The River Avon at Ibsley, Hampshire

10. Rivers and streams

Climate Change Sensitivity: **High**

Introduction

Climate change is predicted to bring about a range of changes to environmental conditions in our rivers and streams, including shifts in thermal regimes, flow regimes and associated geomorphological processes, and chemical regimes. Some of these changes are already happening and are likely to intensify. The patterns and behaviours of the wildlife associated with our rivers and streams will change as a result. A range of measures are required to help our rivers and streams adapt to these changes.

If, as projected, we get milder winters and hotter summers, the changes in water temperature will impact on a wide range of river species adapted to cool water environments, including plants, invertebrates and fish. Species at particular risk include Atlantic salmon *Salmo salar* and the freshwater pearl mussel *Margaritifera margaritifera*.

A consistent pattern in climate change projections is for a decrease in mean summer rainfall, which is likely to increase the frequency and intensity of droughts. This will place riverine biota at greater risk from low flows, poor water quality, and reduced habitat space (area and depth). This could lead to increased competition and predation, thermal stress, siltation (due to reduced flushing), increased effluent pollution, and reduced dissolved oxygen levels in both sediments and overlying water. The species likely to suffer the most are those that are adapted to cool, fast-flowing waters and those that have poor powers of re-colonisation, such as those without aerial or drought-resistant life stages. Low flows could be exacerbated by increased abstraction during times of warm, dry weather.

Increases in flood magnitude and frequency will have both positive and negative effects. On one hand they could help rivers to reshape and restore themselves following historical physical modifications that have degraded riverine habitats. Conversely, local increases in flood risk to people and property may result in further conventional flood defence activity such as channelisation, dredging, embankments, and hard bank protection, involving further habitat damage. There is also the possibility that populations of some threatened species, such as freshwater pearl mussel, may be washed out by the scouring forces of extreme floods.

Projected increases in extreme rainfall events will increase the energy of catchment run-off, potentially generating enhanced loads of fine sediment and diffuse pollutants, particularly nutrients. Siltation and nutrient enrichment are key impacts on riverine biota, smothering coarse substrates and generating excessive growth of benthic and planktonic algae. This leads to declines in the many species dependent on clean, coarse sediments (e.g. salmonids and many benthic invertebrate species) and of species adapted to low nutrient and well-oxygenated conditions (e.g. freshwater pearl mussel, Atlantic salmon, and many stonefly species). Increased scour in rivers may partly offset increased pollutant loads by transporting pollutants downstream more effectively.

River systems are under threat from a wide range of non-native species, and some of these will have a larger potential range as a result of climatic warming across England. Many of these species originate from Eastern Europe and have already spread into western mainland Europe via a number of routes, most recently the Rhine-Danube canal, and some, such as the so-called 'killer shrimp' *Dikerogammarus villosus*, have recently made their way to the UK.

Habitat Description

This section provides a short summary of how rivers and stream habitats are shaped and how they function. A fuller description is provided in Mainstone *et al* (2016).

There is very wide variation in this broad habitat type, ranging from intermittent and perennial headwater streams to large rivers, and from cool, energetic upland conditions to warm, sluggish lowland examples. The nature of the catchment fundamentally affects the type of rivers and streams it supports. Catchments with more permeable geology generate rivers with high base flows and relatively low peak flows, whereas rivers with less permeable geology generate 'flashy' rivers with low natural base flows and high peak flows. Catchment geology also dictates water chemistry characteristics, from hard, alkaline water to soft, more acidic water. All of these environmental characteristics fundamentally affect the nature of the biota and the sensitivity of both the habitat and the biota to the different consequences of climate change.

At a more detailed level, rivers contain a wide range of biotopes, including riffles and pools, riparian vegetation, exposed sediments, submerged plants, and tree root systems. The availability of these biotopes within a complex mosaic shaped by the river is critical to sustaining characteristic biological communities, particularly in the face of climate change. Biotopes can also vary in their sensitivity to different aspects of climate change.

Rivers change along their length as they flow from source to sea, and these changes lead to broad longitudinal patterns of biological zonation. Within these broad patterns, organisms make a range of migrations, on short and long timescales and of varying distances, to fulfil their life cycle requirements and make best use of available habitat. Connectivity is extremely important to this zonation and associated biological movements - as climate changes, these zonation patterns may migrate upstream and downstream according to shifts in optimal environmental conditions for individual species. The only natural limits to biological movements, apart from occasional natural in-channel obstacles such as waterfalls, are watersheds.

River systems have been modified by man for centuries, through land drainage and flood defence activities, water impoundment, abstraction, diversion, effluent disposal, and energy generation. These modifications impair natural river ecosystem function and impact on the extent and quality of riverine habitats. They also affect the extent to which climate change is likely to damage river ecosystems further, and the scope for adaptation to climate change.

River size has a major influence on the effects of changes in river flow, with smaller rivers being disproportionately affected compared to larger rivers. For such reasons, headwaters might be considered particularly vulnerable to climate change. Groundwater-fed rivers with high base flows might be thought of as more hydrologically resilient to climate change than surface water fed rivers, owing to the scope for groundwater to dampen out short-term reductions in rainfall. This said, the characteristic biota of high base flow rivers will be less well adapted to fluctuations in flow regime, so there may be little difference in terms of broader ecological resilience.

The UK Biodiversity Action Plan (BAP) recognises a number of different river types as being of importance for biodiversity, including chalk rivers, active shingle rivers, and headwaters. However, owing to the continuous nature of habitat change in rivers, and the overlapping nature of different typologies, no attempt has been made in the current UK BAP definitions of priority habitats to separate out different priority river types. A broad priority habitat definition is used for rivers, based around the concept of naturalness. This approach is followed here.

Key ecosystem services associated with rivers and streams

Rivers and streams provide a range of vital ecosystem services, many of which could be affected by climate change. The most important are described below:

Regulating services

Water quality. Rivers and streams are subject to a range of pollutants, from both effluents and diffuse sources. Organic material (particularly from sewage) is broken down by natural microbial processes and released in the form of carbon dioxide and nutrients, which are subsequently taken up by aquatic plants. Particular toxins vary in the extent to which they can be broken down or transformed to harmless substances. Some are merely diluted and dispersed, or tied up in river bed sediments. Over-use of the assimilative capacity of rivers leads to damage to the biological community.

Land drainage and flood defence. Rivers and streams naturally drain catchments by conveying water downstream and ultimately out to sea. They are extensively modified (deepened, widened, straightened) to enhance land drainage and convey peak flows downstream in order to avoid flooding. This results in habitat degradation through simplifying the range of biotopes available, increasing hydraulic hostility, and reducing river length. Some modern forms of flood risk management aim to use natural river processes to promote flooding in suitable areas and thereby reduce flooding of downstream areas, particularly urban areas. In this way, peak flows can be selectively 'vented' by natural river/floodplain interactions, generating low-energy flooding at suitable points in the river network rather than high-energy flooding further downstream. Such flood-management approaches are compatible with the ecological restoration of river ecosystems.

Carbon sequestration. Rivers and streams are net sinks of carbon in their natural state. However, when carrying elevated levels of nutrients and organic pollution they can become net exporters. Methane export similar to some UK peatlands has been recorded for a chalk stream in southern England (Sanders *et al* 2007).

Cultural Services

Rivers and streams are valuable cultural assets, being a focal point in the landscape and providing widespread opportunities for recreation. Over use of some of these services can result in damage to river ecosystems. The highest levels of cultural services are provided by river ecosystems with high levels of natural ecosystem function and where use of the river is adequately managed.

Provisioning Services

Rivers are used to supply water for a range of human activities, including domestic, industrial, and agricultural use. Over-abstraction from rivers or the groundwater on which they depend can lead to ecological damage. Balancing the needs of the river ecosystem with society's needs for water will become more urgent in the face of climate change.

Potential climate change impacts

Cause	Consequence	Potential impacts
Hotter summers and milder winters	Increased annual average water temperatures	■ Declines in the abundance of cool-water species within current distribution and shifts in the distribution of species, including plants, invertebrates and fish. Evaluations of likely shifts in thermal regimes of upland streams have indicated that regimes in some rivers are likely to move out of the tolerance range of some characteristic species (Durance and Ormerod 2007). Within catchments, the climate space of many species is likely to migrate upstream in instances where cooler water exists (particularly where headwaters are at significant altitude), as long as upstream reaches are within the hydraulic and hydrological tolerances of each species. At a larger scale, where climate space shifts northwards and beyond the watersheds of individual catchments, species without aerial life stages (e.g. fish, molluscs, crustaceans) will find it difficult to migrate as their climate space shifts. Cool-water species such as Atlantic salmon are likely to decline in lowland river systems and populations may become unviable (Milner *et al* 2010). Shifts in species with aerial life stages, such as dragonflies are already being reported further north, sometimes by hundreds of kilometres. Differences in the mobility of species will lead to the changing of community composition and interactions between species. ■ Climate change-induced shifts in phenology will also become apparent, with consequences not only for the species involved but also for food webs, generating knock-on effects for higher trophic levels (e.g. invertebrate phenology affecting fish). In the Peak District, shifts between a two-year and a one-year life cycle of the mayfly *Ephemera danica* have been linked to temperature trends. Differences between trophic levels have been reported, with advances in timing slowest for secondary consumers (Thackeray *et al* 2010). ■ Some aquatic and riparian non-native species may become invasive, and other currently geographically restricted species may spread more easily.
Drier summers	Lower flows and drought	■ Prolonged low flows and associated temporary reductions in habitat extent and quality will lead to increased competition and predation, and unsuitable habitat conditions for cool water, current-loving species (Mainstone 2010). This will affect the passage of migratory fish, including Atlantic salmon. Headwaters are at particular risk of losing perennial habitat in favour of intermittent habitat due to the downstream migration of the perennial head of streams. The opposing effects of warming (forcing cool water species upstream) and reduced summer flows (forcing species downstream) are likely to act in concert to reduce the climate space of many species, and in some cases 'pinch' them out of catchments.
Wetter winters	Higher peak flows	■ This may have both positive and negative effects. Greater hydraulic energy will allow greater natural recovery of river habitat degraded by physical modifications (Mainstone & Holmes 2010). However, it may also lead to a surge of flood defence activity, creating more physical habitat degradation. It may also cause populations of priority species (e.g. freshwater pearl mussel) to be washed out of rivers, and a general downstream shift of species that are less well-adapted to high flows. ■ Increased connectivity in flooding events has the potential to spread invasive non-native species across habitats and water bodies.
Reduced total annual rainfall	Reduced total annual river flow	■ Reduced river flows and a general decline in hydraulic energy will result in a loss of habitat space and a consequent decline in populations of those species favouring faster currents. ■ Increased demand for abstraction could place river ecosystems under even greater stress.
Increased frequency of storms	Increased rainfall intensity and run-off energy	■ Enhanced erosion will lead to increased loads of fine sediment and nutrients, causing siltation and eutrophication.
Carbon reduction programmes	Hydroelectric power schemes	■ If adopted widely and inappropriately, these will reduce the scope for restoring the natural function of river ecosystems and hence reduce resilience to climate change.

Adaptation responses

Measures needed to help rivers and stream adapt to climate change are largely the same as those required to restore their health and integrity generally, through attention to natural ecosystem function. A summary of key measures is provided below – further information on restoring natural river ecosystem function is provided in Mainstone *et al* (2016). There is also the potential to lower water temperatures by providing shade from bankside vegetation and further is available from the Keeping Rivers Cool project (Woodland Trust 2016).

In the catchment

The main priority for adaptation within river catchments will usually be to promote land uses and land management practices that maximise natural rainfall retention within the catchment. This will help to reduce run-off energy and associated diffuse pollution. Allowing more water to be stored within the catchment will also help to reduce the extremes of peak flows and low flows. Other priorities will be slowing the spread of invasive species, and increasing the availability of cooler water by providing riparian shade.

Some of the potential adaptation options for this habitat are outlined below:

- Improve the natural infiltration of catchment soils and percolation to groundwater by restoring soil organic matter levels and avoiding soil compaction and capping.
- Create semi-natural vegetation such as woodland and grassland along critical run-off pathways to slow surface water run-off and aid infiltration of water into the soil.
- Restore natural function of headwater streams, including ephemeral and permanently flowing sections – the health of these streams is vital to the health of the river network and the resilience of catchments to climate change.
- Make sure that crops are appropriate to the erosion sensitivity of the land in order to minimise erosion and siltation of water courses.
- Minimise nutrient (nitrogen and phosphorus) applications to crops to the minimum necessary for healthy growth, based on methods with high uptake efficiencies.
- Use low-nutrient livestock feeds with high efficiencies of nutrient uptake.
- Block drainage where possible and consistent with local agricultural land management objectives.

In the river corridor and floodplain

Maintaining and restoring natural river processes constitute the most ecologically effective climate change adaptation measures for river ecosystems (Kernan *et al* 2012). Natural river processes provide the most characteristic and self-sustaining mosaic of river biotopes (Mainstone *et al* 2016), and provide the best environmental conditions for characteristic species to survive in a changing climate. The restoration of natural river features also has important wider benefits for flood risk management and landscape character.

Some of the potential adaptation options for this habitat are outlined below:

- Manage water demand, impoundment and abstraction to minimise impacts on the natural flow regime of rivers.
- Make use of high rainfall periods to store water (e.g. using small-scale winter storage reservoirs for agricultural irrigation) in order to minimise direct river abstraction during low-flow periods.

- Where consistent with managing flood risk to people and property, free river channels from constraints to natural movement and self-recovery of natural morphology and hydrology. This may involve the removal of weirs, flood banks and hard bank protection.
- Assist natural recovery of rivers by minimising maintenance of the river channel by dredging, weed clearance and the removal of woody debris. Large woody debris, in particular, is a critical part of river ecosystems that is often absent from English rivers.
- Where assisted natural recovery is not possible, actively restore river channels, banks and riparian areas, to create a more natural mosaic of characteristic biotopes. This may involve measures such as bed-raising, bank re-profiling, and riparian tree planting.
- As far as possible, avoid creating new constraints to natural river processes, including weirs, hard bank protection, flood banks and flow modifications (e.g. inter-basin transfers).
- Plan land use and management with river movement in mind. Develop long-term plans for managing the river channel within an 'erodible corridor', using set-back tree planting where necessary to constrain movement beyond this.
- Allocate greater areas of floodplain land to flood naturally, to minimise the build-up of peak flows to downstream urban areas.
- Plan biodiversity management in the floodplain with natural riverine processes and river restoration in mind. Develop a long-term vision for semi-natural habitat mosaics that takes account of river dynamics, and modify site designations and conservation objectives accordingly.
- In treeless river reaches, optimise riparian tree cover to provide patchy light and shade. This provides the best mosaic of biotopes, an ample supply of woody debris and leaf litter, and provides buffering against rising water temperatures, shading the water and lowering temperature on sunny days. The Keeping Rivers Cool project (2016) has published **guidance** on improving the level of shading to help keep rivers cool.
- Where possible, restore natural biological connectivity within the river network and between the river channel and floodplain by removing artificial barriers (in-channel structures and flood banks). Where applicable, the removal of barriers needs to be set against the risk of speeding up the spread of invasive non-native species. This is particularly key in situations where there are native crayfish upstream. Generally, weirs only provide short-term protection against non-native spread, and so this would not normally be considered a long-term constraint to weir removal. Natural in-river barriers (typically waterfalls) play a role in the development of certain types of biological community (e.g. fishless headwaters) and should not be removed.
- Where removal of weirs is not possible, minimise their impact on channel morphology/hydraulics and the free movement of species. This may involve reducing the height of the weir and/or providing bypass routes for as many species as possible, including weak swimmers (such as shad *Alosa spp*) where appropriate.
- Where needed, species under threat from shifts in climate space may be targeted for assisted migration, working in line with guidelines for species translocations.
- Manage pollutant loads from effluents to minimise impacts on natural nutrient status and to minimise concentrations of toxins.
- Plan the development of hydroelectric power schemes to avoid constraining the restoration of natural river processes, since the latter is the key climate change adaptation measure for river ecosystems. Development should be focused on existing impoundments that cannot be removed, and on in-line turbines that do not remove water from the river channel.

'Natural' timber posts to slow down water as part of flood management in The Cheviots. © Sarah Taylor

Relevant Countryside Stewardship options

Many of the actions outlined above can be supported by Countryside Stewardship. The most relevant Countryside Stewardship options relating to catchments concern resource protection. Their main aim is to reduce soil erosion and nutrient inputs, but they often work by reducing surface run-off, thereby improving catchment and soil infiltration rates. Further incentives for agricultural erosion and nutrient control are provided by the **Catchment Sensitive Farming** scheme. Options of most relevance to the riparian corridor include the Making Space for Water option (SW12), which provides support for removing constraints to lateral movement of the river channel. Restoring this movement is critical to re-naturalising morphological processes, which is needed to restore the full river habitat mosaic as well as to maximize natural flood management benefits. The Riparian Management option (SW11) supports measures to restore riparian habitat strips, although a more bespoke set of Stewardship options may be needed to restore the riparian zone of river SSSIs and priority river habitat. A range of options for restoring semi-natural habitats in the floodplain can be used to support adaptation measures involving restored lateral river connectivity.

Other actions may be supported by water-related funding streams, particularly Water Framework Directive implementation, Flood Risk Management budgets, and the water industry's Asset Management Plan (AMP) process.

Further information and advice

Woodland Trust (2016) **Keeping Rivers Cool: A Guidance Manual**

Wheeldon, J., Mainstone, C.P. and Cathcart, R. (2010) **Guidelines for the restoration of physical and geomorphological favourable condition on river SSSIs in England**. Natural England guidance.

JNCC (2008) UK BAP habitat description **Rivers**.

Relevant case study examples

Restoring Designated Rivers. The national programme of physical restoration of the river SSSI network. A collaboration between Natural England and the Environment Agency with a wide range of contributors.

Woodland Trust. Winter 2013 edition of their **Woodwise** magazine focuses on trees and woodlands in water management and contains details of a pilot project on the Hampshire Avon to improve riparian shading.

Key evidence documents

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