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CONNECTING WETLANDS

ASSESSMENT OF THE USE OF WETLANDS BY FISH AND GUIDELINES FOR FISH MANAGEMENT IN WETLANDS IN THE BROADS

Broads Authority
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Environment Agency

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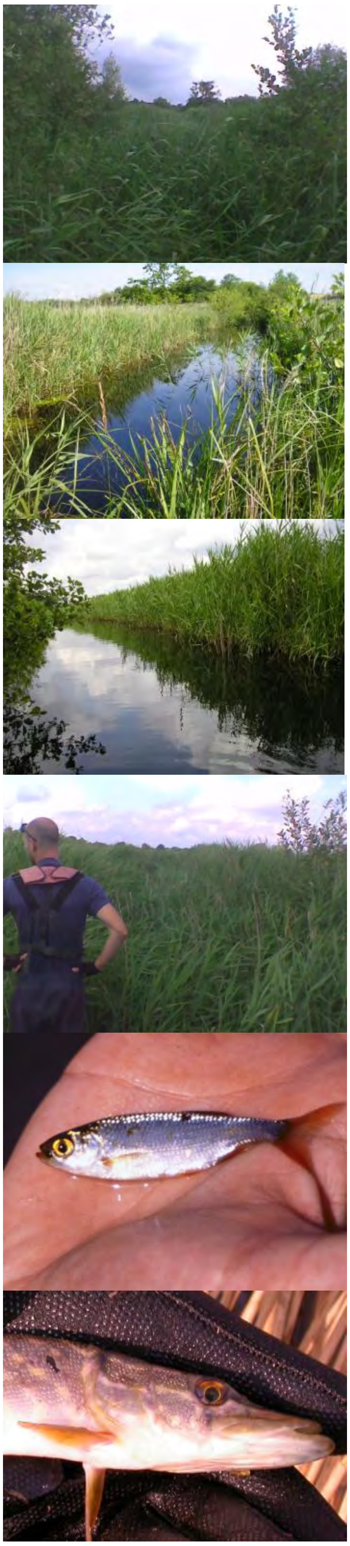

Final Report

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EXECUTIVE SUMMARY

This project had two principal aims: 1) how and why fish, including Eels use wetlands, with particular reference to fen dykes, reed-beds and The Broads and 2) provide guidelines for dyke and wetland management to benefit fish populations. This was to be achieved through desk-based review of literature on fish and wetlands, distillation of previous experiences from fisheries surveys within the Broads over the last 25 years, specific surveys of fish populations in four river-connected and two isolated fens and face-to-face interview with the conservation managers of wetland sites to determine the current scope of management. The fens involved were Cockshoot, Woodbastwick and Ebb & Flow Fens in the catchment of the River Bure and Barton, Buttle Marsh and Reedham Fens in the catchment of the River Ant. Of these, Barton and Buttle Marsh Fens were classed as isolated without a direct connection to a river or broad. The results of the surveys are detailed in the separate supporting document 'Technical Summary of the Connecting Wetlands project'.

Review of Literature

Literature review was conducted using the Aquatic Sciences and Fisheries Abstracts (ASFA) database as well as more general search engines and literature already held on fish in wetlands and wetland functioning. Whilst information from across the world, in a variety of systems was used to establish general principles there was a notable paucity of information relating to fish in European wetlands of direct relevance to the Broads. Notable exceptions were the recent targeted fisheries research in France and work in the UK largely focussed on the potential fish prey resource for Bittern *Botaurus stellaris*, an endangered piscivorous bird. Current concern over the decline of (European) Eel *Anguilla anguilla* appears not to have been fully extended into UK wetlands in the form of specific research despite the potential of this habitat for the species and its value as a prey species of Bittern. For ease of dissemination information was structured into a number of themes 1) dyke functioning 2) fish assemblage structure 3) fish density & biomass 3) seasonal & diel fish movements and 4) fish habitat use & preferences.

The Broads Wetland

In simple terms, the Broads wetland may be defined as a complex of rivers, shallow lakes and fens, peatlands and marshland that are drained by a network of ditches (dykes) of variable quality of water and emergent and submerged flora and attendant fauna. It is the management of the fens (base-rich [pH >5.5] mires on peat and wet mineral soils) and the ditches within them that was the primary focus of this report. In fens, vegetation succession typically leads to domination by scrub and finally by carr woodland. 'Open' fen vegetation often dominated by beds of Reed *Phragmites australis* is of significant conservation value and may be maintained by management, mostly involving cropping of one form or another. The total length of dyke within the Broads fens has yet to be quantified, but even a conservative estimate would suggest many 100's of kilometres. As such, these dykes are a significant resource for wetland flora and fauna, including fish.

Dyke Functioning

Relatively little is known about how dykes function, although research in the Netherlands suggests that the established trophic change and alternative stable states models for shallow lakes are effectively mirrored in ditches. In functional terms, dykes may thus be thought of as 'linear lakes or ponds' with a high edge to open water ratio. There is an important difference between lakes and ditches however, and that is in ditches, increased nutrient loading (to

concentrations of 200-400 µg l^{-1} TP) tends to result in domination of floating-leaved Duckweeds *Lemna* spp. rather than phytoplankton. Importantly, the duckweed-dominated state appears to be more resistant to reduction in nutrient concentration than in the equivalent shallow lake.

A surface blanket of Duckweed may lead to deoxygenation of the water column underneath with consequences for fish. Equally, at lower nutrient concentrations dense populations of submerged plants (macrophytes) may also lead to deoxygenation as a result of oxygen uptake by plants at night. Dramatic fish-kills in the manner described in shallow lakes in the Broads (e.g. at Alderfen, Upton and Cromes Broads) may result. In turn, this may impact on the central role of fish in trophic functioning through both 'top-down' or 'bottom-up' control of the food web. In other words, only fish that are specifically adapted to low oxygen concentrations such as Tench *Tinca tinca* may live permanently in such conditions and these may have little effect on trophic interactions.

There is evidence from wetland sampling around the UK and in lakes and ponds in the Broads that where systems are isolated with the potential for difficult conditions, be it low oxygen, high unionised ammonia concentrations or high salinity (perhaps through tidal incursion) then fish assemblages may become extremely simplified with only a few species (perhaps 1-3) present. This could be Tench and perhaps (Northern) Pike *Esox lucius* and Rudd *Scardinius erythropthalmus* in plant-dominated habitats or Sticklebacks (Three-spined *Gasterosteus aculetus* and/or Ten-spined *Pungitius pungitius*) and Eels in more saline habitats. Intuitively, both fish density and biomass are likely to be low in such circumstances.

Fish Assemblages, Abundance & Movements

Sampling in the isolated Buttle Marsh and Barton Fens as part of this project indicated that at these sites the fish assemblage and its constituent populations were viable, although rather different in character. The former, for example, was relatively species poor and supported low overall density with some evidence that the Rudd populations was sustained by stock in a recreational angling pond in the system. The six-species assemblage at Barton Fen on the other hand was sampled at high density (> 1 ind. m^{-2}). This appeared to be possible as a result of the large size (up to 15 m wide) of the watercourses in the system, which are likely to provide permanent habitat.

The requirement for permanent refuge habitat is a critical recurring theme in the literature. Where this function cannot be provided within the fen wetland system itself, many individuals and species will have to disperse elsewhere to survive. Such seasonal movement of fish is common in many wetlands, with individuals moving from a permanent watercourse such as a river or lake into other wetland habitats to fulfil a particular function, be it to spawn with young remaining in these habitats that then function as nurseries, or to feed, or to escape predators. Movement of migrant fish from a permanent habitat offers the prospect of dramatically increasing local fish species richness (~10 species commonly occur in the Broads and other lowland wetlands) density and biomass within the dyke system. Limited evidence suggests that dykes in the Broads may support high density (> 1 ind. m^{-2}) compared to other waterbodies, but that biomass tends to remain low (50-100 kg ha^{-1}). This may however be partly a function of the sampling technique adopted, which may not sample large fish efficiently.

However, the circumstances surrounding how and why fish move appear to be largely specific to the situation and it is difficult to predict if a site will receive migrant fish. For example, the river-connected Ebb & Flow, Reedham and Woodbastwick Fens all supported high densities of young fish of several species in the summer months, with the supposition that Roach in particular had accessed the sites to spawn. The Ebb & Flow and Reedham fens support good cover of submerged macrophytes which appeared to act as refugia for the YOY fish resulting from spawning. Cockshoot Fen on the other hand supported few fish in the summer, but did support dense winter aggregations of fish. This was also the case at the nearby Woodbastwick Fen. A common characteristic of these latter two sites is the presence of carr woodland, which may offer a suitable winter refuge by reducing the risk of predation from above (i.e. by birds).

Diel movement is a key theme in lake fish ecology (where it is often horizontal from edge to open water) and seems likely to occur in dykes, albeit perhaps more pronounced along dykes or between dykes and connected waterways. However, understanding of the frequency of movements into wetland dykes remains poor without specific sampling. Nevertheless, some researchers have shown that movements in/out of similar backwaters may be far more frequent than expected, with movement of some species throughout the 24-hour period linked to conditions in the main river. Studies of Eels have illustrated a tendency to refuge in particular habitats during the day with ranging movements at night and it remains possible that Eels are particularly prone to move between fen dykes and other habitats. There is also some suggestion of habitat selection varying with lifestage with immature specimens preferring shallow waters with macrophytes and large, pre-spawners selecting deep, open waters. Such patterns could not be confirmed by the current sampling with virtually all specimens seemingly restricted to daytime refuge habitats in littoral reed.

Given their reputation for colonisation, the penetration of Eels into dyke systems was perhaps not as expected, with considerably greater numbers in river-connected compared to isolated fens and with some evidence of higher density closer to river connections (although this may have been partly governed by selection of sites). Workers in France have also indicated limited penetration of Eels into dyke systems with work in the UK describing a similar situation in reed-beds.

For other species of fish, a little more is known on the potential extent of movement. In the Broads, previous work has indicated that Roach for example are capable of undertaking seasonal movements of several kilometres to and from suitable habitat. This was mirrored in the sampling in the dykes with winter aggregations of young fish recorded at 1 km or more from the likely source connection. Clearly, given an appropriate connection some species at least may exploit the full extent of the available habitat.

Fen Management: Implications & Recommendations

It may be concluded that integrated wetlands with connection of fen dykes to larger permanent watercourses such as rivers or lakes offer the best prospect of maximising fish species richness, density and biomass within the wider system by allowing fish to utilise and exploit the full range of habitats available to meet their needs at different life-stages. However, this does not mean that increasing connectivity is always appropriate. Opening connections exposes the receiving fen dyke network to nutrients, sediments, salts and the aquatic flora and fauna of the wider system. The latter may include alien plants and animals and competitors and predators for the indigenous fish fauna of the dyke network. Any of these factors may jeopardise the conservation value of the fen dyke system especially if it is in good condition with a variety of submerged plants, attendant invertebrates and an appropriate fish assemblage. Careful specific consideration must be given to every possible connection scheme to determine likely positive and negative impacts.

Other forms of management may also play a crucial role in maximising the value of a site for fish. Without management, the continuous rain of leaves and twigs where there are overhanging trees may be sufficient to lead to deeper, anoxic sediments, that may ultimately lead to 'in-fill' and succession and a loss of aquatic habitat. A similar process may also occur in open channels where macrophyte growth extends throughout the channel. Moreover, the duckweed-dominated state appears to be more resistant to reduction in nutrient concentration than in the equivalent shallow lake, suggesting an even more intense perturbation through management such as invasive dredging may be required.

The immediate effect of management in the form of weed-cutting, dyke-edge management and especially dredging is likely to have a detrimental effect on fish. In addition to the removal of spawning and foraging habitats, the direct loss of fish may also occur, particular where these are small or associated with the plants that are being removed. Consequently, any intensive management operations must be conducted sensitively. The review of management regimes at all fens sampled as well as in the wider locality by the principal conservation organisations in the area (Broads Authority, Natural England, Norfolk Wildlife Trust and RSPB) suggested that management was indeed generally conducted in an appropriate manner for fish or rather that there was no evidence that the management regimes were likely to have a great impact on the current fish communities or usage of the fens.

Dredging and dyke edge clearance was undertaken on long rotation (5 to 15 year) with the length managed in any one year being relatively small (e.g. 1 km at Hickling) and thus only relatively small areas (<14% in the case of Hickling) were affected at one time, with likely minimal impacts on fish. Management seemed to produce a suitable habitat mosaic of emergent, submerged and overhanging vegetation for the rather adaptable fish species occurring in the sites. In other words there was little suggestion that any habitat feature such as spawning substrate, fry refuge habitat or winter refuge habitat was likely to limiting. There may be circumstances where removal of a particularly favoured bush or clump of sedges that operates as a 'traditional' wintering or spawning site does have a short-term local impact. Seeking specialist advice may be one way to avoid this effect, but more realistically, observation by site staff to assess use by spawning or wintering fish may be a more effective option. A temporary solution in the form of cut branches or artificial spawning media may be effective where the specific habitat does prove to be in short supply.

Grading of dyke profiles appeared to be variably undertaken. In general this is recommended to ensure littoral vegetation does not become 'perched' during low water levels and to allow permanent access for spawning or refuging fish into the littoral margin. It is also recommended that fen entrances should be clear and open as this may encourage fish to enter dykes especially where there is some water flow. Dyke widths should also be maintained at least 2.5 m wide. Depth of water in at least some dykes must be sufficient to prevent freezing of a substantial part of the water column during particularly hard winters and to ensure there is no loss of dissolved oxygen. Deeper sections should at least 1 m deep and preferably more. Provision of some significantly wider and deeper dykes may also be important in isolated systems that are to be maintained in isolation, to provide more permanent habitats for fish. Such dykes are akin to linear open turf ponds. The current management regimes of long rotations for both dyke clearance and submerged and emergent macrophytes from channel and margin should be continued.

The broad recommendations and guidelines provided in the report are best considered as a starting point for future projects. Further sampling in a wider variety of dyke systems is required to develop further understanding of the nature of fish populations in particular circumstances (i.e. isolated vs connected, nutrient concentrations, macrophyte populations, management regimes). It is recommended that where this is achieved that simultaneous monitoring of habitat variables is also undertaken to determine habitat associations of fish. Where actual management is conducted such as connection between a dyke system and a river or perhaps where dredging is undertaken, rigorous before and after monitoring will be required to determine the response of the fish community.

In the case of Eels, understanding their movements is likely to be crucial to both manage their populations and the habitats that support them in the most effective manner. The best means of achieving this is suggested to be through individual-based tagging studies supported by more intensive monitoring of populations, especially in response to any habitat management conducted.

5. MANAGEMENT OF WETLANDS IN THE BROADS

5.1 GENERAL EFFECTS OF HABITAT MANAGEMENT ON FISH POPULATIONS

Management of wetlands appears to be essential to provide diverse habitat for fish populations. Without management, the continuous rain of leaves and twigs where there are overhanging trees may be sufficient to lead to deeper, anoxic sediments, that may ultimately be colonised by other emergent vegetation, ultimately leading to succession and a loss of aquatic habitat. A similar process may also occur in open channels where macrophyte growth extends throughout the channel, although with intermediate succession through reed-swamp this may take longer to 'fill-in'. Equally, the immediate effect of management in the form of 'weed-cutting' and especially dredging is likely to have a detrimental effect on fish. In addition to the removal of spawning and foraging habitats, the direct loss of fish may also occur, particular where these are small or associated with the plants that are being removed.

In the UK, there is concern that management may have serious impacts on Spined Loach, a species that requires Special Areas of Conservation (SACs) (Perrow & Jowitt 2000). Mechanical weed-cutting has been demonstrated to result in the loss of at least 8% of the adult stock of the endangered Weatherfish *Misgurnus fossilis*, a similar loach species, from a drainage channel of the lower River Havel region in Germany (Meyer & Hinrichs 2000). This was considered a minimum figure, as YOY fish especially were undetected and that dredging would likely result in greater losses. The measures were thought to similarly affect Tench, a species common to the Broads.

Conversely, comparative studies of fish populations in relation to the frequency of dredging within dykes the Ouse Washes SAC also showed the benefits of invasive management relative to the risks (Perrow & Jowitt 1997, Perrow & Tomlinson 2001). Here, although species richness and overall density was poor within the dykes in both 1997 and 2001, the higher densities of fish was recorded in dykes that had undergone dredging at least one or two years previously. Dykes managed within a year of the survey, had only one species present, predominantly Ten-spined Stickleback. It is also of note that no Eels were captured in the recently managed sections. These patterns tend to reinforce that management of dykes and drainage channels should be undertaken in sections and at regular intervals as is often quoted as best practice.

The potential general effects of management on fish populations in the wetlands within the Broads are discussed below. However, this is based on primarily on observational material from the limited survey work undertaken by ECON for this and preceding projects. It therefore can only supply broad guidelines and cannot be considered conclusive and should ultimately be tested.

5.2 CURRENT MANAGEMENT REGIMES OF BROADLAND FENS

Information on the management regimes received from the site managers of the river-connected fens detailed in the Technical Summary of the Connecting Wetlands project is summarised in Table 3 below. Information from two further site managers of wetlands within the Norfolk Broads has also been included.

Table 3. Summary of the management regimes of wetland sites in the Norfolk Broads.

Cockshoot & Woodbastwick Fens – Rick Southwood, NE	
Reed Cutting	• Reed is cut commercially on a two year rotation, although as the site is not cut in its entirety, reed-cutting takes place each year on the site. In some circumstances, reed adjacent to the river is cut annually. • Sedge beds also cut commercially on a three year rotation. • The Cockshoot Fen reedbeds had been drying out and were scraped.
Dyke Management	• Dyke edges are hand cut in alternate years (water vole mitigation). • Clearance by excavator or mud-pumping conducted dependent on siltation rates, approx. 15 year cycle. Some dykes within the site cleared recently (in past three years). • Reprofiling of dykes undertaken when necessary (dykes infilling). Hand cutting regime results in slow infill by emergent macrophytes, therefore, reprofiling is rarely undertaken.
Scrub Clearance	• Scrub clearance undertaken over open fen dykes within site. • Dykes within 'wet woodland', clearance only undertaken access purposes. • Within the fen itself, clearance on a 'little and often' basis to maintain a scattering of small bushes within fen (c. 5% cover).
Water Level Management	• Both fens blind-ended. A single river connection allows tidal variation. • Woodbastwick Fen connected via Decoy Broad. This connection was opened in 2000. • Cockshoot Fen connected directly to River Bure via the main dyke.
Additional information	• Cattle present in Woodbastwick Fen to replace long rotation (5-10 years) mowing/scrub clearance as a form of retarding succession to wet woodland. Cattle open up areas of fen to increased light penetration, allowing seedling regeneration (eg *Peucedanum*).
Ebb & Flow Fen – George Taylor, NWT	
Reed Cutting	• Reed is cut on a two year rotation, with half the site cut each year. • Cut reed is burnt on site. • Sedge is cut by a contractor on a three year rotation. There are three blocks of harvested sedge within the site (see map).
Dyke Management	• Dykes cleared by excavator when required. • Main dyke cleared in 2003. Some clearance undertaken in spring 2009.
Scrub Clearance	• Scrub clearance is undertaken when required. Some works imminent.
Water Level Management	• Site is tidal. • Temporary dams used during high water when reed cutting.
Additional information	• Northern area of Ebb & Flow Fen grazed by Konik ponies.
Reedham Fen – Rob Andrews, BA	
Reed Cutting	• Reed is cut commercially on a one or two yearly rotation and non-commercial on a five year rotation. • Reed cutting undertaken during the dormant season. • Sedge beds cut commercially on a four year rotation.
Dyke Management	• Dykes are cleared by excavator when necessary, although usually linked with reed-cutting and the transportation of machinery around site. Therefore approx. five year rotation. • Dykes generally not graded to reduce spoil.
Scrub Clearance	• Scrub is cleared throughout site and overhanging branches removed

	over dykes.
Water Level Management	• Reedham Fen is tidal
Additional information	• Following a salt incursion at the fen, Pike were a notably affected, possibly indicating a possible spawning ground for the species.
Hickling - John Blackburn, NWT	
Reed Cutting	• Commercial cut annually (Bygrave's Marsh), between December and March. • Conservation cut (The Hundred Acres Marsh) on a six to eight year rotation. Four c.50 x 50m block cut each winter (completed before end of January).
Dyke Management	• Dykes cleared ('weed cutting bucket out') approx. six to eight years. • Whiteslea dykes, 4m wide, trapezoidal in profile. • Perimeter dyke of Hundred Acre Marsh, 7m wide and profiled on one bank. Internal dykes, wide and shallow in profile. • Approx. 1km of dyke cleared each year.
Water Level Management	• Water drained off the reedbeds every winter for the reed cutting. Dykes also affected, reduces water depth approx. 30cm.
Additional information	• Circular pools or 'meres' (25m wide and 1.5m deep) at the end of dykes have been dug out, which would allow a weed cutting boat to turn. •
Strumpshaw Fen (Mid Yare) - Tim Strudwick, RSPB	
Reed Cutting	• Part of the site (35ha) has approximately a 7 year rotation of conservation mowing, which is burnt. This is undertaken between November and December. • The remaining area (22ha) on an approx. 5 year rotation of conservation mowing and burnt between August and September. • Mowing is currently under review.
Dyke Management	• Dykes (5km) cleared out on a 10-15 year rotation. • Many dykes reprofiled between 1995-99, producing very shallow batter on edge. • Some dykes deepened to potentially improve conditions for fish.
Scrub Clearance	• Since 1976, approx. 15ha of scrub removed; • Scrub currently maintained at target level.
Water Level Management	• Connected to River Yare via a sluice, but river floods over bank into fen at high tides in any month. • Stable water level at mean fen level maintained in spring; gradual drawdown (30-40cm) to late summer levels. • Water kept low when possible during autumn to carry out management work. • In recent years, the sluice has been left open for much of winter to allow tidal flow in and out to help flush saltwater from system. • Modifications to water management planned in next few years.
Additional information	• A salt incursion resulted in a fish kill before a survey was conducted to confirm that management had improved fish stocks (see above). • The fen supports important breeding bird populations including Bittern, Bearded Tit, Marsh Harrier, Pochard, Gadwall and Shoveler. • Dykes supports diverse communities.

In principle, the site managers have similar management regimes for the dykes within their sites. Dyke clearance by excavator is undertaken 'when necessary' at all the sites described, although the approximate length between repeated works, or rotation, is different between sites. For example, Reedham Fen has the shortest rotation of approximately 5 years, whereas both Woodbastwick and Strumpshaw Fen have up to a 15-year rotation. Whilst there is a possibility of direct fish loss in the spoil, smothering of important habitats under fine sediments or simply general disturbance to fish leading to their movement away from the area, all these effects are ameliorated by the amount of dyke that may be cleared in any one season. For example, this is 1 km of dyke per year at Hickling. The impact to the whole site is thus generally reduced.

There are differences in the management of the dyke edges, or littoral margin. At both Hickling (with the exception of Whiteslea dykes) and at Strumpshaw, the profile of at least one bank has been graded to improve habitat for foraging birds, in particular the Bittern. At Reedham management of dyke edges is undertaken in conjunction with the dyke clearance and no profiling is undertaken to reduce the amount of spoil. Both these approaches will have an immediate detrimental effect on fish through disturbance and possible habitat loss for up to a year. The 'hand-cut' conducted at Cockshoot and Woodbastwick Fens in alternate years, undertaken to mitigate for Water Voles *Arvicola terrestris*, would intuitively have the least impact on fish.

Clearance of scrub is undertaken on an *ad hoc* basis to maintain current or target levels. Cattle and ponies are utilised to reduce the amount of scrub clearance at numerous sites. It is assumed that scrub clearance as described does not include management of bushes overhanging dyke edges, which are likely to be managed during management of dyke edges. Consequently, no additional impact of scrub clearance upon fish is anticipated.

5.3 ASSESSMENT OF FEN CHARACTERISTICS & THEIR CURRENT MANAGEMENT REGIMES IN RELATION TO FISH USAGE

Based on the information detailed in 5.2 above and observations made during sampling, an assessment is made of the suitability of the sites for fish (see Technical Summary). This includes information from two fisheries surveys of the four river-connected fens conducted in the summer months of 2007 and 2008 and a single survey representing the winter period. Barton Fen, an isolated wetland was also been surveyed in the same studies, with the isolated Buttle Marsh included in the final summer survey programme. The surveys were designed to establish species composition of the dyke systems within the fens and provide overall density estimates. As such, no attempt to determine microhabitat relationships with fish or quantify limiting factors. Therefore, the following broad statements on seasonal fish usage of the fens are based on observations and experience.

5.3.1 Spring / summer

The surveys conducted during the summer months determined whether YOY fish utilised the river-connected fens and thus indirectly indicate whether spawning grounds were present within the fens. Good densities of YOY fish (Roach, Rudd and Perch) were present in the summer surveys of Ebb & Flow, Reedham and Woodbastwick Fens, suggesting they were being used as nursery sites and thus likely contain spawning grounds for a number of species. In contrast, the surveys of Cockshoot Fen (not all sites were surveyed in 2009 due to excessive macrophyte growth) indicate that it is not utilised as a key spawning ground or nursery.

The differences could not be explained by gross habitat differences as similar habitat deemed to be generally suitable for spawning and subsequent refuge (predominantly reed margins and submerged macrophytes present within the dyke channels respectively - see 4.4 above) was present in all the river-connected fens surveyed. Moreover, there is little difference in the management practice, particularly regarding reed and dyke management (Table 3). A basic difference in the nature of the connection between river and fen, does however offer some potential to explain the differences in density of YOY during the summer month.

At Cockshoot, the single entrance dyke to Cockshoot fen from the River Bure is 'overgrown' and from the river at least simply appears to be a continuation of the littoral margin. Whilst fish can gain access to the fen, it is unlikely that there is continuous movement between river and fen. Fish may also be vulnerable to sit-and-wait predators such as Grey Heron *Ardea cinerea* or Pike at a restricted entrance. In contrast, at both Ebb & Flow and Reedham Fens, the interface between the river and fen is large and 'open' offering the potential for easy and frequent access for adult fish in and out of the fen. A large opening between river and dyke may also create distinct patterns of flow, which is known to be a particularly important factor in fish movement, with fish orientating towards the flow (rheotaxis) or swimming with it. Flow in either direction at the entrance to the dyke may thus trigger movement into the dyke. The ability to move readily between the two habitats allows fish to rapidly assess spawning grounds. Such prospecting behaviour has often been observed around traditional spawning grounds in the Broads prior to the main spawning event. Moreover, as some species may undergo protracted spawning in a series of events over the spring/summer period, easy and rapid access may enable co-ordination of relatively spontaneous events.

It was also noted in the Technical Summary of the Connecting Wetlands study, in the case of Ebb & Flow Fen, two side dykes with direct connection with the river had large sheltered openings suitable for spawning and that the resultant progeny could refuge further into the dyke. Another possible factor that makes Reedham Fen suitable as a spawning/nursery ground is that the dyke system is continuous, with no structures or culvert connections between dykes. As the management of the dyke (i.e. removing macrophytes from the channel), is essentially reactive and based on need there will always be sections of the dyke that are 'overgrown', with relatively dense *Phragmites* in the channel. The rationale for this is to promote diversity within the dyke system, but equally could benefit fish populations as sizeable areas of this habitat will be present within the single dyke system. The presence of dense submerged macrophytes throughout the majority of the fen in 2009 was also thought to enhance its status as a nursery ground for fish. As the development of dense stands of submerged macrophytes has been a recent phenomenon at Reedham Fen (Rob Andrews – *pers. comm.*), the importance of the fen as a nursery ground may have increased correspondingly in recent times.

Woodbastwick Fen differs from the other river-connected fens in the study in that it is connected to the River Bure via Decoy Broad, which has a number of river connections. The surveyed area is therefore a minimum distance of 1 km from the river. A fisheries survey of the broad in 1999 (Zambrano *et al*. 2006) revealed that Roach dominated the broad numerically and that only YOY specimens were captured. This indicated that Roach spawn successfully in Decoy Broad, with the resultant fry utilising the littoral margin. In contrast, the vast majority of the fish captured in the 2009 summer survey of the fen were Rudd (see Technical Summary), which may indicate that Rudd are permanent residents of the fen. This is further supported by the capture of several age classes suggestive of an age-structured permanent population rather than a transitory population of a specific age or size class. The only winter survey conducted at the fen (2007/8) also revealed domination by Rudd although the density was low (0.01 ind. m^{-2} – Tomlinson 2008) as a result of the capture of only older age classes with a lack of YOY fish. This may have resulted from poor recruitment in that year, mortality of young fish over the winter months or simply that aggregations of YOY were missed during during sampling.

It is of note that the bulk of the fish were captured in sections within wet woodland, rather than the reed bed areas in the south of the dyke system. Good areas of submerged macrophytes, providing suitable refuges for the YOY fish, were present throughout most of the dyke system, but it would appear that the fish selected the additional cover provided by overhead branches during daylight.

The two summer surveys of Barton Fen reveal the necessity to manage the dyke systems within the fens. The main dyke through the fen, the Hundred Stream, has not been managed for over ten years (Gary Elliot, lease owner – *pers. comm.*) and contained very dense submerged and emergent macrophytes, dominated by Lesser Water-parsnip *Berula erecta*. Such conditions may lead to deoxygenation of the underlying waters, which become unsuitable for fish. These are then likely to avoid these areas or if they cannot escape elsewhere, may suffer mortality. The presence with only a single Pike and Ten-spined Stickleback captured in the dyke during the summer surveys appears to vindicate the suggestion that the site has become unsuitable for fish, although it must be remembered that this may be influenced by low sampling efficiency.

The single survey of the isolated Buttle Marsh indicated the potential for different life-stages of fish to utilise different habitats. Here, the recently created wide (c. 15m) outer soke dyke supported older (>1+) Roach and Rudd, whereas the inner soke dyke, with a more typical width of 3m and overhanging reed and bushes, contained the YOY fish of the two species.

5.3.2 Winter

As the summer surveys aimed to identify spawning and nursery grounds within the river-connected fens, the winter survey conducted in February 2008 aimed to reveal over-wintering sites used by fish. Three sites, Cockshoot, Ebb & Flow and Woodbastwick supported winter aggregations of fish, whereas Reedham Fen supported a very low density of fish.

The key characteristic shared by both Cockshoot and Woodbastwick Fens, is that their dyke systems run through, or are adjacent to, areas of wet woodland. As described in section 4.4 above, cover from aerial predation appears to be a major contributory factor in selecting over-wintering sites. Whilst the sections adjacent to the wet woodland in Cockshoot are relatively small in area, fish aggregate in large dense shoals and all the Roach present in the three sites adjacent to the wet woodland were captured at two points. Unlike Cockshoot, Woodbastwick Fen, contains a high proportion of wet woodland. The southern area, where the majority of fisheries sites have been sampled, is the main area of reed bed, whereas to the east of the broad and the north of the dyke system is predominantly in woodland. Over-wintering Roach, potentially originating from Decoy Broad were captured in two sites both adjacent to the woodland.

Whilst the management of these sites by NE aims to prevent encroachment of wet woodland, overhanging / trailing branches are only removed from the dykes if access becomes impaired (Table 3). Thus the areas of wet woodland are subjected to limited management.

In contrast, in Ebb & Flow Fen a large aggregation of Roach (all YOY) was encountered in the widest dyke sampled with little cover from emergent or riparian vegetation. As dykes in the interior of fen with riparian cover were available to fish, why this boundary dyke, unconnected from the interior of the fen, was utilised is unclear. The winter survey of Reedham indicates that fish utilising the fen as a nursery migrate elsewhere over the winter period.

5.3.3 European Eels

In principle, Eels do not necessarily require a direct connection to gain access to the Broadland fen dykes as they are capable of making short crossings across land. However, the circumstances surrounding the Eels coming onto land are not well understood apart from this is more likely at night and during damp conditions. Intuitively, there must be a pronounced cue or cues for Eels to risk dessication or predation to reach a waterbody they can have little advance knowledge of, even if they can be sense its presence in some way.

As a consequence it is perhaps not surprising that whilst Eels were present in the isolated fens at Barton Fen and Buttle Marsh these had the lowest catch-per-unit-effort (CPUE). In contrast, Ebb & Flow with an open entrance dyke had the highest CPUE. This catch may also have been influenced by the fact that the three sites sampled specifically for Eels were within 300 m of the river connection.

The main habitat used by Eels in the dykes at least as a daytime refuge, was the reed margin. This type of habitat was abundant within all the fens surveyed in the 'Connecting Wetlands' project and will be maintained through the current management regimes. However, it is currently unknown if this habitat was also selected in the winter as it was unclear whether the lack of Eels sampled at this time was a result of their absence or inability to sample them efficiently (see 4.5 above). It is also unknown how Eels utilise the habitat in the fen dykes, how far they travel, whether they also exploit connected habitats, if they maintain a home range and how they may interact with each other. Clearly, much remains to be learnt of the basic ecology of Eels in dyke habitats.

5.4 CONCLUSIONS & RECOMMENDATIONS FOR FEN MANAGEMENT IN RELATION TO FISH COMMUNITIES

In general, the basic principles for the management of fens and their dyke systems for the benefit of fish populations, are that of promoting biodiversity. A fen with a dyke system that contains a diverse submerged and emergent macrophyte community has the potential to support diverse invertebrate and ultimately fish populations. This suggests that the nutrient status of the system is best maintained at $<100 \mu g\ l^{-1}$ total phosphorous (TP).

As with the restoration projects conducted at selected Broads, the ideal fish community within the dyke systems of wetlands should contain Rudd and Tench, rather than Roach and Common Bream, supported by piscivorous Pike and Perch. Eels should be present along with small populations of sticklebacks. The small amount of sampling undertaken to date suggests fen dyke systems should support similar densities of fish to those of the broads i.e. 0.5 to 1.0 ind. m^{-2} at the end of a growing season in autumn. Where the system is connected there is potential to increase overall density on a seasonal basis, for example by Roach utilising sites as over-wintering grounds. Figure 15 shows a stylised profile of an integrated wetland, with the main waterbody, either a broad or the river, connected to smaller bodies of open water by dyke systems and also by overland flow at high water levels. Such an integrated system provides habitat to maximise both fish density and diversity, with separate resident fish populations within each body of water, which may mix and increase local density and diversity as a result of seasonal migration.

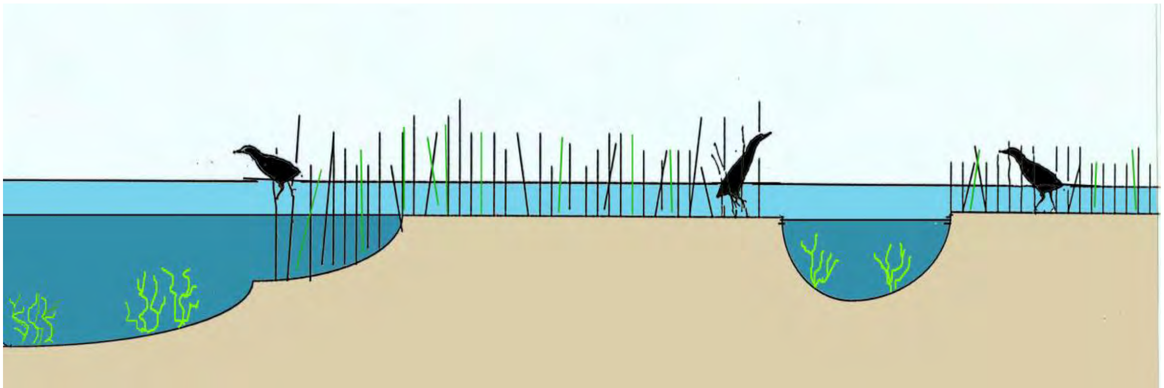

Figure 15. Stylised profile of an integrated wetland based on the connection of a main waterbody, either a broad or the river, to the dyke system of the surrounding wetland. Connection may occur through direct connection and/or by overland flow at high water levels.

The following sections of this report should be viewed as a starting point for future projects. Implementation of any of the broad guidelines provided below needs to be supported by rigorous monitoring at greater resolution than has been undertaken for this project. Should any management be undertaken, such as making connections between a river or broad and the surrounding wetland dyke system, then before and after monitoring is recommended. Appropriate sampling methodologies would have to be devised and greater understanding of the age class distribution of fish species and habitat variables would be required. With the prospect of considerable fish movement occurring at night or between seasons research on movements of key species such as Eels should be considered using radio telemetry or PIT-tags and transponders. Greater knowledge of fish use of the fens within the Broads will ultimately be essential to determine the impacts of management in fen dykes.

5.4.1 Connecting wetland systems

The potential for seasonal migration of fish between wetland habitats within the Broads, first documented by Jordan & Wortley (1985) was evident in the fisheries surveys of the river-connected fens detailed in the Technical Summary of this Connecting Wetlands project (see5.3 above). Considerable seasonal variation in fish densities was noted within the four river connected fens, with fish thought to be selecting sites based on the presence of suitable habitat for spawning, associated nursery grounds or as over-wintering sites.

Greater connectivity, through new connections and/or maintained openings, within the Broads wetland, would increase habitat available for seasonal migrations and thus potentially support greater numbers of fish overall. However, improved connectivity between wetlands should not necessarily entail re-connection with the main river. For instance, a fen could be connected to an adjacent broad. This would create a larger, structured wetland, increasing habitat availability for the indigenous fish populations of the separate water bodies, and providing potential to increase overall population size and species diversity.

Nevertheless, caution should be applied before re-connecting all isolated fens with the river, or associated broad. In general, both waterbodies to be connected should be in good condition to increase available habitat for fish and maintain general biodiversity. It is recommended that each fen is assessed individually in regard to re-connection with its associated river, or associated broad, and a number of factors, discussed below, should be assessed prior to reconnection.

Water quality

The location of the wetland within Broadland could influence the potential for overall biodiversity. For example, wetlands in the Upper Thurne catchment are already prone to incursion of salt tides with the prospect of serious fish kills. In such circumstances, isolated fens supporting good fish communities may be best maintained through isolation. As sea levels continue to rise, where there are no barriers to tidal influence the vulnerability of sites further upstream will increase. Clearly, it may be anticipated that fish communities in some sites will change markedly in the future and careful assessment of the longer-term viability of freshwater fish populations in some sites will be required. Likely change needs to be incorporated into future planning.

Nutrient levels and general ecological quality of the two waterbodies to be connected should be carefully considered. If the trophic status is high and the fish community dominated by few species, e.g. Roach and Common Bream, biodiversity is unlikely to increase through connection. For example, the excellent water clarity and diverse macrophyte community of the isolated Buttle Marsh could potentially be lost through re-connection to the River Ant. Reedham Fen is in close proximity to Buttle Marsh, and whilst the inner dyke systems are clear and support good macrophyte communities, the main boat dyke parallel to the river, similar to the outer soke dyke of Buttle Marsh, is as turbid as the river itself. Re-connection to the River Ant, could result in the loss of water clarity and potentially submerged macrophyte in the outer soke dyke.

Shifts in fish community

Desirable fish communities (see above) within isolated wetlands could potentially be affected by re-connection, increasing the contact with or even introducing, competitors such as Roach and Common Bream. Moreover, re-connection also carries the potential for introduction of alien or naturalised species such as Common Carp (and its derivatives) into the wetlands fish community. Similarly, there is also potential for the introduction of alien plant or animal species into the previously isolated wetlands. This may have consequences for a range of flora and fauna.

If direct re-connection of an isolated fen with its adjacent river is considered potentially detrimental to the biodiversity of the fen, a more specific solution to allow access of specific desirable fauna may be achieved. For example, the installation of 'ladders' for Eels could improve Eel density within wetlands. The sampling conducted to date suggests that distance from the river, rather than distance upstream, is a key factor behind the colonisation by this BAP species. At suitable fens directly adjacent to rivers locations, the colonisation of small Eels in particular may be enhanced by careful placement of re-used cobweb brushes from broad restoration projects (Broads Authority 2010).

Wet woodland

Results of the fen surveys detailed in the technical summary of this Connecting Wetlands project and other fisheries work conducted within the Broads suggest that fish, particularly Roach, often select areas with aerial cover such as that provided by the branches of trees, as over-wintering sites. In simple terms, an increase in the proportion of fish that successfully over-winter increases the size of the breeding stock (although there may be density-dependent reductions in population fecundity should food resources become limiting). Maintaining connections and the water levels within areas of wet woodland is therefore suggested to be beneficial to fish populations. However, dykes and open water within wet woodland accumulate leaf litter, resulting in low DO levels and ultimately infill and territorialisation. Maintenance of the dykes, such as those at Cockshoot and Woodbastwick, is thus likely to be essential to maintain potential as high quality over-wintering sites although how this should be undertaken remains unclear. Overall, the true value of wet woodland relative to other wetland habitat types requires further investigation.

5.4.2 Dyke management

There is considerable potential for management regimes in dykes to impact on fish populations both directly and indirectly. Equally, a total lack of management is likely to result in the loss of habitat for fish through infill and siltation. Management is therefore an essential tool that must be wielded in a considered manner that is sensitive to fish and other fauna.

Based on the information and personal observations gathered for this project, the following 'guidelines' have been produced. These guidelines have not been tested and in the absence of targeted experimentation, it is recommended that any management undertaken is subject to targeted, specifically-designed before and after monitoring (see above).

Fen entrances

For river-connected fens, maintaining a clear entrance dyke, free of dense emergent macrophytes and high volumes of silt is recommended. This is considered particularly important for fens believed to provide spawning grounds and nursery zones for fish. Prior to the spawning event, or indeed if there is a protracted spawning event, adult fish could frequently pass between river and fen in the spring and/or the early summer. Maintenance of an open entrance allows the free passage of fish between the wetlands during this period.

This practice would also be beneficial for the colonisation of young Eels (pre-spawners) and large adults attempting to return to the sea to spawn. Moreover, it remains plausible that Eels utilising the reed margins of the fen dykes as refuges during daylight hours travel large distances to forage, with this movement encompassing other wetland habitats. As Eels become active and forage as water temperature increase, movement between the different habitats would be more pronounced between spring and autumn.

In contrast to the need for unrestricted movement of spawning fish, access to over-wintering sites do not necessarily need to be free from reed and/or other emergent macrophytes, as fish are unlikely to undertake a number of between the two areas but rather remain *in situ* in the overwintering site (which could either be the main river or the fen dyke) during the winter period. However, siltation of the entrance could prevent access during periods of low water levels and thus aggregations of fish attempting to gain access to the fen may be prone to attract predators thereby increasing predation pressure.

Dyke profile

Graded banks are intuitively more likely to enhance the cover and diversity of both emergent and submerged macrophytes, thus providing habitat for both invertebrates and fish. Grading also means that margins are not likely to become 'perched' above water level in periods of low rainfall or flow. This may be especially important for spawning fish, which require access to an appropriate spawning medium in spring and early summer.

All the Eels captured in fen dykes were present in the littoral margin and increasing the area of littoral margin through graded banks would appear likely to increase habitat available for refuging Eels. Rudd also utilise littoral margins, with both juveniles and adults potentially remaining within reed during the winter period (see above). Grading the banks of dykes is thought likely to increase the penetrability of fish into adjacent reed-beds or wet woodland. In the case of the former, the grading of dyke margins has been considered to be a successful means of improving the Bittern population (Self 2005) as a result of increasing the foraging habitat (Bitterns tend to forage in depths of <20cm) and the potential for overlap between Bitterns and the Rudd and Eels that form a major part of their diet.

Site managers of fens in the Broads clear or dredge dykes based on siltation rates, which range from five to 15 year rotations (see 5.2 above). Whilst these actions have direct and indirect short-term effects on fish, the size of the fens and time constraints means that dyke systems are not managed in entirety in one season. For example, 1 km of dyke is cleared in each season at Hickling, which is the equivalent to 14% of the habitat. It seems most likely that the worst-case scenario is that fish occupying the area to be managed are displaced elsewhere. There seems no clear reason to suggest anything other than the continuation of the current dyke clearance regime. However, monitoring of the response of the different fish populations would be beneficial.

Dyke width

The width of the dykes sampled or observed for the surveys detailed in the Technical Summary ranged between 2 m (Cockshoot and Ebb & Flow Fens) and 15 m (Buttle Marsh and Woodbastwick Fen), with the majority at c. 5m in width. It is recommended that dykes should not be narrower than 2.5 m due to the potential for infill by vegetation and increased siltation rates decreasing available habitat for fish. The sampling to date also suggested that few fish were captured in the smaller dykes. This does however require confirmation coupled with an investigation as to why this should be the case.

Moreover, there is a potential case for parts of the dyke system in each fen to be increased in width to up to 15 m. The wider dykes, notably the outer soke dyke at Buttle Marsh and also a section within Woodbastwick Fen, specifically supported adult Rudd, Perch and Roach. It may be that such sections, which are essentially similar to ponds or small lakes, could provide permanent habitat for fish populations within the wetlands.

Dyke depth

Dykes should be of sufficient depth not to freeze solid during particularly hard winters and to ensure there is no loss of DO. However, other than suggesting the deeper sections should be >1 m deep, it is difficult to determine what depth should be maintained. The current management regime adopted in the sampled fens suggests this is already being achieved. At Strumpshaw dyke depths were increased by 0.3 to 0.5m, resulting in depths of 0.9 to 1.3m at winter water levels and 0.6 to 1.0 m at low summer levels. The increase in depth resulted in anecdotal reports of an increase in the fish populations.

Macrophytes

Both emergent and submerged macrophytes within dykes may be important for certain species of fish (see 4 above) that are seen to be desirable (e.g. Rudd). Emergent macrophytes, such as *Phragmites*, contribute a major component of the littoral margins of the dyke systems, and frequently occupy the channel in sections of the dyke system within open fens. Other emergent species such as Reedmace and sedges are also typically present. The current management regimes of clearing banks in alternate years and/or clearing sections of dykes on long rotations (see 5.2 above) appears to maintain suitable conditions for most species.

Dense areas of submerged macrophytes such as a Bladderworts *Utricularia* spp. and Water Starwort *Callitriche* spp. may provide spawning substrate for fish within the fens, provide refuges for the resultant fry and support the invertebrate food resources of fish of all ages. In general, submerged macrophytes require suitable nutrient levels and light penetration to establish and be maintained. The current management regimes of weed cutting on a long rotation at the larger sites or general dyke clearance with excavators (see 5.1 above) again appears to be sufficient to maintain a suitable cover of submerged macrophytes.

5.4.3 Summary of Management Recommendations & Further Research

Table 4 briefly summarises available management options, recommendations and current status within the Broads (i.e. whether they are currently undertaken). With respect to dyke maintenance many of the management practices are already implemented and it is recommended that such activities are continued. The maintenance of dyke profiles (including dimensions), submerged and emergent macrophytes is essential to the provision of quality fish habitat regardless of whether connections are introduced.

Clearly there are some substantial benefits to be gained through the increase in connectivity of specific wetland areas. However, rigorous assessment of any proposed management action should be undertaken.

Although this document provides a synthesis of the current understanding of wetland fish habitat use and management, with specific reference to the Broads, clearly there is much still to learn. Further studies should:

- Increase understanding of fish populations where different conditions prevail (i.e. isolated vs connected, nutrient concentrations, macrophyte populations, management regimes). Such research would need to encompass a wide range of habitats with different characteristics to allow the construction of a reference database to shed further light on dyke and fen system states. Thus, any surveys should incorporate simultaneous monitoring of habitat variables to assess associations with fish abundance and diversity.

- The consideration of management actions such as connections between dyke systems and other waterbodies, or perhaps where dredging is undertaken, should involve rigorous baseline monitoring. If works are carried out the response of the fish community should be assessed to determine any changes and whether objectives have been met.

- Examine seasonal and diel fish movements within the Broads to improve knowledge about spatial and temporal variations in habitat utilisation. This is a crucial step in the understanding of Eel movements, allowing more informed and effective management of populations and supporting habitats. It is suggested that individual-based tagging studies, supported by more intensive and targeted populations monitoring, should be carried out. This would be especially necessary where habitat management actions are considered or implemented.

- Finally, it would highly beneficial to survey and categorise existing barriers and connections with respect to fish (specifically Eels) movements between the main waterways and the wider wetland system. Such baseline data is a fundamental step that should be addressed before any practical action is taken to increase wetland connectivity.

Table 4. Summary of management recommendations for promotion and maintenance of wetland fish habitat within the Broads.

Management activity	Recommendation	Currently status
Re-connection of fens to dykes, rivers or broads,	Connections could increase habitat diversity and availability for fish populations. Any proposed re-connection activity should be assessed individually to prevent any negative impacts. Such assessments should take into account water quality aspects, potential shifts in fish community structure and management of wet woodland areas where applicable.	How Hill NNR – Reedham Marsh and Woodbastwick marshes connections enhanced Other sites unknown
Installation of Eel passes	Where direct connections cannot be made, the installation of Eel passes may aid or encourage movements into isolated waterbodies.	New Mills in planning stage
Clearing entrances to river connected fens	Entrances to river connected fens should be cleared to provide uninhibited fish access to habitat	Site basis
Dyke profiling (including vegetation clearing and digger work)	Dyke grading should be conducted to enhance habitat diversity and stability for fish.	Vegetation clearance or digger work based on siltation rates, ranging between 5 and 15 year rotations
Dyke width	Maintained at >2.5 m. Potential to widen some dyke sections, within a fen, up to 15 m in width to increase fish habitat diversity.	Current management practices generally maintain suitable widths, though some dykes were only 2 m in width
Dyke depth	Maintained at >1 m to prevent full water column freezing and significant levels of deoxygenation.	Current management practices generally maintain adequate depths
Clearing banks	Emergent macrophytes provide valuable habitat for fish and play a role as refuge, areas of abundant food supply and potential spawning substrate.	Yes, banks cleared in alternate years and clearing sections on long rotation
Weed cutting	Submerged macrophytes provide spawning substrate, refuge and food resources for fish and suitable cover should be maintained.	Yes, long rotation at larger sites or general dyke clearance with excavators appears to be sufficient

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