Appendix B – Open freshwater habitats

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This account is largely based on material in the 'freshwater and wetlands habitat narrative' (Mainstone et al*. 2016), which can be consulted for further information on these habitats.*

B1. Habitat variation

There is immense natural environmental and hence biological variation in open freshwater habitats in England, from tiny pools and runnels in mire habitats to major lakes and rivers. This variation is divided up into running and standing water habitats in the brief description below, but in reality there is no clear dividing line between the two – naturally functioning intermittent headwater streams cycle between running water, standing water and dry phases (Stubbington *et al.* 2017), and many rivers have backwaters, margins and 'dead zones' and in-channel pools that support species associated with standing water habitat all year round.

Running water habitat variation is strongly governed by hydraulic energy and water chemistry. Individual river systems exhibit longitudinal variation in character, from headwaters to their connection with estuaries and the sea. We often think of larger rivers when we think of running waters, but nearly 70% (by length) of the running water habitat resource consists of headwater streams.

A bewildering array of typologies exists for categorising river habitat, mostly operating at the river reach-scale and designed for different purposes. In the current context it is useful to think in terms of the following categories:

- Headwater streams – these are small streams at the upstream end of river networks, (commonly defined as being within 2.5 km from their source). They cover a wide range of climatological, hydrochemical and hydraulic variation, from tufa-forming lowland streams to upland cascades.
- High energy river sections – these largely occur in the uplands or in hillier parts of lowland England, and can exhibit a range of water chemistries and trophic conditions.
- Moderate/low energy river sections – these occur in lowland areas, and again can vary widely hydrochemically and in terms of natural nutrient status.
- Tidally influenced sections – these occur at the downstream end of river systems and are strongly influenced by salinity gradients.

Standing water habitat variation is strongly governed by water chemistry and many typologies for lakes are based around nutrient status and/or alkalinity, with peat-stained dystrophic lakes as an additional type often defined by colour. Another major form of variation is associated with size, which is related to depth. Deep lakes function differently to shallow ones and a greater proportion of a small water body, such as a pond, is influenced by its riparian habitat, although the catchment obviously affects all standing water bodies regardless of size. The biological assemblages present within a water body can additionally be influenced by whether they are connected to other water bodies and the permanence of the water body

The transitions between freshwater habitats and other habitats are exceptionally important for characteristic biological assemblages. So much so that the margins of freshwater habitats are considered to be an intrinsic part of the habitat, to include the wetland hydrosere stretching away from the water's edge onto dry land.

B2. Factors affecting ecological position in the landscape

Natural open freshwater habitats are shaped by a combination of climate and the physiographic and geological character of the catchment which directs water into and through them. The development of vegetation in the landscape modifies the passage of water, altering its retention and conveyance. As water gathers along surface and sub-surface hydrological pathways, it forms flushes which gather into runnels across vegetation, which progressively increase in hydraulic energy to the point where channels can be carved in soils and rocks. Channels increase in size downstream as more and more hydrological pathways feed in and channels converge. Variations in soils, geology and topography, and the erosive and depositional effects of hydrological pathways, create pools, ponds and lakes across the landscape, some with high connectivity to running waters and some isolated from them.

The precise physical character, hydraulics, hydrochemistry and nutrient status of freshwater habitats depends on the precise journey of water through the catchment and the detailed physiography of the land underlying the freshwater habitat. Catchments with permeable soils and geologies generate habitats fed mainly by groundwaters. Rivers in this situation tend to have more stable hydraulic regimes (less energy and more reliable water supply) whilst groundwater-fed lakes can, but do not necessarily, exhibit extremes in water level fluctuations; this can be seen in the Breckland meres which periodically naturally completely dry out. In contrast, catchments with impermeable soils and geologies generate ‘flashy’ rivers with longer intermittent headwater stream sections – these are most energetic in upland areas where the topography of the catchment is more extreme. Either scenario can lead to base-rich or base-poor water chemistry, depending on the character of the catchment soils and rocks.

The distribution of different types of river, lake and pond reflects the geology of the catchment in which they are found. In a natural system there should be a strong correlation between the alkalinity and nutrient status of the freshwater habitat. 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. Whilst oligotrophic water bodies are predominantly associated with less productive upland catchments there are exceptions and oligotrophic water bodies can be found in the lowlands on sandy plains. In contrast naturally eutrophic rivers and lakes can predominantly be found in the lowlands.

There are no naturally deep eutrophic lakes in England although some have been artificially created. Dystrophic lakes and pools can be found on upland blanket bogs, raised bogs and basin mires. They can also be created by the encroachment of schwingmoor on eutrophic lakes isolating the lake from the groundwater. Brackish running and standing waters are characteristic around the coast, but also occur naturally inland in some locations where salt deposits influence surface water conditions (e.g. around Cheshire).

Human modifications of the landscape have had a dramatic effect on the occurrence of some types of freshwater habitat, but for other types the main human influence has been degradation of habitat condition. Smaller natural habitats such as runnels and pools have been drained from the landscape on a widespread basis, along with the mires, springs and flushes that sustained them.

Some small water bodies such as ponds would not necessarily have been long-lived due to successional processes, but would have constantly been present at a landscape scale due to natural processes creating new ponds. 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 or in low points of floodplains. Pools would also be common in flushes and bogs. Therefore, the continued presence of natural ponds requires the existence of these natural processes and naturally functioning wetlands or an equivalent (Williams *et al*., 2000).

Streams, rivers and larger natural lakes are a more permanent consequence of the passage of water through catchments, but they have been subject to a wide range of direct and indirect impacts that simplify physical habitat provision, alter hydrology and degrade water quality.

Drainage and water manipulation have artificially created freshwater habitats in the landscape at the expense of natural freshwater habitats. In both the uplands and lowlands, impoundments of stream and river systems have created reservoirs and small lakes and ponds that mimic natural on-line lakes but eliminate and disconnect headwater stream networks. In the lowlands, ditch systems act as refuges for many freshwater and wetland species displaced from natural wetland habitat mosaics by the land drainage schemes that created the ditches. In more hilly landscapes (including the uplands), drainage can effectively artificially extend the upstream limit of headwater streams into the degraded mire habitat, and can even appear to be natural in origin. In some cases gravel pits have created new opportunities for freshwater species displaced by drainage, although the biodiversity interest is generally limited compared to natural habitats. The smaller running and standing water habitats that were naturally provided in valley mires, blanket bogs and natural floodplains (with their associated valleyside spring lines) have been replaced by a range of artificial habitats that lack the complexity (and often the water quality) to support the characteristic assemblages of natural freshwater habitats.

In the absence of naturally created ponds and pools, artificially created examples can support comparable biodiversity, but it is important both for their own functioning and the functioning of the landscape in which they sit that they do not adversely affect the natural hydrology of the landscape. Small water bodies created by artificially impounding streams damage the stream habitat, and often receive elevated nutrient and sediment loads so that water quality is poor and succession can be accelerated. Succession in ponds is only a problem where natural landscape processes are not creating new small water bodies and consequently on-going management of existing ponds or creation of new ones is required in these situations.

B3. Ecological function and relationships

Abiotic processes shaped by climate and catchment provide a natural template for freshwater habitats. They create complex and dynamic open water habitat mosaics, intimately associated with wetland habitats that both sustain them and rely on them.

Rivers and streams carve out their own physical character through sediment erosion and deposition, creating sinuous channels with high levels of variation in bed sediments, water depth, current velocities and bankslopes (Figure B1). Riparian trees interact with these processes to enhance the habitat mosaic, accentuating channel sinuosity and providing patterns of light and shade, exposed tree root systems, scour pools, debris dams and leaf litter. High energy river sections constantly rework their physical character, creating an unstable bed and large exposed gravel shoals. Lower energy rivers develop luxuriant submerged and emergent vegetation, progressively encroaching into the river channel and forming a critical component of the habitat mosaic. Natural variations in water chemistry generated by catchment geology further increase the habitat heterogeneity at various spatial scales.

Figure B1. Some components of the river habitat mosaic

Lakes receive all that the catchment delivers to them and can accumulate a lot of it. However, whether this is added to the sediment, cycled within a lake or passed on downstream depends on the quantities delivered and flushing rate and depth of the lake. Consequently the functioning of the catchment in terms of hydrology, nutrients and soil and sediment is imperative to the functioning of the lake. Vegetation within a lake will help buffer a lake from nutrient related impacts, so the vegetation needs to be protected, but its capacity to do this is far from limitless. The local hydrology, soil and nutrient functioning will also affect pond functioning, but the much greater edge-to-surface area ratio means that the nature of the surrounding vegetation also plays a greater role in determining the nature of the pond with different biological assemblages being found in wooded and open ponds.

Individual species, and life stages of species, are distributed according to the traits and behaviours; they have evolved to exploit particular niches in the habitat mosaics provided by naturally functioning freshwater systems. They move around as environmental conditions change (e.g. through a flood event, through the seasons) to maintain optimal conditions for their survival and fulfil their life cycle requirements within the habitat mosaic; sometimes moving over short distances (e.g. to avoid temporarily high river flows) and sometimes much longer (e.g. to migrate from or to the sea to reproduce).

In addition to the natural habitat template, characteristic freshwater assemblages are reliant on natural levels of connectivity within freshwater systems for their full expression. Short- and long-distance movements within the habitat mosaic require a lack of artificial obstructions such as weirs and dams, whilst natural discontinuities such as waterfalls and catchment watersheds shape important genetic and assemblage variation (e.g. genetically unique fish populations, or naturally fishless assemblages where invertebrates become top predators).

Large-scale variation in river systems creates biological zonation, in which different parts of the river system support different assemblages, but with considerable ecological interaction. Headwaters provide unique habitat opportunities for a variety of species, but they also provide natural food sources to reaches downstream. Equally, headwaters provide spawning and nursery conditions for species living further downstream, constantly generating new colonists to repopulate downstream areas. Looking from downstream to upstream, free movement through tidally influenced river reaches is critical to the full expression of the characteristic fish assemblage, in terms of both long-distance migrators such as eel and salmon and short-distance migrators from the estuary such as flounder, mullet and bass.

Non-native species generate major disruption of characteristic biological assemblages, either directly through impacts on foodwebs or indirectly through alteration of the abiotic habitat. Some non-native species, such as signal crayfish, cause disruption by both mechanisms, reaching very high densities in running and standing waters, degrading marginal and bankside habitat with heavy burrowing activity, and skewing the composition of the biological community by exerting huge predatory pressure on certain species (e.g. soft-bodies invertebrates).

Freshwater habitats sit in and run through a range of other habitat types (bogs, fens, woodlands, grasslands, heathlands etc.), providing a critical component of the broader habitat mosaic. This integration of freshwater and terrestrial habitats is critical for a wide range of freshwater and terrestrial species: for cover, juvenile development and adult feeding. Natural hydrological pathways through the landscape provide the template for this broader freshwater and terrestrial habitat mosaic, generating transitions between dry, wet and fully aquatic habitats in patterns that characteristic assemblages have evolved to exploit.

B4. Current levels of natural function

Drainage and other forms of water manipulation have eliminated small natural running and standing water habitats (runnels and pools) from much of the landscape along with their broader wetland habitat mosaics (flushes and mires). Larger natural freshwater habitats remain but the transitions between terrestrial and aquatic habitats have become more defined, squeezing out marginal wetland zones. Remaining natural freshwater habitats have been degraded to varying extents by a range of direct and indirect pressures, including diffuse and point source pollution, abstraction and water diversions, impoundment and engineering works (e.g. river channelization and bank stabilisation).

All of this can be thought of in terms of sucking water out of catchments, reducing water retention capacity and speeding the passage of water to the coast. These hydrological changes in catchments not only affect freshwater assemblages, but also create major water management challenges associated with water resource availability, water quality for human uses, and flood management.

Associated with these catchment changes, artificial freshwater habitats have been created (ditch systems, farm and urban ponds, gravel pits, reservoirs), which now provide refuge for many of the species that have been lost from their natural habitat niches. Many of these artificial refuges occur at the lower end of catchments and in the coastal plain where flood defences and drainage schemes have created extensive freshwater ditch systems.

Before presenting an expert judgement of the habitat resource in relation to natural function, it is necessary to explain how the five pillars of natural function outlined in Section 3 of the main report have been interpreted in respect of freshwater habitats. Note that the structure of natural function used in this report does not quite fit the way in which such function is typically portrayed in freshwater habitats (see Mainstone *et al*. 2016), because the structure has to be applicable to all habitats considered by this report. It does however suffice for the purposes of providing a more integrated evaluation of habitats in respect of natural function.

- ***Hydrology*** – this is interpreted as hydrological impacts from abstraction, land drainage and water impoundment and diversion.
- ***Nutrient status*** – for open freshwater habitats this is interpreted as the supply of phosphorus, nitrogen and carbon in the water, including the additional adverse effects of the additional productivity (which in shallow lakes can causes the production of large amounts of unconsolidated organic sediment). Also included here are other impacts on water quality such as acidification and toxic pollution, which are major issues in the freshwater environment.
- ***Soil/sediment processes*** – For freshwater habitats this is interpreted as impacts on the ability of freshwater habitats to shape their physical character through natural erosion and deposition mechanisms, including the physical habitat impact of land drainage and flood defence schemes and bank reinforcements. These processes are important for both rivers and lakes as they determine the diversity and naturalness of substrates and banks.
- ***Vegetation controls*** – this is interpreted as management of aquatic and waterside vegetation that has a detrimental effect on sustaining characteristic habitat mosaics formed by natural processes. This includes not only intensive grazing but also artificial cessation of any grazing, even at natural levels, due to fencing off freshwater margins. The dynamism of many freshwater habitats means that natural abiotic controls on vegetation are highly influential (e.g. seasonal cycles of hydraulic scour), although in smaller standing waters successional changes lead to loss of open water over time.
- ***Species composition*** – this is interpreted as effects on composition beyond those caused by impacts on the other four pillars above, relating to the impacts on non-native species or direct management intervention of species composition (e.g. fish stocking or fish removals).

Four tables are presented (B1 – B4), dividing freshwater habitats crudely into headwater streams, rivers, lakes and ponds. This portrayal hides a considerable amount of variation between river and lake types, which is partly described in the explanation below.

In each table, the whole habitat resource is considered, rather than the habitat resource defined by the priority habitat inventory. Rivers and lakes assigned as ‘priority habitat’ (under England’s biodiversity strategy) are associated with the highest levels of natural function, and represent a very limited subset of the total resource of rivers and lakes (see Mainstone *et al*. 2016, Mainstone *et al.* 2014, Hall *et al.* 2014).

Headwater streams (Table B1) are little monitored, generally being too small and numerous to feature significantly in Water Framework Directive monitoring or other national monitoring programmes. Natural function in headwater streams appears generally higher in the uplands, except in and around blanket bog and the immediate moorland fringe where gripping, burning and over-grazing by sheep degrades physical habitat and the legacy of atmospheric acid deposition remains in some areas. Headwater streams in more lowland areas have been affected by agricultural drainage on a widespread basis, but pockets of highly naturally functioning stream habitat remain, often associated with ancient woodland, or mire, grasslands and heathland which have not been subjected to drainage and water level management (and where riparian trees have been retained).

Groundwater abstraction can affect the hydrology of whole headwater stream networks in a locality, whereas surface abstraction from headwater streams is highly localised and difficult to judge at the habitat resource level. Intensive management of riparian zones is very widespread, often leaving no semi-natural riparian zone of vegetation. Close bankside fencing is often introduced to prevent livestock damage to stream banks and bed, but this typically leaves the riparian zone on the wrong side of the fence and can generate continuous cover of tall ruderal vegetation on the streamside (particularly in artificially enriched situations). Non-native species impacts are generally lower in headwater streams relative to larger rivers, because of their remoteness and relatively low natural accessibility. However, this is partly because many non-native species have not yet had sufficient time to reach the more remote parts of the stream network, rather than the presence of fixed natural barriers to their colonisation.

Table B1. Indicative levels of natural function in the headwater stream resource.

State of naturalness	Prevalence of state within the habitat resource				
	Hydrology	**Nutrients**	**Soil/sediment**	**Vegetation control**	**Species composition**
Good	Moderate	Low	Moderate	Low	Moderate
Intermediate	Moderate	Moderate	Moderate	Moderate	Moderate
Poor	Moderate	Moderate	Moderate	Moderate	Low
Confidence	*Low*	*Low*	*Low*	*Low*	*Low*
Comments	*Often affected by groundwater abstractions. Information on stream flows is sparse.*	*Point and diffuse pollution. Very little data available on streams.*	*Many headwater streams have been ditched to drain the land. Very limited data on physical naturalness*	*Intensive land use up to the bank top is commonplace. Extensive stream length lacking riparian trees and where woody material is removed from the channel. Very little data for the stream resource.*	*Headwater streams are more remote and more difficult for non-native species to reach. May just be a matter of time however. Worsening problem with new species arriving from Europe*

Rivers (Table B2, i.e. everything except headwater streams) are more uniformly damaged by both catchment and in-river activities, with the nature and extent of impacts largely reflecting the nature of the catchment and the position of reaches within the catchment. The chances of a river escaping major impacts on natural function generally reduces downstream, as the size of the catchment increases and the likelihood of the presence of significant damaging activities within it increases as a result. Water quality and hydrological impacts tend to accrue downstream, whereas physical habitat impacts associated with direct river management are patchily distributed as the river passes through different intensities of land use. Both energetic and lower energy river sections have been extensively engineered: straightened, deepened, widened, reprofiled and controlled with in-channel structures (Environment Agency 2010). Non-native species are generally more widespread than in headwaters, with catchment watersheds presenting the largest natural barrier to further colonisation.

Table B2. Indicative levels of natural function in the river resource (i.e. excluding headwaters).

State of naturalness	Prevalence of state within the habitat resource				
	Hydrology	**Nutrients**	**Soil/sediment**	**Vegetation control**	**Species composition**
Good	Low	Low	Low	Low	Low
Intermediate	Moderate	Moderate	Moderate	High	High
Poor	Low	High	Moderate	High	Moderate
Confidence	*Moderate*	*Moderate*	*Low*	*Low*	*Low*
Comments	*From abstractions, impoundments and water diversions. There is a relatively good information on the impacts on natural flow regimes for rivers*	*Point and diffuse pollution. There is relatively good information on the impacts on nutrient status and other common pollution types for rivers*	*Physical modifications and fine sediment inputs from enhanced soil erosion are considerable in many parts of England.*	*Intensive land use up to the bank top is commonplace. Extensive river length lacking riparian trees and where woody material is removed from the channel. Data are patchy*	*Larger rivers are generally easy for non-native species to colonise. Worsening problem with new species arriving from Europe*

For both lakes (Table B3) and ponds (Table B4) nutrient enrichment is the overriding impact on the current resource, although a greater proportion of naturally eutrophic water bodies are affected than naturally oligotrophic ones. Sediment loads from the catchment contribute to the nutrient concentration in a water body and high nutrient loads lead to greater productivity, which leads to increased quantities of dead organic matter being added to the sediment. This creates loose sediments, which are easily resuspended in the water column. Even when not resuspended nutrient-rich sediment may continue to release nutrients back to the water column for many years after the nutrient enrichment has stopped. Resuspension of sediments is exacerbated by the feeding behaviour of benthivorous fish such as carp (an invasive non-native species introduced to many of England's standing waters). Fish assemblages dominated by benthivorous fish are particularly likely to occur in nutrient enriched conditions. Nutrient enrichment can also be exacerbated by hydrological modifications which help drain the land and accelerate the delivery of nutrients and sediments to a water body. This illustrates how the lack of natural ecosystem functioning interacts across the five pillars to the detriment of standing water habitat.

In some areas where eutrophication has resulted in a loss of biodiversity from larger standing waters, some species have been maintained in smaller water bodies such as ditches. In some cases this is due to them being relatively hydrologically isolated from nutrient sources - some of the ditches with the better water quality are groundwater-fed. Additionally they fare better because the vegetation and/or sediment is regularly removed, removing a proportion of the nutrients with it, although even with regular maintenance ditches cannot survive excessive nutrient enrichment and too much maintenance can equally be detrimental. Ditch habitat would be lost to succession if maintenance halted all together, thus making sympathetic maintenance of the ditches a continued requirement if species are to continue to be supported in this way at a local level. Species which currently have their strongholds in ditches would naturally be found in other small lowland water bodies if good quality examples had not been lost from the environment.

It is estimated that pond numbers in England and Wales decreased by around three quarters during the 20th Century from a maximum of about 800,000 to around 200,000 by the 1980s (Rackham 1986, Barr *et al.* 1994, Biggs *et al.* 2005). There is evidence that since the 1980's this trend has been reversed, with CS 2007 estimating a net increase of approximately 33,400 ponds between 1998 and 2007 as pond creation exceeded pond losses. This illustrates the additional threats of infilling and drainage to small water bodies which is not fully captured in the Table B3, (since once lost they are no longer part of the pond resource). We currently rely heavily on artificial pond creation or maintenance (resisting succession) to continue to have ponds in the landscape, because natural pond-creating processes have been lost in most English landscapes. However it is of note that the natural life-span of a pond (i.e. in the absence of vegetation control) is not necessarily very short –

nutrient enrichment tends to accelerate vegetation succession and reduce the natural lifespan of a pond.

Table B3. Indicative levels of natural function in the pond resource.

State of naturalness	Prevalence of state within the habitat resource				
	Hydrology	Nutrients	Soil/sediment	Vegetation control	Species composition
Good	Low	Low	Low	Low	Low
Intermediate	Moderate	Moderate	Moderate	High	High
Poor	Low	High	High	Low	Low
Confidence	*Low*	*Moderate*	*Low*	*Low*	*Low*
Comments	*There is little information available but water control structures on outflows and attached drainage ditches are common. Drainage also leads to the loss of ponds*	*Water pollution in the form of acidification is included along with nutrient enrichment.*	*Soil erosion adds to the nutrient problems and due to historically high nutrient loads lake sediments release nutrients. Infilling and over deepening have also reduced the number and quality of ponds.*	*In the absence of recreational use little aquatic vegetation control is undertaken, however many ponds do not have natural riparian vegetation.*	*Most in state of intermediate naturalness due to not many sites having lots of INNS, but many sites do have some e.g. carp or New Zealand pygmyweed.*

Table B4. Indicative levels of natural function in the lake resource.

State of naturalness	Prevalence of state within the habitat resource				
	Hydrology	Nutrients	Soil/sediment	Vegetation control	Species composition
Good	Moderate	Low	Low	Low	Low
Intermediate	Moderate	Moderate	Moderate	High	High
Poor	Low	High	High	Low	Low
Confidence	*Low*	*Moderate*	*Low*	*Low*	*Low*
Comments	*There is little information available but water control structures on outflows and attached drainage ditches are common*	*Water pollution in the form of acidification is included along with nutrient enrichment.*	*Soil erosion adds to the nutrient problems and due to historically high nutrient loads lake sediments release nutrients*	*In the absence of recreational use little aquatic vegetation control is undertaken (although the rise in use of dye is worth being aware of), however few lakes have natural riparian vegetation.*	*Most in state of moderate naturalness due to not many sites having lots of INNS, but many sites do have some e.g. carp or New Zealand pygmyweed.*

B5. Scope for restoration of natural function

There are many constraints to restoring more natural function in freshwater habitats. Some are immovable, associated with the location of cities, towns and villages and costly major infrastructure. Some are relatively simple to resolve and have little effect on existing human activities (e.g. such as the removal of historical in-channel structures that have no contemporary use). In between there are various constraints that are potentially amenable to addressing if the right solutions can be agreed for implementation over workable timescales. Some of these constraints can be other wetland and terrestrial habitats that have developed as a result of water management activities (e.g. land drainage, water level management) that have caused the loss of natural function, and where refuge is provided for some of the species that inhabited the original naturally functioning habitat mosaic.

There are often no quick fixes, and long-term strategic thinking is needed to conceive solutions. But where the opportunities exist the biodiversity benefits (to freshwater and wetland habitats and species) are considerable, and improved ecosystem services can be generated in terms of water resource management and flood risk management.

What can be realised in practice is highly site-specific, and varies between different types of landscape. Restoration in headwater catchments directly affects relatively little land and has benefits for all downstream freshwater habitat, as well as downstream water management. Larger floodplains present greater socio-economic challenges but at least some aspects of natural function can be restored, particularly in those areas with relatively little human development. Restoration of valleyside springlines, to restore runnels, streams and pools amongst restored fen, marsh and wet grassland, has great potential even where restoring natural main river function (river movement, river-floodplain interaction) is difficult.

The consequences of restoring more natural function for existing biodiversity need proper local evaluation, particularly in relation to the consequences for artificial refuges for freshwater biodiversity and also wetland and terrestrial habitat and species that may be affected. An understanding is needed of how habitat provision is likely to change and what that means for species that currently use the landscape (see Section B6). If properly planned, some existing habitat may be lost but replaced with better habitat mosaics with greater habitat opportunities which a wider range of species characteristic of natural ecosystem function can colonise. The implications for human uses of the landscape also need to be evaluated, in relation to landscape, built heritage and land use and management.

The freshwater and wetland habitat narrative (Mainstone *et al*. 2016) lays out principles by which local strategic plans can be developed. This narrative does not attempt to prescribe local outcomes since they will depend on specific local constraints. The most important issue is basing decisions on an understanding of the natural habitat template for the local landscape, and layering practical constraints on top of this.

Taking into account the explanation above, Tables B5 to B8 provide a crude indication of the desirability and scope for restoration of the key elements of natural function. Generally, elements of natural function need to be addressed in tandem to achieve good biodiversity outcomes. Restoring more natural hydrology requires reasonable levels of water quality to realise biodiversity benefits, whilst alleviating physical constraints to natural river function is most beneficial to characteristic biota when accompanied by restoration of natural flow regimes. Restoring virtually any aspect of natural lake function requires at least a reasonable level of water quality to generate biological benefits and there can be considerable lag-time between water quality improvements and biological response.

One key issue is the potential for restoration of natural function to change the relative contributions of groundwater and surface water to existing freshwater and wetland habitats, particularly as a result of increased inundation from a river or the sea. This can profoundly change conditions (nutrient status, salinity) in existing habitats; unless pre-restoration conditions persist somewhere within restored naturally functioning habitat mosaics, or are recreated elsewhere in the landscape, then the viability of some species within the locality will be put at risk.

Table B5. Desirability and scope for restoring more natural function in the headwater stream resource.

	Hydrology	Nutrients	Soil/sediment	Vegetation control	Species composition
Desirability	Yes	Yes	Yes	Yes	Yes
Comments	Needed to restore natural ephemeral and perennial streams and the transitions between them, as well as associated springs, flushes and mires	Needed to restore naturally functioning foodwebs, including species adapted to processing leaf litter and low nutrient availability generally.	Needed to restore full characteristic diversity of in-channel and riparian habitat mosaics	Restoring at least patchy riparian tree cover and a supply of woody material to the channel is much needed, as is a reduction in the intensity of management in riparian corridors.	Needed to restore natural species assemblages.
Biodiversity synergies/ conflicts	Strong synergies with restoration of mire and other wetland habitats. The headwater resource is extensive with large numbers of individual hydrological units so scope is high.	Natural nutrient levels are generally a shared conservation goal across all habitats and species	May cause channel movement and affect neighbouring grassland or heathland habitat	May generate additional shading of neighbouring open habitats of high conservation value.	No biodiversity conflicts. Availability of control techniques is very poor. Generally need to be species-specific.

Table B6. Desirability and scope for restoring more natural function in the river resource (i.e. excluding headwaters).

	Hydrology	Nutrients	Soil/sediment	Vegetation control	Species composition
Desirability	Yes	Yes	Yes	Yes	Yes
Comments	Natural river flow regimes restore the extent and character of in-channel and riparian habitat mosaics.	Needed to restore naturally functioning foodwebs, including species adapted to processing leaf litter and low nutrient availability generally.	Needed to restore full characteristic diversity of in-channel and riparian habitat mosaics	Restoring at least patchy riparian tree cover and a supply of woody material to the channel is much needed, as is a reduction in the intensity of management in riparian corridors.	Needed to restore natural species assemblages.
Biodiversity synergies/ conflicts	No significant biodiversity conflicts	Natural nutrient levels are generally a shared conservation goal across all habitats and species	May cause channel movement and affect neighbouring grassland or heathland habitat	May generate additional shading of neighbouring open habitats of high conservation value.	No biodiversity conflicts. Availability of control techniques is very poor. Generally need to be species-specific.

Table B7. Desirability and scope for restoring more natural function in the pond resource.

	Hydrology	Nutrients	Soil/sediment	Vegetation control	Species composition
Desirability	Yes	Yes	Yes	Sometimes	Yes
Comments	Will benefit the nutrient issues, create habitat heterogeneity and is important for the landscape scale approach	Biggest issue for standing waters	Is in part a consequence of and a contributor to the problems associated with nutrients	Restoring, creating or maintaining a range of ponds to include wooded and open ponds with vegetated and bare mud edges will require a range of vegetation control. Maintaining ponds in agricultural settings is more likely to involve vegetation control.	Some invasive aquatic species have profound ecosystem changing impacts e.g. carp, and New Zealand pygmyweed and therefore these are the species most in need of control.
Biodiversity synergies/ conflicts	Restoring natural hydrology may result in the loss of some standing waters, so restoration/creation of alternative habitat may be required as a precursor.	Generally beneficial	Generally beneficial	Some control of riparian vegetation may be required to maintain a diversity of shorelines and prevent losses due to succession in some cases, especially where new ponds cannot be created.	Generally beneficial, but needs to be species-specific

Table B8. Desirability and scope for restoring more natural function in the lake resource.

	Hydrology	Nutrients	Soil/sediment	Vegetation control	Species composition
Desirability	Yes	Yes	Yes	Sometimes	Yes
Comments	Will benefit the nutrient issues, create habitat heterogeneity and is important for the landscape scale approach	Biggest issue for standing waters	Is a consequence of and is part of the problem associated with nutrients	Whilst control of in lake vegetation is not desirable, it can be for the riparian habitat	Some invasive aquatic species have profound ecosystem changing impacts e.g. carp and therefore these are the species most in need of control.
Biodiversity synergies/ conflicts	Restoring natural hydrology may result in the loss of some standing waters, so restoration/creation of alternative habitat may be required as a precursor.	Generally beneficial	Generally beneficial	Some vegetation control of riparian vegetation may be required to maintain a diversity of shorelines	Generally beneficial, but should be species-specific.

B6. Provision of habitat for particular species

B6.1 General

Freshwaters in England support a considerable number of rare and threatened species. An analysis of the requirements of 'priority species' in England (listed under Section 41 of the CROW Act) has confirmed that the ecological needs of those species associated with freshwater habitats are satisfied by the conditions that are provided by natural ecosystem function: unpolluted water, natural hydrological regime and natural physical habitat form and function (Webb *et al*. 2010). Together with variation in biotic vegetation controls (grazing pressure etc.) this creates a dynamically diverse mosaic of micro- and meso-habitats for characteristic assemblages to exploit. The big question is to what extent can natural ecosystem function be restored in the open freshwater habitat resource in ways that restore our full species complement without causing unintended adverse consequences for remaining populations of rare and threatened species?

The link between natural function and species composition in freshwater habitats is very strong. Negative impacts on natural function, mainly eutrophication, engineering and hydrological modifications, will inhibit species richness and may lead to local extinction. Modified freshwater habitats do provide niches that support species that would not otherwise be there. A good example is weirs on lowland rivers that often support waterfall species that are normally more characteristic of upland streams. Although restoring natural function would lead to the loss of these habitats and the species they support in those specific locations, the overall benefits to the characteristic biological assemblage are very large. Species losing artificial habitat niches are catered for within the restored habitat mosaic unless they are completely uncharacteristic of the naturally functioning habitat. If they are uncharacteristic then they are not part of the flora and fauna we should be seeking to conserve in that location, although there may be a conservation case for *ex situ* protection if they are greatly threatened within their natural range.

Species occur where their requirement for resources and conditions are met. Some man-made artificial habitats will meet these requirements and can be considered analogies for natural habitat. Examples include gravel pits, which often support species associated with exposed riverine sediments, and; ditches in coastal marshes, which are analogous with the elements of original brackish wetland that would have once been present. These artificial habitats may support some species of conservation interest, often at population levels higher than would exist in naturally functioning habitat mosaics, but they are not as species-rich or often as ecologically resilient as the natural habitat they imitate.

B6.2 Invertebrates

A large number of the invertebrate species on the Section 41 priority species list are associated with open freshwater habitats and related wetlands (See Webb *et al.* 2010 for more detail). The Pantheon database provides details of the habitat preferences of over 2,800 invertebrate species associated with all types of freshwater wetlands (See Box B1).

High energy rivers with natural function create large banks of exposed riverine sediments (ERS). This can consist of boulders, shingle and finer sand and are home for a great many beetles and flies, such as the very rare ground beetle, *Bembidion testaceum*. These specialist species are dependent on high energy rivers that scour vegetation from its banks in the winter. Species will disappear if the flow regime or sediment supply is reduced, or the river is canalised, or coarse sediments are removed by dredging. Conversely restoration of natural function restores the habitats they need.

The upper reaches of streams have a specialist fauna associated with splash zones, plunge pools, stream riffles and other biotopes, all part of the dynamic habitat mosaic created by natural riverine processes. A good example is the waterfall beetle, *Dianous coerulescens*, which clings to mosses in cascades and uses its harpoon-shaped tongue to spear insects. Riparian trees are an extremely important part of the stream habitat mosaic, which they actively help to shape, but they are particularly important for certain invertebrate species that use fallen wood as a substrate to live in and on – e.g. caseless caddis fly larvae of the genus *Lype* only build their homes (galleries) on submerged rotting wood.

There is considerable invertebrate interest in large, slow flowing rivers associated with submerged or emergent vegetation, or exposed soft sediment such as silt. When functioning naturally (flow regime, lack of physical river modifications) the habitats on these slower rivers tend to merge with floodplain marshland and ponds, creating a matrix of wetland alongside the river. The infrequent patches of riffle habitat in these large lowland river sections are the only places where certain invertebrate species will thrive, for instance the critically endangered and possibly extinct stonefly *Isogenus nubecula*. These riffles have largely been removed from such river sections for land drainage and flood defence purposes, or smothered by silt and deep water as a result of water level control.

In ponds and lakes, water chemistry and nutrient loading play a huge role in the number and type of species present. The latter will often increase invertebrate biomass but hugely decreases the biodiversity. Vegetation also influences invertebrate assemblages, not only in providing habitat for terrestrial life stages of aquatic species and lifelong habitat for wetland species, but also because it influences water temperatures and substrate and provides habitat and a food source when material of riparian origin falls into the water.

Species of freshwater ponds vary considerably in their ecological preferences, reflecting the wide range of environmental conditions found in ponds. Ponds can occur in peatlands, along river valleys, as temporary water bodies and as man-made pools. Lake-side species tend to be associated either with wave-washed edges (where hydrological disturbance is high) or with emergent vegetation (where water levels are more stable); the latter tends to have a similar fauna to many smaller ponds. It should be noted that many wetland species can live along pond edges, requiring drawdown zones and/or peripheral vegetation. Consequently natural hydrological regimes are very important for determining invertebrate biodiversity.

Box B1. Using the Pantheon database to characterise the invertebrate importance of open freshwater habitats including their margins.

Pantheon (http://www.brc.ac.uk/pantheon/) is an analytical tool developed by Natural England and the Centre for Ecology & Hydrology to assist invertebrate nature conservation in England.

Running waters

Pantheon describes 895 invertebrate species as being associated with running water. These habitats range from seepages and trickles through to streams and large rivers. Species range from fully aquatic invertebrates, those aquatic for part of their life cycle and terrestrial species leaving along the edges of rivers and streams in the riparian zone.

- 226 species are associated with Exposed Riverine Sediments (ERS). Many of these are not found in any other habitat.
- 211 species are associated with unmodified fast-flowing streams.
- 472 species are associated with muddy drawdown zones alongside both rivers and in floodplain marsh.

Standing waters

Pantheon recognises:

- 89 species associated with lakes and 676 associated with freshwater ponds.
- 374 species associated with freshwater ponds in peatlands, where water levels are stable and hydrological disturbance in minimal, and 386 species associated with marshland. This latter grouping tend to occur in floodplains where water levels are very variable and peat does not form.

It is difficult to put an exact number on species utilising pond edges but a significant number of the 2795 Pantheon wetland species will fit into this category.

B6.3 Fish

Fish assemblages are strongly zonated in rivers and streams according to natural catchment and river characteristics. Headwaters and strongly flowing streams tend to be dominated by species such as bullhead and juvenile salmon and trout, with rivers of moderate flows dominated by fastwater cyprinids such as chub and dace, and sluggish lowland river reaches dominated by lake species such as bream, roach and perch. Tidal river sections are extremely important for a range of estuarine and coastal species such as mullet, flounder, smelt, and allis and twaite shad. Superimposed on this zonation are long-distance migratory species such as eel, river and sea lamprey, salmon and sea trout, which move through river systems according to season and life stage.

Habitat simplification from channel engineering, pollution and abstraction have had major impacts on fish assemblages. Weirs have restricted access to spawning and nursery grounds and drowned out and silted up essential micro-habitat, creating major impacts on long distance migratory species. Restoration of natural function is vital for characteristic river fish assemblages including the many priority species. Restoration of natural geomorphorlogical function will often benefit juvenile life stages the most, as weirs are removed and channel profiles are restored to their shallower natural character. This will help restore self-sustaining fish populations.

Fish assemblages of lakes can be broadly divided into those of cold oligotrophic lakes characterised by species such as brown trout, arctic charr, vendace and schelly, and those of warmer eutrophic lakes with a greater species diversity including cyprinids, Some species are sufficiently adaptable to span both types of lake, particularly the predatory pike and perch. Both types of assemblage are highly sensitive to nutrient enrichment, and can be affected by artificial drawdown of water levels. A number of species require free connectivity to river systems to complete their lifecycles. Littoral habitat is particularly important for spawning, whether the requirement is for wave-washed coarse substrates or well vegetated margins. The introduction of non-native species, or locally non-native species (e.g. such as ruffe in Cumbria) has caused considerable impact on natural fish assemblages. Restoration of natural function, in terms of water quality, hydrological regimes, physical habitat condition and control of non-native species, is therefore highly important for lake fish assemblages.

B6.4 Higher plants

Most higher plant species exploiting open freshwater habitats are strongly associated with natural ecosystem functioning, distributed according to natural hydrological regimes, nutrient status, physical habitat form and an absence of invasive non-native plant species such as *Crassula helmsii*. However, many of these species also occur in artificial habitats such as reservoirs, gravel pits and ditch systems. This is particularly true of early successional species in both open water and marginal habitats.

Some species have become particularly associated with artificial habitats and are less commonly thought of in terms of their natural habitat niches. For instance, the fine-leaved pondweed *Potamogeton compressus* is now largely confined to a small number of ditch systems, where regular ditch maintenance provides suitably disturbed open water conditions. Similarly, a range of declining annual species are associated with muddy, sparsely vegetated drawn-down zones around ponds and small lakes – so-called 'mud-annuals' including cut-grass *Leersia oryzoides,* starfruit *Damasonium alisma* and lesser water-plantain *Baldellia ranunculoides*. The original natural niches of these species included watering holes of native herbivores, habitats which have been superceded in agricultural landscape by ponds in pastureland. The decline in livestock in some areas has led to a cessation of grazing and consequent vegetation succession at sites, whilst in other areas intensification of livestock farming has created excessive disturbance, or complete segregation of livestock from freshwater habitats by fencing, or elimination of plants through herbicide applications. Restoration of the natural concentration of grazing pressure around some ponds can restore this natural habitat niche for these species.

In general terms, restoration of naturally functioning open freshwater and wetland habitat mosaics, including naturally patchiness of grazing pressure and associated disturbance, should provide abundant niches for declining higher plant species that are now more associated with artificial habitats. However, care will be needed to conserve remaining populations of these species for recolonization of restored habitat.

B6.5 Lower plants

Bryophytes occurring in freshwater habitats can be divided into obligate and facultative aquatics, namely those that are submerged for most of their life cycles and intolerant of exposure to air for long periods, and those that are able to tolerate considerable fluctuations in water levels, and are able to tolerate short or extended periods of dessication. As a general principle mosses tend to be more dessication-tolerant than liverworts.

Aquatic bryophytes can be classified as Limnophylous, rheophilous or semi-emergent aquatics (Porley & Hodgetts, 2005). Limnophylous bryophytes are typical of fens, marshes, mires, pools and ponds where the water is stagnant or slow-moving, and cannot tolerate dessication or fast currents. Examples include the moss *Scorpidium scorpioides* and the liverwort *Ricciocarpos natans*. Rheophilous bryophytes are characteristic of flowing water such as streams and rivers, and some species show adaptations to physical stress and periodic exposure. Examples include Greater Water-moss *Fontinalis antipyretica*, probably the best known aquatic bryophyte in Britain, and the liverwort *Nardia compressa*. Semi-emergent aquatic bryophytes are rarely completely submerged, and although their bases may be in water their growing shoots are exposed to the air. Examples include various *Sphagnum* and *Palustriella* (previously known as *Cratoneuron*) species, the latter being a critical element of the Habitats Directive Annex I habitat type of tufa-forming springs.

A total of 13 Section 41 bryophytes occur primarily in freshwater habitats. Six of these naturally occur in the margins and draw-down zones of ponds and lakes (the liverworts *Fossombronia foveolata* and *Riccia canaliculata*, and the mosses *Bryum cyclophyllum*, *Ephemerum cohaerens*, *Micromitrium tenerum* and *Physcomitrium eurystomum*), five occur on rocks beside streams and rivers (the mosses *Bryum gemmiparum*, *Fissidens serrulatus*, *Seligeria carniolica*, *Thamnobryum angustifolium* and *Thamnobryum cataractarum*), one occurs in very wet lowland calcareous fens (the liverwort *Leiocolea rutheana*), and one occurs in base-rich upland flushes (the moss *Splachnum vasculosum*).

The distribution of these Section 41 species and other bryophyte species are strongly driven by the natural function of the freshwater habitats they inhabit. However, some species will exploit modified or artificial habitats where they are suitable, and this includes the draw-down zone of artificial reservoirs and the faces of concrete weirs and brick or stone bank revetments. Restoring natural function to freshwater habitats is generally highly beneficial for restoring bryophyte assemblages, for instance the restoration of riparian woodland to headwater streams restores the humid zone vital for many semi-emergent species. However, in some cases a population of a vulnerable species may be threatened by restoration, typically where it is exploiting a niche created by habitat modification that would not naturally be present. In such cases proper evaluation and planning is needed to ensure that the right measures are taken to conserve the species within its natural range. In some cases it may become clear that the species involved would thrive in the restored natural habitat mosaic, but at lower levels of occurrence consistent with the natural availability of its habitat niche – all that may be required is an acceptance of the natural carrying capacity of the habitat.

B6.6 Birds

Of the bird species on the Section 41 list, Bewick’s Swan is the only species strictly associated with open waters, although many other priority species are dependent on wetland habitats on the fringes of open water (e.g. Bittern, Savi’s Warbler in reedbeds) or in headwaters (e.g. mires supporting Curlew). Internationally important numbers of waterbirds are associated with open water habitats, but the majority use artificial wetlands, derived from impoundment and mineral extraction.

In the case of still waters the general requirements for birds are extensive areas of open water free from disturbance and with abundant food supplies (fish, invertebrates and aquatic plants). Artificial habitats now support many species that previously exploited extensive wetlands, including temporary and permanent open water bodies in river floodplains and other low-lying areas. Although birds are less sensitive than other groups to changes in hydrology, nutrient status, water depth and substrate conditions, it is likely that in many cases the replacement habitats are less suitable than the earlier, natural habitats, being less extensive and often subject to rapidly fluctuating water levels (reservoirs), eutrophication and natural succession, and recreational activities such as angling, wind-surfing and sailing. Lack of connectivity of the artificial wetlands might also affect birds, for example if the movements of important prey species such as fish and amphibians are restricted.

A small number of bird species are strongly associated with rivers, including Dipper, Grey Wagtail, Goosander, Kingfisher and Sand Martin. Other more widespread and generalist wetland birds also use rivers for nesting and feeding, including Mute Swan and other wildfowl. Issues relevant to these species are eutrophication and other causes of poor water quality, which reduces invertebrate prey (e.g. Dipper), removal of aquatic plants for boat navigation, which reduces food availability for wildfowl species, and hard engineering works which reduce the availability of soft, eroding earth banks suitable for hole-nesting birds (Kingfisher and Sand Martin). Loss of bankside vegetation due to cutting or overgrazing by livestock can also reduce nesting habitat for a range of species.

Restoration of natural processes which results in a greater extent of open water and associated habitats (marginal vegetation, headwaters), and greater connectivity of habitats, is likely to benefit many bird species, including several of moderate to high conservation concern. More natural bank profiles (in contrast to rapidly shelving gravel pits) are likely to be beneficial, especially to dabbling and wading species requiring shallow areas of water. Restoration of naturally functioning floodplains will benefit a great number of species. As well as providing a large expanse of open water in the winter, falling water levels during the spring and breeding season can provide abundant food for foraging waders in particular (e.g. curlew and lapwing). On rivers, reducing nitrogen inputs and other pollutants will benefit insectivorous species and promotion of more natural bank profiles and undisturbed bankside vegetation will benefit a range of nesting species.

The creation of more permanent floodplain habitats, such as fens and reedbeds, would be of great benefit to a wide range of scarce or declining wetland birds, some of very high conservation concern (Bittern, Spotted Crake, Crane, Savi's and Aquatic Warbler). A large proportion of reedbed habitat is located on the coast where its protection and maintenance is generally not consistent with a more sustainable approach to managing intertidal habitats. The creation of replacement habitats in more sustainable (naturally functioning) environments in fluvial floodplains is therefore an urgent priority.

B6.7 Mammals

Mammal species that are strongly associated with freshwater habitat include otter, beavers and water voles, although many other mammal species will use freshwater habitats for feeding, such as many bat species.

Otters can be found in a wide range of freshwater systems including rivers, streams, ditches, ponds and lakes. They can also be found in coastal systems, although otters in these areas they need a supply of freshwater to maintain their fur. Stable populations of otters are a strong indicator of habitats in favourable condition, given their requirement for unpolluted habitats which support a wide variety of prey species. In the early 1980's the otter was almost completely lost from England. The dramatic decline of the species was closely linked to the introduction of certain organochlorine pesticides – such as dieldrin, which was used in agricultural seed dressings and sheep dip. The impacts were greatest amongst apex predators due to bioaccumulation in the food chain. Once these products were removed from use the species gradually began to recover and is now present in every county in England. Restoration of natural riverine processes will benefit otters by providing both the habitat and prey which they require, including holt and laying-up sites and also high quality habitat for a range of prey items.

Watervoles generally prefer slow-flowing freshwater systems with widely vegetated riparian margins for food and shelter. They also prefer substrates which are easily penetrable i.e. earth and silt, to dig their burrows. Rocky or impenetrable substrates, over-shading from trees, fast flowing or shallow water and the presence of American mink are unlikely to attract water vole (Strachan *et al*., 2011). Water voles often live in linear habitats such as streams, rivers and ditch systems, though they can often be found in reedbeds and they occasionally occupy estuaries and saltmarshes where there are established reedbeds. They can be locally abundant in within highly modified river and drainage systems as these systems can offer the habitat they need. In the uplands, it appears that water voles occur as meta-populations, showing local extinctions and re-colonisations. These upland populations are often subdivided into colonies consisting of a small number of individuals and occasionally as few as a single male-female pair (Aars *et al*. 2001, Telfer *et al*. 2001, 2003). In these areas the local riparian habitat needs to be large enough to maintain a complete population and may cover the whole upper catchments of a river system (and possibly more than one river).

Restoration of more natural river function from highly modified systems would provide the habitat needed by watervoles within a more diverse habitat mosaic, but needs to be done carefully and in a staged manner to ensure persistence of existing populations throughout and after the works. It is acknowledged that populations of watervoles could be lower after restoration, but it is expected that the benefits to wider species assemblage overall would outweigh the impact of a reduction in numbers of watervoles. Greater connectivity of habitat that is able to support a much wider assemblage of species overall should ensure watervole populations are stable and in line with the carrying capacity of the natural ecosystem.

Beavers are believed to have gone extinct in Britain in the 16th Century. Wild beavers have been re-introduced under licence to Scotland in 2009 and England in 2015. The beaver is a keystone species that can aid the restoration of habitats back to natural function (Gurnell *et al*. 2009). Beavers provide a natural grazing pressure along river corridors and in wetlands, creating structurally diverse and patchy tree cover together with open areas of herbaceous vegetation. In certain circumstances (areas with lower water availability and water that is very shallow) they modify habitats by building woody debris dams and creating wetland networks which help restore river habitat complexity and wetland biodiversity, providing further ecosystem service benefits through improvements to water quality, water storage and flood risk. However, care is needed in the development of any populations given their considerable capacity to modify habitats and affect the socioeconomic capability of adjacent land. The benefits that can be achieved from their habitat restoration activities need to be balanced against any local adverse effects, and suitable population regulation and targeted removal strategies introduced as populations develop.

B6.8 Amphibians and reptiles

Amphibians and water-related reptiles are classic species of diverse freshwater, wetland and terrestrial habitat mosaics, spending large amounts of time in and out of open freshwater. Nearly all types of open freshwater habitat will be exploited some species, including ephemeral ponds and streams, sluggish areas of river systems, upland pools, permanent ponds and lakes, as long as acidity levels are not too high. The common frog *Rana temporaria* exploits a surprisingly large range of natural opportunities for spawning and juvenile development, including pools in intermittent headwater streams and the back–channels of high-energy upland rivers. For all amphibians, as well as the grass snake *Natrix natrix,* the close proximity of semi-natural wetland and mixed terrestrial vegetation to open freshwater is critical, providing a combination of sites for breeding, feeding, shelter and over-wintering.

The presence of fish in a waterbody is often considered to be detrimental for amphibian species, but in reality it is bad for some species and good for others. Some species are more vulnerable to fish predation and are suppressed or excluded, allowing other amphibian species to exploit the habitat. The common toad (*Bufo bufo*) is a major beneficiary of the presence of fish, and as a result fares better in larger and permanent waterbodies relative to the common frog.

Most species can live quite happily in artificial habitats, although species such as the natterjack toad (*Bufo calamita*) are more particular in their requirements and require more naturally functioning habitat mosaics - the impoverished open pools and ponds provided by dune slacks, sandy heaths and the upper parts of salt marsh. Individual waterbodies are less important to amphibian and reptile species than networks of adjacent waterbodies, because they occur in metapopulations where individual populations are connected by dispersing individuals. This maintains the genetic integrity of all the individual populations and generates recolonization in instances where a population is eliminated (which can happen for various reasons, natural or man-made). Metapopulations increase the ecological resilience of species, but can only exist in areas with multiple suitable habitats. Metapopulations are particularly important for great crested newt (*Triturus cristatus*).

Naturally functioning mosaics of water, wetland and terrestrial habitats, with diverse vegetation from open vegetation to scrub and woodland, provide the perfect landscape for amphibian and reptile metapopulations, particularly where a range of waterbody types occurs (ephemeral, permanent, small and large, with and without fish populations) to cater for the widest range of amphibian and reptile species possible.

B7. Key messages

- Improving natural function across all five key elements of natural function is the principal means by which freshwater habitats and their characteristic assemblages need to be restored, and is a critical activity for climate change adaptation in freshwater ecosystems.
- The needs of individual freshwater-related species (including priority species) are well-catered for by natural ecosystem function, as long as a dynamic and flexible perspective is taken of their habitat niches and an approach to population size based on natural environmental carrying capacity is taken.
- There are some potential conflicts with other habitats and their associated species (e.g. herb-rich floodplain meadows which may be cut through by natural river movement), but many of these are resolvable through a wider appreciation of the biodiversity importance of natural ecosystem function and a large-scale approach to habitat and species conservation.
- Some biodiversity conflicts will be difficult to resolve (e.g. where rare species are threatened and more naturally functioning niches cannot be restored), and these will act as a constraint to restoring natural freshwater habitat function.
- The highly interconnected relationship between open freshwater habitats and their catchments means that there are considerable socio-economic constraints that need to be considered when targeting action to restore natural function and in developing restoration plans.
- There are strong synergies between restoring natural ecosystem function and the objectives of the Water Framework Directive, as well as a range of critical ecosystem services (e.g. flood risk management, water supply etc.).

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