all that apply

- ☐ University
- ☐ Government Agency
- ☐ Non-governmental organisation or charity
- ☐ Research Centre
- ☐ Commercial/business
- ☐ Student
- ☐ Other

Please elaborate on your response

12. What is the geographic coverage of your work on lakes within your organisation? Please tick all that apply

- ☐ Local catchment scale (e.g. District or County scale)
- ☐ Regional level (e.g. UK regions)
- ☐ National level (e.g. UK nations or UK as a whole)
- ☐ International (e.g. European, Global)

Please elaborate on your response

11 / 14

Page 5: Follow up

13. If you would be willing or interested to discuss some of these responses in more detail, in a short follow up discussion, please leave a contact email address or phone number here.

14. Any further comments on your experience/ knowledge of lake shoreline and lake wetland habitat restoration?

Page 6: Final page

Thank you very much for taking the time to complete this survey. It will inform our review of lake shoreline restoration techniques for Natural England and lead to improved implementation of lake shoreline habitat restoration techniques on the ground.

If you would like to discuss this survey or other aspects of this project please contact Ellie Mackay.

Appendix 2 Expert survey results

This appendix provides an overview of the online survey results. Respondents were asked a range of questions relating to a list of shoreline restoration techniques, scores for each technique are provided under the different assessment criteria below.

1. Familiarity with techniques

Technique	Average score (1= never heard of it, 5 = know a lot about it)
Coarse woody debris	3.7
Floating islands	3.6
Tree/ scrub management to enhance or reduce shading	4.2
Fencing or exclosures for grazing	3.9
Fencing or exclosures to limit access	3.8
Reed bed/ fen restoration in the riparian zone (e.g. using dredged sediment, coir rolls pre-planted with reeds)	3.5
Reedbed restoration in open water	3.0
Artificial embankments (e.g. log piling/ revetments, willow fascines/ bundles)	3.4
Shoreline reprofiling	3.6
Offshore structures to dissipate wave energy	2.7
Shoreline structures to dissipate wave energy	3.5
Drain blocking/ rewetting	2.3

The techniques that respondents were most familiar with were tree/ scrub management and the use of fencing/ exclosures to limit grazing. Techniques associated with drain blocking or rewetting of habitat and the use of offshore structures to dissipate wave energy were least familiar.

2. Effectiveness of techniques when applied or considered for application

Technique	Average score (1 = poor effectiveness, 5 = highly effective)
Coarse woody debris	5.0
Floating islands	3.7
Tree/ scrub management to enhance or reduce shading	4.8
Fencing or exclosures for grazing	4.7
Fencing or exclosures to limit access	4.7
Reed bed/ fen restoration in the riparian zone (e.g. using dredged sediment, coir rolls pre-planted with reeds)	4.5
Reedbed restoration in open water	3.6
Artificial embankments (e.g. log piling/ revetments, willow fascines/ bundles)	4.4
Shoreline reprofiling	5.0
Offshore structures to dissipate wave energy	3.7
Shoreline structures to dissipate wave energy	5.0
Drain blocking/ rewetting	NA

The use of coarse woody debris, shoreline re-profiling and shoreline structures to dissipate wave energy were considered to be the most effective measures. Knowledge of the effectiveness of drain blocking and rewetting was negligible.

3. Ease of deployment and construction

Technique	High (frequency of response)	Medium	Low	Don't Know
Coarse woody debris	3	1	3	2
Floating islands	4	2	2	1
Tree/ scrub management to enhance or reduce shading	4	2	1	2
Fencing or exclosures for grazing	2	4	1	1
Fencing or exclosures to limit access	2	4	1	1
Reed bed/ fen restoration in the riparian zone (e.g. using dredged sediment, coir rolls pre-planted with reeds)	3	2	1	2
Reedbed restoration in open water	2	2	2	2
Artificial embankments (e.g. log piling/ revetments, willow fascines/ bundles)	3	1	1	3
Shoreline reprofiling	3	3	0	2
Offshore structures to dissipate wave energy	1	2	1	4
Shoreline structures to dissipate wave energy	2	2	1	3
Drain blocking/ rewetting	0	1	0	6

When asked about the ease of deployment and construction of measures, tree/ scrub management and float islands scored the highest for this measure, followed by fencing and shoreline re-profiling. Coarse woody debris had mixed views with respondents, with one third scoring it high for this measure and another third scoring it low. Offshore structures and drain blocking/ rewetting had the highest frequency of don't knows.

4. Long-term sustainability and maintenance

Technique	High (frequency of response)	Medium	Low	Don't Know
Coarse woody debris	3	3	1	1
Floating islands	2	4	1	1
Tree/ scrub management to enhance or reduce shading	3	3	1	1
Fencing or exclosures for grazing	1	3	3	0
Fencing or exclosures to limit access	2	3	3	0
Reed bed/ fen restoration in the riparian zone (e.g. using dredged sediment, coir rolls pre-planted with reeds)	2	2	2	1
Reedbed restoration in open water	1	2	2	2
Artificial embankments (e.g. log piling/ revetments, willow fascines/ bundles)	3	2	2	1
Shoreline reprofiling	2	0	3	2
Offshore structures to dissipate wave energy	0	1	2	4
Shoreline structures to dissipate wave energy	4	0	1	3
Drain blocking/ rewetting	1	0	0	5

Coarse woody debris, tree/ scrub management scored the highest for long-term sustainability and maintenance requirements amongst the respondents. Offshore structures to dissipate wave energy and drain blocking/ rewetting had the highest frequency of don't knows.

5. Cost-effectiveness

Technique	High (frequency of response)	Medium	Low	Don't Know
Coarse woody debris	3	2	2	1
Floating islands	3	2	2	1
Tree/ scrub management to enhance or reduce shading	3	2	2	1
Fencing or exclosures for grazing	3	2	1	1
Fencing or exclosures to limit access	4	1	2	1
Reed bed/ fen restoration in the riparian zone (e.g. using dredged sediment, coir rolls pre-planted with reeds)	1	4	1	1
Reedbed restoration in open water	2	2	1	2
Artificial embankments (e.g. log piling/ revetments, willow fascines/ bundles)	2	3	1	1
Shoreline reprofiling	3	1	1	2
Offshore structures to dissipate wave energy	1	1	1	4
Shoreline structures to dissipate wave energy	2	3	1	2
Drain blocking/ rewetting	0	0	0	6

Fencing, tree/ scrub management, coarse woody debris and floating islands were considered the most cost-effective measures by the survey respondents.

6. Wider consideration for the application of shoreline restoration techniques

When asked about the need for wider considerations for implementing lake shoreline restoration measures, respondents highlighted issues such as risks of introducing or spreading invasive species and the need to consider protected species at sites. Using local materials for interventions was also suggested to try and ensure local genetic diversity of species used and other considerations around maintaining the natural integrity of the site and minimising transport and other environmental costs. It was also highlighted that some measures are likely to require for planning permission and consent to undertake the work. Ensuring that nutrient concentrations at sites had been appropriately reduced before implementing measures was also raised as an important consideration.

7. Alternative techniques for hard engineering, wetland restoration, bank erosion or improving biodiversity in artificial waterbodies

A number of techniques were listed under this section, these included artificial nature-based structures as shelters for fish and habitat improvement in artificial water bodies;

coir roll and fascines are suggested for low energy areas; rock rolls, rock mattresses, Aqua rock bags can be used instead of large block stone, gabions, bitumen, concrete and rock where wave action is focussed.

Appendix 3 Broads Authority Protection Barrier Locations

Environmental Protection Barrier

The Broads Authority has numerous environment protection structures throughout the Broads ranging from silt curtains (wave barriers) to geotextile tube structures. These require visual checks to ensure the structures are maintained in good and safe condition. The Rangers over a year will every quarter while on their regular patrols visual assess the condition of any structures and raise any issues that require maintenance or replacement. Environment Officer twice a year will carry out a more detailed check of the structures and implement any necessary repairs discovered. The table below has a list of these structures, providing site names and location, its description and the relevant Environment Officer to contact regarding any faults found during quarterly visual inspections.

Site Name	Description of Structure	Map	River
Hall Fen, Irstead	A Nicospan structure holding dredged material; vegetated and protected with gooseguard & yellow hazard posts	Ant 1.1 EP Structures Sat & Ant 1.2 EP Structures	Ant
Pleasure Island, Barton Broad	Piled edge on island	Ant 3.1 & 3.2 EP Structures	Ant
Hill Common, Hickling Broad	Nicospan, floats and tall goose guard held in place with stakes	Hickling Broad EP Structures 1.0 & 1.1 Sat	Thurne
Studio Bay Wave Barrier, Hickling Broad	Wave barrier & inner line of Nicospan with posts, there are a line of weights at the bottom of the silt curtain and mud weights at each join, with a double float and short goose guard on the surface	Hickling Broad EP Structures 1.0 & 1.1 Sat	Thurne
Church Hill Bay, Hickling Broad	Wave barrier & inner line of nicospan with posts	Hickling Broad EP Structures 1.0 & 1.1 Sat	Thurne
Chara Bay, Hickling Broad	TO BE INSTALLED 2018/19- geotextile tube structure, filled and covered with dredged sediment, planted and protected with weighted silt curtain with floats and gooseguard on the Eastern side and goose guard fixed with stakes on the Western side	Hickling Broad EP Structures 1.0 & 1.1 Sat	Thurne
Duck Broad, Hickling	Planted gabion baskets with goose guard	Duck Broad EP Structure 1.0 & 1.1	Thurne
Womack Island	Line of Nicospan with wooden posts	Thurne 1.0 &1.2 EP Structure	Thurne
Anchor St, Coltishall	Line of Nicospan with posts	Bure1.0 EP Structures & Bure 1.1	Bure
Bridge Broad	Metal structure (similar to gabion baskets)	Bure1.0 EP Structures & Bure 1.1	Bure
Salhouse Broad	Vegetated geotextile tubes holding dredged sediment; with gooseguard fixed to stakes	Bure 2.0 EP Structures & 2.1	Bure

Rockland Broad	Slit curtains with goose guard on top, chains and weights	Yare 1.1 EP Structures & 1.2	Yare

Appendix 4 Delta Lake Llanelli, Shoreline habitat enhancement

Cyfoeth Naturiol Cymru Natural Resources Wales

Cyngor Sir Gâr Carmarthenshire County Council

Delta Lake Llanelli, Carmarthenshire Shoreline Habitat Enhancement

The Lake

Delta lake is an artificial lake in an urban, post-industrial setting in the coastal town of Llanelli in south west Wales, national grid reference is SS506 906. It's owned and manged by Carmarthenshire County Council. The lake was formed by the construction of a tidal flood defence structure as the downstream end of the Dafen river. The site supports a small, vulnerable water vole population and is also used by otters and wildfowl. Dog walkers and joggers frequent the grassy paths surrounding the lake.

Habitat Enhancement

During January and February 2011, the Environment Agency Wales (as was) and Carmarthenshire County Council undertook a partnership project to enhance the shoreline of the lake, with a particular objective to increase habitat availability for the small population of water voles on the north shore. This shore was largely devoid of marginal habitat due to erosion by wave wash and unsuitable bank profiles.

The project entailed the installation of plain and pre-planted coir rolls to provide bank protection and marginal habitat. Protective netting placed over planted rolls for the first year to protect the young plants from being grazed by wildfowl. A total of 220m of shoreline was enhanced.

Scheme design

The scheme was designed and installed by Salix, a local specialist bioengineering contractor. Locations for coir roll installation were agreed on site, based on where maximum benefit was anticipated. The map and schematic cross sections below provide further information on scheme design.

The work took one week to complete using a tracked excavator and two personnel.

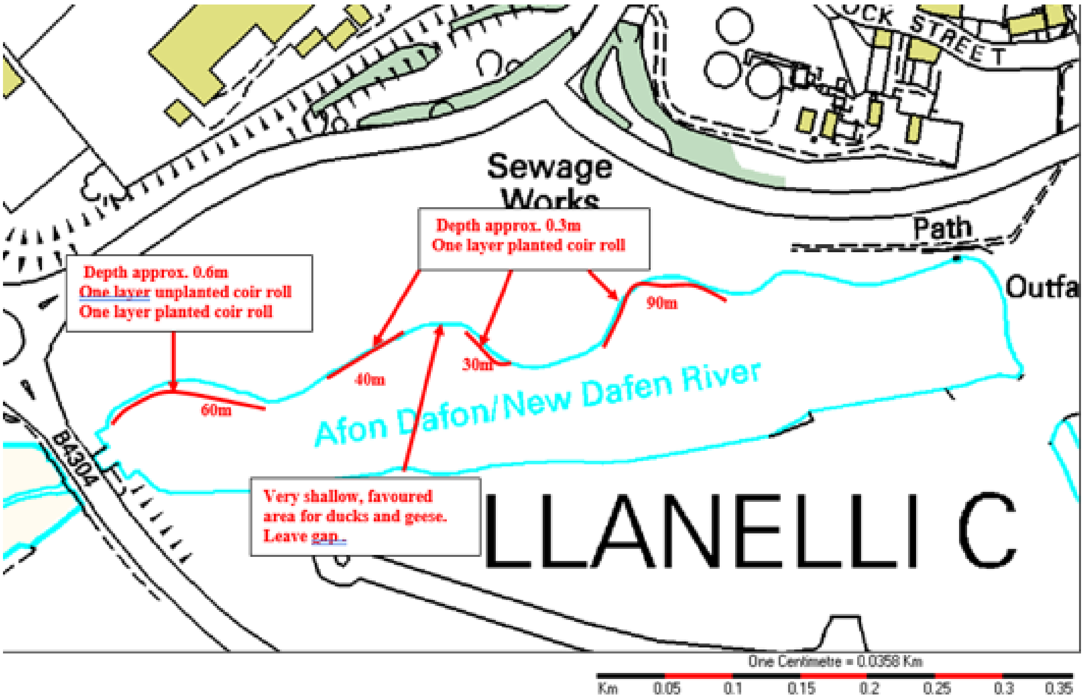

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Figure 1 Map of coir roll installation at Delta Lake Llanelli

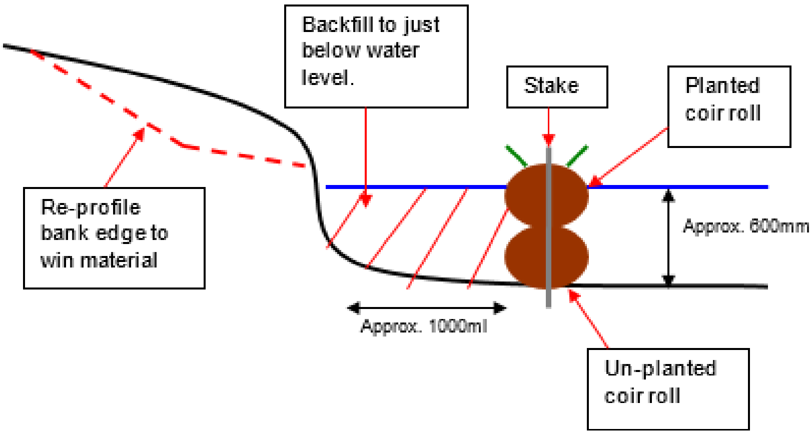

Figure 2 Coir roll installation in deeper water (approx. 0.6m water depth)

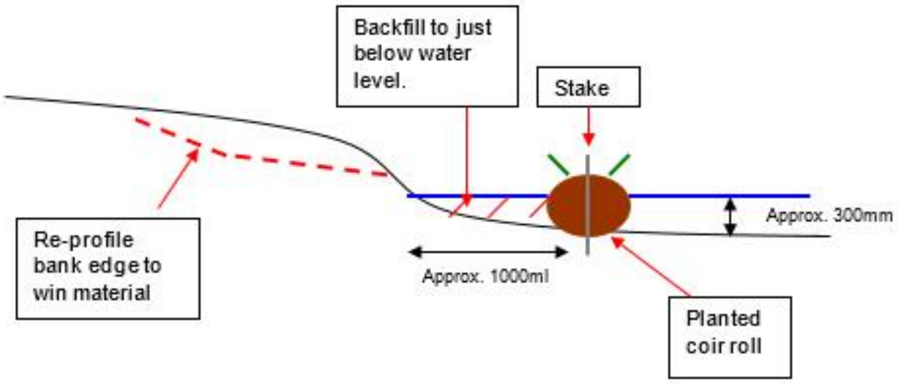

Figure 2 Coir roll installation in shallow water (approx. 0.3m water depth)

Cost

Materials (coir rolls, stakes, fencing) including delivery - £7,700

Installation - £5000 (excavator and two personnel for one week)

Total -£12,700

(All costs exclude VAT)

Results

The project has succeeded in providing shoreline habitat along the north shore of the lake which has benefitted the water voles, wildfowl and other wildlife as well as improving the aesthetics of the site. The vegetation in some areas took longer to establish, however within two or three growing seasons all sections were growing well. The vegetated margin is now up to approximately 3m wide on most sections, providing habitat and protection from wave wash.

Before: 2009

After: 2018


2009


2022


2009


2022


2009


2022


2011


2022


2011


2022

INVESTORS IN PEOPLE

Athena SWAN Bronze Award

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