Natural England Research Report NERR064

A narrative for conserving freshwater and wetland habitats in England

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Executive Summary

Summary

This evidence-based narrative provides an overview of circumstances relating to the conservation of freshwater and wetland habitats in England, considering their ecological function, the natural and anthropogenic factors affecting them, the management principles that can be drawn from the evidence, and the respective roles of the main policy mechanisms involved in their conservation. It covers all running and standing water habitats, of whatever size, and terrestrial wetland habitats including bogs, fens, swamp and wet woodland.

The evidence regarding the importance of natural habitat function in freshwater and wetland ecosystems is presented. The management principles drawn from the evidence are relevant to a range of spatial scales, to the relationship between habitat and species conservation, and to specially protected wildlife sites, priority habitat and the wider freshwater and wetland environment. They are in line with climate change adaptation principles, Lawton principles for better ecological networks, and the objectives of the key policy mechanisms of relevance to freshwater and wetland habitat conservation.

1) Value natural ecosystem function, based on natural environmental processes, as the best and most sustainable expression of freshwater and wetland habitats and their characteristic wildlife.
2) Aim to conserve species within naturally functioning habitat wherever possible, based on natural environmental processes.
3) Cherish remaining examples of naturally functioning habitat and take opportunities to restore natural function elsewhere as far as possible.
4) Recognise that restoring natural catchment processes (hydrology, hydrochemistry) is a fundamental part of restoring freshwater and wetland ecosystems.
5) Recognise restoring natural ecosystem function as the art of the possible, working in locations that are most conducive to restoration and accepting immovable constraints.
6) As part of this recognition, generate a long-term strategic vision and seek to make short-term decisions in the light of that vision.
7) Take a large-scale perspective that maximises opportunities for natural ecosystem function, provides greatest opportunity for species to find habitat niches within a more naturally functioning landscape, and encourages a strategic approach to site management that provides these niches within site networks.
8) Accept dynamic change as a natural component of ecosystems, the magnitude of which varies between broad habitat types but is high in freshwater ecosystems.
9) Plan for change in the distribution and population size of species where needed (as a result of landscape-scale restoration measures or direct climate change), to ensure key species are catered for appropriately within more naturally functioning landscapes.
10) As part of recognising environmental and population change, factor in the effects of climate change to ensure that expectations for supporting individual species at a given location are realistic.

These principles can be summarised as a hierarchical approach to decision-making that is:

1) Landscape-led, natural process-aware
2) Natural process-led, habitat-aware
3) Habitat-led, species-aware

This narrative underpins various workstreams relating to freshwater and wetland habitat conservation in England, including:

- Natural England's notification strategy for Sites of Special Scientific Interest;

- the approach to priority habitat objectives under Biodiversity 2020 and longer-term European and international biodiversity aspirations;
- the promotion of freshwater ecosystem conservation within the wider work of implementing the EC Water Framework Directive; and
- the use of key delivery mechanisms such as the new Countryside Stewardship grant scheme.

The main body of the document provides links to reports and projects that apply this narrative to these various workstreams.

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1 Introduction

1.1 Naturally functioning freshwater and wetland habitats (including rivers, streams, lakes, ponds, bogs, fens, flushes, swamp, wet woodland and wet grassland) are moulded by natural environmental processes (hydrological, geomorphological, chemical, biological). These processes also create intimate hydrological and biological connectivity between these habitats, generating natural ecological networks. Naturally functioning river corridors, including the channel itself, backwaters and the riparian zone, facilitate the dispersal of organisms through the landscape, often acting as informal 'protected areas'. Lakes and ponds have the potential to play a similar role, but act as stepping stones rather than corridors. This dispersal function is not only relevant to freshwater and amphibious organisms but also to many terrestrial animals and plants.

1.2 Natural environmental processes conserve freshwater and wetland habitats for characteristic biological communities and their individual species. Rare and threatened species associated with freshwater and wetlands all have their niches within naturally functioning ecosystems. Analysis of 'priority' species in England (i.e. those listed under Section 41 of the Natural Environment and Rural Communities Act 2006) has confirmed that the ecological needs of those species associated with freshwater and wetlands are satisfied by the conditions that are provided by natural environmental processes (unpolluted water, natural water supply and natural physical habitat form and function) (Webb et al. 2010 – see Appendix 1).

1.3 Natural freshwater and wetland ecosystem function provides a sustainable basis for management at small and large spatial scales, providing a framework within which the Lawton principles for generating better ecological networks (Lawton et al. 2010) can be implemented. It provides the foundation for helping freshwater and wetland ecosystems adapt to climate change (Clarke 2009, Kernan et al. 2012, Natural England/RSPB 2014). It also provides the basis for a range of vital ecosystem services, including flood risk management, water retention in catchments to moderate the effects of drought periods, and the provision of clean water for a variety of uses.

1.4 Yet freshwater and wetland habitats are arguably subject to a greater variety of anthropogenic pressures than any other, since they can be affected by any activity occurring in the catchment (as well as by atmospherically transported pollutants)). Impacts include pollution from point and diffuse sources, modifications to water supply, physical modifications and invasion by non-native species. The loss of natural functioning in these habitats has led to the harbouring of some threatened species in highly modified habitats that are disconnected from natural environmental processes, such as ditch systems.

1.5 This narrative aims to provide an ecological explanation of why natural ecosystem function is important to our freshwater and wetland wildlife, and a rationale for how we can recognise this importance in the steps we take to conserve these habitats and their associated species. Protecting and restoring natural freshwater and wetland ecosystem function in a crowded and developed country like England can seem a daunting task. In some landscapes there may be little that can be done, whilst in others there is great scope for protecting what remains and reversing at least some of the damage. As this narrative attempts to explain, an informed and strategic approach to decision-making provides the basis for grasping the opportunities that exist, whilst not forgetting the important role that modified and artificial freshwater habitats can play for individual species. The ecosystem service benefits of such an approach are considerable, and can help to address many of the socioeconomic problems we face with the water cycle.

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2 Running water

The natural habitat template

2.1 Streams and rivers are highly dynamic habitats that are shaped by the intrinsic characteristics of the catchment and its climate. Together these generate characteristic flow, water chemistry, and sediment and nutrient delivery regimes that govern the morphology, hydraulics and productivity of the river and the assemblages it supports. River networks are highly heterogeneous, with natural processes generating repeated mosaics of small-scale habitat features (individual substratum particles, riffles, pools, margins etc.) nested within variation at progressively larger-scales (river segments, reaches, tributaries, main stems etc.) (see Figure 2.1).

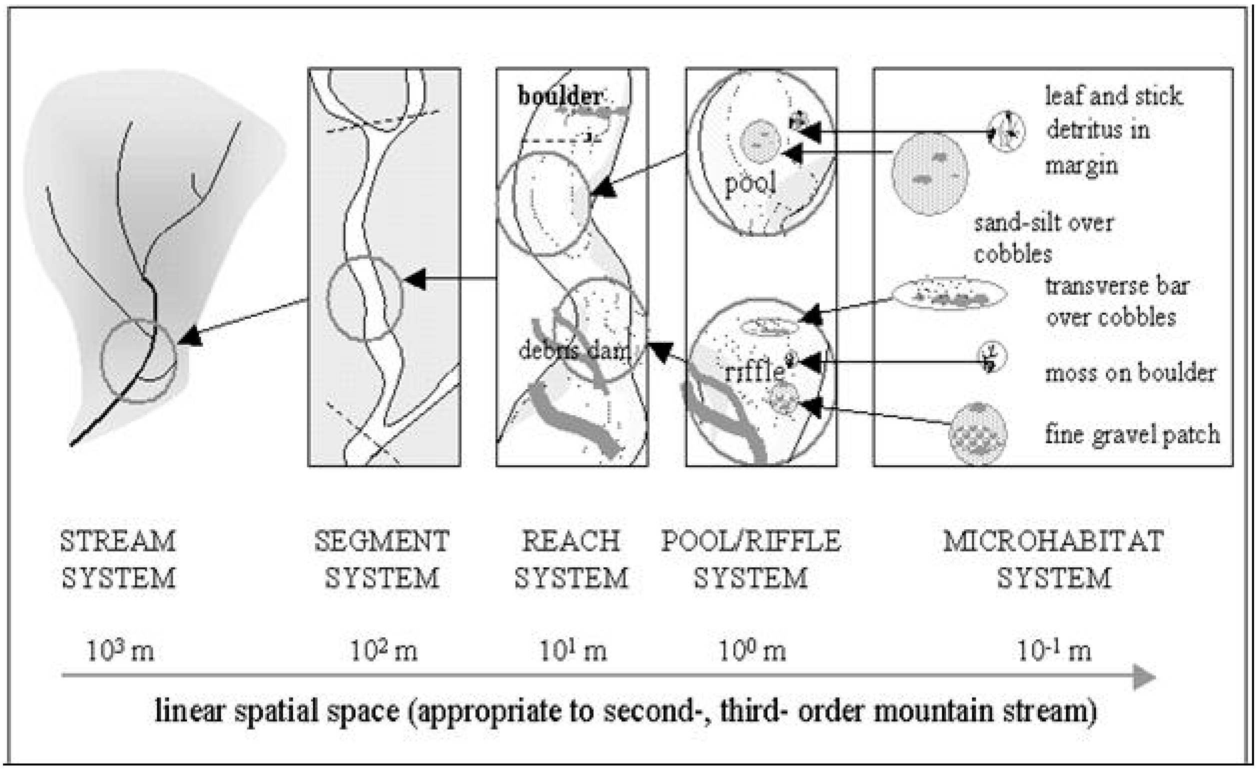


Figure 2.1 Hierarchical organisation of stream systems (based on Frissell et al. 1986)

2.2 There is an overall longitudinal change in environmental conditions from source to sea (Vannote et al. 1980): hydraulic energy (such as near-bed shear stress) generally declines, mean temperature increases, extremes of alkalinity are moderated, nutrient accumulate (and nutrient spirals become longer), while dominant bed sediments change from coarse to fine grain. These large-scale longitudinal trends are obscured by smaller scale diversity and complexity of river systems, in which for instance a riffle (energetic habitat dominated by gravels and cobbles) may give way to a pool (low energy habitat dominated by silt) over short lengths of river.

2.3 River habitats have strong natural connectivity, within the river channel itself and with other types of habitat. Longitudinally, headwater streams link to upland and lowland mires, whilst downstream reaches link to the coast through the saline transition zone. Lateral connectivity between the river corridor and floodplain, through lateral movement of the channel and floodplain inundation during flood flows, both supports and connects aquatic and wetland habitats beyond the river channel and its banks (Junk et al. 1989). Vertical connectivity with the hyporheic zone and ground water underlying the river bed provides further habitat opportunities for many invertebrates, including some species that are confined to these zones (Boulton et al. 2010). Upwelling of water from below the bed can be important for river diversity and productivity, and may winnow fine particles that can clog up coarse gravels.

2.4 At the reach scale, under natural processes, streams and rivers form dynamic habitat mosaics including riffles, pools, cascades, waterfalls, backwaters, ox-bow lakes, swamps, coarse and fine-grained substrata, marginal vegetation, woody debris, exposed tree roots, cliffs and river banks of varying gradients, and exposed sediments such as shingle and sand bars (Figure 2.2), all associated with different water depths and current velocities. Fluctuations in flow alter environmental conditions in these habitats over daily to long-term timescales, some experiencing strong fluctuations in current velocity and shear stress and some providing refuge against high flows. Others, such as shingle bars, marginal zones and the ephemeral sections of headwater streams, become dry for part of the summer.

Figure 2.2 Some elements of the riverine habitat mosaic

Biological patterns

2.5 Riverine species and assemblages are distributed naturally in river systems according to this natural habitat mosaic (Macan and Worthington 1951, Hynes 1970, Vannote et al. 1980, Townsend and Hildrew 1994, Armitage et al. 1995, Harper et al. 1996, Townsend et al. 1997). Under natural conditions these species distributions are interrupted only by hindrances to colonisation or recolonisation (Thompson and Townsend 2006, Demars et al. 2014) caused by watersheds between catchments and natural physical barriers such as waterfalls. For riverine species without aerial life stages (such as fish), species distributions are affected by historical connectivity with European mainland rivers during and following the last glaciation (Davies et al. 2004), leaving some species (such as grayling and barbel) naturally absent from suitable habitat in the north and west of the UK.

2.6 Habitat use is governed by the various traits (anatomical, physiological or behavioural) exhibited by individual species and their different life stages (e.g. Menezes et al. 2010, Demars et al. 2012). Organisms may move between small-scale habitats to find optimal conditions according to the state of flow, seasons and stage of life cycle, and are often dependent on the close juxtaposition of suitable habitat patches and unhindered movement to do this (e.g. Mainstone et al. 1999). Short-term fluctuations in flow generate a very dynamic picture of biological movement through space and time. A complex small-scale habitat mosaic is also vital in providing refugia against predators and therefore allowing long-term persistence of species (Hildrew 2009).

2.7 Over longer timescales, the adult stages of fish and some invertebrate species migrate upstream for reproduction, thus countering the tendency of river flows to wash individuals downstream. The resulting eggs and juveniles are taken passively downstream in the flow to distribute themselves in available habitat (Hynes 1970). Some of these migrations are relatively short (such as those of brook lamprey and bullhead), some are longer (as in dace and chub), whilst others are extreme and extend into marine waters to exploit better opportunities for feeding (salmon, sea trout, shad and lamprey species) and spawning (eel). The larvae of the freshwater pearl mussel attach themselves to fish (particularly salmonids) and make use of the fish's upstream migration (Skinner et al. 2003). Invertebrates with aerial life stages are freed from the requirement to migrate upstream against the current, dispersing freely in the air.

2.8 Larger-scale patterns in biological assemblages are recognisable against the natural habitat template, both down the course of an individual river (Figure 2.3) and between river systems. For example, headwater communities contain specialist animals and plants capable of withstanding seasonal drought through various adaptations (e.g. Mainstone et al. 1999). Plant assemblages are distributed along river systems according to hydraulic tolerance (Riis and Biggs 2001), with high energy streams being dominated by attached algae (periphyton), mosses and liverworts, while submerged vascular plants appear progressively as hydraulic energy declines and substrate stability increases downstream. Fish and invertebrate assemblages follow similar patterns (Carpenter 1928, Huez 1959, Hynes 1970), dictated fundamentally by hydraulic tolerances but also by associated shifts in the nature of food availability and hydrochemistry. Small headwater streams are naturally lower in nutrients and conductivity and are generally more heavily influenced by riparian trees, shading and woody material in the channel. This generates a different foodweb to larger and more open river sections downstream, where light and higher nutrient availability generate higher levels of plant productivity. At the downstream end of rivers, salinity gradients play an important role, with a range of euryhaline fish species exploiting the saline transition zone of lower river reaches for feeding and spawning.

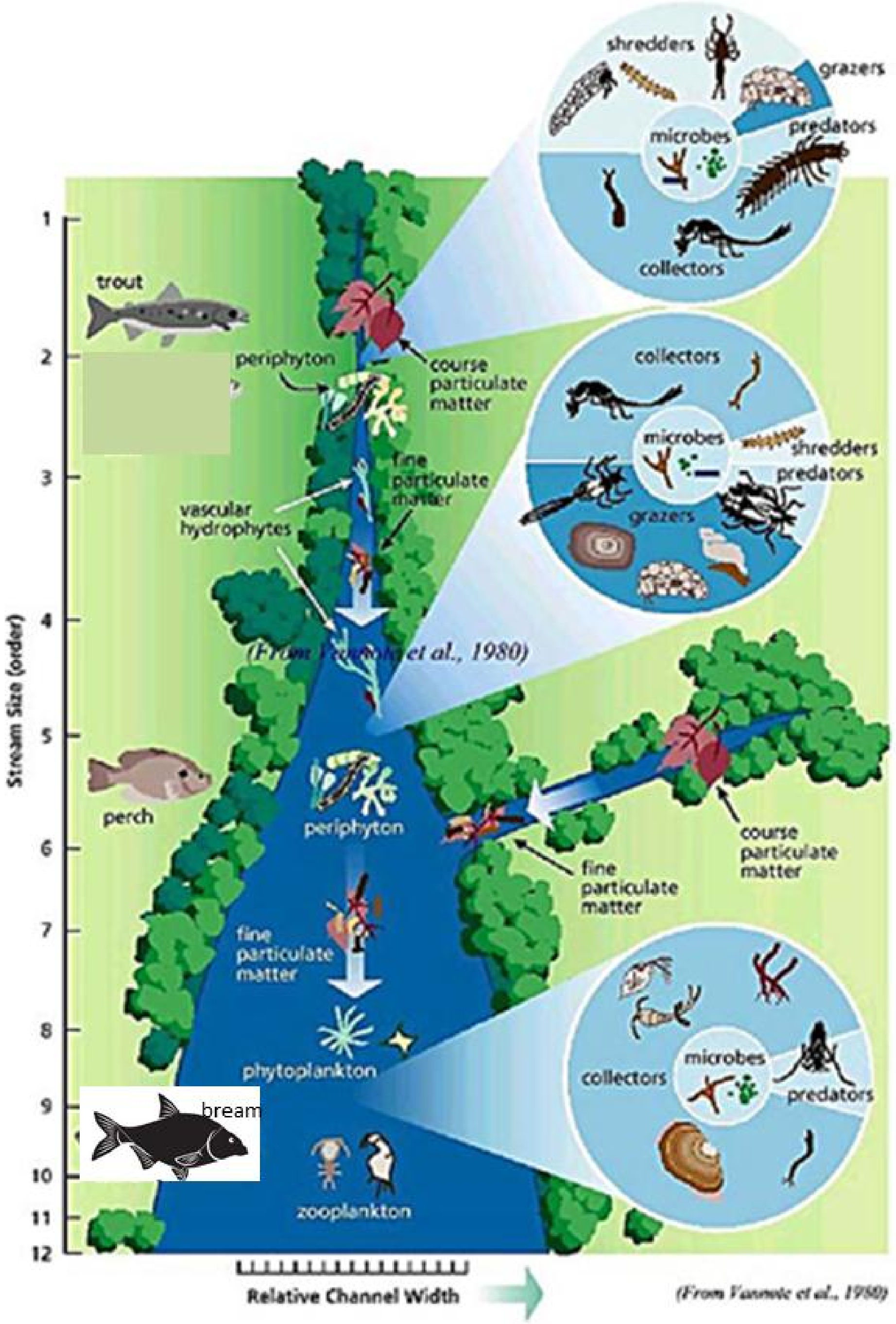


Figure 2.3 The river continuum concept, characterising changes in biological assemblages along the continuum of environmental change within a river system (adapted from a schematic by the US Federal Interagency Stream Restoration Working Group, FISRWG)

2.9 Organisms also move laterally between the river channel and freshwater habitats associated with floodplains and the wider landscape, either during periods of flooding (fish, molluscs, plants) or by active dispersal (mammals, aerial life stages of insects). As a result of this, and the considerable tolerance of some species to a range of hydraulic conditions, many species occur in both running and standing waters in river-floodplain landscapes (Williams et al. 2004). Floodplain species without aerial life stages (e.g. mollusc species such as *Anisus vorticulus*) are generally dependent on flooding episodes to maintain populations across the landscape, colonising or recolonizing suitable habitat as it becomes available. Vertical movements can also be important – some species move in and out of the deeper gravels of the hyporheos, such as the stonefly *Capnia bifrons* (Natural England 2015).

2.10 Rivers are extremely diverse in the habitats they provide, and in some senses each river can be considered unique in its habitat provision.This makes describing the characteristic flora and fauna of river systems a difficult task.

2.11 The next section gives a flavour of the variation in biological assemblages across broadly defined river 'zones'. The dynamic and varied character of individual rivers needs to be borne in mind – any river can change naturally from fast-flowing to slow-flowing over short distances, for instance in response to a resistant seam of bedrock on the riverbed. The characteristic biological assemblage is dependent on these small-scale changes to provide the habitat mosaic that supports it.

Headwater streams

2.12 Headwater streams make up nearly 70% of total stream length in Great Britain (based on the estimated length of first and second order streams in Smith and Lyle 1979), so in ecological terms they should be seen as the essential foundation for healthy functioning river systems. They are vital both as habitat in their own right and as a support system for larger rivers downstream. One study of headwater streams in England and Wales found that nearly 13% of invertebrate taxa found in catchments were exclusive to headwaters, including a range of priority species (Furse et al. 1991). Many other species were also found in downstream rivers, fed by a constant supply of new colonists by the drift of individuals from headwater streams.

2.13 Headwaters vary hugely in environmental conditions, from high gradient, naturally treeless cascades on moorland to chalk winterbournes in lowland England. The permanence of flowing water has a major bearing on the flora and fauna, with ephemeral sections favouring a range of species adapted to a seasonally dry channel, such as the scarce mayfly *Paraleptophlebia werneri* and the stonefly *Nemoura cinerea*. Below the upland treeline, the presence of riparian trees and woody material within the channel is a critical component of the habitat mosaic (Figure 2.4), whether in woodland or more open landscapes, adding a high degree of habitat complexity through the creation of debris dams, exposed tree root systems and channel sinuousity. Debris dams create partial blockages to flow, generating slack water upstream and scour holes and riffles downstream. This habitat pattern provides niches for a wide range of species, particularly for lower plants and invertebrates but also higher plants in more open reaches. Woody material is also a habitat in its own right; for instance, the larvae of caddis-flies in the genus Lype build feeding galleries in submerged rotting wood.

Figure 2.4 The habitat mosaic of a woodland headwater stream, showing a debris dam creating a scour pool, riffle and exposed sediments

2.14 In tree-lined or woodland headwater streams, leaf litter provides the main natural nutrient source and generates a food web based on leaf-shredding, dominated by freshwater shrimps (*Gammarus* spp) and stoneflies including *Nemoura cambrica* and the rare *Rhabdiopteryx acuminata* (classified as Vulnerable in Great Britain – Natural England 2015). In lowland acidic streams, the predatory nymphs of the golden-ringed dragonfly (*Cordulegaster boltonii*) thrive in slackwater areas of the channel habitat mosaic, and emerge as adults (Figure 2.5) to feed on flying insects. In treeless upland streams, attached algae replace leaf litter as the most important nutrient source, and invertebrates with a scraping or grazing feeding habit are favoured, such as the rare caddis-fly *Glossosoma intermedium*.

Figure 2.5 Golden-ringed dragonfly – its nymphs develop in pools within the habitat mosaic of heathland streams (© Natural England)

2.15 In open lowland headwater streams, better habitat opportunities are created for higher plants, including the chalk winterbourne specialist brook water-crowfoot (*Ranunculus peltatus,* Figure 2.6). Headwater streams provide a disproportionate amount of marginal habitat for their length compared to larger rivers, and this is exploited fully in open lowland streams by encroaching species such as brooklime (*Veronica beccabunga*) and water-cress (*Rorippa nasturtium-aquaticum*). In turn this provides an additional habitat niche for plant-dwelling invertebrates such as the nymphs of the southern iron blue mayfly (*Nigrobaetis niger*).

Figure 2.6 Brook water-crowfoot, *Ranunculus peltatus,* flowering in the main channel – a characteristic species of chalk winterbournes

2.16 Headwater streams are limited in the diversity of their fish assemblages, but are a key habitat for the European protected species brook lamprey (*Lampetra planeri*) and bullhead (*Cottus gobio*) for which parts of the UK are major strongholds. Headwaters also provide critical and extensive spawning and juvenile habitat for a number of other fish species (Mainstone et al. 1997), including brown and sea trout (*Salmo trutta*) and Atlantic salmon (*Salmo salar*, another European protected species). The accessibility of a headwater stream to fish has a fundamental effect on the characteristic biological community. Some streams are made naturally permanently inaccessible by waterfalls, but others flip between being accessible and inaccessible through the effect of temporary debris dams, with dramatic consequences for the foodweb.

2.17 Natural headwater streams are highly connected to the springs and flushes that feed them with water, providing a wetland transition zone of high conservation importance. Acid (Figure 2.7) and calcareous springs generate their own distinctive flush communities, and very calcareous waters form the European protected habitat 'petrifying springs with tufa formation (*Cratoneurion*)' (Figure 2.8). In addition to the characteristic flora, specialist invertebrate communities exploit the flush and runnel habitat provided, including the nymphs of the stonefly *Nemurella picteti*, the southern damselfly (*Coenagrion mercuriale),* the scarce blue-tailed damselfly (*Ischnura pumilio*) and the caddis-fly (*Plectrocnemia brevis*, a specialist of tufa-forming springs).

Figure 2.7 Acidic spring and flush habitat at the head of a woodland stream – the vegetation is dominated by *Sphagnum* mosses

Figure 2.8 Tufa-forming spring/flush/stream mosaic

High energy river sections

2.18 High energy river sections are characterised by coarse bed substrates, ranging from gravel to cobbles to boulders, depending on the hydraulic energy and scale of sediment supply generated by the upstream catchment and the natural physical constraints on the river channel. The invertebrate fauna of fast-flowing rivers tends to be highly diverse, with a rich array of caddis-flies, mayflies and stoneflies including the large predatory *Dinocras cephalodes*, and (generally in more alkaline waters) molluscs such as river limpet (*Ancylus fluviatilis*) and the crustacean white-clawed crayfish (*Austropotamobius pallipes*).

2.19 More stable larger substrates can host luxuriant growths of mosses and liverworts, particularly in woodland or through gorges and ravines where humidity develops (Figure 2.9). Species supported include the rare moss *Fissidens serrulatus* and the river jelly lichen *(Collema dichotomum).* Invertebrates such as the stonefly *Brachyptera risi* live in the mosses, providing a valuable food source for birds such as dipper (*Cinclus cinclus*) and grey wagtail (*Motacilla cinerea*). Waterfalls and their splash-zones generate rivulets and humid moss-covered rocks, providing habitat for a range of invertebrates including the waterfall beetle (*Dianous coerulescens*, Figure 2.10). So far a total of 15 beetle species have been found associated with this habitat, many of which are rare or restricted in range (pers comm Jon Webb, Natural England). The freshwater pearl mussel (*Margaritifera margaritifera*) also prefers a high energy river environment with more stable (gravel and cobble) substrates, where juveniles and adults can live out their long lives without being washed out by very spatey flows.

Figure 2.9 High energy, boulder-strewn river running through a humid wooded ravine, well-suited to lower plant assemblages

Figure 2.10 The waterfall beetle (*Dianous coerulescens*) and its natural habitat (courtesy of Jon Webb)

2.20 In rivers with more mobile sediments (so-called active shingle rivers) the high levels of sediment disturbance are hostile to most plants, and attached algae (periphyton) become more dominant. Some invertebrate species are adapted to life in the unstable gravels, such as the stonefly *Perla bipunctata*. Larger rivers with high coarse sediment supplies throw up great shoals and bars of gravels and other material (Figure 2.11), often generating braiding of the channel. Those sediments that are seasonally exposed (at normal or lower-than-average flows) provide habitat niches for specialist assemblages of invertebrates, most notably beetles (e.g. Figure 2.12) and in particular 'ground' and 'rove' beetles, many of which are rare or threatened. The beetle assemblage of exposed sediments varies according to the coarseness of the sediment (from shingle to sand), so that different shoals can support different assemblages.

2.21 There are over 200 beetle species using exposed shingle habitat in England, many of which are specialists and only occur on riverine shingle and sand (pers comm Jon Webb, Natural England). They are omnivorous or predatory, feeding directly on other insects (stoneflies, mayflies and caddis flies) emerging from the river or the pupal cases they leave behind. In the winter months, when the river levels rise, many of these beetle species either leave the river edge to find over-wintering sites nearby, or tunnel deep into the sediment to find refuge.

2.22 The more permanently exposed shoals of active shingle rivers are important for early successional vegetation (Figure 2.13), including butterbur (*Petasites hybridus*), tansy (*Tanacetum vulgare*, host of the endangered tansy beetle) and willow scrub, and birds such as ringed plover (*Charadrius hiaticula*) and oystercatcher (*Haematopus ostralegus*). Once the sediments become sufficiently exposed and stable for vegetation their importance to many invertebrate species declines. Seasonally exposed sediments in a river system can therefore been seen as a dynamic set of related habitats, shifting and changing with natural riverine processes and providing conditions for a range of biological assemblages at different locations and points in time. These assemblages require adjacent suitable habitat in riparian and floodplain areas to fulfil their life cycles.

Figure 2.11 Active shingle river. Exposed shingle is apparent in this section but it lacks riparian trees and the components of the habitat mosaic they bring

Figure 2.12 The ground beetle *Bembidion tibiale*, a specialist species of exposed riverine sediments with a preference for cobbles and boulders (courtesy of Jon Webb)

Figure 2.13 Early successional plants on stabilised gravel shoals

2.23 Natural fish assemblages are characterised by brown and sea trout, salmon, bullhead and stoneloach (*Noemacheilus barbatulus*), giving way to grayling (*Thymallus thymallus*) and fastwater cyprinids (such as dace *Leuciscus leuciscus*, chub *Leuciscus cephalus*, and gudgeon *Gobio gobio*) as current velocities decline (depending on their natural geographical distribution). Grayling and fastwater cyprinids have the same habit as trout and salmon of laying eggs in (or in some cases on) the gravel of the river bed.

2.24 Slackwater refuges (such as pools, back-eddies and submerged tree root systems) are a critical natural component of high energy rivers. They provide the habitat niches for species that are not adapted to withstand high current velocities, and provide temporary refuges for fastwater species during spate flow conditions. They also provide finer substrates (silts and sands) that are essential to some characteristic species: for instance, the juveniles of lamprey species develop in silt beds, and the stonefly *Leuctra nigra* is strongly associated with silty habitats within gravel-bed streams. Channel sinuousity is critical in providing these slackwater refuges, as are riparian trees and large woody material fallen in the channel, both of which promote sinuosity and create scour pools and undercut banks.

Low/moderate energy river sections

2.25 In the lowest energy sections, extensive deposition of finer sediments occurs, and species that exploit these muds, silts and sands (such as pea and unionid mussels, including the uncommon depressed river mussel *Pseudanodonta complanata*), become more prominent in the biological assemblage. Submerged higher plants (such as the water-crowfoot *Ranunculus fluitans*) and luxuriant marginal vegetation (including rare species such as greater water parsnip, *Sium latifolium*) are a characteristic feature. These plant assemblages provide conservation interest in their own right but also supporting habitat for a range of plant-dwelling fauna such as the nymphs of dragonflies, damselflies (Figure 2.14), the rare ram's-horn snail *Gyraulis acronicus*, and the stonefly *Taeniopteryx nebulosa*. Naturally shallow river bed levels support a high water table on the adjacent floodplain, giving rise to fen and wet grassland vegetation and associated fauna including the European protected mollusc *Vertigo moulinsiana* and plants such as the increasingly uncommon tubular water-dropwort (*Oenanthe fistulosa*) and marsh stitchwort (*Stellaria palustris*).

2.26 The fish assemblage of low energy rivers is dominated by cyprinids adapted to slow-moving or still water, such as perch (*Perca fluviatilis*), roach (*Rutilus rutilus*) and bream (*Abramis brama*). These species lay their eggs on submerged vegetation, which the fry are also dependent on for shelter.

Figure 2.14 The banded demoiselle damselfly, *Calopteryx splendens*, the nymphs of which dwell in the abundant submerged and emergent vegetation of slow-flowing lowland river sections (© Natural England)

2.27 Whilst fast-moving water and coarse substrates are a less common feature of these river sections, where fastwater habitat naturally occurs it is essential in maintaining the full characteristic assemblage. Many of the species of these low energy rivers cannot persist without coarse substrates and the processes that sustain them. For instance, the critically endangered stonefly *Isogenus nubecula* (Natural England 2015) is a riffle-dwelling specialist of large lowland river sections and would have no habitat if coarse substrates were not present.

2.28 Similarly, exposed sediments are naturally less prevalent in these river sections but are still a critical part of the natural habitat mosaic for supporting the full characteristic assemblage.

Again, channel sinuosity, in association with riparian trees and large woody material fallen within the channel, provides the habitat complexity that allows fastwater habitat and exposed sediment niches to occur within the broader habitat mosaic.

2.29 Where there is a reasonable amount of hydraulic energy and relatively low levels of fine sediment generated by the catchment, stable gravel substrates can still be extensive in lower energy rivers. This is the case with lowland chalk rivers (Figure 2.15), which are of international importance and confined to England in the UK. The alkaline waters and extensive gravels generate highly diverse invertebrate assemblages, luxuriant submerged and emergent plant communities, and abundant populations of salmonids and fastwater cyprinids (Mainstone et al. 1999). The uncommon fine-lined pea mussel (*Pisidium tenuilineatum*) is only found in this river habitat.

Figure 2.15 A chalk river, with a predominantly gravel bed and high baseflows supporting riparian fen vegetation

Tidally influenced reaches

2.30 The lowest reaches of rivers, just as the river enters the estuary, provide a profoundly different type of habitat that is essential to a range of species (Figure 2.16). These reaches are termed the saline transition zone, where the purely freshwater river progressively acquires the salinity regime of the estuary. This zone is often neglected in river conservation because it is not considered classically riverine but neither is it considered classically estuarine. The saline transition zone is typically of low species diversity compared with wholly freshwater reaches upstream because few freshwater species can withstand significant levels of salinity. However, it is an essential spawning and juvenile nursery area for a range of estuarine fish species, including smelt (*Osmerus eperlanus*), thin-lipped, thick-lipped and golden mullet (*Liza ramada*, *Chelon labrosus* and *Liza aurata* respectively), bass (*Dicentrarchus labrax*) and flounder (*Platichthys flesus*). It is also an essential migratory route for longer distance migrators including European eel (*Anguilla Anguilla*), sea lamprey (*Petromyzon marinus*), river lamprey (*Lampetra fluviatilis*), Allis shad (*Alosa alosa*), twaite shad (*Alosa fallax*), Atlantic salmon (*Salmo salar*), and sea trout (*Salmo trutta*). It is a highly productive environment, with marginal zones of mud that support burrowing bivalves and wading birds such as greenshank (*Tringa nebularia*) and redshank (*Tringa totanus*). The swollen spire snail (*Mercuria similis*) is a specialist of this brackish environment, living on the exposed mud and emergent vegetation.

Figure 2.16 Tidally influenced river, with exposed mud and free connectivity to the estuary and adjacent floodplain (© Natural England)

2.31 Under natural conditions, there is unhindered passage for migrating species between the estuary and the freshwater river. Water levels rise and fall with the tide to expose mud for wading birds to forage in. The main river is linked to tidal creeks that are fed by freshwater springs in the valley sides and themselves undergo a saline transition along their length. This is the niche of brackish water plant specialists such as the water-crowfoot *Ranunculus baudotii*, and of saltmarsh communities.

Nature of impacts

2.32 Rivers are never completely physically destroyed as a result of anthropogenic impacts in the way that a wetland, woodland or grassland can be destroyed, since the drainage of water through a surface water network of channels is an intrinsic environmental characteristic of catchments. However, river length (and therefore physical habitat area) can be greatly reduced by channel straightening, often eliminating more than 50% of river habitat area as a result. Channel engineering, and subsequent flood defence and land drainage maintenance activities, can heavily degrade the quality of the remaining river habitat, through the loss of natural habitat mosaics. This degradation may involve loss of fast-water or slack-water biotopes). Pollution, hydrological modification (including abstraction), non-native species and fisheries management generate additional stresses that further degrade the habitat and its characteristic biological assemblages. Impacts on the river are associated with even more severe impacts on valley mire and floodplain wetlands, which are often eliminated from the landscape by drainage.

2.33 Organic pollution (Jones et al. 2009, Natural England 2010), eutrophication (Mainstone 2010a), acidification (Battarbee et al. 2014), enhanced fine sediment delivery and siltation (e.g. Larsen and Ormerod 2009) and other water quality problems (such as pesticides, e.g. Beketov et al. 2013) result in the loss of sensitive species and the proliferation of tolerant species. These problems are widespread in river systems and the depth of their resolution sets a limit on the success of measures aimed at restoring physical habitat condition. Whilst organic pollution levels in England have reduced considerably in recent decades, this has revealed more insidious problems with eutrophication and siltation, and the more subtle effects of mild organic pollution are still widespread. Headwater streams with poor buffering capacity (in both the uplands and lowlands) are slowly recovering from the legacy of acidification from sulphur deposition, but acidification stress from on-going nitrogen deposition remains (Battarbee et al. 2014).

2.34 Bed lowering for land drainage and flood defence has removed vital coarse bed sediments that, for many lower energy rivers, are difficult to replace (Mainstone et al. 1999). Hydrological connectivity with floodplain habitats is lost as river-bed levels are dropped and flood flows are confined to the river channel, often consolidated by floodbanks (Figure 2.17). Bank reprofiling (typically associated with straightening) results in loss of variety in bank profiles and reduction or loss of wetland riparian areas (Figure 2.18). Bank reinforcement fossilises channel planform and prevents natural dynamic processes of habitat creation and change (Figure 2.19). Hydraulic energy increases in shortened, oversized, and constrained channels, eliminating slackwater habitats and (in energetic rivers) often leading to channel destabilisation through enhanced erosion of the bed and banks.

Figure 2.17 Channel oversizing and flood embankments eliminating hydrological connectivity with the floodplain

Figure 2.18 Channel straightening and bank reprofiling eliminating the natural river habitat mosaic

Figure 2.19 Bank reinforcement aimed at preventing lateral channel movement, but actually exacerbating bank and bed destabilisation

2.35 If coarse sediment supply is artificially reduced, for instance by capture behind upstream weirs and dams or by active gravel removal from the channel, channel incision and enhanced bank erosion may again be the result (Figure 2.20).

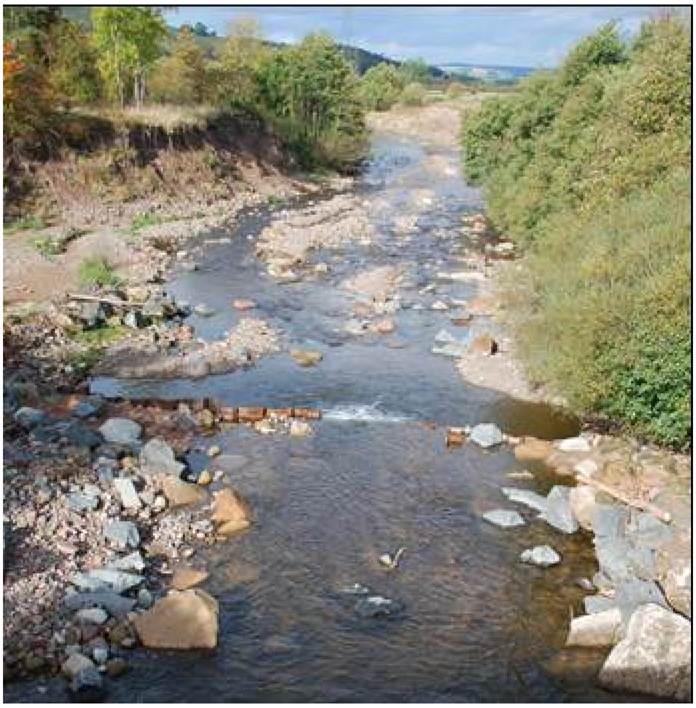
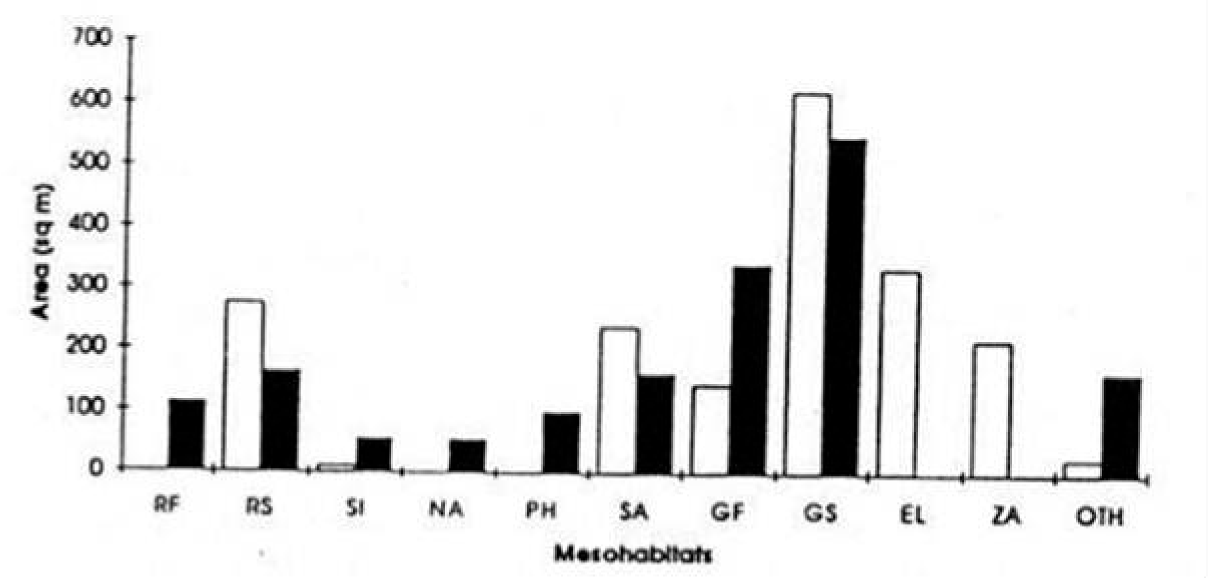


Figure 2.20 Artificially induced channel incision (in this case caused by coarse sediment starving due to historical gravel extraction upstream

2.36 Alternatively, if coarse sediment supply is high and the channel held in place by floodbanks, the channel can become perched above the floodplain due to the accumulation of bed material, further modifying natural processes and hampering restoration of natural river-floodplain interactions. Figure 2.21 shows the effects of this process on the River Glen in Northumbria, resulting in a major avulsion of the river out of the perched channel through agricultural land.

Figure 2.21 Channel avulsion caused by the pinning and embankment of the channel against the valleyside to facilitate agricultural management of the floodplain (photograph supplied by the Environment Agency)

2.37 Weirs and dams add further layers of change to channel hydraulics and sediment processes, resulting in the ‘drowning’ of characteristic habitat mosaics in impounded sections (e.g. Figure 2.22), the silting of bed sediments and stabilisation of water level regimes, in addition to the interruption of coarse sediment supply already mentioned. Water level stabilisation is particularly damaging for ephemeral habitats such as exposed riverine sediments, since it prevents natural water level recession through the summer low flow period which is critical to the exposure of these habitats (Sadler and Bates 2007). Biological movement within river systems is also fragmented by these artificial barriers to movement (e.g. Lucas et al. 2009), with major consequences for long-distance migratory species (such as shad, river and sea lampreys, salmon, sea trout and eel) and also for all species making shorter within-river migrations (such as bullhead and dace). At the coast, weirs and other tidal structures eliminate the natural saline transition zone and its characteristic assemblage, often replacing it with an impounded, enriched stretch of freshwater habitat.



Columns are the area of different meso-scale habitats in upstream regulated (white columns) and downstream unregulated (black columns) sections of the Mill Stream, River Frome, Dorset. RF = Ranunculus Fast flow; RS = Ranunculus Slow flow; Si = Silt; NA= Nasturtium; PH = Phragmites; SA = Sand; GF = Gravel Fast flow; GS = Gravel Slow flow; EL = Elodea (a non-native plant preferring slow-flowing or standing water); ZA = Zannichellia (a native plant preferring slow-flowing water); OTH = Other. The graph shows the loss of fastwater habitats, marginal encroaching vegetation, and also silt patches that occur within the natural habitat mosaic.

Figure 2.22 The effect of a weir on the characteristic river habitat mosaic (Armitage and Pardo 1995)

2.38 Headwater reservoir impoundment and abstraction alter natural flow regimes in various ways, exacerbating or augmenting natural low flows, reducing or enhancing peak flows, altering temperature regimes, and sometimes fundamentally altering the size of the river channel (Petts and Gurnell 2005). All of these flow modifications have impacts on environmental conditions and characteristic biota, which vary according to the nature of the flow modification and the natural character of the river and its associated biological assemblages (Mainstone 2010b). Both the spatial extent and hydraulic character of riverine habitats may be affected, disrupting the characteristic balance within the habitat mosaic. Species that are adapted to higher levels of hydraulic energy are often disadvantaged, whilst species adapted to lower energy environments often benefit. In some cases, the hydraulic character of the river changes little but habitat extent is reduced, affecting population sizes. Flow modifications that occur in combination with physical channel modifications that simplify the habitat mosaic generate the greatest impact, because habitat niches that provide refugia for species at high and low flows are lost.

2.39 In the headwaters, drainage and associated intensification of land management (including afforestation) can have a severe effect on headwater streams, typically associated with the loss of mire and flush habitats from which the streams drain. In lowland areas, natural mire/stream transitions have been lost through drainage for intensive agriculture, and in many cases artificial (typically poor quality) headwater stream habitat has been created by artificial extension of channels into mire areas that are consequently drained and lost. In contrast, groundwater abstraction can result in the downstream contraction of headwaters, including the loss of ephemeral sections that support specialist species. In upland headwaters, in addition to the loss of natural mire transitions, the invertebrate community have been found to be suffering from heavy organic siltation associated with peat erosion caused by drainage (so-called ‘gripping’) and burning (Figure 2.23, Ramchunder et al. 2009, 2011, 2012; Brown et al. 2014). Given the widespread nature of these moorland practices, these impacts are likely to be widespread in the upland headwater resource. This adds to the stress on upland headwaters from the continuing legacy of acidification (Evans et al. 2014).

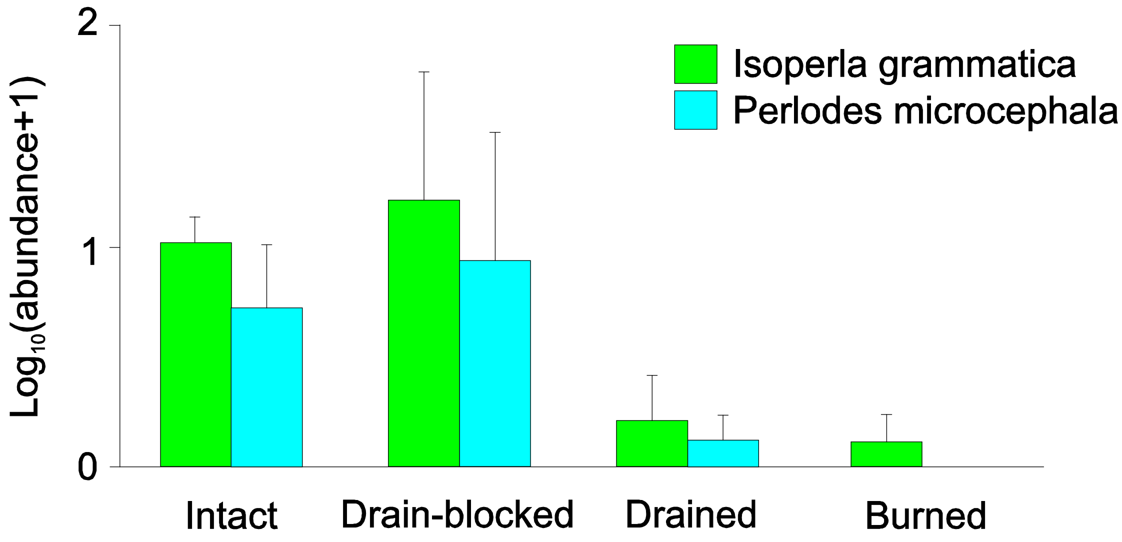


Figure 2.23 The effect of moorland drainage on stream invertebrates (Ramchunder et al. 2011). Data are for two stoneflies characteristic of high quality moorland streams with clean stony substrates. The graph shows heavy declines associated with high levels of siltation of the streambed from eroded peat.

2.40 Non-native species can damage river habitats and have direct predatory and competitive impacts on species composition and abundance (Strayer 2010). The impact of species such as signal crayfish and Chinese mitten crab on the physical habitat and characteristic biological communities of English rivers can be considerable, and can greatly reduce the benefits that might be secured through restoration of natural environmental processes. Fisheries management can either promote or interfere with characteristic biological communities, depending on the intensity and nature of management activities (e.g. Mainstone et al. 1999).

2.41 These impacts do not all occur everywhere in England, but most are widespread. Some are more focussed on upland rivers and some in the lowlands, some on headwaters and some on floodplain areas. Impacts typically occur in combination (i.e. 'multiple stressors'), making biological consequences more difficult to understand, characterise, tease apart, predict and address at a local level.

2.42 The distribution and abundance of individual species, including priority species, are affected by these anthropogenic impacts. Whilst species characteristic of natural habitat function will generally suffer, some species (which may or may not be characteristic at a given location) will benefit. These latter species may be tolerant of certain human stresses, or may exploit an artificial reduction in a natural stress (for instance, a reservoir impoundment that moderates the extremes of natural flow regimes), or utilise specific biotopes that are increased in extent as a result of habitat modification (for instance, artificial 'pool' habitat forming behind weirs, or extensive fastwater habitat created by straightening of upland rivers). If such species are priority species for conservation, this can confuse the characterisation of impacts and result in conflicting management perspectives.

2.43 Many of these impacts are a problem for both biodiversity and human uses of water and land. The limitations of traditional flood defence approaches have become increasingly apparent (The Pitt Review 2008) and there are progressive moves towards promoting 'low energy' flooding in suitable parts of catchments to avoid the propagation of flood flows downstream (Parrot et al. 2009). In terms of water use, heavy use in one area affects water availability elsewhere, whilst the quality of the water affects its usability. The landscape, historic and amenity value of river habitats are also adversely affected by many of these impacts, although some artificial modifications to river systems have value from these perspectives (for example, historic weirs).

2.44 Climate change is already altering environmental conditions and biological assemblages in UK rivers (e.g. Durance and Ormerod 2007), with more extreme winter flooding events and drier, warmer summers, and is predicted to continue to alter regimes of temperature, flow, sediment and water quality to a considerable degree (Johnson et al. 2009, Kernan et al. 2012). Overall, the impacts of human activities in catchments greatly reduce the ability of river ecosystems to cope with climate change (Kernan et al. 2012).

General aspirations for running water habitats

2.45 Streams and rivers operating under natural processes, free from anthropogenic impact and with a characteristic and dynamic habitat mosaic that caters for characteristic species assemblages, provide the best and most sustainable expression of running water ecosystems. Natural processes include natural flow, nutrient and sediment delivery regimes, minimally impacted water quality generally, minimal physical modifications to the channel and banks, natural longitudinal and lateral hydrological and biological connectivity, an absence of non-native species, and low intensity fishery management. These conditions provide the best defence against climate change, maximising the ability of riverine ecosystems to adapt to changing climate conditions (Clarke 2009, Kernan et al. 2012), and provide the best and most sustainable interfaces with other habitats, including lakes, wetlands and coastal habitats. They allow species to be distributed within river systems according to their natural habitat preferences and requirements.

2.46 In practical terms, there are major socio-economic constraints on the extent to which these conditions can be achieved in modern landscapes in England. These constraints vary widely depending on population density and the spatial distribution of different anthropogenic activities. Immovable constraints to restoring natural processes have to be recognised in developing practical management plans. The extent to which any one river can express natural processes will depend on site-specific circumstances.

Key management messages

2.47 The evidence presented above leads to a range of important conclusions about how we aim to conserve running water habitats and their characteristic species.

2.48 ***Restoration of natural processes*** – This is the top priority. Any measures that seek to restore natural processes, in terms of natural flow, geomorphological and water quality regimes, should be seen as an important contribution towards river habitat conservation. It is important to understand the river system as it would operate under natural processes and plan from that foundation, factoring in implications for priority riverine species and related riparian and floodplain habitats and species. A catchment-scale approach is required to consider natural processes properly.

2.49 ***Large-scale perspective*** – Running water ecosystems are complex and physically connected within catchments by overland or subterranean flow. The condition of the river depends on many factors, including what is happening in upstream reaches and in the catchment. Restoring flow, sediment and water quality regimes is key - it is not only about addressing direct physical impacts on the reach of concern (Mainstone and Clarke 2008, Mainstone and Holmes 2010).

2.50 ***Taking the long view*** – There is considerable enthusiasm in England for restoring rivers by active physical intervention, and in many cases some intervention is essential to trigger natural recovery of river habitat function (such as the removal of weirs, hard bank protection and floodbanks, and strategic tree planting). However, natural recovery should always be allowed to play the fullest role possible, even if this means being patient. Importantly, socio-economic constraints that are immovable in the short-term may be more amenable to resolution in the longer term – a long-term vision and associated planning makes for the best and most sustainable decisions.

2.51 ***Rationalising issues relating to species distribution and abundance*** – Prioritisation of locations for conservation measures based on the existing distribution of priority species can be flawed as that distribution may reflect past impacts on river habitat and its characteristic biological assemblages. Species conservation plans need to take account of any changes in the distribution and abundance of species that will result from restoration of natural processes if they are to be sustainable. Equally, ecosystem restoration plans based on natural processes need to recognise any significant implications for priority species that may be affected, ensuring there are suitable habitat opportunities in a more naturally functioning system and sources of colonists to exploit them. In extreme cases where the survival of a species is in jeopardy, direct population intervention should be considered to assist in the transition to restored environmental conditions (for instance, captive breeding of pearl mussels at the Freshwater Biological Association in Windermere), taking into account likely changes in climate space resulting from climate change.

2.52 ***In-channel structures*** – Weirs and dams have a range of physical effects on river habitats, as well as blocking the free movement of some species. The only way to eliminate these impacts is to remove the structure completely and this should be the aim wherever possible. Modification to minimise all impacts is the next best option, preferably using a by-pass channel. It is important to remember that fish passes mitigate only one impact (species movement), and only for a small number of species, and that fish pass installation can be used to help justify the longer-term retention of a weir or dam that could potentially be removed. If this is all that can be done, the pass should be permeable to as many species as possible, and to relevant priority species as a minimum.

2.53 ***Allowing lateral channel movement*** – This is a key step in restoring the dynamic habitat mosaics on which characteristic biota depend. An attainable ambition in many cases is an enhanced active river ('erodible') corridor (Piegay 2005), bounded by some form of resistance to further movement (such as set-back tree lines), within which the channel can move and create at least limited physical dynamism and habitat heterogeneity.

2.54 ***Restoring low energy flooding in suitable areas*** – Restoring natural channel dimensions and removing floodbanks in suitable rural areas will reconnect the river channel with its riparian zone and floodplain, benefiting a range of wetland habitats and species. It will also help to prevent the build-up of peak flows to downstream urban areas at high flood risk. The re-creation of areas of wet grassland and woodland in targeted areas of the floodplain helps to naturalise sediment regimes by trapping fine sediments carried by flood waters. This type of restoration may be achievable by natural processes, or will otherwise require intervention such as bed-raising. The quality of floodwaters needs to be properly considered in relation to the sensitivity of relict wetland habitat on floodplains - naturalising nutrient and sediment loads in floodwaters needs to form part of the restoration process.

2.55 ***Riparian vegetation*** – A patchy mosaic of riparian vegetation should be the aim, with a mix of long and short swards, trees and shrubs, and bare ground created by natural river processes. Riparian trees are involved in a number of key processes: they interact directly with river flow to restore habitat complexity (exposed tree root systems, scour holes), provide leaf litter (the most important natural food source in headwater streams and on which a range of specialist species depend), generate large woody debris (as a habitat in its own right and as a force for generating diverse habitat mosaics), and provide patchy light and shade in the channel (another important part of the habitat mosaic). In addition to their natural ecological function, they are important in buffering the river corridor against adjacent intensive land management (Poole et al. 2013) and are critical in providing stability against extreme channel movement (a critical issue for land managers). Riparian tree cover is also an important mitigation measure against rising air temperatures resulting from climate change (Natural England/RSPB 2014). It is suggested that increasing tree cover to at least a minimum level (30%) provides a good general habitat mosaic and contributes to climate change mitigation. In some situations, increasing tree cover beyond this will be appropriate, most notably in headwater areas where extensive tree cover is particularly consistent with restoring natural ecosystem functioning.

2.56 ***Management of large woody debris*** – Woody debris is a critical component of a naturally functioning river, adding physical habitat complexity, refuge and a specialised substratum on which organisms live and feed (Gurnell et al. 2005, Gurnell and Petts 2006). It should be left *in situ* wherever possible, or pinned to the bank or riverbed where there is a public safety risk. Greatest benefit in restoring natural habitat mosaics is generated by material that is set across or obliquely to the flow rather than parallel to the banks, since it increases the geomorphological effect (differential erosion and deposition of bed and banks). Ideally, the river should be zoned according to risk and woody debris managed in accordance with that risk. Headwater streams can have low hydraulic energy and can be of low risk in terms of allowing large woody debris to accumulate. Passive restoration of woody debris in rivers (i.e. tree planting to generate native woody input over time) is preferable to active restoration (i.e. importing of material and engineering woody structures) (Kail et al. 2007).

2.57 ***Ensure ephemeral habitats are catered for*** – Seasonally exposed habitats house much of the biodiversity of rivers (e.g. Sadler and Bates 2007). Ephemeral headwaters, seasonally exposed sediments (shingle bars), riparian wetland zones and seasonally encroaching marginal vegetation are critical but often neglected elements of the habitat mosaic (e.g. Mainstone et al. 1999, Sadler and Bates 2007). Natural seasonal flow and water level recession is essential, as is protection against disturbance (from maintenance works or heavy livestock trampling). Wide and shallow banks have been found to be important in providing good levels of ephemeral riparian habitat (Pedersen et al. 2006) – this can be provided as part of the variability in bank form generated by natural geomorphological processes.

2.58 ***Avoid bankside fencing wherever possible*** – A great deal of close bankside fencing has been erected to protect river banks from high densities of livestock in riparian fields. Whilst this does have benefits to in-channel fauna, it can generate a ruderal riparian vegetation of low conservation value and eliminates both short-sward plant species and bare ground habitat for a range of invertebrates and characteristic pioneer plant species (e.g. Mainstone et al. 1999). It prevents a naturally functioning riparian zone from developing since it permits high intensity land use right up to the bank top. If can be counter-productive on rivers more prone to lateral movement – fences lost to natural bank erosion are then sometimes used as a justification for bank reinforcement, further removing the river from natural processes. Fencing should be avoided where livestock grazing intensity can be reduced to a degree that avoids heavy damage to riparian and in-channel habitats, particularly where flooding is frequent and fencing is likely to be damaged and impede floodwaters. Where this is not possible, and in situations where any level of livestock grazing may damage critical habitats (such as exposed shingle), set-back fencing should be established that provides a sufficiently wide riparian corridor, with room for lateral river movement. Access for periodic and selective grazing, cutting or other management of the riparian zone is recommended.

2.59 ***Understanding the location of existing freshwater biodiversity*** – To maximise the benefits of restoration work, and eliminate unwanted damage to populations of priority or endangered species, it is useful to ensure that there is good local knowledge of the distribution of freshwater biodiversity, ideally in a landscape context (indeed, this knowledge is legally necessary for some species). It is valuable for projects to take account of both running and still water and wetland biodiversity. There are currently initiatives which will help to identify important locations, including 'Important Areas for Ponds' and 'Important Freshwater Areas' being undertaken by the Freshwater Habitats Trust.

Indicators of natural river habitat function

2.60 Defining appropriate indicators of natural function, capable of characterising all aspects of the river ecosystem, is vital in properly capturing impacts and evaluating progress with protecting and restoring riverine habitats. Table 2.1 lists a range of elements of natural function and components of river habitat that are frequently overlooked in routine monitoring and assessment programmes. The use of such indicators in evaluating riverine habitats is discussed further in Section 5, where links to more detailed information are provided.

2.61 Biological indicators should be the ultimate check on whether protection or restoration of natural riverine processes is having the desired biodiversity effect. However, routine biological indicators and monitoring regimes are not capable of providing sufficient resolution of improvements (e.g. Feld et al. 2011). For instance, a single routine macroinvertebrate monitoring point in a long river section will not be able to detect the benefit to the in-stream habitat mosaic of removing a weir some kilometres away within the water body. Equally, a routine fish monitoring site in a water body will not be able to detect the restoration of river length (and hence habitat area) generated by restoring lateral movement of the channel. In addition, considerable problems remain over our ability to predict reference biological communities at site-level without sufficient examples of unimpacted rivers and characterisation of natural biological variability, which further hampers the robust use of biological indicators in conservation assessment and decision-making. Some routinely used biological indicators in rivers permit a coarse indication of biological status that is useful in detecting certain types of impact on natural habitat function but not others.

Table 2.1 Aspects of natural river habitat function requiring consideration in monitoring and assessment regimes

Aspect	Concept
Elements of natural function	
Longitudinal connectivity	Relates to the natural freedom of movement of water, sediment and biota through a river system. Impacts on longitudinal connectivity mainly relate to impounding structures (weirs, dams), of which around 26,000 have been recorded in the UK. Of these, disproportionate numbers are located in England.
Lateral connectivity	Relates to the hydrological and ecological interaction between the river, its riparian habitat and wider floodplain habitats. Historical loss of river-floodplain habitat connectivity has major implications. Linked to habitat simplification by river channelization, loos of floodplain habitats and the generation of catastrophic high energy floods causing severe economic damage.
Vertical connectivity	The deeper substrates of the river channel, within the hyporheos, are important for the interchange of water and as a refuge for a range of species. Can be affected by artificially enhanced siltation (which clogs bed substrates and restricts water flow), abstraction (weakening upwelling from the hyporheos) and inappropriate river restoration (bed-lining).
Naturalness of flow regime	Natural flow regimes are fundamental to healthy river ecosystems. Flow regimes are under severe stress in England and are under further threat from development pressure and climate change.
Naturalness of water quality regime	High water quality is a critical requirement for protecting and restoring characteristic biological communities including priority species such as freshwater pearl mussel. Nutrient status is a key factor, and nutrient enrichment is implicated in a range of ecosystem effects. Others include acidification, organic pollution, and toxic pollution.

Table continued…

Aspect	Concept
Absence of non-native species	Non-native species can have physical effects on riverine habitats and can also directly alter characteristic assemblages to a considerable degree. Whilst some non-natives appear quite benign, others are highly invasive and have disproportionate effects on native assemblages.
Habitat mosaics	Mosaics of different meso-scale habitats shaped and sustained by natural processes are critical to natural ecological function and the provision of niches for the full characteristic biological assemblage. A range of physical habitat modifications have degraded or altered natural habitat mosaics.
Naturalness of biological community	The extent to which the biological community is characteristic of the river in its unimpacted state is a fundamental biodiversity consideration. However, the practicalities of assessment and its linkage to natural habitat function are problematic (see text).
Neglected habitat components	
Headwater streams	Headwaters comprise a large component of the river habitat resource, host a range of specialist species and provide critical functions for the rivers they feed, They receive little monitoring attention.
Riparian habitat	Riparian habitat is a vital component of the river ecosystem, comprising a mosaic of bankside trees, scrub, herbaceous swards and bare ground of varying wetness and height. It is often degraded by intensive land use up to the banktop, typically associated with close bankside-fencing. Some components of the in-channel biota are dependent on riparian habitat but can be accommodated by narrow strips of coarse ruderal vegetation of low conservation value, so the status of in-channel biota is not a good indicator of riparian habitat condition.
Exposed riverine sediments	These sediments host unique biological assemblages within the river ecosystem but are impacted by a range of factors including dredging, water level stabilisation and low flow augmentation.
Large woody debris	Woody debris is a vital component of a healthy river ecosystem but historically has been cleaned out of rivers due to flood risk concerns. Woody debris supply is also often lacking due to low levels of riparian trees.

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3 Standing waters

The natural habitat template

3.1 Lakes and ponds form naturally via a range of hydrological and geological process (Figures 3.1). Human activity has created many additional standing waters, via excavation for resources such as marl, gravel and peat and purposeful creation of standing water such as reservoirs, droving ponds, and forge ponds (Figures 3.2). For the purpose of this document all these standing waters will be referred to as lakes and ponds. Regardless of their origin, many are of great value for biodiversity and man-made water bodies can have similar physical, chemical and biological properties to natural lakes and ponds. An artificial origin does not therefore preclude a lake or pond being of conservation value.

3.2 Standing water systems that are naturally functioning (in terms of water chemistry and quality, hydrological regime, morphology and biological assemblages) provide the best and most sustainable expressions of freshwater habitats and the biodiversity they support. Some artificial standing water systems cannot operate in this way due to their very nature, despite potentially supporting freshwater biodiversity. These systems require constant intervention to maintain their interest and/or can restrict restoration of natural processes and natural levels of connectivity in the wider landscape. Examples include:

1) lakes generated by impounding rivers, which prevent natural river habitat function, often act as a silt trap and will inevitably become in-filled and eutrophic;
2) canals, which cut across watersheds and interfere with the hydrological and chemical function of natural freshwater habitats and by their nature have an artificial morphology and require dredging to prevent succession;
3) ditches, which constrain the restoration of natural wetland mosaics and rely on regular maintenance to prevent succession; and
4) reservoirs with artificial hydrological regimes or highly artificial lake margins that restrict connectivity.

3.3 These systems can still be important for biodiversity and consequently are valued for the species they support (Figures 3.3 and 3.4) rather than the habitat in its own right. They are particularly important where no good quality natural standing water habitats remain in the landscape. However, if naturally functioning standing waters can be restored, these will provide a more sustainable habitat to support this biodiversity in a way that also allows natural functioning of other habitats in the same landscape, which supports the full natural range of biodiversity at the landscape scale.

a) Ullswater

b) Quoisley Mere

c) A pool within Wybunbury Moss

Figure 3.1 A range of natural standing waters. (a) A lake typical of the Lake District, formed by a glacier deepening the valley which then filled with water after the glacier retreated. (b) and (c) Both part of the West Midland Meres and Mosses, which developed in natural depressions in the glacial drift left by the ice sheets which covered the Cheshire-Shropshire plain some 15,000 years ago.

a) Rixton clay pits, which supports a diversity of plant species typical of ponds as well as great crested newts.

b) Cotswold water park, gravel pits supporting a range of aquatic plants, including charophytes and an important site for wetland birds.

Figure 3.2 Standing waters of artificial origin created by mineral extraction

Figure 3.3 Cannock Extension Canal SSSI, (Staffordshire) The site supports floating-water plantain (*Luronium natans*), a species protected by the Habitats Directive (© Natural England/Peter Wakely).

Figure 3.4 Botanically diverse ditch system - Amberley Wild Brooks SSSI

3.4 Lakes and ponds also steadily infill under natural sediment and nutrient loads, but this process is not excessively fast (the 1850 reference sediment accumulation rate varies from 0.005-0.04 g cm^{-2} yr^{-1} depending on lake type; Rose et al. 2012). Infilling is most rapid in shallow water bodies with stream inflows and large stands of emergent vegetation and these water bodies can be expected to progress more rapidly towards fen vegetation (Keen 2000). Succession can also be extremely slow in temporary water bodies where organic material does not accumulate because it is exposed to the atmosphere and only inorganic sediments contribute to infilling; consequently temporary water bodies such as the pingos have existed since the last ice age are in excess of 8,000 years old (Williams et al. 2001).

3.5 Smaller water bodies can be seen as being particularly transient in nature. Despite this, in a natural environment they would constantly be present, as new ponds would continually be created replacing those lost to successional processes. Ponds may be formed by tree fall in wet woodland, river channel cut-offs and erosion and deposition in the flood plain, and temporary water bodies would occur wherever water accumulates in winter, e.g. at the base of slopes. Pools would also be common in flushes and bogs. Therefore, the continued presence of ponds requires the existence of these processes or an equivalent (Williams et al. 2000).

3.6 Natural water quality is the most important requirement for a lake or pond to support a natural biological community (Hering et al. 2013). This includes nutrients, acidity, oxygen, lack of other pollutants and colour. There is a natural continuum of trophic states from oligotrophic to eutrophic and, if the lake or pond is in a natural condition, the nutrient status of the water should reflect the geology, soils and vegetation of the catchment. In a natural system there should be a strong correlation between the alkalinity and nutrient status of the lake or pond. This is because both alkalinity and nutrients will have originated from the surrounding geology and readily weathered rocks will lead to both higher nutrient concentrations and higher alkalinity (Cardoso et al. 2007). For lakes this is reflected in work undertaken for the Water Framework Directive which classifies all water bodies according to alkalinity and depth. In clear water lakes phosphorous and nitrogen limit the productivity of the system. Table 3.1 provides a summary of the indicative characteristics of the various lake types found in England.

3.7 Light availability also limits productivity; this varies naturally with the input of coloured terrestrial organic matter, which makes the water brown. Lakes with high humic colour are found in peaty catchments and are termed dystrophic, such lakes are generally unproductive and tend to be acidic due to high amounts of humic and acidic substances entering the lake from the catchment. The colour of the water limits productivity at the base of the food chain by limiting benthic algal production (which represent a high proportion of productivity in low nutrient lakes) and the maximum depth of colonisation by macrophytes (Søndergard et al. 2012). At higher trophic levels benthic invertebrate and fish production and biomass are altered (Karlsson et al. 2009).

3.8 Acidity naturally varies with geology, with photosynthetic activity (higher pH at times of higher carbon dioxide uptake) and as a consequence of hydrological events such as high levels of precipitation, snow melt and drought. Acidity is an important aspect of water quality as it influences all chemical and biological processes in lakes, e.g. phosphorus binding in sediments, availability of carbon for photosynthesis, chemical speciation and the development of toxic effects of pollutants. Changes in pH, either through eutrophication or acidification can, therefore, have considerable effects on lake ecology.

3.9 As dissolved oxygen is essential for the respiration of most aquatic organisms, it is another important aspect of water quality. Three main physical factors influence the natural solubility of oxygen in water: temperature, salinity and atmospheric pressure. Water holds less oxygen at higher temperatures, salinity and altitude. The concentration of dissolved oxygen will vary between lakes depending on; depth, season, productivity and exposure. Deep lakes become stratified in summer as the epilimnion is warmed by the sun and floats on the cooler denser water (water is densest at 4°C) isolating the hypolimnion from the atmosphere. Inverse stratification can occur in winter when the surface waters freeze again isolating the hypolimnion from the atmosphere. Oxygen in the hypolimnion can then be depleted, as organic matter is decomposed and dissolved oxygen consumed in the process. In stratified lakes, this loss of dissolved oxygen may not be replenished by oxygen from the atmosphere until lake turnover. Sufficient oxygen in the cool depths of lakes is essential for species such as shelly (*Coregonus lavaretus*) and vendace (*Coregonus albula*).

Table 3.1 Indicative characteristics of different lake types found in England

Lake type	Alkalinity mg $CaCO_3$ l^{-1}	Indicative annual mean pH	Water colour	Productivity	Littoral zone	Geographic distribution
Dystrophic	Variable – often very low	<5.0	Brown peat stained	Extremely low, plants limited by a lack of light penetration.	Peaty often dominated by *Sphagnum* spp. Larger dystrophic lakes may have coarse inorganic shoreline as wave action increases with fetch.	Predominantly on upland blanket bogs, raised bogs and basin mires They can be created by the encroachment of schwingmoor on eutrophic lakes isolating the lake from the groundwater.
Oligotrophic	<10	5.5-7.0	Clear	Low, plants limited by a lack of nutrients.	Coarse substrates often without dense emergent vegetation.	Predominantly in the north and west although others can be found on base-poor sandstones or drifts further south.
Mesotrophic	10-50	Circa 7.	Clear	Moderate often with high diversity Some oxygen depletion may occur in the hypolimnion of deeper examples.	Exposed shorelines often coarse whilst sheltered shorelines are more silty.	Often on the borders between uplands and lowland sand on the tertiary sands of the south.
Eutrophic	>50	7-9	Clear	High Oxygen depletion may occur in the hypolimnion of deeper examples.	Silty substrates often supporting dense emergent vegetation.	Predominantly in the lowlands of the south and east, few deep examples exist.
Marl	> 65% of the catchment is on limestone	7-8.5	Clear	Low phytoplankton production but high macrophyte production.	Site dependant	A rare habitat type.
Brackish	N/A	Variable	Clear	Variable, but phytoplankton generally sparse.	Site dependant	Coastal regions.

3.10 Lake substratum can vary naturally throughout the lake with exposed shores being rocky or dominated by coarse particles whilst more sheltered shores and deeper water are dominated by fine silts and muds. The different types of substrata are essential for invertebrate habitat and fish spawning. The type of substratum available, in conjunction with the water level, is important. Seasonally exposed muddy banks are important in lakes and ponds for plants such as starfruit, and a number of priority invertebrates (Webb et al. 2010). In contrast, clean gravels that do not dry out at critical times of the year are required by some fish species (e.g. vendace) as spawning grounds. The type of substrate will depend on lake type and size (with large water bodies having a greater fetch and therefore exposure) examples of typical substrates in different lake types can be seen in Figures 3.5-3.7.

Figure 3.5 Wastwater SSSI, Cumbria. An oligotrophic lake with a typically stony substrate (© Natural England/Peter Wakely)

3.11 Water-level naturally fluctuates in lakes and ponds both within and between years. The extent of these fluctuations varies between water bodies; some will completely dry out in summer and others will hardly fluctuate at all. Water-level fluctuations are essential for the distinctive biological communities of temporary water bodies and drawdown zones (Williams et al. 2001). Bare substrate, be it rock, pebbles, sand or silt, exposed by water level draw-down can be of great importance to invertebrates, especially where the gradient is very shallow and the transition zone is wide as it provides a habitat for insect larvae and their associated predators.

Figure 3.6 Crag Lough, Roman Wall Loughs SSSI, Northumberland. Typical substrate and emergent vegetation of a mesotrophic lake (© Natural England/Peter Wakely)

Figure 3.7 View of ponds and reed beds with bare mud, illustrating the finer substrate typical of eutrophic water bodies. Yare Broads and Marshes SSSI, Mid-Yare National Nature Reserve, Norfolk (© Natural England/Paul Glendell)

3.12 Water level also influences hydrological connectivity between water bodies. Lakes and ponds can be naturally (permanently or temporarily) hydrologically connected or permanently isolated, and this can have a major bearing on the characteristic biological assemblage (Scheffer et al. 2006). Lakes formed along river corridors are connected longitudinally by their inflows and outflows while lateral hydrological connections may occur between a lake and its surrounding wetlands.

Figure 3.8 Lesser water-plantain (*Baldellia ranunculoides*) growing on the exposed mud of a New Forest pond

3.13 Lateral hydrological connectivity is important and results in the expression of a natural hydrosere. This is the natural transition from a fully aquatic (downslope) to a terrestrial community (upslope) and is critically dependent on natural water levels and shorelines. The extent of the hydrosere will depend on the morphology of the lake or pond and the topography of the surrounding area, as well as the substratum and underlying geology. Typical emergent vegetation (part of the hydrosere) of different lake types can be seen in Figure 3.9. The natural environmental diversity encompassed by a natural hydrosere includes a range of water depths, light climates, wave exposure and sediment types. Natural hydroseres also play a role in the maintenance of water quality and dissipation of wave energy (Schmeider, 2004).

a) Watendlath Tarn, an upland lake

b) Woolston Eyes SSSI, a lowland lake

c) Hatchet Pond SSSI (Hampshire) – rich marginal vegetation on a peatland site

Figure 3.9 Typical emergent vegetation in various types of standing water (a & c © Natural England/Peter Wakely)

3.14 Connectivity is also related to the density of freshwater habitats within an area. Species such as otters *(Lutra lutra)* will use multiple water bodies within an area, whilst invertebrates with terrestrial life stages may use different water bodies in an area in subsequent generations as conditions change, and others including many bird species may use the different water bodies as stepping stones across the wider landscape. This illustrates that it is not just direct hydrological connections which are important, but also the wider freshwater patchwork within the landscape (Sayer 2014).

Biological patterns

3.15 Littoral zones are usually dominated by plants ranging from emergent species in the shallowest water through to submerged species in the deepest water (Figure 3.10 depicts an example of emergent and floating plant species which constitute part of the littoral vegetation). Exposed rocky littoral zones of lakes may be able to support only periphyton due to the constant wave action. Shallow lakes and ponds may be entirely dominated by plants and, if the water is very shallow and/or temporary, these may be predominantly emergent. However, grazing pressure can result in submerged plants dominating shallow and temporary ponds as is seen in the New Forest. The Littoral zone provides habitat for invertebrates, epiphytic algae, zooplankton, fish (which use macrophyte beds as refugia, and for spawning, maturation and feeding grounds) and birds (providing nesting and feeding habitat). The plants (both in and around the water body) and epiphytic algae provide a direct food source and a detrital food source to many invertebrates. Tree roots and dead wood have been found to be particularly important as refuges for invertebrates in the littoral zone, but shading may supress submerged and emergent vegetation and leaf litter may smother sediments. Semi-natural vegetation surrounding water bodies aids the emergence of some invertebrate species (e.g. many dragonflies and all damselflies) and is essential for the terrestrial part of the lifecycle of many organisms (McGoff et al. 2013) as illustrated in Figure 3.11.

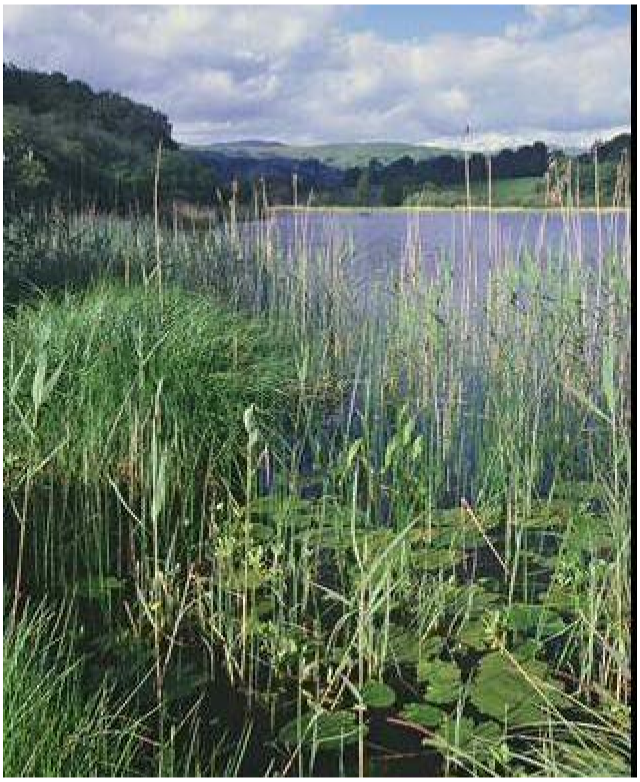


Figure 3.10 A range of plant species both emergent and floating can be seen in the littoral zone at Blelham Tarn SSSI, Cumbria (© Natural England/Paul Glendell)

Figure 3.11 Common blue damselfly, *Enallagma cyathigerum,* a widespread species of standing waters with abundant emergent and submerged vegetation (© Natural England/Paul Lacey)

3.16 The pelagic (open water) zone of lakes is dominated by plankton and the profundal benthos (the bottom-dwelling assemblage) is a community of animals and bacteria able to take advantage of organic matter that falls to its depths. Many macro-invertebrates (such as water beetles) avoid the deep open water as it is both cold and dangerous. These species tend to stick to shallow warm waters and the protection of emergent vegetation. Fish move freely between all the zones to find food, shelter and suitable areas for spawning as required at different life stages. Some species, such as bream (*Abramis brama)*, feed mainly in the sediments, whilst roach (*Rutilus rutilus*) feed mainly in mid-water. Owing to their smaller size and sometimes temporary nature, ponds are often unsuitable for fish. This can make them important for amphibians (whose larvae are susceptible to fish predation) and larger invertebrates. However, in good quality standing waters with sufficient structural complexity to provide refuges these species can coexist.

3.17 Some species require lakes and ponds to be hydrologically connected to flowing waters to enable them to complete their life cycle. Fish such as eels (*Anguilla anguilla*), lamprey (*Lampetra* spp. and *Petromyzon marinus*) and trout (*Salmo trutta*) may migrate through or into lakes taking advantage of the habitat and food available. Species such as trout and Arctic char (*Salvelinus alpinus*) need to be able to move out of lakes and into streams to spawn. Direct hydrological connectivity is also a route for macrophyte and invertebrate dispersal; although macrophytes are also often dispersed by birds and humans and invertebrates may have an adult aerial life stage. Other species may have no requirement for such direct hydrological connectivity to other water bodies and naturally carry out their entire lifecycle in one lake: this can lead to genetically unique populations e.g. vendace and slender naiad (*Najas flexilis*).

Dystrophic standing waters

3.18 Dystrophic lakes and pools often have little submerged vegetation because of the naturally peat stained water and low nutrient conditions, although they can support *Sphagnum* spp. and floating leaved species such as bogbean (*Menyanthes trifoliata)*, bog pondweed(*Potamogeton polygonifolius)* and white water-lily (*Nymphaea alba*) (Figure 3.12). Molluscs are often absent, due to the naturally acidic water chemistry, whilst dragonflies, beetles, water bugs and chironomids are abundant, as are copepods and cladocerans, a number of these are specific to such waters. Due to the hydrologically isolated nature of many bog pools these are often fishless; however larger dystrophic water bodies may contain Arctic charr, eel, and three-spined sticklebacks (*Gasterosteus aculeatus)*. Trout can also exist in these large isolated water bodies where coarse wave-washed sediments (which are similar to those which would be found in rivers) are available for spawning.

Figure 3.12 Dystrophic water body within the West Midland Meres and Mosses

Oligotrophic standing waters

3.19 Oligotrophic standing waters (Figure 3.13) characteristically have zones of the rosette forming species: shoreweed (*Littorella uniflora),* water lobelia *(Lobelia dortmanna)*, and quillwort (*Isoetes spp.*). These water bodies are characteristically clear and can support plants such as quillwort at depths greater than 6m; this is due to the naturally nutrient-poor conditions which limit algal productivity. This lake type characteristically supports a predominantly salmonid fish assemblage. The rare fish shelly , and Arctic charr are found in this lake type within the Lake District. These species require wave-washed coarse substrates and relatively high oxygen concentrations in the hypolimnion all year round. The most characteristic insect species of oligotrophic shorelines are mayflies, stoneflies, beetles and flies. These include a series of terrestrial ground beetles (Carabidae) that prey upon aquatic insects moving onto the shore to emerge into adults. The shoreline habitat is not dissimilar to that of rivers with well oxygenated water and silt free substrates.

Figure 3.13 An oligotrophic standing water

Mesotrophic standing waters

3.20 Mesotrophic standing waters (Figure 3.14) are the most botanically diverse, often supporting a range of both the rosette forming species common in oligotrophic standing waters and a range of taller growing species including a number of pondweeds (*Potamogeton* spp.). They can also support rare species such as slender naiad and least water-lily (*Nuphar pumilla*). The fish assemblages in these lakes are often a mixture of those found in eutrophic and oligotrophic lakes; in addition shelly, vendace and Arctic charr are all found in this lake type within the Lake District. Mayflies and caddisflies associated with aquatic vegetation are more abundant in mesotrophic than oligotrophic water bodies, as are the freshwater shrimps (*Gammarus* spp.) and water hoglouse (*Asellus aquaticus*) and a range of molluscs, along with a large number of chironomid species. This diverse species assemblage of flora and fauna is possible due to moderate nutrient concentrations, clear water, suitable oxygen levels, sufficient carbon dioxide, and a mix of substrates and emergent vegetation providing habitat for a range of fauna.

Figure 3.14 Bassenthwaite Lake (Cumbria), a mesotrophic lake (© Natural England/Peter Wakely)

Eutrophic standing waters

Eutrophic standing waters (Figure 3.15) characteristically support a range of pondweeds and floating vegetation such as frogbit (*Hydrocharis morsus-ranae,* Figure 3.16a) and greater bladderwort (*Utricularia vulgaris*). Such floating vegetation is particularly prominent in smaller water bodies with less exposure. The best remaining examples of this type of vegetation in the lowlands are often found in ditches as their nutrient concentrations are often kept low by spring-fed water and repeated removal of organic material. Such vegetation-rich habitats often support good numbers of macro-invertebrates, such as water beetles, water bugs and molluscs. Shallow, warm edges with a varied vegetation structure are of key importance. Other species rarely found in larger water bodes include Norfolk hawker (*Aeshna isosceles,* Figure 3.16b) and fen raft spider (*Dolomedes plantarius,* Figure 3.16c), which favour floating vegetation that is most frequently found in pools, ponds and ditches. Eutrophic standing waters typically support a cyprinid fish assemblage, many of which require submerged vegetation for spawning.

Figure 3.15 Rockland Broad, a eutrophic lake in the Yare Broads and Marshes SSSI Norfolk (© Natural England/Peter Wakely)

a) Frogbit, (*Hydrocharis morsus-ranae)*

b) Norfolk hawker dragonfly, (*Aeshna isosceles)* (© Natural England/Allan Drewitt)

c) Fen raft spider (*Dolomedes plantarius)* Redgrave and Lopham Fen National Nature Reserve, Suffolk (© Natural England/Peter Wakely)

Figure 3.16 Some species of small eutrophic standing waters

Marl standing waters

3.21 Marl standing waters (Figure 3.17) characteristically support dense charophyte beds and have clear water and low nutrient concentrations. These standing waters are also those which often support white-clawed crayfish (*Austropotamobius pallipes)* due to the relatively high alkalinity. Molluscs also tend to be abundant in this standing water type. The fish assemblage is largely dictated by the nature of the shoreline, with upland marl lakes supporting species associated with coarse substrates and more lowland standing waters supporting species associated with more vegetated shorelines.

Figure 3.17 Malham Tarn, a marl lake

Brackish waters

3.22 Brackish waters range from oligotrophic to eutrophic depending on the geology. With increasing saline influence they can support marine macro algae such as serrated wrack (*Fucus serratus)*, egg wrack (*Ascophyllum nodosum)* and gutweed *(Ulva intestinalis)*. The most saline resistant angiosperms include tasselweeds (*Ruppia cirrhosa, R*. *maritime*) and fennel pondweed (*Potamogeton pectinatus*). Certain charophytes will be found only in brackish conditions. Typical emergent species include sea club-rush (*Bolboschoenus maritimus)* and grey club-rush (*Schoenoplectus tabernaemontani)*, great fen-sedge (*Cladium mariscus)* and common reed (*Phragmites communis)*. Brackish waters can support interesting assemblages of macro-invertebrates, particularly, molluscs, water beetles, waters bugs and flies. The reason is often twofold: the water bodies are coastal and thus low-lying and warm, and secondly; there are a series of specialist brackish species that are restricted to these habitats. These can occur in both natural ponds and man-made ditches.

Ponds and temporary waters

3.23 Whilst ponds (Figure 3.18a) and temporary water bodies are represented in the range of waterbodies above, there are a number of species which are predominantly found in these smaller water bodies. These include: many of the amphibians, plant species such as pillwort (*Pilularia globulifera*), snails such as the mud pond snail (*Omphiscola glabra*) and certain water beetles. The bare mud, which is exposed when water levels fall (the drawdown zone) or created by poaching around the edge of ponds, is a particularly important habitat for a range of plants and invertebrates. The diversity of species in these drawdown zones can be large in comparison with the truly aquatic habitat. They include a range of flies (such a dance flies and shore flies) whose larvae live in the mud, and a series of predatory beetles, such as ground beetles (*Carabidae*) and rove beetles (*Staphylinidae*). Many of the plants which grow on the bare mud do not compete well with the taller emergent vegetation that often occurs in margins with less disturbance or stress. In some areas, high quality ponds form particularly significant elements of the landscape, for example, marl pits in Norfolk and the Cheshire Plain, the New Forest ponds and the pingos of East Anglia.

3.24 Naturally fluctuating water bodies are particularly important for the species which take advantage of these transient habitats such as the tadpole shrimp (*Triops cancriformis*) and the fairy shrimp (*Chirocephalus diaphanous*). The aquifer-fed naturally fluctuating meres are a distinctive type of fluctuating habitat and occur over chalk in the Norfolk Breckland. They are unique in England and have an intrinsic regime of extreme fluctuation in water level, with periods of almost complete drying out as part of the natural cycle. They have characteristic concentric rings of vegetation (see Figure 3.18b) in response to this hydrological cycle.

a) 
b) 

Figure 3.18 Contrasting small standing water bodies: a) Farm pond within an agricultural landscape; b) concentric rings of vegetation at a Breckland fluctuating mere

Nature of impacts

3.25 Lakes are generally not completely lost as a result of anthropogenic impacts in the way that a woodland or grassland can be destroyed, since their size often prevents this, although there are exceptions such as the draining of Whittlesea Mere. This does not apply to ponds, many of which have been lost to drainage and infilling (Hume, 2008). The quality of the remaining lakes and ponds can be seriously damaged by pollution (both point source and diffuse from both air and water), physical habitat modification (mostly of the shoreline and littoral zone, hydrological modification (including abstraction and impoundment), non-native species and fisheries management.

3.26 Eutrophication is the process by which unnaturally high concentrations of nutrients leads to increases in phytoplankton, reductions in water clarity and a reduction in macrophytes. The increased productivity of a lake or pond, particularly in the form of short-term algal blooms (Figure 3.19b), leads to an increase in dead organic matter accumulating on sediments. As bacteria mineralise this material they consume oxygen, depleting its concentration in the water, which can lead to fish dying. This results in turbid, algal-dominated lakes and ponds (e.g. Moss 2010). Eutrophication has led to the loss of many species from previously biodiverse water bodies such as the Broads. However, it is worth noting that water bodies do not need to become completely dominated by algae before species are lost. For example slender naiad has been lost from sites which still support a good range of other macrophytes; this is thought to be because it is competing for carbon dioxide rather than light. In such situations it can be out-competed by macrophyte and algal species that can utilise bicarbonate rather than carbon dioxide, which is often the dominant form of carbon during periods of high photosynthesis enabled by higher nutrient concentrations (Wingfield et al. 2004).

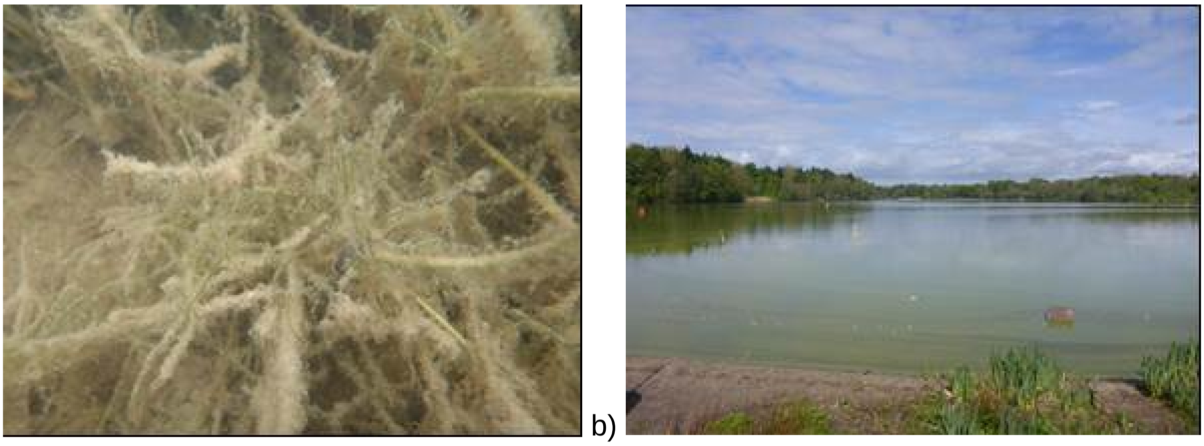
a)  b)

Figure 3.19 Algal growths: a) heavy periphyton burden on submerged macrophytes, b) an algal bloom at Cole Mere

3.27 On base-poor geology, predominantly in the uplands, there is a legacy from air pollution where lakes and ponds continue to experience acidic conditions. Whilst emissions of sulphur dioxide have been greatly reduced, historically deposited sulphur is still being leached from soils and pH is recovering very slowly. Recovery from acidification is also leading to increases in the concentration of dissolved organic carbon (Monteith et al. 2007). Although this is a problem for drinking water supply it is regarded as a positive response to the reduction in acid rain and a sign of a return to more naturally coloured waters. However, much of England continues to suffer from high nitrogen deposition; the consequence of this may be more pronounced in the uplands where other sources of nitrogen are limited. Continuing high levels of nitrate in upland waters in England is an additional barrier to recovery from acidification and may be a cause of eutrophication at some sites, although the exact nutrient impact of N deposition is still poorly understood. Where lake and pond water chemistry has begun to recover from acidification, biological recovery has been slight and not always predictable. At some upland sites, acid-tolerant species are being replaced by species which have never been recorded before acidification. It is hypothesised that this may be due to nitrogen enrichment and/or climate change (Battarbee et al. 2014).

3.28 Shoreline habitats can be impacted by many anthropogenic pressures including artificially modified water level fluctuations (e.g. from abstraction, compensation releases and hydropower generation), shore reinforcement, siltation, and also increased wave action and direct disturbance due to increased use. Because of the value of these littoral zones, for biodiversity and other ecosystem services, and the impacts of shoreline modifications, some authors suggest that shoreline modification, alongside eutrophication, is among the most severe threats to the integrity of lake ecosystems (Schmeider, 2004). However, this pressure is not well represented in the present monitoring of lakes under WFD (Hering et al. 2013).

3.29 Abstraction directly from water bodies and from their catchments can result in a reduction in their extent (Figure 3.20). Drainage of surrounding land can also lower the water level and truncate the hydrosere. Impoundments reduce within year water level fluctuations resulting in the loss of typical plant communities of the natural drawdown zone (Zohary and Ostrovsky 2011). Dams and weirs create impermeable barriers to migratory species, both long migrations, such as those undertaken by eels and short migrations, such as those sometimes undertaken by Arctic charr, to reproduce in tributaries. Draining of large peat bodies has led to a reduction in small dystrophic pools, but others have been created by peat cutting and ditch excavation (Figure 3.21). In order to restore peatlands ditches are often blocked, creating multiple small standing waters. These water bodies appear to have a similar biological assemblage to natural ponds, but their long–term persistence is unknown (Beadle et al. 2015).

Figure 3.20 Ladybower Reservoir, Derbyshire, showing the devegetating effect of draw-down in the marginal zone (© Natural England/Peter Wakely)

Figure 3.21 Re-wetted peat workings at Thorne Moors, Thorne Crowle and Goole Moors SSSI, South Yorkshire (© Natural England/Peter Roworth)

3.30 Increased sediment and nutrient loads and/or water abstraction and drainage can lead to an acceleration of successional processes in all standing waters. Due to their small size, often naturally transient nature, and the lack of natural pond creating processes in the contemporary landscape, terrestrialisation is a particular issue for ponds and is resulting in a decline in the number of ponds, particularly early successional macrophyte dominated ponds. In agricultural areas, such as Norfolk, ponds were previously managed to reduce shading and leaf litter input and the successional process was periodically reset by clearing out ponds. This kept this early successional pond type common in the landscape, but this type of management has declined (Sayer 2012, 2013). In more natural landscapes grazing would have kept some ponds open and the natural creation of new ponds would have replaced those that became terrestrialised. Other ponds such as some temporary ponds and bog pools naturally appear to be more permanent features of the landscape (Williams et al. 2000). This loss of small water bodies imposes a constraint on potential biodiversity at the landscape scale.

3.31 Shoreline reinforcement interrupts the natural continuity of the substratum and moisture gradient, resulting in a loss of wetland species associated with it. Shoreline reinforcements often reduce littoral areas by truncating the full hydrosere; areas subject to natural seasonal drying are often lost. Wave reflection at walls leads to increased erosion and shifts wave energy to other areas. Increased sediment loads from catchment sources or from within a lake, can lead to the reduction of gravel substrata (Schmeider 2004; Rowan 2008).

3.32 Increased wave action can be caused by increased boat activity and can lead to the erosion and re-suspension of the sediment and the destruction of macrophyte beds. Increases in use of the shoreline for activities such as boat moorings can impact plants directly by breaking and dislodging them and indirectly by disturbing and shading the sediments when boats are moored.

3.33 Non-native species can damage lake and pond habitats and may have direct predatory and/or competitive impacts on species composition and abundance. Invasive species, such as the common carp, can significantly alter the habitat. Their feeding behaviour destroys macrophyte beds and re-suspends the sediment (which releases nutrients to the water column). This can contribute to the problems associated with eutrophication and can lead to an algal-dominated lake or pond (Weber & Brown, 2009). Water bodies which are hydrologically connected are more likely to have invasive species, due to the ease of dispersal between sites. Water bodies popular with visitors are also often colonised by invasive species, indicating the role of humans as vectors of dispersal.

3.34 Fisheries management can promote or interfere with characteristic biological communities, depending on the intensity and nature of activities (Figure 3.22). Fish stocking and bait use can alter characteristic biological communities and add nutrients to a water body, whilst fishing platforms and access routes can damage the waterside vegetation, although they may be preferable to unrestricted access in some situations. However, fisheries and anglers are often the custodians of these water bodies and their presence, especially in easily accessible sites, can limit dumping, vandalism and illegal stocking. Fisheries and anglers are also important for highlighting water quality issues as they arise (e.g. Cowx et al. 2010).

Figure 3.22 Bay pond, Godstone Ponds SSSI (Surrey). A fishing pond with angling platforms and an introduced water lily (© Natural England/Peter Wakely)

3.35 Climate change is already altering environmental conditions and biological assemblages in UK lakes and ponds (e.g. Thackeray et al. 2008; 2010; Carvalho et al. 2012), with more extreme rainfall events and drier, warmer summers. These trends are predicted to continue to alter regimes of temperature, sediment and water quality to a considerable degree (Mooij et al. 2005, Shimoda et al. 2011, Kernan et al. 2012). Overall, the impacts of human activities in catchments greatly reduce the ability of lakes and ponds to cope with climate change (Kernan et al. 2012, Moss et al. 2011). Different lake and pond types will be differentially sensitive to climate change, particularly in relation to changes in rainfall, based on their depth and hydrological connectivity.

3.36 These various impacts do not all occur everywhere in England, but most are widespread. Some pressures are more focussed in the uplands and others in the lowlands. Impacts typically occur in combination (as multiple-stressors: Omerod et al. 2010), making biological consequences more difficult to understand, characterise, tease apart and predict at a local level.

3.37 The distribution and abundance of individual species, including priority species, are affected by these anthropogenic impacts. Whilst species characteristic of unimpacted conditions will generally suffer, some species (which may or may not be characteristic) will benefit. The change in flora associated with nutrient enrichment is an example of this. Moderate nutrient enrichment can cause a naturally oligotrophic lake to become mesotrophic and thus support a greater number of plant species. If these species of enriched conditions are priority species, this can confuse the characterisation of impacts on the habitat and result in conflicting management perspectives.

General aspirations for standing water habitats

3.38 Lakes and ponds operating under natural processes, free from anthropogenic impact and with a characteristic habitat mosaic that caters for characteristic species assemblages, provide the best and most sustainable expression of standing water habitats. This condition comprises natural hydrological, nutrient and sediment delivery regimes, minimal physical modifications to the shoreline and littoral zone, natural hydrological and biological connectivity, an absence of non-native species, and low intensity fishery activities. These conditions provide the best defence against climate change, maximising the ability of these ecosystems to adapt to changing conditions. They also provide the best and most sustainable interfaces with other habitats, including rivers and mires. They allow priority species to be distributed within lakes and ponds according to their natural habitat preferences and requirements. Importantly, and for the reasons above, these conditions also form the basis of the definition of reference conditions under the WFD.

3.39 In practical terms, there are socio-economic constraints on the extent to which these conditions can be achieved. The constraints vary widely depending on population density and the spatial distribution of different anthropogenic activities. Immovable constraints to restoring natural processes have to be recognised. The extent to which any one lake or pond can operate to natural processes will therefore depend on site-specific circumstances.

Key management messages

3.40 The evidence presented above leads to a range of important conclusions about how we aim to conserve standing water habitats and their characteristic species.

3.41 ***Restoration of natural processes*** – This is the top priority. Any measures that seek to restore natural processes, in terms of natural water quality, geomorphological and hydrological regimes, should be seen as a contribution towards lake and pond habitat objectives. Where water quality is the issue measures must include reduction of the external pollutant loads first but may also include direct intervention such as removing sediment to reduce internal loads where appropriate. To know what action is required it is essential to seek to understand the system as it would operate under natural processes and plan from that foundation, factoring in implications for related adjoining habitats.

3.42 ***Large-scale perspective*** – The condition of a lake or pond depends on many factors including what is happening in the catchment and in the atmosphere above it. Restoring natural water quality, sediment and hydrological regimes is key – it is not only about addressing direct impacts in the lake or pond of concern.

3.43 ***Taking action in the right order*** – Many direct interventions undertaken to restore lakes or ponds such as sediment removal or biomanipulation are effective only if external pollutant inputs have been reduced to acceptable levels. It is therefore critical to ensure that the initial sources of excess pollutants are controlled prior to expensive work within the water body to rectify the symptoms, otherwise restoration will not be sustainable.

3.44 ***Taking the long view*** – Whilst there may be an impetus to help lakes or ponds by active physical restoration, and in many cases this may be needed to trigger natural recovery, it may be appropriate to take a longer term approach. Natural recovery processes should always be allowed to play the fullest role possible, even if it means being patient for decades as internal P re-cycling becomes gradually less important in lakes suffering from eutrophication and as legacy S and N levels decrease in the catchment soils of lakes recovering from acidification. Equally, socio-economic constraints that are intractable in the short-term may be resolved in the longer term – a long-term vision and planning make for the best and most sustainable outcomes.

3.45 ***Species management*** – The artificial manipulation of fish assemblages (e.g. removal of planktivores or the addition of piscivores) and the introduction of macrophytes have been widely applied to lake restoration. These biomanipulation techniques should be undertaken with the long-term aim of restoring native and appropriate mixed fish and plant communities. This is most likely to be successful after external nutrient reduction.

3.46 ***Rationalising changes in species distribution and abundance*** – Prioritisation of locations for conservation measures based exclusively on the existing distribution of priority species can be flawed as the distribution of some species may reflect past and current impacts on lake and pond habitat and its characteristic biological assemblages. Species conservation plans need to take account of any changes in the distribution and abundance of species that will result from restoration of natural processes if they are to be sustainable. Equally, ecosystem restoration plans based on natural processes need to recognise any significant implications for priority species that may be affected, ensuring there are suitable habitat opportunities in a more naturally functioning system and sources of colonists to exploit them. In extreme cases where the survival of a species is in jeopardy, direct population intervention should be considered to assist in the transition to restored environmental conditions, taking into account likely changes in climate space resulting from climate change.

3.47 ***Succession*** – Where succession/infilling is attributable to increased sediment and nutrient loads, it is better to deal with these problems than repeatedly undertake expensive and regular removal of sediment. Where natural succession/infilling is occurring, especially where this is leading to new habitats of conservation value, it may be most appropriate to allow this to happen. If new water bodies are not being created via natural processes in the landscape (as is typical in the UK) new early successional water bodies can be artificially created. This approach is an option for small water bodies where habitat creation is possible and is particularly amenable to semi-natural landscapes where there is sufficient space available. Where this is not possible, often in agricultural landscapes where there is less land available for pond creation, active management of the pond resource, involving partial scrub and sediment removal, can ensure that early successional ponds and the biodiversity they support remain part of the landscape (Sayer et al. 2012, 2013).

3.48 ***In-water structures*** – weirs and dams have a range of physical effects on lake and pond habitats as well as blocking the free movement of biota. Structures on the outflow and in rivers and streams entering the water body can have a serious effect on animals that naturally use rivers and streams for part of their life cycle (e.g. fish spawning) or for feeding. The only way to eliminate these impacts is to remove the structure completely: this should be the aim wherever possible. Modification to minimise all impacts is the next best option. The installation of a fish pass only mitigates one impact, and only for a small number of species. If this is all that can be done, the pass should be permeable to as many species as possible, and to relevant priority species as a minimum.

3.49 ***Shoreline structures*** – dealing with shoreline structures is a key step in restoring a naturally functioning water body with lateral connectivity to the wider environment. Non-natural shoreline structures should be removed where possible; modification of any shoreline structures to minimise all impacts of these structures is the next best option e.g. soft engineering options.

3.50 ***Seasonality*** – Seasonally exposed habitats support an array of characteristic flora and fauna. Ephemeral ponds and seasonally exposed sediment can be destroyed by drainage, infilling or deepening. Natural seasonal water-level fluctuations are essential for their continued functioning.

3.51 ***Waterside vegetation*** – Semi-natural waterside vegetation is part of a fully functioning hydrosere, providing habitat for characteristic fauna. It can also stabilise the shoreline and can help reduce nutrient and sediment loads. Tree roots and woody debris have been found to be particularly important for many invertebrates. In addition tree cover provides shade, a mitigation measure against rising air temperatures. However, around smaller bodies of standing water, trees can shade almost the entire habitat and leaf litter can swamp the water body. In landscapes with many ponds it may be appropriate to have some ponds shaded by trees and keep others open through carefully considered pond management, thus catering for shade and leaf-litter specialists (e.g. the emerald dragonfly *Cordulia aenea*) as well as the many species dependent on open margins. For larger water bodies a mosaic of waterside vegetation incorporating some trees, but not dominated exclusively by them, is preferable.

3.52 Shoreline fencing should be avoided where livestock grazing intensity can be reduced to suitably low levels that avoid heavy damage to in-water and adjoining habitats. Where this is not possible, set-back fencing should be established to provide a sufficiently wide zone to allow the development/maintenance of the hydrosere. Access for periodic and selective grazing, cutting or other management of the waterside vegetation is recommended.

3.53 ***Understanding the location of existing freshwater biodiversity*** – To maximise the benefits of restoration work, and eliminate unwanted damage to populations of priority or endangered species, it is important to ensure that there is good local knowledge of the distribution of freshwater biodiversity, ideally in a landscape context (indeed, this knowledge is legally necessary for some species). It is valuable for projects to take account of standing water, running water and wetland biodiversity. There are currently initiatives which will help to identify important locations, including 'Important Areas for Ponds' and 'Important Freshwater Areas' being undertaken by the Freshwater Habitats Trust.

Indicators of natural lake and pond habitat function

3.54 Defining appropriate indicators of natural function, capable of characterising all aspects of the ecosystem, is vital in properly capturing impacts and evaluating progress with protecting and restoring standing water habitats. Table 3.1 lists a range of elements of natural function and components of standing water habitat that are frequently overlooked in routine monitoring and assessment programmes. The use of such indicators in evaluating standing water habitats is discussed further in Section 5, where links to more detailed information are provided.

3.55 Biological indicators should be the ultimate test of whether restoration of natural processes is having the desired biological effect. However, routine biological indicators and monitoring regimes are not capable of providing sufficient resolution of improvements (e.g. Feld et al. 2011). Some routinely used biological indicators in lakes permit a coarse indication of biological status that is useful in detecting certain types of impact but not others and ponds are rarely monitored sufficiently.

Table 3.2 Aspects of natural lake and pond habitat function requiring consideration in monitoring and assessment regimes

Aspect	Context
Natural habitat function	
Longitudinal connectivity	Relates to the natural connectivity up/down stream in standing water bodies connected to a river system. This allows movement of all species to complete their life cycles (e.g. migration and spawning in inflows and outflows), and dispersal of all species to maintain resilience to change. This also ensures the natural residence times and flushing rates, which enables the natural movement of substances through the system. Impounding structures such as weirs and dams are the main structures which prevent this.
Lateral connectivity with surrounding land and wetlands – natural shoreline	Relates to the presence of a natural transition between water and land that provides essential habitat and provides various ecosystem services such as the protection of the shoreline from erosion and reducing inputs of silt and nutrients from the catchment. Access to riparian vegetation is essential to allow many species to complete their life cycles. Lateral connectivity also allows the development of a natural hydrosere which as well as providing habitat provides ecosystem services.
Connectivity- frequency of habitat occurrence	Pond numbers have declined historically. They need to provide a network of characteristic habitat in their own right but need also to provide landscape scale refugia in the face of climate change and stepping stones for a range of aquatic and terrestrial biota that are associated with ponds and other freshwaters.
Naturally Hydrological regime	Natural hydrological regimes are fundamental to healthy lake ecosystems. Both extreme fluctuations and loss of fluctuations can potentially cause the loss of species. Residence times and flushing rates also influence water quality.
Naturalness of water quality regime	High water quality is a critical requirement for protecting and restoring characteristic biological communities including priority species such as slender naiad. Nutrient status is a key factor, and nutrient enrichment is implicated in a range of ecosystem effects. Others include acidification, organic pollution, and toxic pollution.
Absence of non-native species	Non-native species can modify standing water habitats and directly alter characteristic assemblages to a considerable degree. Whilst some non-natives appear quite benign, others are highly invasive and have disproportionate effects on native assemblages.
Naturalness of biological community	The extent to which the biological community is characteristic of the standing water in its unimpacted state is a fundamental biodiversity consideration. However, the practicalities of assessment and its linkage to natural habitat function are problematic (see text).

Table continued…

Aspect	Context
Neglected habitat components	
Ponds	Ponds are a critical component of the standing water habitat resource which host a range of specialist species, and contribute to the density of standing waters within the landscape, but receive little monitoring attention.
Riparian habitat condition	Riparian habitat, consisting of both bare substrate and vegetation, is a vital component of the standing water ecosystem. Some components of the in-water biota are dependent on riparian habitat, but these biota are rarely routinely surveyed in standing waters.
Woody debris	Woody debris is a vital component for many invertebrates, but is rarely considered in lakes and ponds.

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4 Terrestrial wetland habitats

The natural habitat template

4.1 Terrestrial wetland habitats are naturally formed by the flow and retention of water in the landscape, The diversity of wetland types is generated by variation in the types of hydrological pathway (surface, sub-surface and groundwater, dependent on landscape geology and topography), the magnitude and regularity of water supply, water chemistry (itself a product of the journey of water through soils and rocks) and, finally, the climatological and biological influences (e.g. grazing/browsing pressure) on the ensuing vegetation. The variety of landform and climate across a landscape naturally forms a mosaic of terrestrial wetland habitats of various degrees of wetness and types of hydrochemistry, interspersed with running and standing open waters of different types and sizes.

4.2 Important landforms for wetland habitats include:

- valley heads where hydrological pathways converge to form valley mires;
- the interface between valley sides and river floodplains where springlines form;
- depressions in the landscape that give rise to basin wetlands;
- glacial deposits in flatter landscapes generating microtopographical variation that gives rise to gradients of wetness,
- river floodplains where the erosional and depositional activity of the river creates a complex microtopography, generating different periodicities of inundation by floods;
- outcropping; bedrock features that cut across hydrological pathways and can create water accumulation anywhere in the landscape; and
- upland plateaus of low permeability and high rainfall giving rise to blanket bog.

4.3 Superimposed on this characterisation of wetland habitats are various dynamic processes that dictate that wetland habitats change or shift in the landscape to varying degrees. Natural annual weather variation and longer term climate variation can create reductions or increases in wetness at any given location, with either short- or long-term consequences for the assemblages and individual species present. Natural erosion processes, or the formation and decay of woody vegetation or development of *Sphagnum* carpets, generate changes in the level of water retention and hydraulic energy at any given point in the landscape, which can result in either gradual or step changes in wetland conditions and therefore biological assemblages.

4.4 A good example of this dynamism is the influence of abiotic and biotic controls on headwater mire systems. Outcropping bed rock cutting across a hydrological pathway may create long-term controls on water retention, generating quite stable conditions for the development of mire vegetation (Figure 4.1) until erosion of the bedrock generates a drop in water retention and increase in hydraulic energy, and a consequent shift from mire to stream habitat. Alternatively, the growth of trees in the valley mire may provide short term stability in water retentiveness, caused by the trapping of vegetation within tree root systems and fallen boughs and trunks (Figure 4.2). Decay of this material can result in a drop in water retention and increase in hydraulic energy, again creating a shift from mire to stream habitat. Cycles of woody growth and decay of this type can create a cycling between mire and stream habitat at any one point in a headwater valley system, with mire/stream transitions migrating up and down the valley.

Figure 4.1 Bedrock control of a mire-stream transition in a hanging valley head mire system, Cumbria (© T. Holland)

Figure 4.2 The stabilisation of mire and swamp communities in a valley head from tree roots and fallen wood

4.5 Natural vegetation succession creates a further level of dynamism in the wetland habitat mosaic. Standing open water habitats naturally gradually succeed into swamp, and then onto fen and finally rain-fed bog or fen woodland, unless prevented from doing so by site-specific environmental conditions or the action of biological factors (grazing or trampling by animals). Again, the specifics of water supply/retention and water chemistry dictate the path of succession through different wetland habitat types, although succession 'end-points' are not always predictable or even necessarily permanent.

Biological patterns

4.6 The variation within the habitats encompassed by the term 'wetlands' is immense, including not only fens and bogs (which themselves display high diversity) but extending into wet woodland, wet grassland and wet heath. Detailed descriptions of natural wetland habitat features and associated assemblages and species are provided in various sources including McBride et al. (2011) for fens, Hawke and Jose (1996) for reedbeds, Benstead et al. (1997) for grazing marshes and wet grasslands, Brooks & Stoneman (1997) and Lindsay (1995) for bogs and Wheeler et al. (1999) for wet woodlands. The Nation Vegetation Classification (NVC) helps to describe the variation in wetland vegetation types but it is important to remember that at any given site natural wetland mosaics tend to be dynamic and transitional in nature, in both space and time, consisting of a complex and changing pattern of NVC types. Some formally recognised wetland habitats (such as those listed under the Habitats Directive) fit together in an ecological hierarchy, with small-scale wetland features (e.g. 'Depressions on peat of the *Rhynchosporion')* nesting within larger scale features that are essentially habitat mosaics in their own right (e.g. blanket bog). Some examples of wetland variation, and its dependency on natural environmental processes, are given below.

Floodplains

4.7 The absence of unmodified floodplains in England can act as obstacle to understanding the natural biological patterns in these wetland systems, and consequently to developing restoration strategies that aim to restore the natural hydrological processes that give rise to them. Models are provided however by relatively natural systems such as the Biebzra river floodplain in Poland (e.g. Wassen et al. 2002), and also less modified British examples, such as the Norfolk Broads, which although historically highly modified by peat digging have been allowed to develop hydroserally and retain some natural features (e.g. Pallis 1911).

4.8 Such unmodified systems tend to show a strong nutrient gradient across the floodplain, with high nutrient availability in frequently flooded areas closer to the river, and decreasing nutrient availability as the floodplain rises towards the valley sides. Species predominating in the wet, nutrient rich conditions are tall vigorous grasses such as common reed *Phragmites australis* and reed sweet-grass *Glyceria maxima* (Figure 4.3). The vegetation is generally species-poor but highly productive. These areas provide habitat for highly valued species such as bittern *Botaurus stellaris* and marsh harrier *Circus aeruginosus*. Areas closer to the river also tend to experience greater fluctuations in water level than those towards the back of the floodplain. Further from the river the fen becomes less nutrient-enriched, and support a wider range of species, for example common meadow-rue *Thalictrum flavum* (Figure 4.4) and milk-parsley *Thyselium palustre*, the food plant of the swallowtail butterfly.

Figure 4.3 Reed-dominated fen along a more natural stretch of floodplain, River Test, Hampshire

Figure 4.4 Common meadow-rue in drier reed fen alongside River Test, Hampshire

Valley sides and headwaters

4.9 At the valley sides, the water levels tend to be more stable, but the water supply is quite different; very little river floodwater, with its nutrient-rich sediments and dissolved salts, reaches this area, and low-nutrient groundwater emerging from the base of valley slopes as springs and seepages can form a significant water source. The chemical nature of the groundwater will vary depending on aquifer geology. In areas with calcareous geology, the vegetation around springs and seepages can be very species-rich. This is characterised by a diversity of low-growing sedges, including dioecious sedge *Carex dioica* and flat sedge *Blysmus compressus* (Figure 4.5, a Section 41 species), growing in a carpet of 'brown mosses' such as *Palustriella commutata*, *Campylium stellatum* and *Scorpidium scorpiodes* (Figure 4.6). These are accompanied by a rich variety of broadleaved plants, including grass-of-Parnassus *Parnassia palustris*, marsh valerian *Valeriana dioica* and butterwort *Pinguicula vulgaris*.

Figure 4.5 Flat–sedge growing in a spring-fed alkaline fen next to the River Wye, Derbyshire

Figure 4.6 A 'brown moss' carpet in a base-rich runnel, with *Campylium stellatum* and *Scorpidium scorpioides*

4.10 This habitat also occurs around springs and seepages in upland headwater systems and is widespread on limestone and other calcareous rocks, but individual stands are typically very small – the vast majority are less than 0.1 ha in size (Tratt et al. 2013).

4.11 It is extremely rich in invertebrates, including several threatened snail species, including the Habitats Directive Annex 2 species Geyer's whorl snail *Vertigo geyeri*, and soldier flies, including the very rare clubbed general *Stratiomys chamaeleon* (Figure 4.7). For many of these species the open, permanently saturated mossy conditions are critical to their survival, and loss of saturation through drainage and nutrient enrichment leading to shading of moss carpet by tall vascular plants are very damaging.

Figure 4.7 The clubbed general, a rare soldier fly of mossy calcareous seepage fens, Cothill, Oxfordshire (© Judy Webb)

4.12 Various other wetlands develop between the nutrient-rich tall fen and valley side fens, including pools and runnels taking water from higher ground and groundwater outflow across the floodplain, as well as fens and fen meadows and seasonally flooded grasslands. The exact configuration and species composition of the habitat mosaic depends on the character of the river and surrounding geology. In certain situations, raised bogs have developed in floodplains (Figure 4.8). Following a classic hydroseral trajectory, rain-fed bog vegetation develops on top of deep peat following millennia of accumulation of plant material in saturated conditions. Floodplain bogs can develop from the terrestrialisation of a single lake basin, or over more undulating terrain in which a number of small basins coalesce to form a single dome (Lindsay, 1995).

Raised bogs

4.13 Raised bogs occurred more widely in England than is generally recognised, with evidence for bog development in most parts of the country including the south east, e.g. the Arun valley in Sussex, and the East Anglian Fens. The best remaining examples of raised bogs in river valleys are found in Cumbria, where for example in the Duddon Valley and the Lyth Valley, domes of peat that still support bog vegetation survive in otherwise drained and modified floodplains. Raised bog can also develop in other landscape contexts, particularly in basins and in coastal plains over estuarine sediments.

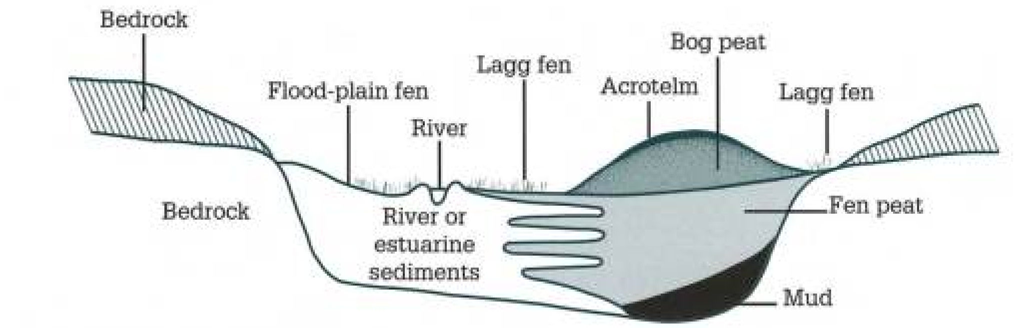

Figure 4.8 Conceptual cross-section of a floodplain showing raised bog development over accumulated fen peat and lake muds (from Lindsay 1995)

4.14 A raised bog is a morphological feature in its own right, comprising various structural components and different types of wetland vegetation, including communities referable not only to the Habitats Directive feature Active Raised Bog, but also to other Habitats Directive features such as Depressions on peat of the *Rhynchosporion* around bog pools, and Transition Mire and Quaking Bog in the lagg area around the fringes of the feature (Figure 4.8). The integrity of all the separate features of the bog is co-dependent and relies on an intact hydrological regime across the whole system including the lagg fen where water draining from the bog meets water draining from the surrounding landscape.

4.15 Undisturbed bogs typically have an almost continuous carpet of *Sphagnum* species, creating a very acid and nutrient-poor environment. Within this are rooted vascular plants such as cross-leaved heath *Erica tetralix*, common cotton-grass *Eriophorum angustifolium*, cranberry *Vaccinium oxycoccus* and various sundew *Drosera* species. Unmodified bogs exhibit a very distinct natural patterning, with different species occurring in different positions relative to the water table. The three native sundews demonstrate the variety of niches within this structural complex, with round-leaved sundew *D. rotundifolia* tending to occur on higher, drier hummocks, great sundew *D.anglica* on the wetter low ridge/*Sphagnum* lawns, and oblong-leaved sundew *D. intermedia* on the edge of pools and bare, exposed peat in hollows. The degree of patterning varies according to climate, with the most complex patterning in the wetter north and west, as shown in Figure 4.9, and least pronounced in the drier parts of the range.

Figure 4.9 Extreme patterning in an unmodified bog, with pools, hummocks, hollows, and lawns. Claish Moss, Lochaber, Scotland

Valley bog systems

4.16 Valley bog systems support a broadly similar range of vegetation types to raised bogs, but have a different mode of water supply – usually groundwater from extremely base-poor sands and gravels – and consequently a very different spatial and temporal arrangement of the vegetation (Rose, 1953). Figure 4.10 shows the typical arrangement of these vegetation zones. The equivalent to the peripheral lagg fen zone in a raised bog lies in the centre of the valley bog system, where conditions are wettest and, owing to the accumulation of drainage water in this central zone, mineral and nutrient availability is highest. In the least damaged sites this very wet zone (zones 2 & 3) can be very rich, supporting now extremely rare species such as the large marsh grasshopper *Stethophyma grossum* (Figure 4.11), slender cotton grass *Eriophorum gracile* (Chatters and Sanderson 2014) and bog sedge *Carex limosa*.

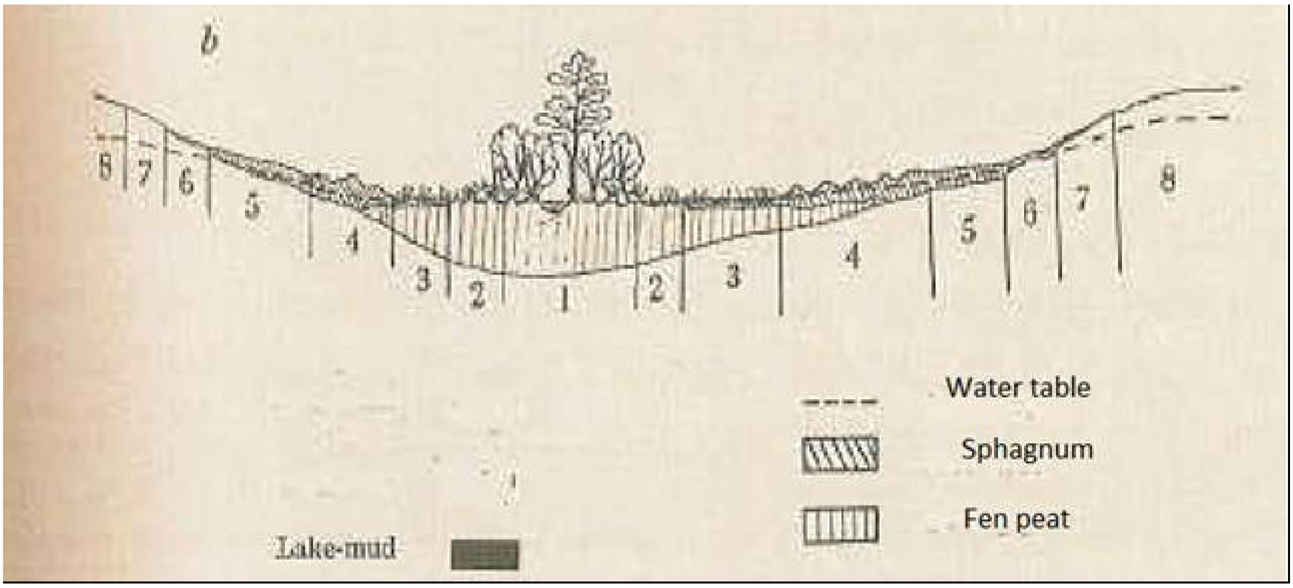

Figure 4.10 Diagrammatic cross-section through a valley mire/bog showing zonation (after Rose 1953 and Wheeler 1984)

Key:

1) Carr or swamp-carr along central stream
2) Mesotrophic swamp with little or no Sphagnum
3) Sphagnum pulchrum-Eriophorum angustifolium-Juncus acutiflorus fen developed over semi-fluid peat
4) Molinia caerulea-Myrica gale fen, on firmer peat in drier conditions
5) Sphagnum hummock complex (especially S. papillosum, S, capillifoilum, S. magellanicum, S. cuspidatum). Molinia and ericaceous shrubs may be abundant
6) Wet heath, with an ericoid shrub layer and a more or less continuous carpet of Sphagnum (especially S. compactum and S. tenellum)
7) Damp heath with Calluna vulgaris, Erica tetralix and Molinia caerulea but little Sphagnum
8) Dry heath

Figure 4.11 Large marsh grasshopper, a nationally rare species of very wet mires that has suffered an 85% reduction in range between 1985 and 2010 (Sutton 2015)

4.17 The *Sphagnum* dominated zone lies adjacent to this and receives its water from the sand and gravel aquifer units. Upslope of the *Sphagnum*-hummock zone are progressively drier zones, including areas of intermittent seepage that support species intolerant of competition such as marsh club-moss *Lycopodiella inundata* and oblong-leaved sundew.

Figure 4.12 Marsh club-moss *Lycopodiella inundata* growing on an intermittent seepage in wet heath/valley bog interface, New Forest, Hampshire

4.18 Wetland with trees, or wet woodland, is characteristic of the biggest and most intact valley bog systems, often with species such as greater tussock-sedge *Carex paniculata* and marsh marigold *Caltha palustris* (Figure 4.13). Wet woodland can occur in almost all wetland systems and is generally dominated by alder *Alnus glutinosa*, willow *Salix* species and birch *Betula* species, and shrubs including alder buckthorn *Frangula alnus* and guelder-rose *Viburnum opulus*. Many open wetland species also occur in wooded wetlands (Wheeler et al. 1999), although some species such as elongated sedge *Carex elongata* appear to be restricted to wooded wetlands.

Figure 4.13 Wet alder woodland along stream in the New Forest

Nature of impacts

4.19 A wide range of human activities, past and present, have damaged and changed the natural wetland habitat resource (Table 4.1). The most fundamental impacts relate to modifications to natural hydrology and hydrochemistry, which have brought about great change in the extent and types of wetlands in the landscape. Superimposed on this are activities relating to on-site vegetation management, including inappropriate woodland planting and agricultural improvement.

4.20 The hydrology of most, if not all English terrestrial wetlands has been modified by historic drainage both within sites and in the surrounding environment, eliminating wetlands from much of the landscape. Many of the declines in wetland wildlife can be directly related to drainage schemes (Purseglove 1988). Different drainage practices in different types of landscape have generated distinctive impacts. Moorland gripping has resulted in the loss of active blanket peat, with its distinctive and diverse habitat mosaic of dystrophic pools, *Sphagnum*-dominated bog, drier areas with ericaceous vegetation, and bog-stream transitions. The digging of catch-drains in the margins of floodplains, along with associated underdrainage of the lower valley sides, has resulted in the loss of flush habitat around valleyside springs and the dewatering and loss of fen vegetation at the valleyside/floodplain interface, (e.g. Harding et al. in press). The underdrainage and ditching of springs and streams in headwater valleys have resulted in the loss of valley mires and natural mire/stream transitions.

Table 4.1 Causal factors of modification to 'natural' wetland habitat (based on Wheeler et al. in Perrow & Davy 2002)

Factor	Management (cropping)	Drainage	Chemical enrichment	Peat wastage or removal	High water/inundation	Planting
Farming		*	***	**	*	
Forestry	*	**	*	*		***
Turbary		**	*	***	*	
Water supply		**		*	*	
Flood storage			**		**	
Flood defence		**		*		
Sewage			***		*	
Industrial emission and effluent			**		*	
Wildlife conservation	** (to maintain biodiversity & landscape)	* (to control water levels)		* (to create pools and scrapes)	* (to create pools and scrapes)	* (to reinstate former species; to provide habitats for new colonists)

Note: the number of *s represents approximate intensity of the process that is typical for many regions. Actual intensities show great variation at local scale, however.

4.21 Added to the major effects of drainage are the impacts of abstraction, water level management and pollution. Abstraction and water level management further modify patterns and volumes of water supply, often altering the chemistry of the water delivered to a given site in ways that create a shift in wetland type. Nutrient pollution, either through water pollution from agriculture and effluent discharges, or through atmospheric deposition of nitrogen, can create major shifts in vegetation and associated fauna. Acid deposition adds a further pressure to wetland types with low buffering capacity such as bogs and wet heaths.

4.22 An example of the impacts experienced in the terrestrial wetland habitat resource is given by the Habitats Directive feature 'Depressions on peat of the *Rhynchosporion*', which occurs in the wettest parts of blanket bogs, raised bogs, valley bogs and transition mires (Figure 4.14). In common with many micro-features within wetlands, it is often wholly dependent on the integrity of the wider ecosystem in which it is embedded. *Rhynchosporion* vegetation in various types of bog ecosystem has been lost from many sites throughout the UK following drainage and other forms of damage. Its characteristic species have experienced perhaps the greatest losses of any habitat in England (e.g. Stroh et al. 2014), including some national extinctions, e.g. Rannoch-rush *Scheuchzeria palustris*. Some of the species survive on some sites in man-made features, such as peat pits and wheel ruts in bogs and heaths.

Figure 4.14 Bog pool with white beak sedge (*Rhynchosporion*) on quaking bog

4.23 Almost all remaining terrestrial wetland habitats are affected by a history of hydrological and hydrochemical modification (See Box 4.1 for a detailed case study). In fact, Wheeler et al. (2002) describe how true 'naturalness' can be difficult to assess for our remaining terrestrial wetlands, not least because it is believed that the development of some appears to have been initiated through human activity (e.g. Neolithic forest clearance), and the character of many has subsequently been shaped by further human interference, such as periodic burning, light grazing and cutting.

Box 4.1. Case study of wetland impacts - Bomere, Shomere and Betton Pools SSSI

Bomere and Shomere Pools comprise three basin wetlands embedded in the Shropshire Plain, to the south of Shrewsbury. Bomere Pool is a deep mesotrophic lake with both sandy and peat areas around the shore; the Shomere basin is filled with up to 8 metres of peat with a small dystrophic pool at its southern end; a smaller circular basin to the south of Shomere supports a floating bog, or schwingmoor, with a complete transition from open water and mesotrophic swamp around its margin to a floating ombrotrophic bog at its centre. As a group these supported a staggering number of now rare and regionally extinct species up until the end of the 19th century, including water lobelia, oblong-leaved sundew, Rannoch-rush and marsh fritillary.

All three basins had been modified by drainage – all had deepened and/or newly created outflows, done at some point in the 19th century, and further deepened after WWII. It is highly probable that in a natural state the three basins were effectively closed. The effect of this drainage has been severe across the basins, with the peat bodies in all three significantly drained by up to a metre or more, with impacts on Bomere and Shomere the greatest – all Sphagna lost from Bomere and dense tree cover around the lake shore, Shomere covered in rhododendron, pine and birch woodland, and the small basin developing dense soft rush cover, tree colonisation and a plantation of conifers at its centre. In addition to this pressure, Bomere Pool was subject to surface water abstraction for agriculture resulting in an additional annual drawdown of around 10 cm depth.

Not all biological interest had been lost however. Bomere retained the only population of floating water plantain in a natural lowland lake in England, Shomere had a small residual area of bog and transition mire vegetation, as well as base-rich wet woodland with marsh fern, and the small basin remarkably still supported a relatively undamaged area of transition mire and weakly minerotrophic bog, including the regionally rare *Sphagnum magellanicum*.

4.24 To complicate the picture, some of our existing wetland sites have formed in hydrologically degraded landscapes in areas that would not naturally have supported them, at least not in their current form; for example, floodplain grazing marsh and some lowland wet meadows (Natural England 2015). Some of these sites are large, in large and heavily modified landscapes (some of which are below sea level). The maintenance and condition of these sites in their current form is dependent on a continuation of the modifications that created them.

General aspirations for terrestrial wetland habitats

4.25 Terrestrial wetlands operating under natural processes, free from anthropogenic impact and with a characteristic mosaic of wetland habitat types that caters for characteristic species assemblages, provide the best and most sustainable expression of wetland habitats. This condition comprises wetland habitats located in the landscape according to natural hydrological pathways, water supply and retention, nutrient and sediment delivery regimes, and natural hydrological and biological connectivity, and an absence of non-native species. These conditions provide the best defence against climate change, maximising the ability of these ecosystems to adapt to changing conditions. They also provide the best and most sustainable interfaces with other habitats, including running and standing waters and dry habitats. They allow priority species to be distributed within wetland habitat mosaics according to their natural habitat preferences and requirements.

4.26 In practical terms, there are major socio-economic constraints on the extent to which these conditions can be achieved in English landscapes. The constraints vary widely depending on human population density and the spatial distribution of different anthropogenic activities, particularly agriculture. Immovable constraints to restoring natural wetland processes in the landscape have to be recognised. The extent to which any one wetland can operate to natural processes will therefore depend on site-specific circumstances.

Key management messages

4.27 The evidence presented above leads to a range of important conclusions about how we aim to conserve wetland habitats and their characteristic species.

4.28 ***Restoration of natural processes –*** Any measures that seek to restore natural processes, in terms of natural water quality, geomorphological and hydrological regimes, should be seen as a key contribution towards wetland habitat objectives. Measures can range from protection (e.g. stopping external pollutant loads) to direct intervention such as infilling and blocking of drains, and re-establishment of groundwater inputs. To know what action is required it is essential to seek to understand the system as it would operate under natural processes, understand historical modifications and their impacts, and plan from that foundation, factoring in implications for existing habitats in and adjacent to the site. The development of ecohydrological conceptual models (e.g. Wheeler et al. 2009) for floodplains and other wetlands can help in establishing an understanding of how sites have developed and how they would have functioned in an unmodified state.

4.29 ***Large-scale perspective –*** The condition of a wetland depends on many factors including what is happening in the catchment and in the atmosphere above it. Restoring hydrology and natural water quality and chemistry is crucial – it is not only about addressing direct impacts on the wetland site.

4.30 ***Taking action in the right order –*** Many direct interventions undertaken to restore wetlands such as water-level raising and drain blocking are effective only if external pollutant inputs have been reduced to acceptable levels. It is therefore likely to be critical to ensure that the initial sources of excess pollutants are controlled prior to expensive work within the wetland to rectify the symptoms, otherwise restoration will not be sustainable.

4.31 ***Taking the long view –*** Whilst there may be an impetus to help wetlands by active physical restoration, and in many cases this may be needed to trigger natural recovery, it may be appropriate to take a longer term approach. Natural recovery processes should always be allowed to play the fullest role possible, even if it means being patient for decades. Equally, socio-economic constraints that are intractable in the short-term may be resolved in the longer term – a long-term vision and planning make for the best and most sustainable outcomes.

4.32 ***Species management –*** The artificial manipulation of water levels and land forming are often used in wetland restoration for particular species. This may be at a small scale for, e.g. breeding waders, or at a larger scale, e.g. for bitterns. These techniques can be very successful, however, in some situations they will prevent the development of a naturally occurring wetland type, sometimes of greater conservation significance, and will often require intervention in perpetuity to maintain the specific conditions required by the target species. Ideally, the provision of habitat for these species should be part of landscape–scale initiatives employing a natural processes template that allows the intrinsic environmental characteristics of the wetland to be expressed. Recognising that this may not always be possible, it is critical that conservation initiatives focused on individual species do not prevent the restoration of scarce habitats requiring a more natural hydrological function, e.g. calcareous fens vs. reedbed.

4.33 ***Rationalising changes in species distribution and abundance –*** Prioritisation of locations for conservation measures based exclusively on the existing distribution of priority species can be flawed as the distribution of some species may reflect historic modifications to habitats and their characteristic biological assemblages. Species conservation plans need to take account of any changes in the distribution and abundance of species that will result from restoration of natural processes if they are to be sustainable. Equally, ecosystem restoration plans based on natural processes need to recognise any significant implications for priority species that may be affected, ensuring there are suitable habitat opportunities in a more naturally functioning system and sources of colonists to exploit them. In extreme cases where the survival of a species is in jeopardy, direct population intervention should be considered to assist in the transition to restored environmental conditions, taking into account likely changes in climate space resulting from climate change.

4.34 ***Succession –*** As wetlands represent stages along the hydrosere, and many wetlands will have a complex developmental history, deciding which point along this succession is most desirable for conservation can be difficult, particularly when restoring from a very damaged state. In large highly natural wetland landscapes, allowing succession to proceed undisturbed is desirable; in other more managed landscapes, it may be desirable to maintain a wetland at a particular stage of the hydrosere. Underpinning this however, should be the same principles of restoration of intrinsic environmental characteristics and unimpacted water supply mechanisms.

4.35 ***Barriers to connectivity with wider environment –*** Dealing with these is a key step in restoring a naturally functioning wetland with connectivity to the wider environment. Non-natural features within and around the wetland, such as catchwater drains separating the ‘upland’ from the wetland (e.g. Harding et al. in press), or a deepened river flowing through a floodplain fen, should be addressed where possible; modification of structures to minimise all impacts of these structures is the next best option e.g. soft engineering options. A long view will often need to be taken here, as often impacts will be felt more widely than the wetland feature, for example, neighbouring land may become wetter, and poor water quality in water courses may need to addressed before physical restoration is initiated.

4.36 ***Seasonality –*** Seasonally exposed habitats support an array of characteristic flora and fauna. Ephemeral ponds and seasonally exposed peat can be destroyed by drainage, infilling or deepening. Natural seasonal water-level fluctuations are essential for their continued functioning.

4.37 ***Understanding the location of existing wetland biodiversity –*** To maximise the benefits of restoration work, and eliminate unwanted damage to populations of priority or endangered species, it is important to ensure that there is good local knowledge of the distribution of existing biodiversity, ideally in a landscape context (indeed, this knowledge is legally necessary for some species). It is important that any 'wetland' restoration projects have a holistic approach to the water environment and take account of standing water, running water and wetland biodiversity.

Indicators of natural wetland function

4.38 Defining appropriate indicators of natural function, capable of characterising all aspects of the ecosystem, is vital in properly capturing impacts and evaluating progress with protecting and restoring habitats. Table 3.1 lists a range of broad indicators that cover key components of natural function and elements of wetland habitat that are frequently overlooked in routine monitoring and assessment programmes. Including these indicators in monitoring and assessment programmes is important to ensure that natural habitat function is properly recognised, protected and restored.

4.39 Biological indicators should be the ultimate test of whether restoration of natural processes is having the desired biological effect. However, the typical vegetative indicators of habitat condition used in wetland systems are incapable of differentiating between wetland conditions generated by natural processes and condition generated by artificial management. This makes them of limited value in evaluating natural wetland function.

Table 4.2 Indicators of natural wetland function

Indicator	Context
Natural processes	
Lateral connectivity with surrounding semi-natural habitats and open waters	This allows the development of natural transitions and the restoration of hydrological integrity across the core wetland system. Not only does this confer greater resilience to wetlands and associated ecosystems, it should provide conditions for the full range of dependent species.
Connectivity - frequency of habitat occurrence	Wetlands need to provide a network of characteristic habitats in their own right but need also to provide landscape scale refugia and stepping stones for a range of aquatic and terrestrial biota that are associated with wetlands and other habitats.
Naturally hydrological regime	Natural hydrological regimes are fundamental to healthy wetland ecosystems. Extreme fluctuations and loss of fluctuations both potentially cause the loss of species.
Naturalness of water quality regime	High water quality is a critical requirement for protecting and restoring characteristic biological communities. Nutrient status is a key factor, and nutrient enrichment is implicated in a range of ecosystem effects. Others include acidification, organic pollution, and toxic pollution.
Absence of non-native species	Non-native species can modify wetland habitats and directly alter characteristic assemblages to a considerable degree.
Naturalness of biological community	The extent to which the biological community is characteristic of the wetland in its unimpacted state is a fundamental biodiversity consideration. However, the practicalities of assessment and its linkage to natural habitat function are problematic.

Table continued…

Indicator	Context
Neglected habitat components	
Natural hydrological function in traditionally 'dry' habitats	Habitats considered non-wetland, such as wet woodland and wet heaths often have significant hydrological modification, particularly drainage and ditching, which goes unremarked. There is significant potential for restoration of natural hydrological processes within these habitats, with potential benefits for declining taxa, such as willow tit (*Poecile montanus)* and marsh club-moss.
Natural open water features within wetlands	Natural pools and runnels comprise a very important component of the wetland habitats and host a range of specialist species, but receive little monitoring attention.
Transitions between wet and dry habitats	Unmodified transitions between wet and dry habitats are rare particularly in the lowlands. These zones support their own specialist species as well as allowing full expression of hydro-topographical zonations.
Woody species	Trees and scrub are a vital component for many invertebrates, but are often considered negative indicators in wetlands. The context is important particularly when occurring in natural wetland ecosystems. Impacts of wet woodland development may not always be damaging to open wetland features.

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5 The role of key policy mechanisms

Specially protected wildlife sites

5.1 The two principal types of protected site in England are the domestic series of Sites of Special Scientific Interest (SSSIs) and the European series of Natura 2000 sites. Natura sites comprise Special Areas for Conservation (SACs), notified under the EC 'Habitats and Species' Directive, and Special Protection Areas (SPAs), notified under the EC 'Birds' Directive. To this can be added 'Ramsar' sites, notified as wetlands of international importance under the Ramsar Convention. The European and internationally important wetland sites form a subset of the domestic SSSI series.

5.2 Within the protected site rationale, notified freshwater habitat features (running and standing waters, SSSI and SAC) are defined to capture the habitat in a holistic way, encompassing all physical components (the full habitat mosaic including marginal zones and other hydrologically connected areas) and the characteristic biological assemblage (including but not restricted to plants, fish and invertebrates). Wetland habitat features are defined by reference to National Vegetation Council (NVC) vegetation types, but can be notified as dynamic mosaics of types.

5.3 Decision-making on freshwater SSSIs and SACs designated for their freshwater habitat features is founded on the protection and restoration of natural ecosystem function. Decision-making on sites designated for wetland habitats is moving in this direction as far as possible (see later in this section). The operational rationale for protecting and restoring freshwater SSSIs is based on limiting anthropogenic modifications to key components of habitat integrity (Figure 5.1, Mainstone and Clarke 2008). This approach is embedded in UK Common Standards guidance on setting targets for monitoring the condition of SSSI and Natura freshwater sites). Importantly, the approach promotes the nesting of individual species requirements within the habitat template provided by naturally functioning freshwater ecosystems.

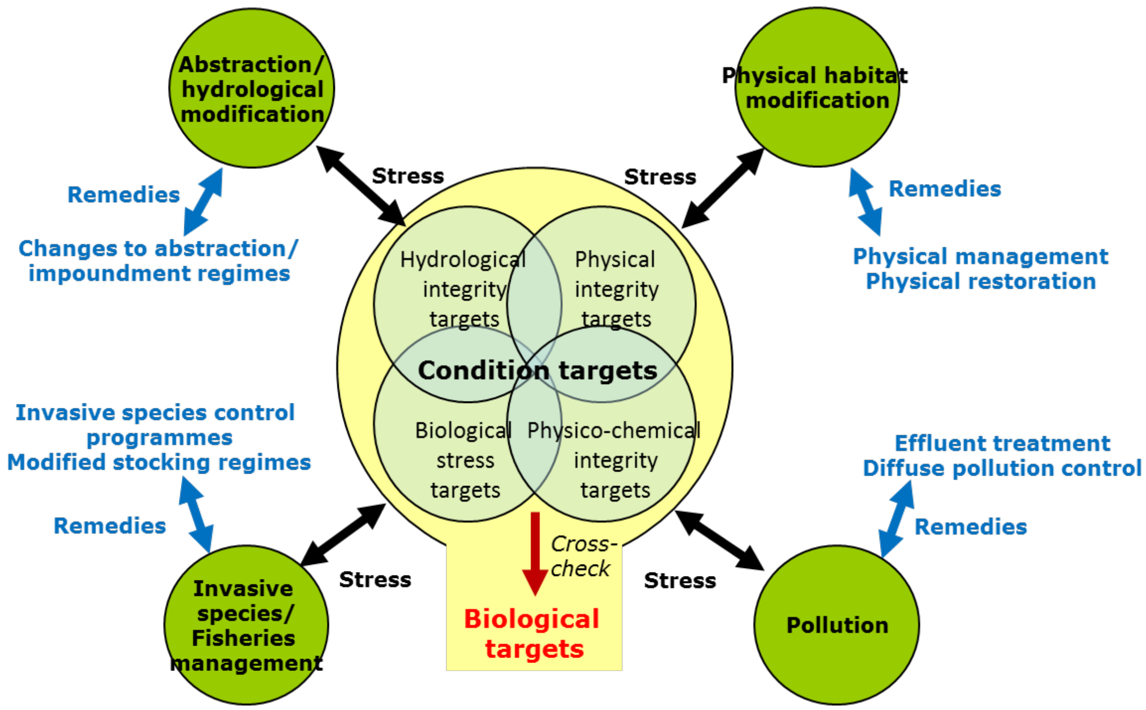

Figure 5.1 Components of condition of SSSI freshwater habitats and links to key remedies

5.4 Protected freshwater sites are an unusual challenge for the protected site concept (Mainstone 2008). They are highly connected to (and influenced by) the land within the catchment, including all of the activities taking place in the catchment. Traditional approaches to protected sites, consisting of delineating a land area and managing the vegetation within it, fall a long way short of what is required to protect the natural function of a freshwater ecosystem (unless the land area delineated is the entire catchment). A further challenge is that, unlike many terrestrial and terrestrial wetland habitats, the freshwater habitat resource has generally not suffered heavy losses of habitat extent but rather has been damaged by loss of natural function. All of this means that notifications have to be used in a highly strategic way to create a suitably small and representative subset of the national habitat resource in which the protected site mechanism can be used to full effect. If this were not the case, then the justification for protecting freshwater SSSIs and SACs more rigorously and ambitiously than the rest of the habitat resource would be weakened.

5.5 As part of Natural England's SSSI notification strategy, the rationale for notifying freshwater and wetland habitats and their associated species is being reviewed, and the SSSI series is being assessed to check its fitness for purpose (for rivers see Mainstone et al. awaiting publication). This process is seeking to ensure that there is sufficient and explicit consideration of the importance of natural ecosystem function, as well as the immense resource of small streams and standing waters that needs to be properly represented in SSSI notifications. The Great Britain selection guidelines for SSSIs are also currently being reviewed, with similar emphases in respect of freshwater habitats.

Priority habitat

5.6 As part of UK commitments to the European Biodiversity Strategy and the International Convention on Biological Diversity, 'priority habitats' are defined at UK-level (JNCC 2011) and their conservation is planned and implemented through country-level strategies (in England, Wales, Scotland and Northern Ireland). Work has recently been undertaken to rationalise the approach to priority freshwater habitats in England, using the principle of natural ecosystem function. This work has involved interpreting the UK definitions of priority river and lake habitat and remapping these habitats to capture the most naturally functioning remaining examples (Mainstone et al. 2014, Hall et al. 2014, Mainstone et al. In Press). The intention is to provide a focus for the protection of our most naturally functioning freshwater habitats and to promote any restoration that may be necessary. Allied to this, work is on-going to build a coherent picture of restoration priorities in the wider river and lake habitat resource, based on restoring natural ecosystem function where possible.

5.7 Further work is seeking to build a coherent condition assessment framework for priority freshwater habitats, based on natural ecosystem function. This framework is intended to exploit available datasets as far as possible, building on the foundation of WFD monitoring and incorporating resources such as Countryside Survey (Mainstone et al. In Prep.). The aim is to provide a means of recognising (within biodiversity reporting processes) any restoration of natural habitat function anywhere in the freshwater habitat resource: within the maps of priority habitat, within sites highlighted as restoration priorities, and in the wider resource.

5.8 The approach to priority wetland habitats needs to evolve to better recognise the importance of natural habitat and wider ecosystem function. As part of this, work is being planned to reconceptualise the current priority habitat 'coastal and floodplain grazing marsh' in England, to remove potential constraints on the restoration of naturally functioning wetland habitat mosaics.

The Water Framework Directive

5.9 Whilst the EC Habitats and Birds Directives provide the primary legal framework for biodiversity protection in Europe, decision-making in the freshwater environment is dominated by water legislation and associated mechanisms. The role of water as a common and critical resource, the management of which affects the whole of society, has generated a strong protection framework for the freshwater environment. The EU Water Framework Directive (the WFD) provides the primary environmental decision-making framework for water management in England, based on the control of anthropogenic effects on the ecological status of waterbodies using minimally affected ('reference') conditions as a baseline. In principle, it is very much in tune with the protection and restoration of natural ecosystem function in freshwater habitats, and provides a good foundation for the protection of freshwater habitats and their characteristic species.

The relationship between key policy mechanisms

5.10 Whilst the WFD can be seen as central to protecting and restoring freshwater habitats, in practice there are significant limitations and uncertainties around how far natural function of freshwater and wetland ecosystems can be protected and restored through meeting the ecological objectives of the WFD.

1) Methods of WFD assessment are based on the structure of certain components of biological communities (fish, plants, invertebrates and algae) and not on assessing natural ecosystem function directly, which means that the Directive might not always be implemented in ways that seek to restore such natural function wherever possible.
2) WFD assessment methods are limited in their coverage of freshwater and wetland habitats, particularly with respect to small waterbodies (ponds and headwaters streams) and transitional habitats (such as lake hydroseres, riparian zones and ephemeral and marginal in-river habitats), fens and bogs.
3) The WFD requires only that water bodies are returned to 'good ecological status' (GES). Waterbodies already at high ecological status (HES) are to be protected at that level, but there are very few waterbodies considered to be at this level in England and so this objective has little bearing on protecting the English freshwater habitat resource. Since standards for GES are intended to apply to most waterbodies, and therefore can imply considerable amounts of restoration effort, they are set at levels that may fall short of aspirations to restore natural habitat function and associated characteristic biodiversity, particularly considering the limitations of WFD assessment methods.
4) Derogations to the requirement to achieve GES are available on socio-economic grounds, including use of the alternative objective of Good Ecological Potential (GEP) which is used on a widespread basis in England. No standards are set for GEP since the constraints on restoration are site-specific. Whilst there is a requirement to restore these waterbodies as far as possible, there is uncertainty about the level of aspiration for restoring natural ecosystem function to these waterbodies under the WFD.

5.11 The approach to specially protected freshwater and wetland sites uses the added weight of protected site legislation to justify a long-term strategic approach to addressing deep-rooted and complex problems to restoring natural ecosystem function. It provides a means of applying a more precautionary and ambitious approach to natural ecosystem function than is possible under the general requirements of the WFD, within a small subset of the habitat resource selected to represent the full variation in freshwater habitats in England. Work on the protected site network provides an important demonstration of how complex problems can be addressed, which can be drawn upon to develop strategies in the wider freshwater environment (Mainstone 2008).

5.12 The approach to priority freshwater habitats can be seen as a means of demonstrating that the WFD is being implemented in a way that delivers more comprehensively for freshwater biodiversity, including at the least impacted end of the naturalness spectrum and in freshwaters that are too small to be considered directly by the WFD. Assessment of habitat condition based on natural habitat function is central to providing this demonstration.

5.13 This narrative is intended to provide a common language across these key policy mechanisms based on natural ecosystem function, and to define a useful and synergistic role for each. This provides a means of better integrating available biodiversity and water delivery mechanisms and resources to achieve a common goal. The central position of the narrative in underpinning guidance on protected sites and priority habitat, and in promoting the concept of natural ecosystem function in WFD implementation, is shown in Figure 5.2. Work is being undertaken within the WFD catchment-based initiative operating in England to translate this narrative into biodiversity advice for local stakeholders involved in practical delivery.

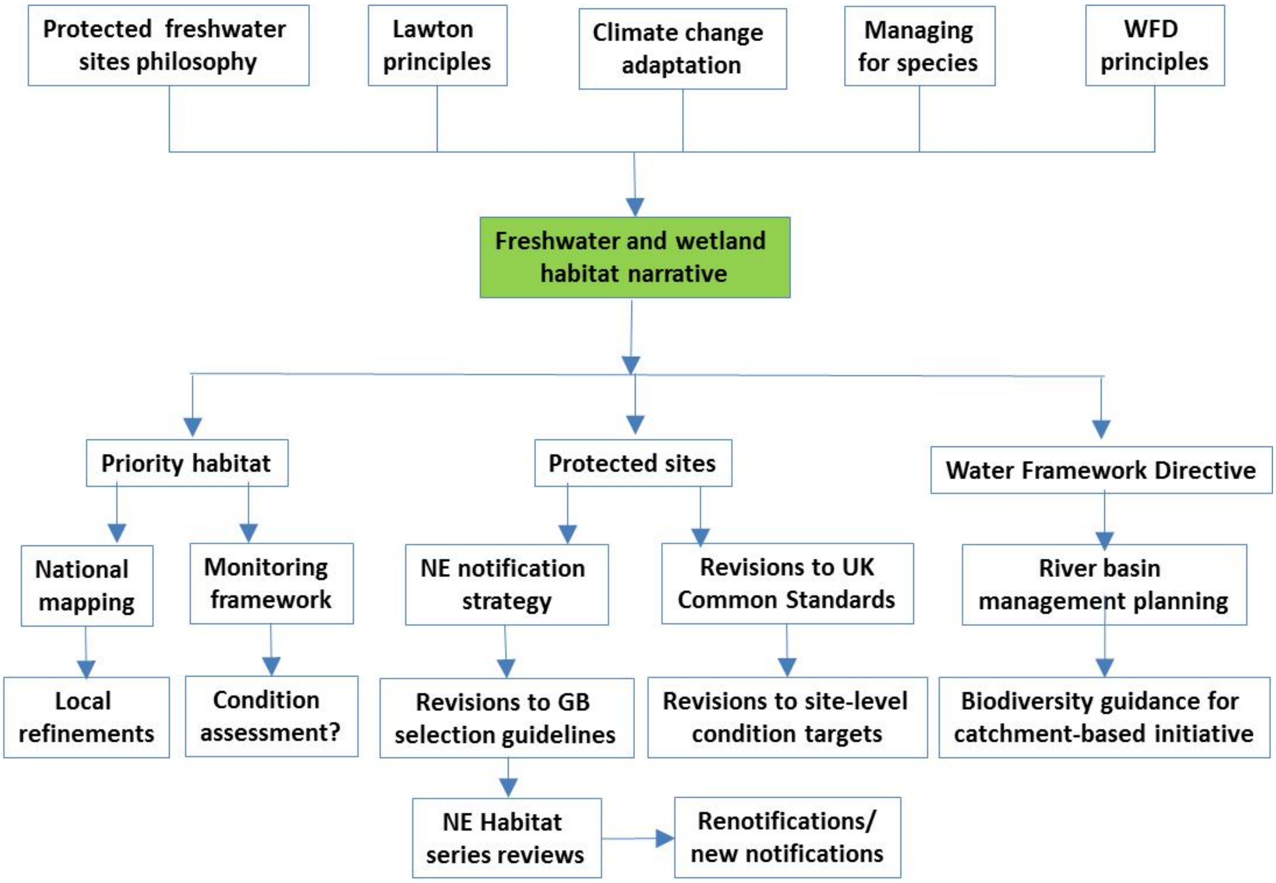

Figure 5.2 The role of this narrative in underpinning approaches to protected sites and priority habitat and in influencing WFD implementation

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6 Landscape-scale planning

Introduction

6.1 The previous sections have demonstrated the critical importance of restoring natural function of freshwater and wetland habitats in conserving these habitats and their characteristic species. Natural habitat function needs to be considered at a range of spatial scales, but good progress cannot be made without consideration of whole catchments. This necessitates integration with planning measures for conserving other habitats and their associated species, and for the provision of wider ecosystem services such as flood risk management and water resources.

6.2 Some habitats and their supporting species can occur or be generated in many places in the landscape, essentially constrained only by soil type (e.g. some dry woodland and grassland types). Freshwater and wetland habitats require certain hydrological conditions, which in natural systems are governed by natural hydrological processes but for some habitats and in some situations can be generated artificially. Water chemistry (particularly in respect of alkalinity and natural nutrient status) is an important additional determinant of where specific water-related habitat types can naturally occur.

6.3 Overlain on these intrinsic natural characteristics of catchments, impacts on natural hydrology, water quality (particularly in respect of nutrient pollution) and air quality (acidification and nutrient deposition) generate alterations to the pattern and integrity of natural habitat mosaics, characteristic assemblages and individual species. These impacts can potentially be resolved through better catchment planning and management, particularly if a sufficiently long time horizon is considered.

6.4 Across all habitats, fragmentation is a key factor in the decline of many priority species and connectivity is a vital part of restoring populations of these species (Webb et al. 2010. The wider strategy for conserving ecological networks for all habitats and species, as laid out by Lawton et al. (2010), is described in Box 1. Intrinsic to this thinking is:

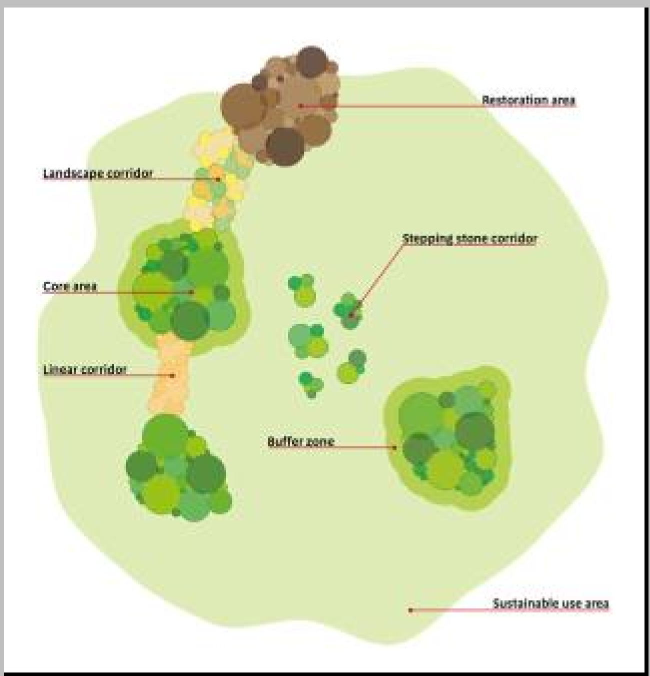
1) planning of ecological networks based as far as possible on restoring ecosystems and natural processes that provide habitat for species;
2) considering how any given site is, or should be, functionally connected with other places in the wider landscape; and
3) the importance of high quality core sites.

6.5 The approach outlined in this report fits well with this broader strategy for ecological networks. Natural hydrological and hydrochemical processes not only provide a reference template for planning freshwater and wetland habitat mosaics in the landscape; they also inform the planning of wider ecological networks based on natural processes, including fully terrestrial habitats and species. Addressing anthropogenic modifications to restore natural hydrological and hydrochemical processes provides the best and most sustainable approach to restoring large-scale habitat mosaics that need to form the core areas of future ecological networks. There are also often wider societal benefits to this approach, including large-scale flood risk management (the Pitt Review 2008) and water resource management, which need to be identified and maximised.

Box 6.1. Lawton principles for better ecological networks and its relationship with this freshwater and wetland narrative.

In response to concerns about habitat loss and fragmentation, there has been a growing emphasis in conservation on ‘ecological networks’. In England, this concept has gained a high profile following the publication of the *Making Space for Nature* report, which defined networks as “a suite of high quality sites which collectively contain the diversity and area of habitat that are needed to support species and which have ecological connections between them that enable species, or at least their genes, to move” (Lawton et al. *2010*). Lawton et al. (ibid.) assessed the network of conservation sites in England against a series of criteria and concluded that it falls well short of meeting all the requirements of a resilient and coherent network. They set out a series of detailed recommendations for improving the situation, summarised by the principles ‘better, bigger, more and joined’. This message has had a strong influence on subsequent conservation policy and delivery (for example in the aspirations set out in the Natural Environment White Paper (Defra 2011) and the establishment of Nature Improvement Areas. More broadly, it gave further impetus to the approach of thinking beyond individual sites to whole landscapes, an approach that had been developing for some time in the conservation sector (e.g. RSPB 2001, The Wildlife Trusts 2007)).

Lawton et al. (2010) conceptualised networks as containing a range of possible elements, including core areas, restored areas, buffer zones, various types of corridors, and sustainable use areas providing a more permeable ‘matrix’ between sites, set out in the figure reproduced below.



This diagram brings to mind patches of vegetation in a terrestrial landscape. The approach to restoring natural function in freshwater and wetland habitats, when considered at landscape-scale, provides a water-related perspective on the concept of ecological networks.

6.6 Restoration of natural function in freshwater and wetland habitats is often more difficult to achieve than accepting existing modifications and using those as the baseline for habitat enhancement, particularly at larger spatial scales where the complexity of the task is magnified. However, whilst some physical and hydrological modifications are effectively immovable (e.g. flood defences within urban areas), many others are potentially modifiable if a sufficiently strategic view is taken.

6.7 Many habitats of biodiversity importance (terrestrial, wetland and open freshwater) have developed in hydrologically modified catchments, and would be affected by restoring natural hydrological processes. In some cases new habitats have been created artificially by hydrological manipulation in ways that accept the status quo of land use and management, for instance by bunding parcels of land and pumping water in to create wetland habitat. Generating a reference hydrological template for the landscape, to understand how habitat mosaics would occur naturally, is an important step in maximising opportunities for restoring natural habitat function. Allowance needs to be made for the repositioning of existing habitats and associated species within the landscape according to restored hydrological and hydrochemical processes, factoring in adequate connectivity to allow species to sustain viable populations.

6.8 The planning of landscape-scale habitat mosaics needs to explicitly incorporate small-scale biotopes that are essential to many priority species but are not explicitly recognised as important habitats in their own right (in relation to formal definitions of priority habitat types and SSSI habitat features). Many of these biotopes are highly disturbed, unvegetated and dynamic and not suited to traditional methods of habitat classification, definition and valuation based on vegetation composition. Some of these biotopes are created naturally within certain types of recognised habitat feature; for instance, within the SSSI and priority habitat feature 'river habitat', lateral movement of the channel creates cliffs and sediment bars that are highly dynamic features and vital for a range of priority species. In coastal areas, inter-tidal mudflats are an important component of the natural dynamic habitat mosaic. Heathland, woodland and moorland habitats have strong elements of smaller-scale biotope mosaics within them, though are not traditionally seen as incorporating some of the more heavily disturbed biotopes required by some priority species. Grassland and wetland priority habitats are traditionally defined according to relatively homogeneous plant community assemblages where disturbed ground would not be a valued feature. In many respects this is an issue of spatial scale, with some formal habitat types naturally encompassing a heterogeneous smaller scale biotope mosaic and others not. As long as this is recognised at landscape-scale then all species needs can be met.

6.9 Finally, climate change is already driving change in the life cycle strategies used by water-related species, as well as the composition of freshwater and wetland species assemblages (Kernan et al. 2012). Restoring natural habitat function is the critical management response to this challenge (Kernan et al. ibid., Natural England/RSPB 2014), providing the best opportunities for species to find sustainable habitat niches and move around the landscape in response to climate change, and for combatting rising water temperatures. Landscape-scale planning for restoring natural habitat function is therefore central to climate change adaptation.

Principles

6.10 The strategic goal, as far as it is feasible, is naturally functioning freshwater and wetland habitat mosaics situated in locations within catchments most suited to their self-maintenance, as part of a wider habitat mosaic with terrestrial habitats that caters for all characteristic assemblages of the locality including their priority species. Although there are many constraints to achieving this at a local level, adopting the following principles in local decision-making (developed from the evidence presented in this document) will help to maximise the opportunities for protecting and restoring naturally functioning habitat mosaics within the landscape.

1) Value natural ecosystem function, based on natural environmental processes, as the best and most sustainable expression of freshwater and wetland habitats and their characteristic wildlife.
2) Aim to conserve species within naturally functioning habitat wherever possible, based on natural environmental processes.
3) Cherish remaining examples of naturally functioning habitat and take opportunities to restore natural function elsewhere as far as possible.
4) Recognise that restoring natural catchment processes (hydrology, hydrochemistry) is a fundamental part of restoring freshwater and wetland ecosystems, and provides a useful framework for planning the restoration of drier habitat types.
5) Recognise that restoring natural ecosystem function as the art of the possible, working in locations that are most conducive to restoration and accepting immovable constraints.

6) As part of this recognition, generate a long-term strategic vision and seek to make short-term decisions in the light of that vision.
7) Take a large-scale perspective that maximises opportunities for natural ecosystem function, provides greatest opportunity for species to find habitat niches within a more naturally functioning landscape, and encourages a strategic approach to small-scale site management that helps provide these niches within site networks.
8) Accept dynamic change as a natural component of ecosystems, the magnitude of which varies between habitats but is high in freshwater ecosystems.
9) Plan for change in the distribution and population size of species where needed (as a result of landscape-scale restoration measures or direct climate change), to ensure key species are catered for appropriately within more naturally functioning landscapes.
10) As part of recognising environmental and population change, factor in the specific effects of climate change on key species to ensure that expectations for supporting individual species at a given location are realistic.

6.11 A landscape containing a sufficient density and natural variety of habitats, with differing levels of connectivity, enables species to exist as more resilient metapopulations, with individuals shifting around the landscape as they move through their life cycle and environmental conditions change. Applying these principles allows those managing individual small areas within a landscape to tailor site management to contribute to larger-scale habitat mosaics. For example, providing a diversity of conditions in a network of small standing waters or headwater streams in respect of the level of tree shading, ecological connectivity, vegetative succession, and the presence of fish are easier to accommodate at larger scales, within which individual waterbodies can be maintained to provide different aspects of this variation at any one point in time.

6.12 These principles need to flow through all aspects of local decision-making, from the notification and management of SSSIs, priority habitat objectives and management, through to water management decisions (Water Framework Directive implementation, flood management). This approach to decision-making can be summarised as in Figure 6.1.

6.13 It is important to emphasise that the approach outlined here does not imply the removal of human vegetation management from the landscape. Many of our most valued habitats are the result of on-site management that maintains the vegetation as a certain stage of succession that is crucial to the biodiversity that the habitat supports. Within a landscape framework of natural abiotic environmental processes, such vegetation management is still critical in sustaining a full range of habitats and their characteristic assemblages. For instance, intervention is required to maintain species-rich grassland in the face of scrub succession. Natural abiotic processes simply provide a spatial template which guides certain types of habitat towards certain parts of the landscape, within which judgements can be made about vegetation management to achieve the most appropriate habitat mosaic. It may be that restoration of these abiotic processes might lead to scope for less intensive vegetation management (for instance, more natural nutrient delivery regimes may result in less frequent management intervention), but it is much less likely to lead to a complete cessation of management of the type associated with the ‘rewilding’ agenda.

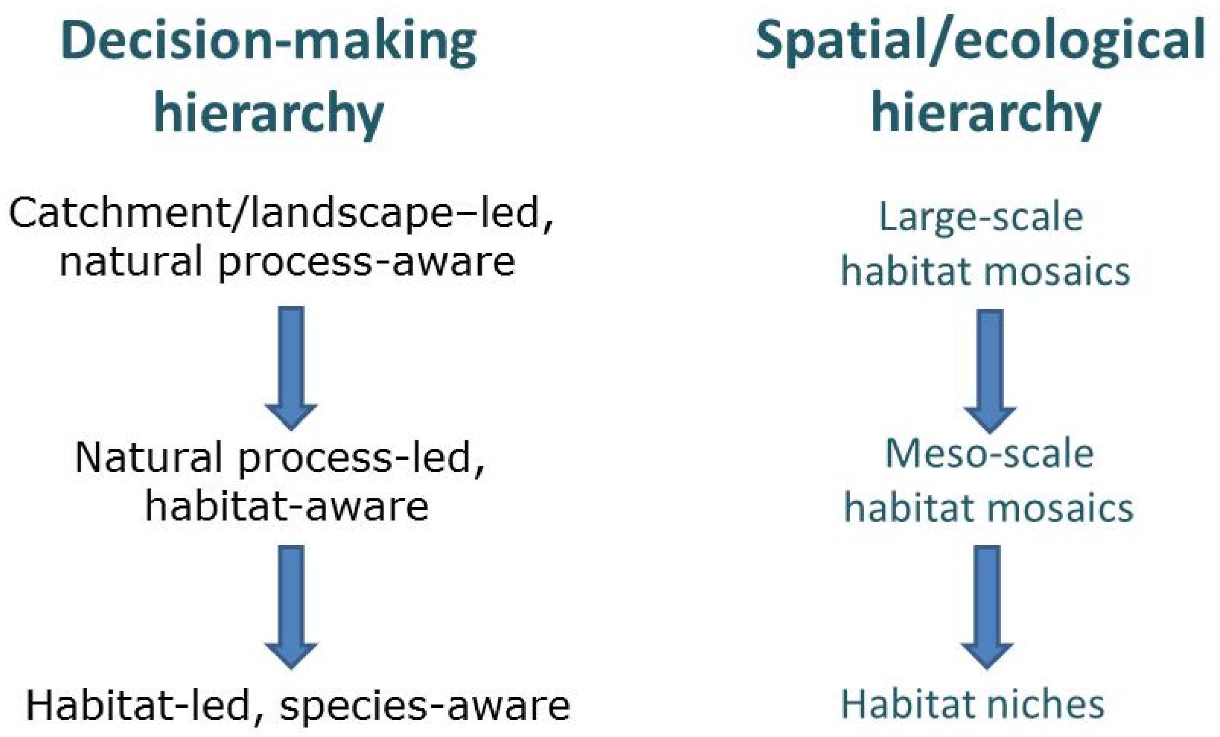


Figure 6.1 Hierarchical approach to decision-making based on promoting natural ecosystem function

Landscape-scale scenarios

6.14 The practical management unit for freshwater ecosystems is the catchment and landscape-scale thinking should always be based on this scale. However, it is useful to consider the general issues in key parts of the catchment, particularly: a) the gathering grounds, b) the floodplain and c) lowland plains.

Gathering grounds scenario

6.15 The gathering grounds of catchments are critical areas for freshwater and wetland biodiversity and also support natural hydrological, hydrochemical and sedimentary processes further down the catchment. Impacts on these areas affect not only the habitats they support; habitats further down the catchment that are dependent on natural flow and sediment delivery regimes and good water quality can also be degraded. In addition to biodiversity impacts, human uses of water can also be impaired and flood management can be made more difficult. Strategic creation or restoration of terrestrial, wetland and even open water habitats in critical parts of a catchment is an important way of restoring natural processes. Such measures provide the twin biodiversity benefits of creating and restoring habitats directly whilst contributing to the restoration of downstream habitats, which may be open freshwaters, floodplain wetlands, estuaries, or coastal waters.

6.16 In the uplands, intact peat moorland supports a complex mosaic of wet and dry biotopes, including dystrophic pools and headwater streams of high biodiversity value. Historical gripping and burning of moorland has severely degraded this biotope mosaic, including loss of pools and degradation of streams through excessive bank erosion and river bed siltation. Enhanced levels of eroded peat and nutrients are carried by the streams to downstream areas to continue their effects on freshwater communities. Water retention within the moorland is affected in ways that damages natural flow regimes in the river network, reducing low flows and enhancing high flows. Grip-blocking is vital for restoring upland moorland including the dystrophic pools and stream network that form a key part of the natural habitat mosaic.

6.17 These gathering grounds can also contain other types of standing waters, some of which will be connected to river systems with obvious inflows and outflows (such as those formed in glacial valleys), whilst others may not be connected or only have outflow streams, such as some cirque tarns. Regardless of this, all standing waters are at the mercy of their catchments, as lakes receive nutrients from their catchment over time via (depending on their hydrological connectivity) inflows, surface water runoff and ground water. These nutrients can then be tied up or lost through the processes of sedimentation, denitrification or flushing of the lake. Under natural conditions this does not lead to the enrichment of waterbodies – instead they become increasingly oligotrophic. It is only as the nutrient load from the catchment artificially increases that eutrophication occurs.

6.18 In more lowland gathering grounds, intact valley mire systems support a wealth of biodiversity in a patchwork of flush, fen, bog, swamp and wet woodland, with valley sides providing areas for drier woodland and grassland types. Flush and mire habitats gradually give way to stream habitat as water collects in surface and sub-surface pathways and flows down the valley.

6.19 These headwater areas provide a haven for biodiversity in their natural form but turn into critical source areas for enhanced level of nutrients and silt to downstream areas in their degraded form. With mire habitat drained, stream habitat channelized, and the land given over to intensive grazing or arable, the delivery of pollutants to freshwater and wetland habitats is highly efficient. Restoration of these complex wetland/dryland mosaics can contribute directly to conserving many priority habitats and species but is also a critical part of restoring downstream water and wetland habitats.

6.20 Re-wooding headwater valleys that have been given over to intensive agriculture provides the basis for both restoring natural stream function and restoring natural hydrological, sediment and nutrient regimes to the catchment, including to downstream freshwater and wetland habitats. Headwater streams are naturally nutrient-poor and rely on leaf litter and woody debris for their productivity, with biological communities that are adapted to this condition. The targeted re-establishment of woodland in these areas can restore natural stream function as well as regulate the delivery of water, nutrients and sediments to freshwater and wetland habitats in the catchment (Nisbet et al*.* 2011). In addition, it can have a major effect on maintaining thermal regimes in these streams in the face of climate change (Brown et al. 2010), which threatens to eliminate many coldwater stream species from parts of their English range. The headwater stream resource contains the majority of the river network by stream length, so the management of these areas has a major bearing on the condition of the river network as a whole.

6.21 Floodplain habitat is limited in the gathering grounds but where present its management can be critical not only to river and floodplain habitats but also to the generation of flood risk. The river channel is often pinned against one side of the narrow floodplain by flood embankments, resulting in the usual loss of in-river habitat mosaic, associated wetland and open water habitats and floodplain connectivity. Lack of lateral movement of the river channel can result in the build-up of river gravels and the gradual perching of the channel above the floodplain. This leads to a greater need to avoid flood events due to greater potential effects on the protected agricultural land. Peak flows are conveyed downstream to contribute to enhanced peak flows that are more difficult to control, often in areas with population centres and therefore greater flood risk. Restoration of lateral channel movement and low-energy inundation of the floodplain in these areas would not only restore river and floodplain habitats, but also contribute to flood management solutions downstream.

6.22 Figures 6.2 and 6.3 illustrate these different aspects of human impacts and their resolution within the landscape.

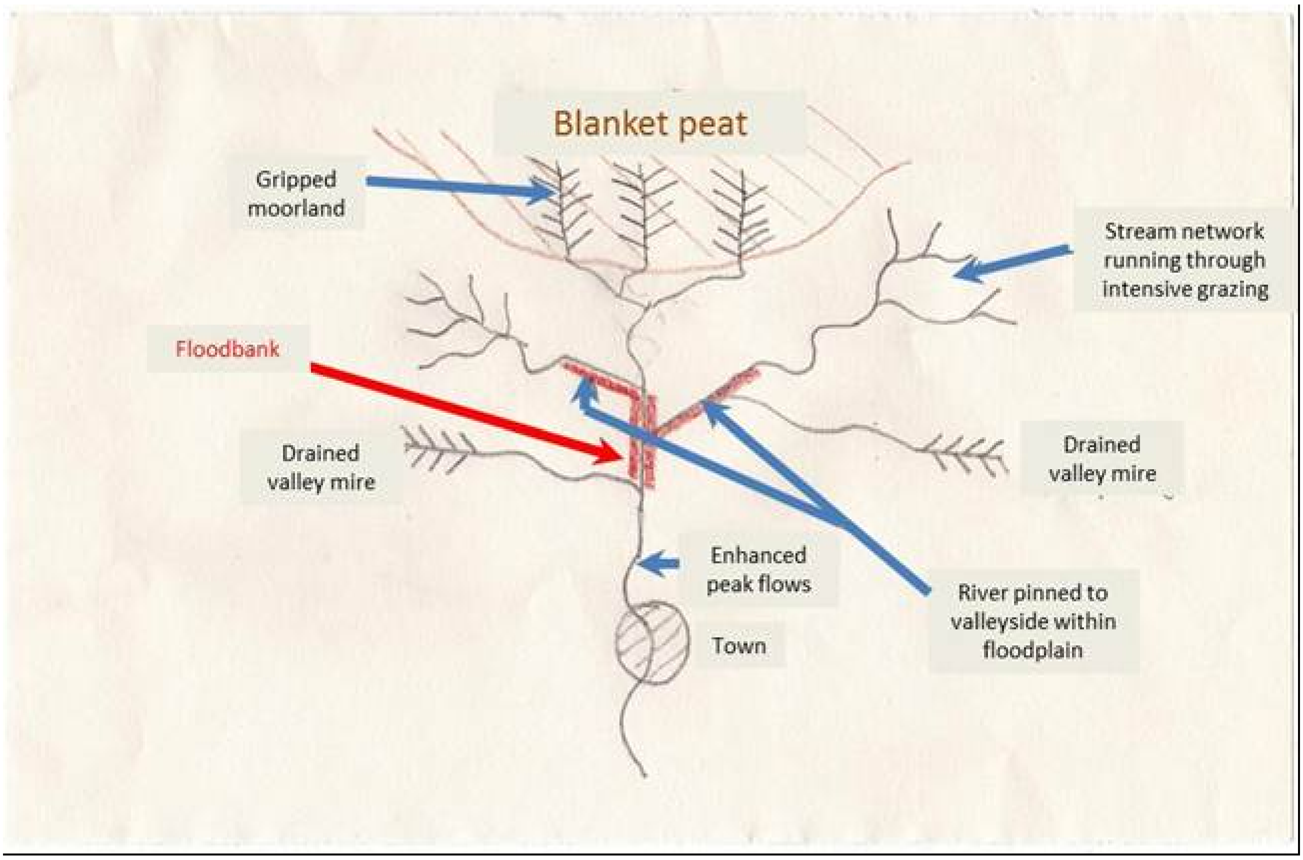


Figure 6.2 Typical hydrological modifications in the gathering grounds of river systems

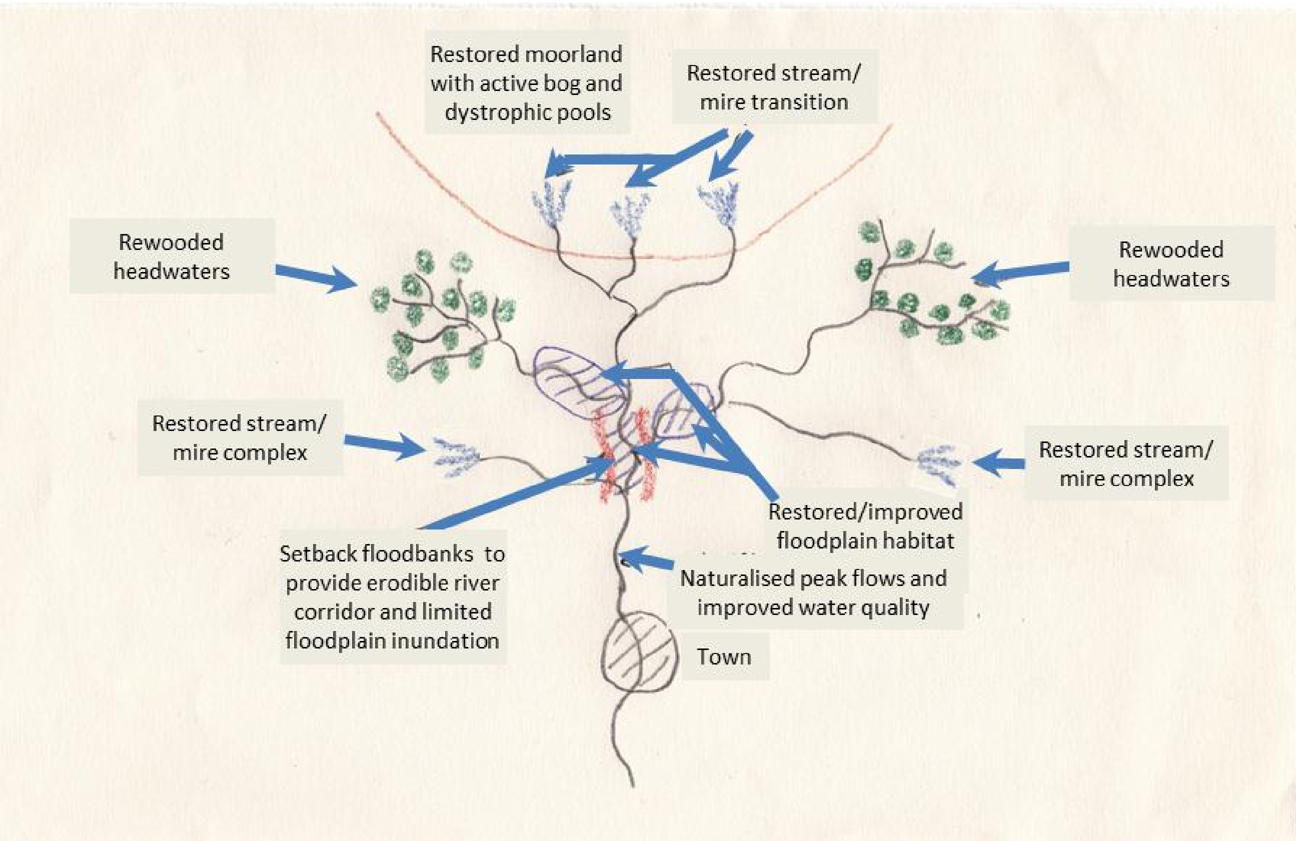


Figure 6.3 Pragmatic restoration of modified gathering grounds

Floodplain scenario

6.23 Natural floodplains support a rich mosaic of habitats (Figure 6.4). Some of the most important areas for natural flushes, mires and associated freshwaters are the valleyside/floodplain transitional areas, where springlines feed into the floodplain margin. Near the coast, under natural conditions these marginal areas can potentially provide fully freshwater wetland and open water habitat, as part of a natural habitat mosaic involving a complete salinity gradient and full expression of relevant priority habitats and associated priority species.

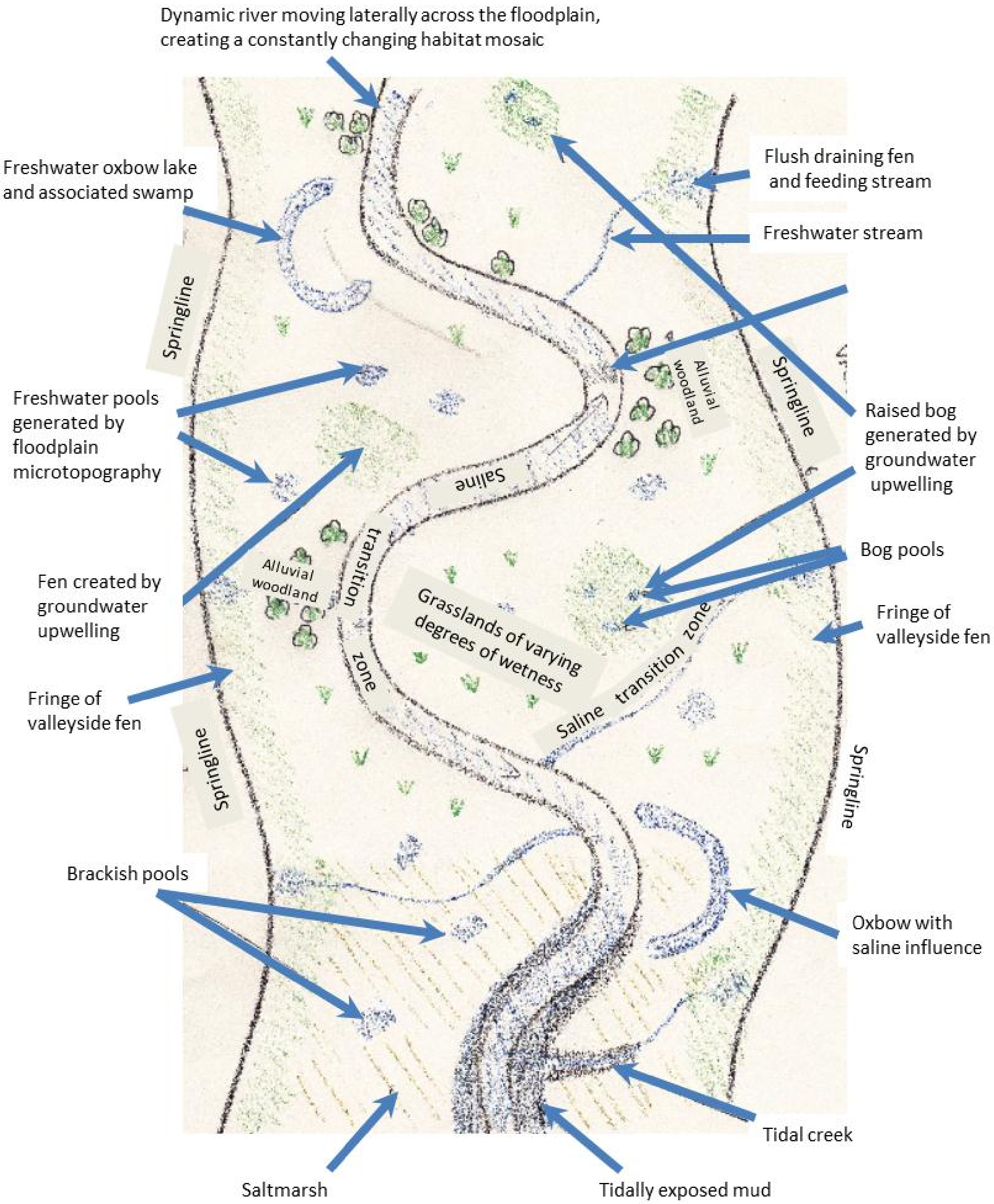


Figure 6.4 Natural river-floodplain habitat mosaic

6.24 Other important natural areas for mire and pool habitat on the floodplain are groundwater upwellings, which create fen and, over sufficient time periods, raised bog. Standing freshwater habitat naturally occurs in oxbow lakes and other backwaters, and in other depressions that are characteristic of a natural floodplain with complex microtopography caused by a long history of natural geomorphological processes. This small-scale variation in topography can also support wet and dry alluvial woodland, other swamp habitat such as reedbed, and wet and dry grasslands. The river meanders across the floodplain, creating its own biotope mosaic within the channel and banks and cutting through existing floodplain habitats to form new ones. Inundation of the floodplain temporarily reconnects isolated freshwater habitats and allows recolonisation and dispersal of biota.

6.25 Drainage and flood defences dry out the floodplain and leave only refuge habitats for freshwater and wetland biota (Figure 6.5). The river is typically straightened and fixed in place by floodbanks, with major loss of riverine habitat area and complexity and loss of connectivity with the floodplain. Springline fens are often drained by catch-drains running along the floodplain margin, whilst the rest of the floodplain is often cut through with a network of drainage ditches. The resulting ditch systems can be of high biodiversity value, often containing a range of priority plant and animal species, but represent the artificial vestiges of a degraded habitat mosaic of far greater importance. The floodplain may be converted to arable, or improved grassland, or be used as rough grazing, or may vary between these over time. Periods of time under arable eliminate floodplain microtopography that is such an essential part of the natural habitat mosaic – only completely undisturbed floodplain land retains this topographical variation. Where grassland is left under extensive management in this drained landscape, biodiversity value is often low.

6.26 Floodplains in England are often highly developed, such that some are more amenable to restoration than others. Full restoration, involving removal of floodbanks and in-filling of drains, might be considered in relatively constrained floodplains given over to low intensity grazing with few or no dwellings. In more developed floodplains, partial restoration, involving as much natural function as possible, is a more appropriate aim. This may include set-back of floodbanks to allow an erodible river corridor, providing a limited area for the development of a dynamic habitat mosaic. Restoration of fens at the floodplain margin can also be relatively simple and provide a home for naturally functioning mire/freshwater systems, even when the rest of the floodplain is not amenable to hydrological restoration – this may involve set-back of the catch-drain from the floodplain margin and targeted drain-blocking around springheads.

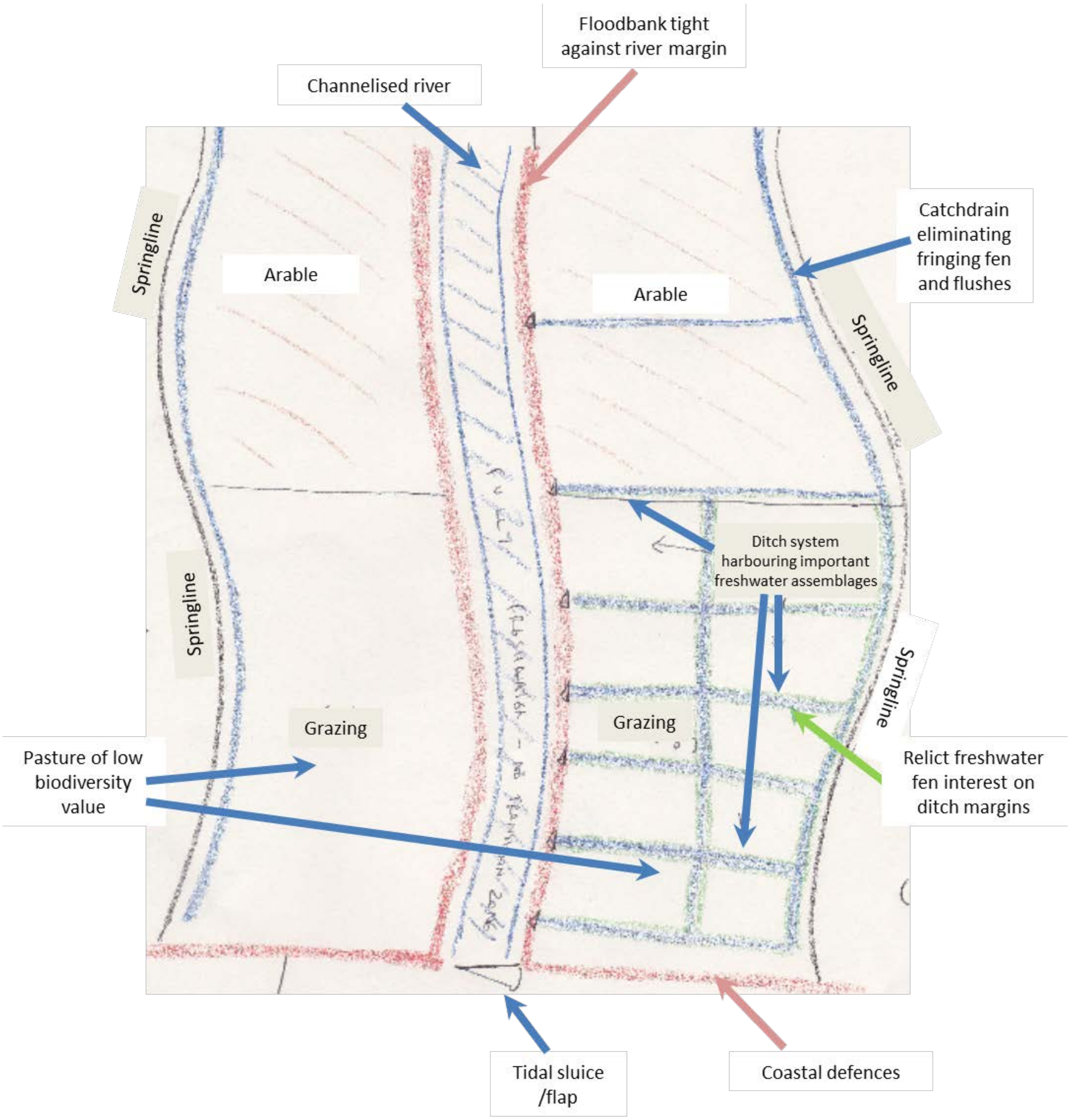


Figure 6.5 Drained floodplain landscape

Lowland plains scenario

6.27 In lowland areas, standing waters and wetlands can be found which are not associated with a river floodplain. This is often where past geomorphological processes have created depressions in the landscape, which are fed from rain fall, ground water and sometimes from small streams. As these depressions steadily fill in schwingmoor and bog can naturally form if natural fluctuations in water level do not allow for drying and consequent loss of organic matter. However, just like the other types of wetland and freshwater habitats, their condition is largely governed by their catchments. Since they naturally have limited out-flows their tendency to accumulate nutrients from the catchment is even greater, even though their surface water catchments can be relatively small. Natural hydrological regimes and semi-natural habitats in these catchments will have the multiple benefits of decreasing nutrient inputs, increasing the area of habitats of conservation value (particularly wetlands), and increasing the connectivity between transitional wetlands and open water.

Practical issues

Preamble

6.28 A catchment or landscape-scale approach based on natural ecosystem function requires a combination of restoring degraded examples of semi-natural habitats and creating these habitats in areas of the landscape where they will contribute most to wider biodiversity (and wider ecosystem services) objectives. These two activities are not independent of each other. Changes in land use and land management have two potential biodiversity benefits: they can have immediate benefits on the specific area subject to change, and they can help restore natural processes to other areas in the landscape. These natural processes may be hydrological, hydrochemical or biological (the latter through enhanced species movements); for instance, re-creating riparian woodland alongside streams feeding a lake will help restore the streams themselves, the environmental conditions in the lake (nutrient and sediment delivery, water temperatures), and also the suitability of the stream habitat for lake species that exploit streams for part of their life cycle (e.g. brown trout and arctic char that migrate from the lake into feeder streams to spawn).

6.29 These aspects of landscape-scale ecological function are not necessarily easily apparent, and require a strongly functional approach to landscape evaluation. The following sections tackle the practical issues of targeting effort at those landscape-scale areas where there is most potential, and how to structure decision-making in those areas based on concepts of ecological function.

Targeting landscape-scale areas

6.30 The example in Section 6.2 may be followed everywhere to a greater or lesser degree, depending on local constraints and opportunities. However, strategic prioritisation of effort is always necessary and there will be geographical areas where effort will deliver greater returns than in other areas. Given the huge array of potential benefits of restoring natural ecosystem function, it is possible to view every catchment or landscape unit as a priority from one perspective or another. However, the best places to target are inevitably those with the most restoration opportunities, the great biodiversity benefits and the most associated ecosystem service improvements. Some circumstances are worth highlighting as they may favour some areas over others.

- Catchments with protected freshwater and wetland sites where there is a strong driver for restoring natural processes and resulting opportunities for wider habitat restoration and re-creation.
- Catchments with freshwater habitats that are a priority for restoration to meet priority habitat objectives.
- Circumstances where there are limited land use consequences to restoring natural function, including degraded freshwater habitats with relatively small catchments and rivers with narrow floodplains, low-intensity agriculture and few dwellings.
- Degraded mire systems where freshwater and mire habitat restoration can easily go hand-in-hand.
- Upland blanket bog where hydrological restoration can be achieved in the short-term, delivering for bog habitat and its associated dystrophic pools and headwater streams as well as for downstream habitats, flood risk and drinking water quality.
- Floodplains where restoration of natural hydrological processes can include restoration of valleyside springlines/flushes and areas of floodplain upwelling, to maintain and restore groundwater-fed habitats whilst restoring river/floodplain interactions.
- Critical areas for threatened species where restoring natural freshwater and wetland habitat function delivers improved habitat for those species as well as for the wider characteristic assemblage.

6.31 Identification of 'biodiversity hotspots' is a popular species-focused approach to prioritising areas for action, and provides valuable biodiversity information to inform both spatial priorities and local decision-making. However, it is important that this information is interpreted in the context of natural ecosystem function to ensure that resources are focused on activities that restore species as part of characteristic assemblages wherever possible, sustained by natural environmental processes. An integrated approach to prioritisation is required, highlighting areas with greatest potential for restoring species through restoring natural ecosystem function.

6.32 All of this might imply that areas where restoration of natural ecosystem function is not possible should not be prioritised for any enhancement works, but it is important to recognise that some highly modified landscapes in England are not obviously amenable to restoration of natural processes yet are critical to existing populations of some priority species (wetland birds for instance). Habitat enhancement of such areas is needed to prevent further decline of these species, but may involve a continuation or intensification of management intervention (particularly hydrological). Allowance needs to be made for such circumstances on a case-by-case basis within an overall decision-making framework that promotes the restoration of natural habitat function, to avoid unintended impacts on the status of individual priority species.

Local decision-making processes within a landscape area

6.33 Within any given catchment or landscape area, the approach to decision-making can follow a similar pattern to the high-level prioritisation of landscape-scale areas above, but may operate at smaller spatial scales. For example:

- Focus on areas within the landscape where it is easiest to restore natural processes to deliver habitat and related species objectives.
- Within those areas, focus on the measures required to restore natural processes rather than to mitigate for their absence.
- Try to avoid situations where action in the short-term would bring major conflicts between habitat and species objectives.
- Identify situations where restoration of natural processes would provide wider ecosystem service benefits, e.g. lower energy flooding upstream of flood risk areas.
- Prioritise individual projects that deliver for priority species through restoration of natural habitat function.

6.34 An outline of a logical process for evaluation and decision-making, developed from the evidence presented in this document, is provided in Box 6.2. This should not be seen as a simple sequential process, but rather requires the iteration of steps and optimisation of measures to arrive at the best local solution.

Box 6.2 Suggested approach to evaluation and decision-making within a catchment or landscape area.

1. ***Landscape/catchment appraisal based on natural environmental processes (particularly hydrological pathways/hydraulics/hydrochemistry)***
   – How have environmental processes been modified over time and what would the landscape look like without this modification?
   – Where would habitats and species be?
   – Where were they (as far as we can tell)?
2. ***To what extent can natural environmental processes and associated ecosystem function be restored?***
   – Focus on underlying environmental processes (hydrology, hydrochemistry, sedimentary processes etc.)
   – Factor in immovable constraints to restoring natural environmental processes (think long-term, strategic)
   – Overlay consideration of the need for on-site management of vegetation to deliver a comprehensive characteristic habitat mosaic
3. ***What are the benefits for priority species and any negative consequences for existing populations of priority species?***
   – Identify measures that maximise benefits and mitigate any negative consequences
   – Consider climate change influences
4. ***How does this fit with key ecosystem services?***
   – Identify synergies with managing urban flood risk, improving drinking water quality and sustaining water supplies
   – Identify positive and negative effects on landscape, historic and amenity value of the area
5. ***What is the catchment/landscape vision?***
   – Build up from underlying natural processes
   – Think long-term, be ambitious
6. ***What is the role of key policy mechanisms in achieving the vision (SSSI notifications, priority habitat, WFD)?***
   - ***SSSIs***
   – Consider how existing notifications might be modified to support the vision and operate in concert with each other
   – Portrayal of notified features – upscaling within the ecological hierarchy promotes a focus on natural habitat function (species to assemblages, assemblages to habitats, habitats to habitat mosaics)
   – Be as flexible as possible about changes in population status and distribution in the face of efforts to restore natural processes, and factor in climate change
   – Value and accommodate natural processes and ecosystem function in notification packages
   – Set boundaries to better capture natural processes and habitat mosaics – allows more flexibility in management decisions
   – Consider new notifications to support the vision
   - **Priority habitat**
   – Use the priority habitat mechanism to recognise areas of land that are key to restoring natural ecosystem function but are not currently suitable for SSSI notification
   – Map areas where restoration action can be labelled as restoration or recreation of priority habitat – may be for any wet or dry habitat type
   – Map areas where restoration action can be labelled as restoration of degraded ecosystems.
   - **WFD**
   – Identify synergies with restoring ecological status and potential
7. **What available delivery mechanisms can contribute to delivering the vision and how they work together?**
   – Use Countryside Stewardship to deliver land management change, focused on options creating and restoring semi-natural habitat
   – Use water management mechanisms to help restore hydrological pathways and water quality
   – Generate long-term plan for using delivery mechanisms to achieve the vision over suitable time periods

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Glossary of technical terms

Avulsion – The cutting of a completely new channel by a river, leaving the old channel as a relict feature.

Ecotone – This is the transition area between two habitats or biological communities.

Ephemeral – Aquatic habitats that are seasonally exposed, such as ephemeral headwater streams and ponds, seasonally exposed marginal habitat, and fluctuating meres.

Epilimnion – The stratum of warm well mixed water above the thermocline.

Euryhaline – Species that are able to adapt to a wide range of salinities.

Habitat – The precise definition of this team relates to the physical environment occupied by a single species, but in conservation the term is used more broadly to encompass habitat for species assemblages and a range of ecological scales up to habitat mosaics and even ecosystems. The relationship between the terms habitat and ecosystem is therefore somewhat blurred in common usage, but attempts have been made in this document to refer to ecosystems where deemed to be most appropriate.

Headwater stream – Small streams that occur in the most upstream parts of a river network. Often defined as streams of no more than 2.5km of source, or streams of first or second order, normally as shown on a 1:50,000 scale Ordnance Survey map. However, headwater streams also include ephemeral sections that occur upstream of the perennial stream head and may not be shown on 1:50,000 maps. Pragmatically, it is useful to think of headwater streams as those with a catchment area of less than $10km^2$, since this description is not dependant on determining the source of the stream, transparently accommodates ephemeral sections, and is compatible with the WFD reporting typology for rivers.

High water line (of a lake) – The high water line is the limit beyond which lake or pond does not reach. The stand Lake Habitat Survey suggests this line separates any beach from the bank. A trash-line of deposited submerged plant material may help indicate the position of the high water line when no obvious beach or bank is visible.

Hydrosere – Strictly this is the natural succession of vegetation over time from fully aquatic, through wetland to terrestrial communities. In this report the term is used to describe the natural spatial transition of vegetation around the margins of standing water, from a fully aquatic community (downslope) to a fully terrestrial community (upslope).

Hypolimnion – The layer of water below the thermocline of a lake

Hyporheic zone (Hyporheos) – This comprises the volumes of sediment underlying and adjacent to a surface stream or river, which provides interstices exploited by a range of specialist and non-specialist species. These interstices are supplied by upwelling (from groundwater) and downwelling (from surface stream flow), providing nutrients, oxygen and cleansing intersitital water.

Littoral zone – The shallow, near shore zone of the lake or pond characterized by light penetration to the bottom

Locally non-native species – Species that are native to Britain but absent from certain regions, and if artificially introduced to these regions would cause changes to characteristic assemblages.

Nutrient spiraling – refers to the transport of nutrients down the length of a river during the process of nutrient cycling (uptake into biological tissue and excretion back to an assimilable form ready for biological uptake). The nutrient spiral length is the average length of river over which a nutrient atom completes a single nutrient cycle – this varies along the course of a river and between rivers depending on environmental characteristics.

Pelagic zone – the zone of open water in a lake or pond (or other type of water body).

Profundal zone – lake sediments at depths beyond where primary producers can live.

Riparian – Strictly speaking this term relates to the land immediately adjacent to streams and rivers, but in common usage the term is extended to include land adjacent to standing waters. It is used in both contexts context in this report.

Riffle – A habitat feature in river channels consisting of coarse mixed substrates (gravels, pebbles, cobbles) and shallow turbulent water. It is formed by natural processes of erosion and deposition and is a critical habitat for a variety of invertebrates, plants and fish (particularly juvenile fish of a range of species).

Saline transition zone – The natural brackish water zone at the downstream end of a river, immediately prior to the estuary proper (taken as the mean low water mark). This zone is highly important to many fish species for migration to and from freshwater and (for some species) spawning, feeding and shelter.

Schwingmoor – Floating raft of peat formed by a layer of vegetation spreading across the surface of a body of water.

Shear stress – Hydraulic force applied to river bed substrates created by a combination of water flow, stream gradient and channel geomorphology.

Stream order – This is a term that describes the position of a river or stream within a drainage network. It relates most closely to river size and distance from source. There are various stream order classifications but the widely used Strahler classification categorises streams as 'first order' until the first confluence with another stream, then 'second order' until the first confluence with another second order stream.

Thermocline – The boundary between the epilimnion and hypolimnion exhibiting a marked thermal change.

Turbary – The ancient right to cut turf, or peat, for fuel on a particular area of bog.

Water body – a river, stream, lake or pond. The term can be used in a general sense, but also has a specific meaning in the context of the Water Framework Directive. Under the WFD, the surface water network is divided up into a series of river, lake and transitional/coastal water bodies, which forms the spatial framework for WFD reporting and management.

Winterbourne – The ephemeral section of a chalk stream, which has a longitudinal succession of vegetation from upstream (driest, least seasonally inundated) to downstream (wettest, more seasonally inundated).

Appendix 1 English priority species associated with a) rivers b) standing waters and c) wetlands (from Webb et al. 2010)

Table A Rivers

Scientific name	Common name	Habitat requirements
Acipenser sturio	Common Sturgeon	HWQ; lower reaches; sizeable deep water pools; flow over gravel beds (no siltation); unobstructed natural systems
Alosa alosa	Allis Shad	HWQ; lower and middle reaches; unobstructed natural systems; flow over gravel beds (no siltation); migratory
Alosa fallax	Twaite Shad	HWQ; lower reaches; unobstructed natural systems; flow over gravel beds (no siltation); migratory
Anguilla Anguilla	European Eel	Unobstructed rivers (natural); links to wetlands - connectivity isuues; moderate WQ - for invertebrate prey; migratory
Cobitis taenia	Spined Loach	Moderate WQ; silty/sandy waterways; aquatic veg (for young); coarse sand with patchy macrophyte cover; connectivity
Lota lota	Burbot	HWQ; cool, shallow water; gravel or sand; natural rivers - overhanging banks, cover
Osmerus eperlanus	Smelt (Sparling)	HWQ; lower reaches; unobstructed natural systems
Salmo salar	Atlantic Salmon	HWQ; unobstructed natural systems; flow over gravel beds (no siltation); lower to upper reaches of river; deep pools; shallow water for juveniles; migratory, exploitation (commercial fishing)
Salmo trutta	Brown/Sea Trout	HWQ; unobstructed natural systems; flow over gravel beds (no siltation); lower to upper reaches of river; migratory, exploitation (commercial fishing)
Lampetra fluviatilis	River Lamprey	Moderate WQ; unobstructed natural systems - connectivity; lower and middle reaches; mosaic of substrates
Petromyzon marinus	Sea Lamprey	HWQ; unobstructed natural systems; flow over sand (no siltation); lower reaches; mosaic of substrates; migratory
Arvicola terrestris	Water Vole	Alongside water - still and running; emergent vegetation/reedbeds; banks to burrow into; prefers slow-flowing rivers and lack of seasonal inundation; no mink

Table continued…

Scientific name	Common name	Habitat requirements
Barbastella barbastellus	Barbastelle Bat	Trees and underground sites old woodland with plenty of dead trees; loose bark; crevices; glades and rides; hunts over water; well-structured woodland with complex understorey
Lutra lutra	Otter	Still (lakes, ditches) and running water from coastal to upland; HWQ; water and wetland veg; refugia
Myotis bechsteinii	Bechstein`s Bat	Hunts within closed canopy woodland and above woodland streams; dense understory (of native species such as holly, hawthorn & hazel); roosts in holes and cracks in old trees (e.g. old woodpecker holes)
Nyctalus noctula	Noctule	Mature/old trees –predominately roosts in tree cavities (also known to roost in buildings); forages above canopy and over water and pasture
Pipistrellus pygmaeus	Soprano Pipistrelle	Generalist - preference for riparian habitats near water; buildings important for roosting; good vegetation linkages for commuting between roosts and foraging grounds
Rhinolophus ferrumequinum	Greater Horseshoe Bat	Roosts in large old buildings, also underground sites; forages in woodland edge, scrub, grazed pasture, along hedgerows and treelines; riparian habitat
Rhinolophus hipposideros	Lesser Horseshoe Bat	Roosts in a variety of buildings and underground sites including caves; buildings (often undisturbed and disused),; mines; forages in woodland edge, scrub, along hedgerows and tree lines, riparian habitat
Natrix natrix	Grass Snake	Mobile; not site restricted; egg-laying sites - decomposing veg - muck heeps; hay; sawdyst etc; crevice in warm spot - flood refuse; fish & amphibians for prey; semi-natural areas; non-intensive - untidy margins
Alisma gramineum	Ribbon-leaved Water-plantain	Shallow, eutrophic water, water edge, aquatic (reproduction); bare mud
Apium repens	Creeping Marshwort	Fluctuating water bodies; shallow ponds; damp meadows; bare wet mud - poached
Blysmus compressus	Flat-sedge	Sedge-rich fen, short (no scrub); damp soils; unimproved; calc/mineral rich; flushing?
Carex vulpina	True Fox Sedge	Seasonal water; shallow water; heavy clay soils; open (unshaded)
Leersia oryzoides	Cut-grass	Nutirent-rich; bare mud; seasonal inundation; not shaded; disturbance
Luronium natans	Floating Water Plantain	Stagnant/slow flow; meso-to-oligotrophic; aquatic and bare mud exposed
Oenanthe fistulosa	Tubular Water-dropwort	Seasonal flooding; open areas; unimproved; emergent and fringing veg by rivers
Potamogeton compressus	Grass-wrack Pondweed	Moderately base-rich; mesotrophic; still/slow flowing

Table continued…

Scientific name	Common name	Habitat requirements
Schoenoplectus triqueter	Triangular Club-rush	Mudbanks; tidal inundation; tolerates brackish
Scleranthus annuus	Annual Knawel	Bare ground, very dry - drought stressed; well drained, nutrient-poor soil; seasonal wetting
Sium latifolium	Greater Water Parsnip	Herb-rich fen; permentantly wet; still/slow moving; open (not shade tolerant); base-rich
Agabus brunneus	Sharp's Diving Beetle	Gravel beds in shallow lowland streams; natural river course
Bembidion quadripustulatum	Scarce Four-dot Pin-palp	Edges of wetlands, rivers and ponds where drawdown zones create beaches with litter
Bembidion testaceum	Pale Pin-palp	Exposed riverine sediments (ERS)
Chrysolina graminis	Tansy Beetle	Large stands of tansy; river banks
Donacia bicolora	Two-tone Reed Beetle	On stands of branched bur-reed in flowing water
Hydrochus nitidicollis	Brass Necked Beetle	Exposed riverine sediments (ERS)
Meotica anglica	Shingle Rove Beetle	Exposed riverine sediments (ERS); shingle
Panagaeus cruxmajor	Crucifix Ground Beetle	Habitat requirements unknown
Synaptus filiformis	a click-beetle	River edge and wetland; waterlogged soils; waterside veg - reed canary-grass *Phalaris arundinacea*
Lophopus crystallinus	a bryozoan	In water column; high quality water; bare substrate upon which to anchor
Glossosoma intermedium	Small Grey Sedge	Fast-flowing shingle streams; high water quality; unmodified
Hydropsyche bulgaromanorum	Scarce Grey Flag	Lower reaches of large rivers, just above the estuary; unmodified; high water quality
Ironoquia dubia	Scarce Brown Sedge	Small streams in woodland that drop in level very considerably in summer. Bankside important for pupation; unmodified; water quality?
Austropotamobius pallipes	White-clawed Crayfish	Clean water with plenty of refuges in the form of tree roots, rocks and stones. Stable banks not poached by cattle
Coenagrion mercuriale	Southern Damselfly	Open and exposed water courses; permanent water flow; in streams & runnels on grazed heathland/ valley mires or in water meadow ditch systems surrounding chalkstreams. Aquatic vegetation (submerged and emergent)
Cliorismia rustica	Southern Silver Stiletto-fly	Sandy banks along river edges; sheltered locations (uneven topography or within scrub)

Table continued…

Scientific name	Common name	Habitat requirements
Empis limata	The Borders Dance-fly	Actually probably requires sandy soils (possibly immersed in water or disturbed
Lipsothrix errans	Southern Yellow Splinter	In woody debris of a certain size category (above 1cm?). Requires the wood to be saturated and the larvae obviously have an opitumum soggy threshold
Lipsothrix nervosa	Northern Yellow Splinter	In seepages woody debris of a certain size category (above 1cm?). Requires the wood to be saturated and the larvae obviously have an opitumum soggy threshold
Lipsothrix nigristigma	Scarce Yellow Splinter	In woody debris of a certain size category (above 1cm?). Requires the wood to be saturated and the larvae obviously have an opitumum soggy threshold
Potamanthus luteus	Yellow Mayfly	HWQ; high energy rivers; natural rivers
Rhabdomastix japonica	River-shore Cranefly	Sand banks and sandy river edge, unmodified
Nigrobaetis niger	Southern Iron Blue Mayfly	On aquatic macrophytes in running waters; good water quality
Gyraulus acronicus	Thames Ram`s-horn Snail	Slow-moving water; densely vegetated river margins; good water quality; muddy bottom; grassy edges
Margaritifera margaritifera	Freshwater Pearl Mussel	Presence of salmonid fish - host for its parasitic larvae (glochidia); high water quality - no turbidity; soft water; gravel, sand or rocky substrate (fast flow); riffles; bankside/tree vegetation that provide shade
Mercuria similis	Swollen Spire Snail	Bare mud exposed at low tide beneath emergent vegetation such as *Phragmites australis* or *Glyceria maxima*; brackish water; does not tolerate high salinity; mosaic of vegetation and small ponds (cattle grazing leading to poaching) - lives in the 'transition zone'.
Omphiscola glabra	Mud Pond Snail	Shallow ponds; exposed mud; emergent vegetation
Pisidium tenuilineatum	Fine-lined Pea Mussel	Calcareous rivers, streams and (occasionally in Britain) ponds; high water quality; fine marginal sediments
Pseudanodonta complanata	Depressed (or compressed) river mussel	Calcareous; lowland rivers, large drains and canals with slow flow; high water quality; host fish for its parasitic larvae (glochidia); requires muddy compact sediments in which it buries
Sphaerium solidum	Witham Orb Mussel	High water quality; clay, silt, sandy, silty, and sand sediments (not blanketed by flamentous algae)
Vertigo moulinsiana	Desmoulin's Whorl Snail	In unshaded calcareous fens especially associated (and climbing at certain times of the year) monocotyledonous species including *Carex spp.*, *Glyceria maxima*, *Phragmites australis.* Associated water tables should be at or close to ground level

Table continued…

Scientific name	Common name	Habitat requirements
Hydraecia osseola subsp. hucherardi	Marsh Mallow Moth	Foodplant - marsh mallow; coastal grazing levels and riverbanks
Brachyptera putata	a stone fly	Upland rivers with a clear rocky substrate, and open to winter sunshine; good water quality
Cryphaea lamyana	Multi-fruited River Moss	Flood zone riparian species; on river banks; on tree roots and rocks encrusted with silt
Dumortiera hirsuta	Dumortier`s Liverwort	Waterfalls and cascasedes - on the edges where it drips; high humidity; shaded
Fissidens curvatus	Portuguese Pocket-moss	Wet rocks adjacent to lowland streams; in shade; acidic clay soil
Fissidens serrulatus	Large Atlantic Pocket-moss	Low rocky banks; partially shaded; forms big mats; periodic inundation
Seligeria carniolica	Water Rock-bristle	Calcareous boulders; wooded stream; shaded; periodic inundation
Thamnobryum cataractarum	Yorkshire Feather-moss	Submerged in rivers on rocks
Collema dichotomum	River Jelly Lichen	Submerged horiz +/- basic siliceous rock
Endocarpon adscendens	a lichen	Often encrusting mosses, periodically inundated acidic rocks; nutrient poor
Lecanora achariana	Tarn lechanora	Upland bird-perching rocks; edges of tarns and streams - crucial - humidity
Peltigera venosa	a lichen	Low competition and disturbance. In uplands on calc rocks; shingle
Phaeophyscia endococcina	a lichen	Nutrient rich bird perches, boulders in around around upland streams and lake shores
Poeltinula cerebrina	a lichen	Hard limestone vertical faces; inundation zone; no scrub encroachment

Note that many species appear in more than one table, because of their movement between running water, standing water and wetland habitats, and the existence of smaller-scale habitat mosaics in each broad habitat category.

HWQ = High water quality

Table B Standing waters

Scientific name	Common name	Habitat requirements	Habitat type*
Bufo bufo	Common Toad	Large water body; land habitat of dense ground vegetation/litter layer/crevices in ground (woodland, scrub and tall grassland)	P, L, D
Epidalea calamita	Natterjack Toad	Ephemeral / near ephemeral. Bare/low vegetation sparse, no scrub, shallow and warm. Early succession; open coastal areas with small-medium ponds	P
Pelophylax lessonae	Pool Frog	Aquatic - medium-sized unshaded permanent ponds; high invert abundance and good vegetative structure. Terrestrial - semi-natural vegetation with adequate cover - rough grass, low scrub; woodland but not overshading pond	P
Triturus cristatus	Great Crested Newt	Open fish-free well-vegetated ponds; high density of ponds in landscape; terrestrial - cover e.g. rough grassland scrub and woodland; extensive terrestrial habitat required	P, D
Cygnus columbianus bewickii	Bewick's Swan (Tundra Swan)	Extensive open wetlands and pools (10ha) with emergent vegetation; proximity to arable and pasture with short, grassy swards in an extensive open landscape, can utilise waste root crops (e.g. potatoes and sugar beet)	P,L
Anguilla anguilla	European Eel	Unobstructed rivers (natural); links to wetlands - connectivity issues; moderate WQ - for invertebrate prey; migratory; exploitation (commercial fishing)	P, L, D
Arvicola terrestris	Water Vole	Alongside water - still and running; emergent vegetation/reedbeds; banks to burrow into; prefers slow-flowing rivers and lack of seasonal inundation; no mink	P, L, D
Barbastella barbastellus	Barbastelle Bat	Buildings, trees and underground sites old woodland with plenty of dead trees; loose bark; crevices; glades and rides; hunts over water; well-structured woodland with complex understorey	P, L, D
Lutra lutra	Otter	Still (lakes, ditches) and running water from coastal to upland; HWQ; water and wetland veg; refugia	P, L, D
Myotis bechsteinii	Bechstein`s Bat	Hunts within closed canopy woodland and above woodland streams ; roosts in holes and cracks in old trees (e.g. old woodpecker holes)	P, L
Nyctalus noctula	Noctule	Mature/old trees - predominately roosts in tree cavities (also known to roost in buildings); forages above canopy and over water and pasture	P, L, D
Pipistrellus pygmaeus	Soprano Pipistrelle	Generalist - preference for riparian habitats near water; buildings important for roosting; good vegetation linkages for commuting between roosts and foraging grounds	P, L, D

Table continued…

Scientific name	Common name	Habitat requirements	Habitat type*
Rhinolophus hipposideros	Lesser Horseshoe Bat	Roosts in a variety of buildings and underground sites including caves; buildings (often undisturbed and disused); mines; forages in woodland edge, scrub, along hedgerows and tree lines, riparian habitat	P, L, D
Natrix natrix	Grass Snake	Mobile; not site restricted; egg-laying sites - decomposing veg - muck heaps; hay; sawdust etc.; crevice in warm spot - flood refuse; fish & amphibians for prey; semi-natural areas; non-intensive - untidy margins	P, L, D
Alisma gramineum	Ribbon-leaved Water-plantain	Shallow, eutrophic water, water edge, aquatic (reproduction); bare mud	P, L, D
Apium repens	Creeping Marshwort	Fluctuating water bodies; shallow ponds; damp meadows; bare wet mud, –poached	P
Blysmus compressus	Flat-sedge	Sedge-rich fen, short (no scrub); damp soils; unimproved; calcareous/mineral-rich.	P, L, D
Carex maritima	Curved Sedge	Damp dune slacks; freshwater seepages; near streams on the shore	P
Carex vulpina	True Fox Sedge	Seasonal water; shallow water; heavy clay soils; open (unshaded)	P
Cicendia filiformis	Yellow Centaury	Cart tracks, ditches and seasonally inundated land	P
Cyperus fuscus	Brown Galingale	Seasonally flooded pond/ditch edge; open (non-shaded) land; peat/high organic substrate	P, D
Damasonium alisma	Starfruit	Shallow ponds; seasonally fluctuating; bare wet ground; acid soils	P, D
Illecebrum verticillatum	Coral-necklace	Seasonally wet tracks; bare ground; winter wet	P
Juncus pygmaeus	Pygmy Rush	Winter wet footpaths and tracks - bare ground and wet areas	P
Leersia oryzoides	Cut-grass	Nutrient-rich mid; bare mud; seasonal variation; not shaded	P, D
Liparis loeselii	Fen Orchid	Infertile soil; seasonally wet water levels; species-rich open fen	P
Lobelia urens	Heath Lobelia	Grassy heaths, wettish, seasonally waterlogged, horse grazing and disturbance	P
Luronium natans	Floating Water Plantain	Stagnant/slow flow; meso-to-oligotrophic; aquatic and bare mud exposed	P, L
Lycopodiella inundata	Marsh Clubmoss	Bare peat, trampled, poached ground, on damp but not wet ground (ecotone between dry and wet)	P
Lythrum hyssopifolia	Grass-poly	Bare mud and earth; seasonal flooding (or goose grazing)	P
Mentha pulegium	Pennyroyal	Temporary wet grassland, on commons, on dry grassland on clifftops and within heathland, Devon, and on Lizard peninsula, trackways	P

Table continued…

Scientific name	Common name	Habitat requirements	Habitat type*
Oenanthe fistulosa	Tubular Water-dropwort	Seasonal flooding; open areas; unimproved	P, L, D
Pilularia globulifera	Pillwort	Bare mud; seasonal flooding; no shade	P, L?
Potamogeton acutifolius	Sharp-leaved Pondweed	Shallow; species-rich drainage ditches; calcareous mesotrophic water	P, D
Potamogeton compressus	Grass-wrack Pondweed	Moderately base-rich; mesotrophic; still/slow flowing	P, L, D
Pulicaria vulgaris	Small Fleabane	Seasonal flooding; very short swards/bare puddled soil and mud (grazing); unimproved	P
Ranunculus tripartitus	Three-lobed Water-crowfoot	Pond edge; tracks puddled; gateways; pinchpoints; disturbance; temp wet	P
Scirpoides holoschoenus	Round-headed Club-rush	Damp dune hollow; seasonal variation; open areas (no scrub)	P
Stellaria palustris	Marsh Stitchwort	Seasonal variation; open sward; damp/wet soil; herb rich; unimproved	P
Teucrium scordium	Water Germander	Damp; seasonal flooding; bare ground and/or very open; dune slacks	P
Agonum scitulum	a ground beetle	Edges of wetlands and ponds where drawdown zones create beaches with litter	P
Bagous nodulosus	Flowering Rush Weevil	Stands of *Butomus umbellatus*; mostly mineral soils	P, D
Bembidion quadripustulatum	Scarce Four-dot Pin-palp	Edges of wetlands, rivers and ponds where drawdown zones create beaches with litter	P
Bidessus unistriatus	One-grooved Diving Beetle	Unvegetated, shallow silt ponds, low nutrient levels	P
Donacia aquatica	Zircon Reed Beetle	On stands of *Carex acutiformis*; water edge	P, L
Graphoderus zonatus	Spangled Diving Beetle	Unvegetated ponds; sphagnum edges; shallow edges	P
Helophorus laticollis	New Forest Mud Beetle	Very shallow seasonal grassy ponds (associated with melt water in other countries). Open grassy lawns	P
Hydroporus necopinatus subsp. Roni	Ron's Diving Beetle	Very shallow seasonal ponds in open peaty heathland	P

Table continued…

Scientific name	Common name	Habitat requirements	Habitat type*
Hydroporus rufifrons	Oxbow Diving Beetle	Seasonal grassy ponds; grass edges; open; good water quality	P
Laccophilus poecilus	Puzzled Skipper (aka Sussex Diving Beetle)	Ponds and ditches, open water with little vegetation	P
Stenus longitarsis	a camphor beetle	Wetland edges	P
Lophopus crystallinus	a bryozoan	In water column; high quality water; bare substrate upon which to anchor	P, D
Macrosteles cyane	a leafhopper	Adults feed on floating leaves of pondweeds, water quality important	P
Austropotamobius pallipes	White-clawed crayfish	Clean water with plenty of refuges in the form of tree roots, rocks and stones. Stable banks not poached by cattle	P, L
Triops cancriformis	Tadpole shrimp	Very shallow, muddy ephemeral ponds	P
Aeshna isosceles	Norfolk Hawker	Clean, unpolluted, and gently flowing water in dykes/ditches on fens and grazing marshes; Presence of *Stratiotes aloides* (UK only) and rich aquatic flora	P, D
Anisus vorticulus	Little Whirlpool Ram`s-horn snail	High water quality; fen vegetation, stable water levels; Drainage channels on traditionally managed grazing marsh with high diversity of aquatic plants (late vegetational stage of succession)	P, D
Omphiscola glabra	Mud pond snail	Shallow ponds; exposed mud; emergent vegetation	P
Quickella arenaria	Sandbowl Snail	Open habitat (unshaded with low vegetation) which remains wet or damp (at or near the water-table)	P
Segmentina nitida	The Shining Ram`s-horn Snail	Structurally rich emergent vegetation; calcareous water; stable water levels	P, D
Dolomedes plantarius	fen raft Spider	In ditches, open water with floating vegetation (water soldier)	P
Prostoma jenningsi	Jennings's Ribbon-worm	Habitat requirements unknown	P
Bryum calophyllum	Matted bryum	Dune slacks - temporary water; humid bare open ground in drawdown	P
Bryum knowltonii	Knowlton`s Thread-moss	Open sandy ground; seasonally covered by water	P
Bryum warneum	Sea bryum	Dune slacks - temporary water; humid bare open ground in drawdown	P
Cephaloziella dentata	Toothed Threadwort	Temporary water bodies winter flooded depressions and ruts	P

Table continued…

Scientific name	Common name	Habitat requirements	Habitat type*
Petalophyllum ralfsii	Petalwort	Dune slacks; paths along sand; requires temp water bodies; compacted bare ground in calcareous places	P
Physcomitrium eurystomum	Norfolk Bladder-moss	Temporary water bodies in meres	P
Riccia bifurca	Lizard Crystalwort	Seasonal pools; open - no vascular plants; no nutrients - HWQ?	P
Riccia canaliculata	Channelled Crystalwort	Exposed mud; damp sand at pond edge; calcifuge; seasonal fluctuations	P
Chara baltica	Baltic Stonewort	Standing water (can be in deep water); HWQ; aquatic; brackish influence	P, L
Chara canescens	Bearded Stonewort	Brackish water; high pH; HWQ; aquatic; early succession - bare areas; lack of competition	P
Chara connivens	Convergent Stonewort	(Often coastal); HWQ; aquatic; early succession - bare areas; calcareous water; lack of turbulent conditions	P, L, D
Nitella tenuissima	Dwarf Stonewort	Shallow water; HWQ; aquatic; early succession - bare areas; calcareous water on peat; lack of competition	P
Tolypella intricata	Tassel Stonewort	Temporary standing water; HWQ; alkaline water; early succession - bare areas; lack of competition	P, D
Tolypella prolifera	Great Tassel Stonewort	HWQ; aquatic; alkaline water; early succession - bare areas; lack of competition	P, D
Tracya hydrocharidis	Frogbit Smut	Smut on underside of leaves of frogbit *(Hydrocharis morsus-ranae)*; aquatic	P
Emberiza schoeniclus schoeniclus	Reed Bunting	Tall herb vegetation (not exclusively next to wetlands); reedbeds, farmland especially overgrown ditches and hedges	D
Hordeum marinum	Sea Barley	Ditches in grazing marsh; upper saltmarsh; bare mud; pond edges on bare mud; winter wet, summer dry	D
Coregonus albula	Vendace	HWQ, cool water, deep lakes, gravels for spawning	L
Coregonus lavaretus	Whitefish (Schelly)	HWQ, cool water, deep lakes, gravels for spawning	L
Lota lota	Burbot	HWQ; cool, shallow water; gravel or sand; natural rivers - overhanging banks, cover etc.	L
Salmo trutta	Brown/Sea Trout	HWQ; unobstructed natural systems; flow over gravel beds (no siltation); lower to upper reaches of river	L
Salvelinus alpinus	Arctic Char	HWQ, cool water, deep lakes, gravels for spawning	L

Table continued…

Scientific name	Common name	Habitat requirements	Habitat type*
Lampetra fluviatilis	River Lamprey	Moderate WQ; unobstructed natural systems - connectivity; lower and middle reaches; mosaic of substrates	L
Calamagrostis stricta	Narrow Small-reed	Neutral mires; neutral lake margins; stable water levels?	L
Corrigiola litoralis	Strapwort	Gravel/shingle/mud with surface veneer of fine gravel; wet;	L
Najas flexilis	Slender Naiad	Silty substrate; stagnant water; open water 1.5m deep; base-rich enrichment; clear	L
Najas marina	Holly-leaved Naiad	Clear; mesotrophic; stagnant; lack of disturbance; nutrient poor 0.5 to 1.5m	L

*L = Lake, P = Pond, D = Ditch, Grazing Marsh

Note that many species appear in more than one table, because of their movement between running water, standing water and wetland habitats, and the existence of smaller-scale habitat mosaics in each broad habitat category.

HWQ = High water quality

Table C Wetlands

Scientific name	Common name	Habitat requirements	Habitat type*
Caprimulgus europaeus europaeus	Nightjar	Nesting - mosaic of bare ground, low/medium vegetation and low/scrubby trees; feed over a wide range of habitats	LRB
Cuculus canorus canorus	Common Cuckoo	Generalist; scrubby/wetland areas that support host species (eg reed warbler, meadow pipit, dunnock) and plentiful food supply (hairy caterpillars)	LRB, RB, GM
Numenius arquata arquata	Curlew	Mosaic of tall herb vegetation for nesting *(Juncus)* and short veg for feeding; extensive open habitats; damp soils; rich invertebrates; in winter also feed on intertidal mudflats and saltmarsh creeks	LRB, GM
Arvicola terrestris	Water Vole	Along side water - still and running; emergent vegetation/reedbeds; banks to burrow into; prefers slow-flowing rivers and lack of seasonal inundation; no mink	LRB, LF, RB, GM
Caprimulgus europaeus europaeus	Nightjar	Nesting - mosaic of bare ground, low/medium vegetation and low/scrubby trees; feed over a wide range of habitats	LRB
Lutra lutra	Otter	Still (lakes, ditches) and running water from coastal to upland; HWQ; water and wetland vegetation; refugia	LRB, RB, GM
Nyctalus noctula	Noctule	Mature/old trees – predominately roosts in tree cavities (also known to roost in buildings); forages above canopy and over water and pasture	LRB, LF
Pipistrellus pygmaeus	Soprano Pipistrelle	Generalist - preference for riparian habitats near water; buildings important for roosting; good vegetation linkages for commuting between roosts and foraging grounds	LRB, LF, RB, GM
Natrix natrix	Grass Snake	Mobile; not site restricted; egg-laying sites - decomposing veg - muck heeps; hay; sawdyst etc; crevice in warm spot - flood refuse; fish & amphibians for prey; semi-natural areas; non-intensive - untidy margins	LRB, LF, RB, GM
Vipera berus	Adder	Tight mosaic of vegetation; heat; mammals lizards; open habitats (noshading); landscape scale species	LRB, LF
Zootoca vivipara	Common Lizard	Tight mosaic of vegetation; heat; inverts; open habaitats (no shading)	LRB, LF
Bembidion humerale	Thorne Pin-palp	Bare damp peat	LRB
Curimopsis nigrita	Mire Pill-Beetle	Bare damp peat	LRB
Coenonympha tullia	Large Heath	Cotton grass - food plant; dense tussocks; poor fen and bogs - stable water levels	LRB

Table continued…

Scientific name	Common name	Habitat requirements	Habitat type*
Hagenella clathrata	Window Winged Sedge	Larval habitat - very small pools shaded out by towering tussocks of Molinia (occasionally Eriophorum vaginatum and Deschampsia caespitosa). Plant litter usually also roofs the pools. No grazing?	LRB, LF
Phaonia jaroschewskii	hairy canary fly	In wet sphagnum	LRB
Erigone welchi	a money spider	Sphagnum lawns - good water quality	LRB, LF
Glyphesis cottonae	a money spider	Sphagnum lawns - good water quality	LRB, LF
Saaristoa firma	a money spider	Wet acidic situations - presumably stable water levels, low level inputs etc	LRB, LF
Sitticus caricis	a jumping spider	Low vegetation in mires - perm water, structural dynamism	LRB, LF
Dicranum bergeri	Waved Fork-moss	Forms hummocks; nutrient poor; stable water levels; open land	LRB
Jamesoniella undulifolia	Marsh Earwort	Raised mires; wet sphagnum hummocks; stable water levels; nutrient poor	LRB, LF
Pallavicinia lyellii	Veilwort	High humidity; acid substrate, bases of molinia tussocks in fens or margins of acid bogs. Also wet woodland near streams; shaded and seepages on sandstone rocks	LRB, LF
Sphagnum balticum	Baltic Bog-Moss	Very wet stable water; nutrient poor	LRB
Bufo bufo	Common Toad	Large water body; land habitat of dense ground vegetation/litter layer/crevices in ground (woodland, scrub and tall grassland)	LF, GM
Acrocephalus paludicola	Aquatic Warbler	Mosaic of tall and short vegetation - sedge beds and herb rich areas, often on edge of reedbed	LF, RB
Emberiza schoeniclus schoeniclus	Reed Bunting	Tall herb vegetation (not exclusively next to wetlands); reedbeds, farmland esp overgown ditches and hedges	LF, RB, GM
Locustella naevia naevia	Grasshopper Warbler	Extensive areas of scattered scrub in mosaic with tall herbs; edges of reedbeds and new forestry plantations	LF, RB, GM
Anguilla anguilla	European Eel	Unobstructed rivers (natural); links to wetlands - connectivity isuues; moderate WQ - for invertebrate prey	LF, GM
Barbastella barbastellus	Barbastelle Bat	Buildings, trees and underground sites old woodland with plenty of dead trees; loose bark; crevices; glades and rides; hunts over water; well-structured woodland with complex understorey	LF, GM

Table continued…

Scientific name	Common name	Habitat requirements	Habitat type*
Rhinolophus hipposideros	Lesser Horseshoe Bat	Roosts in a variety of buildings and underground sites including caves; buildings (often undisturbed and disused),; mines; forages in woodland edge, scrub, along hedgerows and tree lines, riparian habitat	LF, RB, GM
Blysmus compressus	Flat-sedge	Sedge-rich fen, short (no scrub); damp soils; unimproved; calc/mineral rich; flushing?	LF, GM
Calamagrostis stricta	Narrow Small-reed	Neutral mires; neutral lake margins; stable water levels?	LF
Dactylorhiza incarnata subsp. ochroleuca	an early marsh-orchid	Calcareous fen; moist (not very wet) edges of fens where partial drying; herb-rich fen;	LF
Dryopteris cristata	Crested Buckler-fern	Sphagnum lawns; can tolerate shade; high water quality	LF
Liparis loeselii	Fen Orchid	Infertile soil; seasonally wet water levels; species-rich open fen	LF
Luzula pallidula	Fen Wood-rush	Bare wet mud; open fenland; relatively stable water levels	LF
Oenanthe fistulosa	Tubular Water-dropwort	Seasonal flooding; open areas; unimproved	LF, GM
Platanthera bifolia	Lesser Butterfly-orchid	Herb-rich; unimproved; partial and or no shade; fens	LF, GM
Senecio paludosus	Fen Ragwort	Tall herb-rich fen; ditches, open (not shade-tolerant); seasonal flooding	LF
Sium latifolium	Greater Water Parsnip	Herb-rich fen; permentantly wet; still/slow moving; open (not shade tolerant); base-rich	LF
Stellaria palustris	Marsh Stitchwort	Seasonal variation; open sward; damp/wet soil; herb rich; unimproved	LF
Teucrium scordium	Water Germander	Damp; seasonal flooding; bare ground and/or very open; dune slacks	LF
Viola persicifolia	Fen Violet	Bare ground in matrix with herb-rich vegetation; no shade	LF
Agonum scitulum	a ground beetle	Edges of wetlands and ponds where drawdown zones create beaches with litter	LF
Bagous nodulosus	Flowering Rush Weevil	Stands of Butomus umbellatus; mostly mineral soils	LF, GM
Bembidion quadripustulatum	Scarce Four-dot Pin-palp	Edges of wetlands, rivers and ponds where drawdown zones create beaches with litter	LF
Chlaenius tristis	Black Night-runner	Fen vegetation	LF
Cryptocephalus decemmaculatus	Ten-spotted Pot Beetle	On young birch and willow; shelter, low boughs	LF

Table continued…

Scientific name	Common name	Habitat requirements	Habitat type*
Cryptocephalus exiguus	Pashford Pot Beetle	On young willow (shelter, low boughs) in fens	LF
Melanapion minimum	Sallow Guest Weevil	Extensive areas of willow and sallow; near water bodies	LF
Oberea oculata	Eyed Longhorn Beetle	Young shoots of willow	LF
Orchestes testaceus	Alder Flea Weevil	On canopy woodland; sheltered and well lit - open canopy	LF
Boloria selene	Small Pearl-bordered Fritillary	Woodland clearings; scrub edge; (bracken); (grassland where violets survive); foodplant - violets; sheltered locations (uneven topography or within scrub); (nectar)	LF
Euphydryas aurinia	Marsh Fritillary	Tussock forming grasslands, foodplant - devil's bit scabious; (nectar); sheltered locations (uneven topography or within scrub)	LF
Coenagrion mercuriale	Southern Damselfly	Permanent water flow in streams & runnels on grazed heathland/ valley mires or in water meadow ditch systems surrounding chalkstreams. Aquatic vegetation (submerged and emergent)	LF, GM
Aeshna isosceles	Norfolk Hawker	Clean, unpolluted, and gently flowing water in dykes/ditches on fens and grazing marshes; Presence of Stratiotes aloides (UK only) and rich aquatic flora	LF, RB, GM
Asindulum nigrum	Fen Flower Gnat	Damp soils, flower-rich areas	LF
Dolichopus laticola	Broads Dolly-fly	Presume some shade requirement from reeds or wet woodland and stable water levels. Presume shallow water/exposed mud?	LF
Dolichopus nigripes	Black-footed Dolly-fly	Presume some shade requirement from reeds or wet woodland and stable water levels. Presume shallow water/exposed mud?	LF
Eristalis cryptarum	Bog Hoverfly	Seepages; circum-neutral to slightly acid; open - not scrubbed up; (nectar)	LF
Idiocera sexguttata	Six-spotted Cranefly	Seepages where vegetation is sparse	LF
Lipsothrix nervosa	Northern Yellow Splinter	In seepages woody debris of a certain size category (above 1cm?). Requires the wood to be saturated and the larvae obviously have an opitumum soggy threshold	LF
Odontomyia hydroleon	Barred Green Colonel	Clear, shallow, clean water without shade (in Juncus etc)	LF
Stethophyma grossum	Large Marsh Grasshopper	Permanently wet acid mires; matrix of tussocky vegetation	LF

Table continued…

Scientific name	Common name	Habitat requirements	Habitat type*
Anisus vorticulus	Little Whirlpool Ram`s-horn Snail	High water quality; fen vegetation, stable water levels; Drainage channels on traditionally managed grazing marsh with high diversity of aquatic plants (late vegetational stage of succession)	LF, GM
Omphiscola glabra	Mud Pond Snail	Shallow ponds; exposed mud; emergent vegetation;	LF
Valvata macrostoma	Large-mouthed Valve Snail	Late successional ditches; fen vegetation; shallow water	LF, GM
Vertigo genesii	Round-mouthed Whorl Snail	Calcareous fen/mire; stable high water level; at base of short sedges (Carex viridula and mosses, especially Palustriella); matrix of wet exposed ground and vegetation. Also in often incompletely vegetated, rather stony or gravelly wet flushes (on sloping ground) not subject to flooding. Vertigo genesii occurs mainly at altitudes between 300 and 900 metres	LF
Vertigo geyeri	Geyer's Whorl Snail	Open flushes in calcareous fens and mires. It lives in sedges (e.g. Carex viridula, Schoenus nigricans) and mosses (e.g. Drapanocladus, Palustriella) at the interface between the water table and the base of the herb layer where the surface substrates are at or near field capacity but not subject to seasonal flooding	LF
Vertigo moulinsiana	Desmoulin's Whorl Snail	In unshaded calcareous fens especially associated (and climbing at certain times of the year) monocotyledonous species including Carex spp. Glyceria maxima, Phragmites australis. Associated water tables should be at or close to ground level	LF
Athetis pallustris	Marsh Moth	Varied fen vegetation; foodplant - on meadowsweet or plantain at edges; seasonal water fluctuations	LF
Chortodes extrema	The Concolorous	Drier parts of fens, without standing water or dominant common reed; marshy open areas and clearings within lowland ancient woodland on heavy soils; foodplant purple small-reed Calamogrostis canescens and wood small-reed C. epigejos. Also recently found on drier grassland in Leicestershire.	LF
Coleophora hydrolapathella	Water-dock Case-bearer	Foodplant - Rumex hydrolapathum; fens, marshes; shallow standing water. permanent water levels?	LF, GM
Cossus cossus	Goat Moth	Feeds under the bark and in the heartwood of a variety of broad-leaved trees; Found along riverbanks, edges in fens, marshes, heathland, foot of cliffs, parkland and along woodland edges	LF
Orgyia recens	Scarce Vapourer	Scrub; wet woodland; hedgerows; seemingly associated with areas less than 10m above sea level with at least historical inundation	LF
Clubiona rosserae	Rosser's sac-spider	Tall fen; fen litter; stable water levels	LF
Dolomedes plantarius	Fen Raft Spider	In ditches, open water with floating vegetation (water soldier)	LF

Table continued…

Scientific name	Common name	Habitat requirements	Habitat type*
Notioscopus sarcinatus	a money spider	Sphagnum; good water quality; stable water levels	LF
Odynerus simillimus	a mason wasp	Bare ground, aquatic umbellifers in a herb-rich mosaic a.k.a not dominated by reedbed; ecotone between saltmarsh and terrestrial	LF, RB, GM
Leiocolea rutheana	Fen Notchwort	Open wet areas amongst brown moss; stable water levels; nutrient poor?	LF
Physcomitrium eurystomum	Norfolk Bladder-moss	Temporary water bodies in meres	LF
Nitella tenuissima	Dwarf Stonewort	Shallow water; HWQ; aquatic; early succession - bare areas; calcareous water on peat; lack of competition	LF
Amanita friabilis	Fragile Amanita	Soil with alder in wet carr; mycorrhizal	LF
Bovista paludosa	Fen Puffball	Soil in fens with moss eg Aulocomnium palustre; stable water levels, short sward	LF
Tremellodendropsis tuberosa	Ashen Coral	On soil or rootstocks of Filipendula ulmaria (meadowsweet); mycorrhizal	LF
Botaurus stellaris stellaris	Bittern	Permanently wet reedbeds standing in water; 20ha plus pools and dykes (can utilise smaller reedbeds if also have extensive network of ditches); good fish and amphibian pops (not salty); use brackish reedbeds and ditches in winter	RB
Circus cyaenus	Hen Harrier	Tall herb/dwarf scrub for nests; wide open expanses for hunting; in winter require tall vegetation in big stands (reedbeds) for roosting - no disturbance	RB
Locustella luscinioides luscinioides	Savi`s Warbler	Extensive reedbed (20ha) close to water	RB
Sturnus vulgaris vulgaris	Starling	Mature trees (and buildings) with holes for nesting; grasslands for inverts; cultivated land/pastures/gardens for foraging in winter; woods and reedbeds for roosting	RB
Micromys minutus	Harvest Mouse	Tall grass throughout the year; bramble; rank swards	RB
Hydrometra gracilenta	Lesser water-measurer	Pools in a matrix of reedbed	RB
Dorylomorpha clavifemora	Clubbed Big-headed Fly	Phragmites beds	RB

Table continued…

Scientific name	Common name	Habitat requirements	Habitat type*
Lipara similis	Least cigar-gall Fly	In Phragmites beds - possibly where the phragmites is stressed by other herbs and is in a then bed. So also requires a mosaic of veg types and stable high water levels	RB
Archanara neurica	White-mantled Wainscot	In stands of late succesional reed and reedy ditches with abundant dead stems; larvae feed in stems; Don't know about the following - seasonally dry? (at edges of reedbeds)	RB
Chortodes brevilinea	Fenn's Wainscot	Foodplant - Phragmites australis; on edges of reedbed in dry reed; where areas of reed a cut every couple of years or are growing sparsely	RB
Triturus cristatus	Great Crested Newt	Open fish-free well-vegetated ponds; high density of ponds in landscape; terrestrial - cover eg rough grassland scrub and woodland; (difference between toads and GCN are that toads can survive fish and in larger water bodies); extensive terrestrial habitat required	GM
Alauda arvensis arvensis	Sky Lark	Mosaic of tall sward and short sward/bare ground; prefer very open areas not enclosed by trees; mosaics of crops, particularly spring sown, utilises bare or sparsely vegetated ground for foraging	GM
Anser albifrons albifrons	European Greater White-fronted Goose	Roost on remote areas - sandbanks, saltmarsh, grazing marsh with no disturbance; feeding - cattle grazed pasture and other grassland; arable; open areas - no scrub etc	GM
Branta bernicla bernicla	Dark-bellied Brent Goose	Productive grassland (improved) and autumn sown cereals; short swards; unenclosed open land; saltmarsh, inter-tidal flats with eel grass	GM
Crex crex	Corn Crake	Large areas of unintensive grassland, require tall vegetation to provide early spring cover (eg nettles, cow parsley etc), timing of cutting of grassland very important (should not be before august)	GM
Cygnus columbianus bewickii	Bewick's Swan (Tundra Swan)	Extensive open wetlands and pools (10ha) with emergent vegetation; proximity to arable and pasture with short, grassy swards in an extensive open landscape, can utilise waste root crops (eg potatoes and sugar beet)	GM
Limosa limosa limosa	Black-tailed Godwit	Nest in damp tussocky pastures flooded in winter; damp peaty soils for foraging in summer; well-timed flood events; large wetland size; Lack of ground disturbance in nesting period; open extensive landscape; wintering - wet pasture, grazing marsh, saltmarsh, lagoons, gravel pits	GM
Motacilla flava flavissima	Yellow Wagtail	Mosaic of short swards (feeding) and tussocks (nesting); abundant inverts	GM
Vanellus vanellus	Lapwing	Spring tilled arable land; extensive open short grassland; invertebrate abundance; ideal (wet areas, pools with surface water and winter flooding)	GM
Alisma gramineum	Ribbon-leaved Water-plantain	Shallow, eutrophic water, water edge, emergent vegetation; aquatic (reproduction); bare mud	GM

Table continued…

Scientific name	Common name	Habitat requirements	Habitat type*
Apium repens	Creeping Marshwort	Fluctauting water bodies; shallow ponds; damp meadows; bare wet mud - poached	GM
Carex divisa	Divided Sedge	Edges of ditches; open sites (grassland) near sea; brackish, no tidal inundation	GM
Cyperus fuscus	Brown Galingale	Seasonally flooded pond/ditch edge; open (non-shaded) land; peat/high organic substrate	GM
Damasonium alisma	Starfruit	Shallow ponds; seasonally fluctuating; bare wet ground; acid soils	GM
Hordeum marinum	Sea Barley	Ditches in grazing marsh; upper saltmarsh; bare mud; pond edges on bare mud; winter wet, summer dry	GM
Leersia oryzoides	Cut-grass	Nutrient-rich mid; bare mud; seasonal variation; not shaded	GM
Potamogeton acutifolius	Sharp-leaved Pondweed	Shallow; species-rich drainage ditches; calcareous mesotrophic water	GM
Potamogeton compressus	Grass-wrack Pondweed	Moderately base-rich; mesotrophic; still/slow flowing	GM
Lophopus crystallinus	a bryozoan	In water column; high quality water; bare substrate upon which to anchor	GM
Pseudanodonta complanata	Depressed (or compressed) river mussel	calcareous; lowland rivers, large drains and canals with slow flow; high water quality; host fish for its parasitic larvae (glochidia); requires muddy compact sediments in which it buries	GM
Segmentina nitida	The Shining Ram`s-horn Snail	Structurally rich emergent vegetation; calcareous water; stable water levels,	GM
Chara connivens	Convergent Stonewort	(Often coastal); HWQ; aquatic; early succesion - bare areas; calcareous water; lack of turbulent conditions	GM
Tolypella intricata	Tassel Stonewort	Temporary standing water; HWQ; alkaline water; early succession - bare areas; lack of competition	GM
Tolypella prolifera	Great Tassel Stonewort	HWQ; aquatic; alkaline water; early succession - bare areas; lack of competition	GM

*LRB = Lowland Raised Bog, LF – Lowland Fen, RB = Reedbed, GM = Grazing Marsh

Note that this table does not include a full list of wetland types, but relates only to lowland wetland types for which there are recognised priority habitat types. A list of species including upland wetland types would be considerably longer. Note also that the allocation of species to wetland habitat types is only a guide. In reality, species range across naturally functioning wetland habitat mosaics within which these different wetland types occur, in association with larger running and standing water habitats. The habitat ‘grazing marsh’ (GM) is not a natural habitat type, and the species associated with it all have their niches within naturally functioning wetland habitat mosaics.

Note that many species appear in more than one table, because of their movement between running water, standing water and wetland habitats, and the existence of smaller-scale habitat mosaics in each broad habitat category.

HWQ = High water quality

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