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River Restoration and Biodiversity

Nature-Based Solutions for Restoring the Rivers of the UK and Republic of Ireland

Stephen Addy, Susan Cooksley, Nikki Dodd, Kerry Waylen, Jenni Stockan, Anja Byg and Kirsty Holstead

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Scotland's centre of expertise for waters

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Cover image: The River Leith in Cumbria, England. Part of the River Leith near Penrith was restored in 2014 to its natural meandering course for the benefit of plants, animals and people (© Linda Pitkin/2020VISION).

Contents

Foreword

Historically, the conservation movement has paid relatively little attention to rivers. Various types of wetland are very well represented in protected areas, but rivers themselves are hard to conserve in this way, not least because they are often the focus of so much human activity. Yet, rivers are of huge importance for the biodiversity they hold, and the ecosystem services they deliver. Rivers can also be places of great beauty and enjoyment. Walking along a crystal-clear trout stream in early summer, teeming with life, is a wonderful, enriching experience.

Rivers in the United Kingdom and the Republic of Ireland have been subject to multiple threats over many centuries. Weirs, dams and other barriers have broken the migratory routes of a number of once common species, and reduced connectivity along the length of most of our rivers. The loss of catchment forests has increased the risk of seasonal flooding, and various forms of water management (such as straightening watercourses, and the prevention of the lateral movement of river channels) have disrupted natural flooding regimes and broken connectivity within floodplain ecosystems. Added to this, pollution of various types, from pesticides, herbicides, fertilizers, industrial and household waste and the like, have turned some rivers into sewers, largely devoid of life. Rivers are unfortunately also particularly at risk from damaging invasive species, such as American signal crayfish and American mink. The Himalayan balsam along many of our river banks might look beautiful, but it has become a monoculture in many places, reducing the natural diversity of plant life.

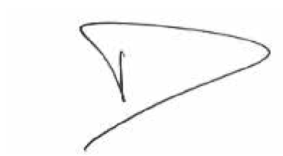
Despite these threats, there has been some good news in recent years. Tighter regulation of activities leading to water pollution has been important in helping to restore many rivers in the UK and Ireland. The recovery of the Eurasian otter in many areas in recent decades is an indicator of broader ecosystem recovery. New steps to restore longitudinal connectivity along rivers stand the chance of reopening migratory routes for much-declined fish species such as allis shad, twaite shad, river lamprey, sea lamprey, and smelt.

However, very much more needs to be done. It is for this reason that we welcome the publication of *River Restoration and Biodiversity*, the results of a collaborative project of British and Irish experts under the auspices of the IUCN National Committee UK. The document provides the blueprint for how to move ahead. The key messages are:

- Healthy rivers are important for people and nature, but much historic damage has caused serious problems that now need to be addressed as a matter of urgency.
- River restoration is important for achieving biodiversity conservation and sustainable development.
- Working with nature allows us to achieve many otherwise conflicting objectives.
- River restoration, working with natural processes and natural flood management, is a cost-effective response to changing climate.

We congratulate the team that brought this outstanding report together. We encourage both the British and Irish governments to take its recommendations very seriously and to set an ambitious agenda for river restoration which can become an example for other countries to follow. As a sign of this, we hope that one day, the Atlantic sturgeon will once again be migrating up British and Irish rivers to spawn, and that the burbot will once again become established in the rivers of eastern England.

Simon Stuart,
Chair, IUCN Species Survival Commission



Piet Wit,
Chair, IUCN Commission on Ecosystem Management

Executive summary

Rivers and their floodplains are among the most important environments in the UK and Republic of Ireland. They support highly diverse habitat and wildlife despite their small area in the landscape. The value of naturally functioning rivers to society both culturally and by the provision of amenity, water supply and flood regulation benefits is clear.

The exploitation of rivers by humans has led to widespread degradation of their natural character, resulting in a loss of characteristic habitat, biodiversity and the benefits we rely on. The extent of alteration justifies the need for river restoration alongside measures that conserve them to prevent further damage.

River restoration should aim to reinstate characteristic river habitat and biodiversity. It can be defined as: ***the re-establishment of natural physical processes (e.g. variation of flow and sediment movement), features (e.g. sediment sizes and river shape) and physical habitats of a river system (including submerged, bank and floodplain areas)***.

Restoring water quality and removing invasive species are equally important for the recovery of river habitat and biodiversity but these issues are not the focus of this report. River restoration in the UK and Republic of Ireland developed in the late 1980s and has become a prominent strand of river management; to date more than 2000 projects have been undertaken. Instead of using a catchment-scale approach, most projects have been carried out at the reach scale, in lowland areas and focused on local issues.

European legislation (European Water Framework, Habitats and Floods Directives) in the UK and Republic of Ireland provides the main driver for river restoration. In the UK, the Natural Flood Management Handbook (2016)[(1)], Pitt Review (2008)[(2)] and Making Space for Water (2004)[(3)] also support the case for river restoration to reduce flood risk.

Well-planned river restoration may benefit physical habitat and biodiversity in the short term, but realising the full benefits takes longer particularly at large (catchment) scales.

Restoration techniques that encourage natural processes and help rivers to recover by themselves are recommended because:

- They result in conditions naturally more in keeping with a given part of a river and therefore characteristic habitat that supports the expected range of plants and animals.
- They result in dynamics and habitat conditions that are more resilient and sustainable than engineered channels or habitats, particularly in the face of climate change.
- Construction and maintenance costs are reduced as natural processes do the work of restoration and maintain the restored channel.
- They are capable of restoring whole river–floodplain ecosystems rather than individual habitat elements or species.
- They support the restoration of ecosystem services such as flood management.

There are four key river processes that underpin natural river habitat and biodiversity that restoration techniques should aim to restore:

- Free sideways movement of river channels by erosion and deposition.
- Free connections of water, sediment, organic material and biota between rivers and their floodplains.
- Free connections of water, sediment, organic material and biota downstream and upstream.
- Natural riparian vegetation communities and the free interaction with their adjacent rivers.

In this report, we make 20 recommendations for policy makers and practitioners to promote and improve river restoration:

Create policies that support restoration

1. Ensure long-term (i.e. >5 years) provision of government-funded resources to facilitate planning, implementation and evaluation of river restoration projects.
2. Streamline regulations and permission processes to aid implementation of small-scale, low-risk restoration projects.
3. Consider innovative approaches to compensating landowners, such as land purchase, land swapping, conservation covenants and easements, and payments for alternative land use.

Provide funding for restoration

4. Encourage greater uptake of voluntary (self-funded or in-kind) work by showing the long-term benefits

of river restoration, such as reduced maintenance costs and flood risk.

5. Make use of long-term funding from a range of sources that already exist including agri-environmental schemes and grant funding.
6. Consider alternative funding sources for restoration planning and actions. These include payment for ecosystem services, developer contribution schemes and persuading food producers to invest in restoration.

Devise effective plans for restoration

7. Assess processes and causes of degradation at the catchment scale to inform the implementation of the right restoration measures in the right places and at the right scale that tackle the root causes of degradation of physical habitat.
8. Adopt existing frameworks such as the REFORM protocol [(4)] and the designated river restoration strategies in England [(5)] to aid decision support for planning at large scales.
9. Encourage a long-term commitment to planning and implementing restoration.
10. Balance 'top-down' strategies with 'bottom-up' initiatives to use and increase existing interest and enthusiasm for carrying out restoration.
11. Assess the level of risk associated with project actions for individual cases to ensure that it is commensurate with the cost of each project [(4)].
12. Involve all stakeholders (landowners, river trusts, NGOs, voluntary groups and communities) at the earliest opportunity, including those that may not already be engaged in restoration, to gain support and maximise use of local knowledge.
13. Set clear and measureable project goals, while taking into account social and economic constraints.

Gather evidence and evaluate projects

14. Improve the evidence for the effectiveness of river restoration by investing in long-term monitoring (i.e. >5 years) at selected sites. These should encompass a large geographical range and use robust scientific approaches to evaluate projects that focus on process-based approaches. Monitoring should be undertaken before restoration and afterwards for a sufficient timescale to detect both rapid and longer-term changes.
15. Promote and implement simple and cost-effective monitoring methods that can be applied across all sites (e.g. fixed point photography). Consistency in these monitoring methods is vital to ensure comparability between projects.
16. Use citizen science to provide useful information and connect people with their river environments.
17. Use monitoring evidence to evaluate projects objectively and help inform the future design and implementation of actions elsewhere.
18. Understand how different projects are carried out so that opportunities and barriers can be identified to help refine future practice.

Communicate the benefits

19. Communicate the principles and benefits of river restoration to raise its profile, overcome barriers, and help inform future projects. In particular, tailor the messages depending on the audience, promote the long-term and catchment-scale benefits and share knowledge with others.
20. Promote river restoration as an activity that overlaps with other conservation, landscape restoration and policy drivers to reinforce its added value.

The reward of river restoration is naturally functioning rivers that support improved biodiversity while bringing benefits for a society that is re-engaged with rivers.

SECTION 1

Introduction

Rivers and their floodplains are among the most important natural environments in the UK and Republic of Ireland. Compared with other ecosystems, rivers support a disproportionately large number of plant and animal species [6]. The concept of biodiversity (Box 1.1) and its conservation and restoration are central to maintaining the natural character of rivers.

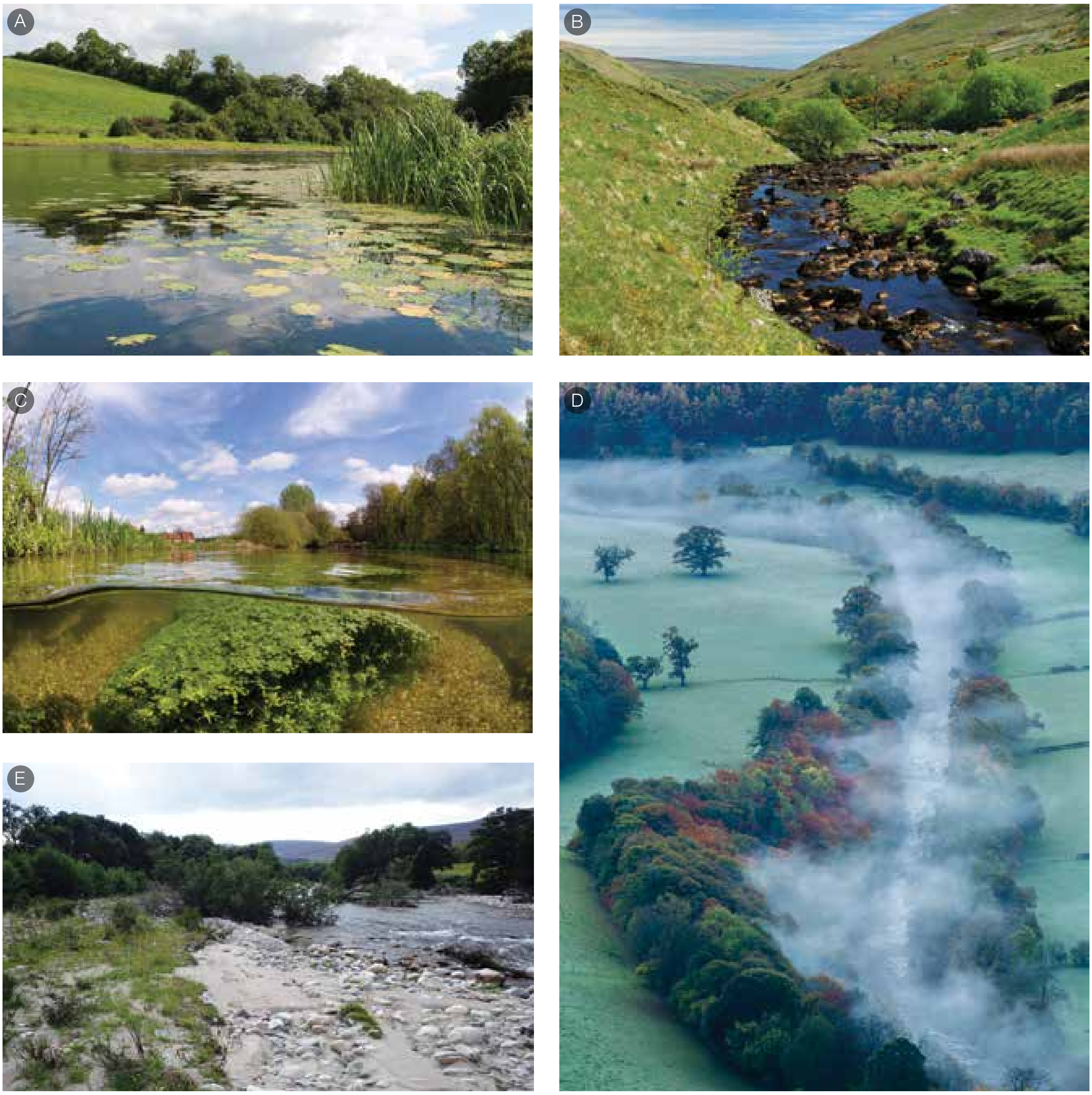


Figure 1.1 The diversity of river environments in the UK and Republic of Ireland. (A) the River Erne, Co. Cavan, Republic of Ireland (© Peregrine, Dreamstime), (B) River Dun in Co. Antrim, Northern Ireland (© Robert Thompson, NaturePL), (C) the River Itchen, Hampshire England (© Linda Pitkin/2020VISION), (D) The River Dee in Denbighshire, Wales (© David Noton Photography, NaturePL) and (E) the River Avon, Moray, Scotland (© Steve McAleer, EnviroCentre).

The rich biodiversity of rivers reflects the diversity of environments they flow through (Figure 1.1). River habitat includes aquatic and terrestrial areas, often changing over short distances and timescales owing to the dynamic nature of rivers. These traits mean that our rivers are of high conservation value and this is reflected by international and national designations that aim to protect their condition.

BOX 1.1 The concept of biodiversity

Biological diversity or biodiversity is defined as: '**the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (Convention on Biological Diversity, 1992)'** [a].

The definition of biodiversity means appreciating the links between organisms, the communities they form a part of, and the habitats that support them.

Biodiversity is under threat worldwide due to human pressures, and river environments are no exception to this. The importance of halting biodiversity decline worldwide through conservation is recognised by 195 states and the European Union which are parties to the Convention on Biological Diversity (CBD). At the Nagoya CBD conference in 2011, 20 targets were set as part of a strategy to mitigate biodiversity decline and the 2011–2020 decade has been declared as the UN Decade on Biodiversity.

A key concept in biodiversity conservation is identifying and safeguarding **characteristic biodiversity**. This means promoting the integrity of biological communities and associated habitat that would be expected for a given environment that is not adversely affected by human pressures. This is important for influencing how river biodiversity is valued for planning river conservation and restoration actions. For example, in a physically degraded river, whole-community diversity may be modified or even similar to that expected under unaltered conditions [(7)] but would not be composed of the *characteristic* range of species of that particular environment. Such a system would be worthy of physical restoration to allow biodiversity to recover to its characteristic state.

Rivers are highly valued by humans for providing a wide range of essential goods and services, but the exploitation of rivers for society's needs – especially since the Industrial Revolution – has led to the widespread degradation of their natural character, resulting in a loss of characteristic habitat, biodiversity and ecosystem services. This means river habitat is one of the most threatened habitat types in Europe [b].

Rivers are subject to a wide range of pressures including point source and diffuse pollution, water abstraction, invasive plant and animal species and physical modification. Concerted efforts to tackle water pollution linked to industry began in the early 20th century and have had considerable success in improving water quality. More recently, the recognition of physical damage caused by alteration of flow, channelisation, flood embankment construction, dredging and impoundment by weirs or dams has led to river restoration to reverse decades of physical change. Restoration actions aim to restore river biodiversity and the key ecosystem services that society depends on such as the provision of clean drinking water and the natural management of flood risk.

There are several ways to describe river restoration but the following broad definition in the context of catchments, streams and rivers is used for the purpose of this report:

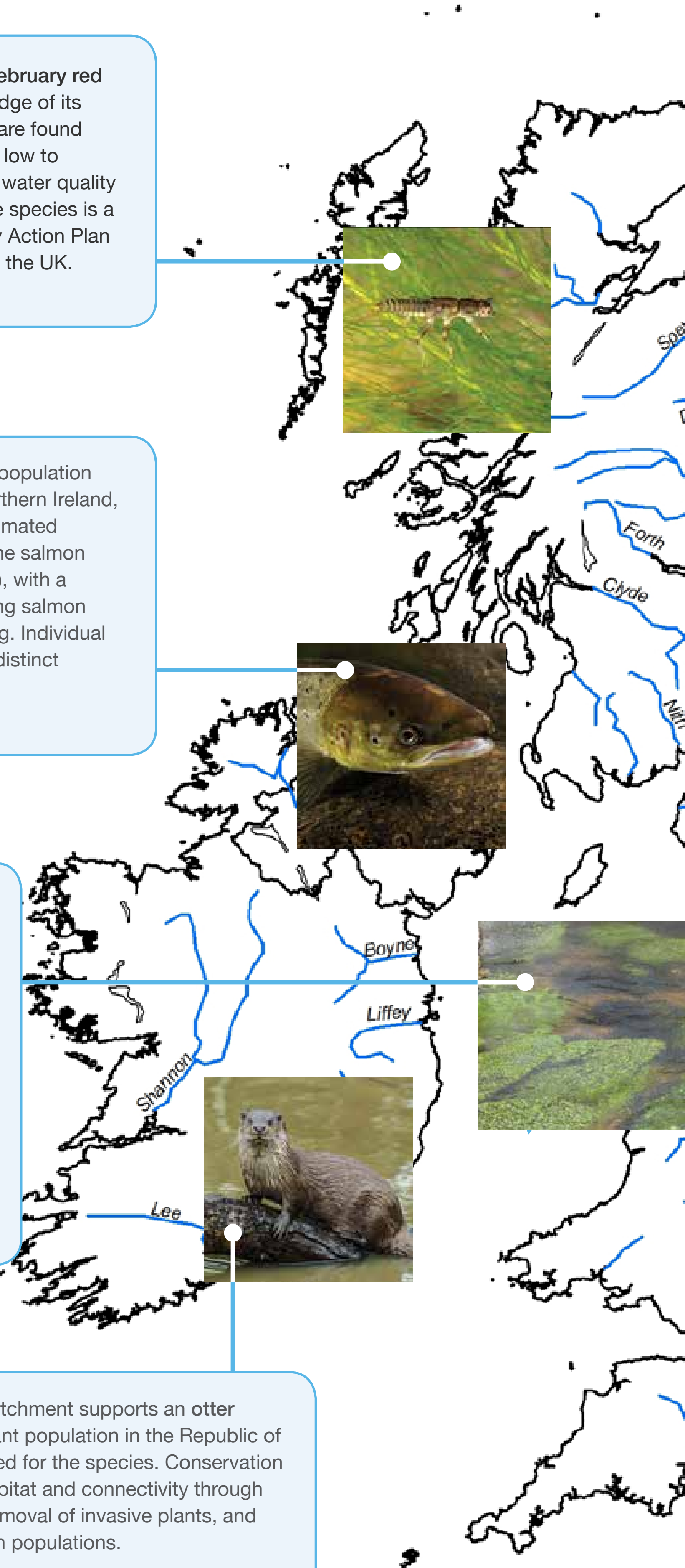
River restoration is the re-establishment of natural physical processes (e.g. variation of flow and sediment movement), features (e.g. sediment sizes and river shape) and physical habitats of a river system (including submerged, bank and floodplain areas).

This definition of river restoration does not imply that rivers should be restored to a pre-Industrial Revolution state. This can be impossible because rivers naturally change over time and because of societal constraints [(8)]. Rather it promotes the idea of encouraging natural processes to create characteristic, self-sustaining, dynamic physical habitat that induces biological recovery [(9)] and restores the benefits humans rely on.

Although restoring water quality and flows and removing invasive species are equally important for inducing biological recovery, these issues are not the focus of this report (Figure 1.2). Instead it concentrates on restoring river morphology and dynamic processes to improve physical habitat, which is defined as the environment where the flow of water and morphology interact. Plants and animals rely on and modify this physical habitat.

Figure 1.2 The different components that determine the overall habitat integrity of rivers. This report focuses on the importance of physical habitat and ways to restore it by improving morphology. (Adapted from Mainstone and Holmes, 2010 [5]; Image Credits: © James King, Inland Fisheries Ireland; © James Hutton Institute; © Martin Janes, RRC; © Creative Commons Licence).

The case for river restoration to safeguard biodiversity and prevent further decline in Europe is endorsed by EU and national legislation. The 1992 European Council (EC) Habitats Directive specifies a range of key river habitat types and species to conserve at a 'favourable status' throughout their natural range. The Habitats Directive, together with the Birds Directive, underpin an EU-wide Natura 2000 network of nature protection areas established to ensure the long-term survival of Europe's most valuable and threatened species and habitats (Figure 1.3). Natura 2000 includes the best examples of habitats and species, comprising Special Areas of Conservation (SACs) and Special Protection Areas (SPAs). Biodiversity Action Plans and the network of Sites/Areas of Special Scientific Interest (SSSIs/ASSIs) in the UK and Northern Ireland (Natural Heritage Areas in the Republic of Ireland) reinforce the need for efforts to safeguard biodiversity. Many of the species listed as priorities in the UK Biodiversity Action Plan and international IUCN Red List are associated with rivers. In the UK, rivers provide habitats for 346 IUCN Red List species and in the Republic of Ireland there are 262 riverine red list species[c]. Further impetus is provided by the 2000 EC Water Framework Directive which aims to maintain or enhance the intrinsic natural character of rivers and the 2007 EC Floods Directive which supports the restoration and maintenance of natural features to reduce flood risk. These types of legislation, endorsement by government agencies, availability of funding and the guidance offered by organisations such as the River Restoration Centre (RRC), mean that restoration has become a prominent strand of river management.



Found only in Britain, the **Northern February red stonefly** *Brachytera putata* is at the edge of its climatic range in Scotland. Its larvae are found among loose cobbles and pebbles in low to moderate gradient streams with high water quality and exposure to winter sunshine. The species is a priority species in the UK Biodiversity Action Plan and classified as Nationally Scarce in the UK.

© Mark Hammit

The **River Foyle** SAC has the largest population of **Atlantic salmon** *Salmo salar* in Northern Ireland, with around 15% of the country's estimated spawning numbers. The majority of the salmon returning are grilse (one winter at sea), with a smaller but important number of spring salmon (multiple winters at sea) also occurring. Individual sub-catchments support genetically distinct salmon populations.

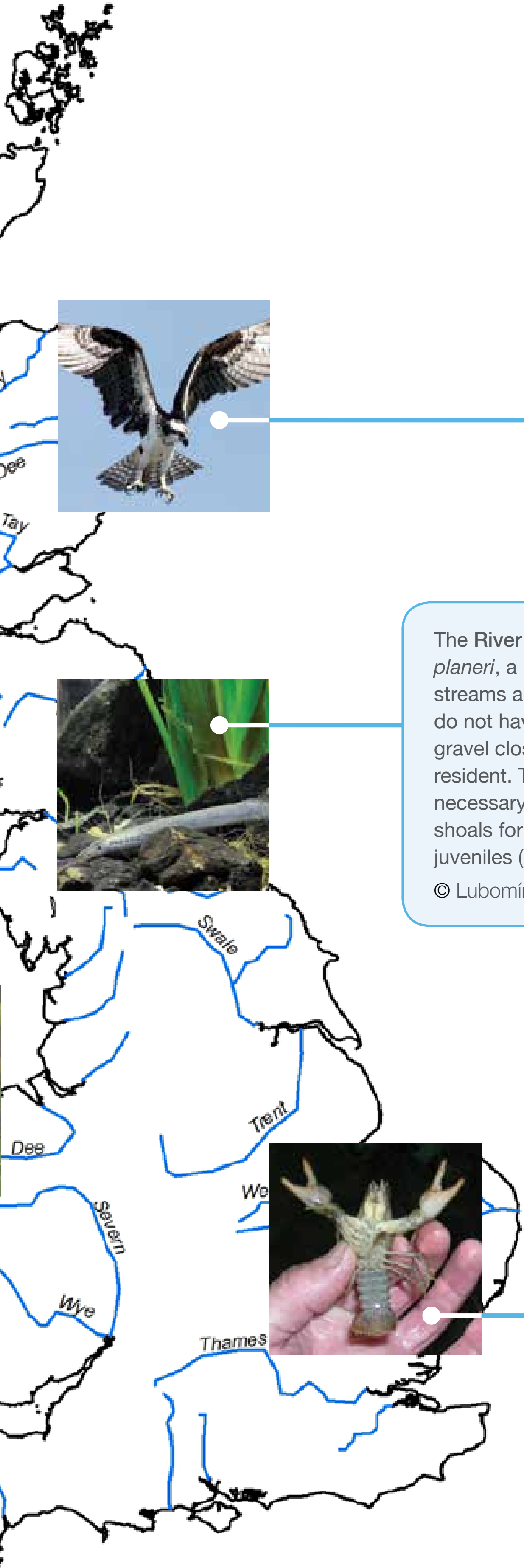
© Linda Pitkin/2020VISION

The nutrient-poor waters of the **Afon Gwyrfai a Llyn Cwellyn** (SAC) in North Wales, are dominated by **stream water-crowfoot** *Ranunculus penicillatus* ssp. *penicillatus*, intermediate water-starwort *Callitriche hamulata*, aquatic mosses *Fontinalis* spp. and bulbous rush *Juncus bulbosus*. The conservation value of the site is enhanced by the presence of good adjacent river corridor habitat.

© Adam Thurtle, Environment Agency

The **Mulkear River** in the Shannon catchment supports an **otter** *Lutra lutra* population. It is an important population in the Republic of Ireland and one of 44 SACs designated for the species. Conservation work includes restoring river-bank habitat and connectivity through tree planting, creating scrub cover, removal of invasive plants, and in-stream habitat work to improve fish populations.

© Dave Webb, UK Wild Otter Trust



The **River Spey's Insh Marshes**, one of the largest and least disturbed floodplain fens in the UK, is a **Special Protection Area** for **osprey** *Pandion haliaetus*, **spotted crake** *Porzana porzana*, **wood sandpiper** *Tringa glareola*, **hen harrier** *Circus cyaneus* and **whooper swan** *Cygnus cygnus*). Other rare or restricted bird species include the corncrake *Crex crex* which was historically dependent on floodplain meadows. The decline of grazing in the area had allowed the open floodplain habitat to deteriorate, with too much encroaching willow scrub and rank grassland. Light mowing of the floodplain and scrub reduction help to restore habitat.

© Wikimedia Commons, NASA

The **River Derwent** is an SAC for the **brook lamprey** *Lampetra planeri*, a primitive, jawless fish resembling an eel. It occurs in streams and rivers. The adults do not migrate to the sea and do not have a parasitic phase (they do not feed) and spawn in gravel close to the soft sediment where they were previously resident. The River Derwent has habitat features that provide the necessary conditions for all life stages: extensive clean gravel shoals for spawning and marginal silt or sand for the burrowing juveniles (ammocoetes).

© Lubomír Hlásek

The **Wensum**, a chalk-fed river, has an eastern example of a **white-clawed crayfish** *Austropotamobius pallipes* population. As with most of the remaining crayfish populations in the south and east of England, the threats from non-native crayfish species and crayfish plague are severe. Designation of the river as an SAC provides as much protection as can be afforded to such vulnerable populations.

© Natural England

Figure 1.3 Examples of rivers with threatened habitats and species that are protected by different conservation policies in the UK and Republic of Ireland. Conservation policies aim to safeguard threatened species by designating special sites and by highlighting certain habitats and species as conservation priorities. (Map: © Esri, DeLorme Publishing Company, Inc.)

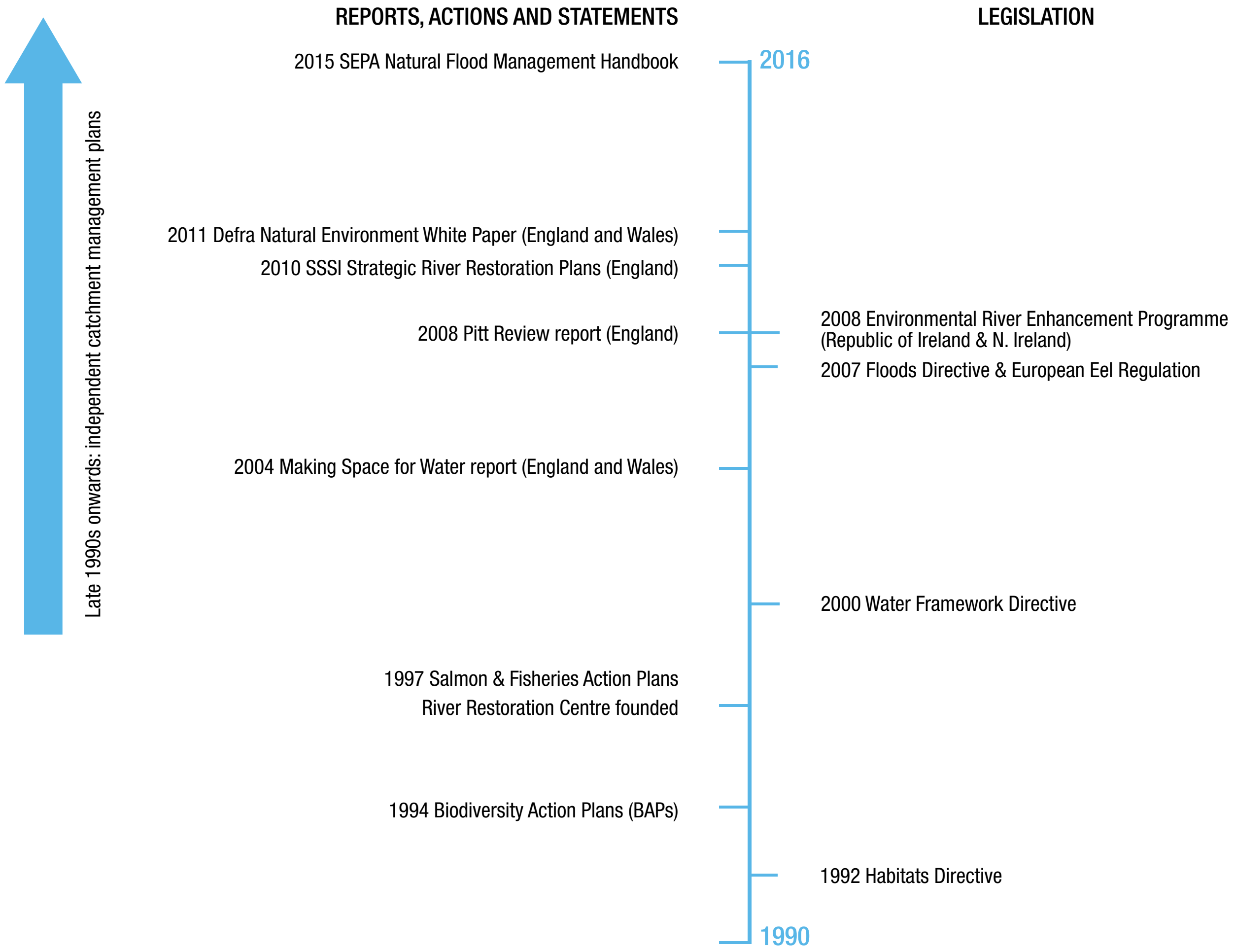


Figure 1.4 Timeline of key events that have built and strengthened support for river restoration over the last three decades. (after Griffin *et al.*[10]).

The UK has a history of river restoration that dates back to the 1980s, and so far, more than 2000 projects have been undertaken with a rapid increase recorded in recent years (RRC database, 2014). In parallel with this, interest from the scientific community has increased greatly[11] and has involved the integration of ecology, hydrology and geomorphology to plan and evaluate restoration. Figure 1.4 gives an overview of the key scientific, policy and NGO support that has been continually rising since the 1990s.

This report gives an overview of restoration based on published information and the Liverpool workshop (Box 1.2). Using this understanding, recommendations for promoting and improving the approach of river restoration are made. In the light of predicted climate change effects (e.g. frequency of droughts and floods), population growth and an attendant increased demand for water, the need to conserve and restore river ecosystems is more important than ever[12].

BOX 1.2 Liverpool IUCN River Restoration Workshop

In November 2014 a workshop was held in Liverpool to review progress made in river restoration and inform recommendations on the best way forward to implement it. The workshop was endorsed by the International Union for Conservation of Nature National Committee UK. The workshop brought together the combined knowledge of 44 practitioners, scientists and representatives of statutory environment and conservation bodies. The following 15 key statements emerged and received strong support (full list given in [13]):

- There is evidence of widespread damage to rivers across the UK and Ireland, thus emphasising the need for a strategic approach to river restoration.
- An ecosystem services approach is needed to complement biodiversity conservation in river restoration but should not replace it.
- Better regulations and incentives are needed for river restoration.
- 'Iconic' species can be useful vehicles for promoting river restoration concepts and projects.
- River restoration projects require long-term funding.
- Businesses should be encouraged to explore options for river restoration that can reduce their costs while aiding natural processes.
- We need to communicate which river restoration techniques are effective for achieving different goals.
- We need to learn from and share our failures in river restoration.
- To influence politicians, landowners, and the wider public we need to demonstrate and communicate that river restoration outcomes are beneficial.
- River restoration should always be discussed in the context of the whole catchment because this brings multiple benefits.
- There is a need for clear, simple and targeted monitoring before and after river restoration projects.
- Lateral connectivity, including floodplain and riparian zones, should be considered more explicitly in river restoration.
- Both physical and biological processes should be considered in river restoration.
- Restoration should be seen not just as a means of replacing lost environments but as a means of protecting key resources against future change.
- Synergies between different sectors need to be identified to maximise the success of river restoration.

SECTION 2

Why are rivers important for biodiversity?

2.1 Introduction

Despite covering less than 1% of the Earth's surface and amounting to less than 0.01% of its surface water, freshwater environments – including rivers – are globally important for wildlife [14]. The communities of plants and animals associated with rivers are rich and varied, owing to the wide variety of shelter, breeding and feeding opportunities that river habitats provide [15] (Figure 2.1).

River habitats are underpinned by the underlying geology and climate. These determine a river's intrinsic characteristics, for example how steep and fast-flowing it is, what sediment it carries and deposits, and whether it has predominantly acidic or alkaline water. Within this intrinsic template, rivers are highly varied environments, where physical, chemical and biological processes (Figure 2.2) work together to create a patchwork of linked habitats called a 'habitat mosaic' [16] (Figure 2.3).

Many different habitats are associated with rivers and streams (Figure 2.4). They include areas defined by flow type (e.g. waterfalls, rapids and pools), morphological features (e.g. gravel bars, river banks), or dominant plant species (e.g. bankside woodland or beds of aquatic plants). Habitats intimately connected to rivers include associated wetland areas, swamps and fens, bogs and mires, floodplain meadows and wet woodland.

Habitat can be viewed at different scales, from a grain of sand to a floodplain meadow. Usually habitat is defined at the medium scale (several to tens of square metres) and these units form the 'building blocks' for a habitat mosaic (Figure 2.3). At a larger scale, a river reach can be defined as a length of river that supports a characteristic assemblage of these habitat units. Reaches are nested within larger river segments that make up a river network [17] (Figure 2.5).

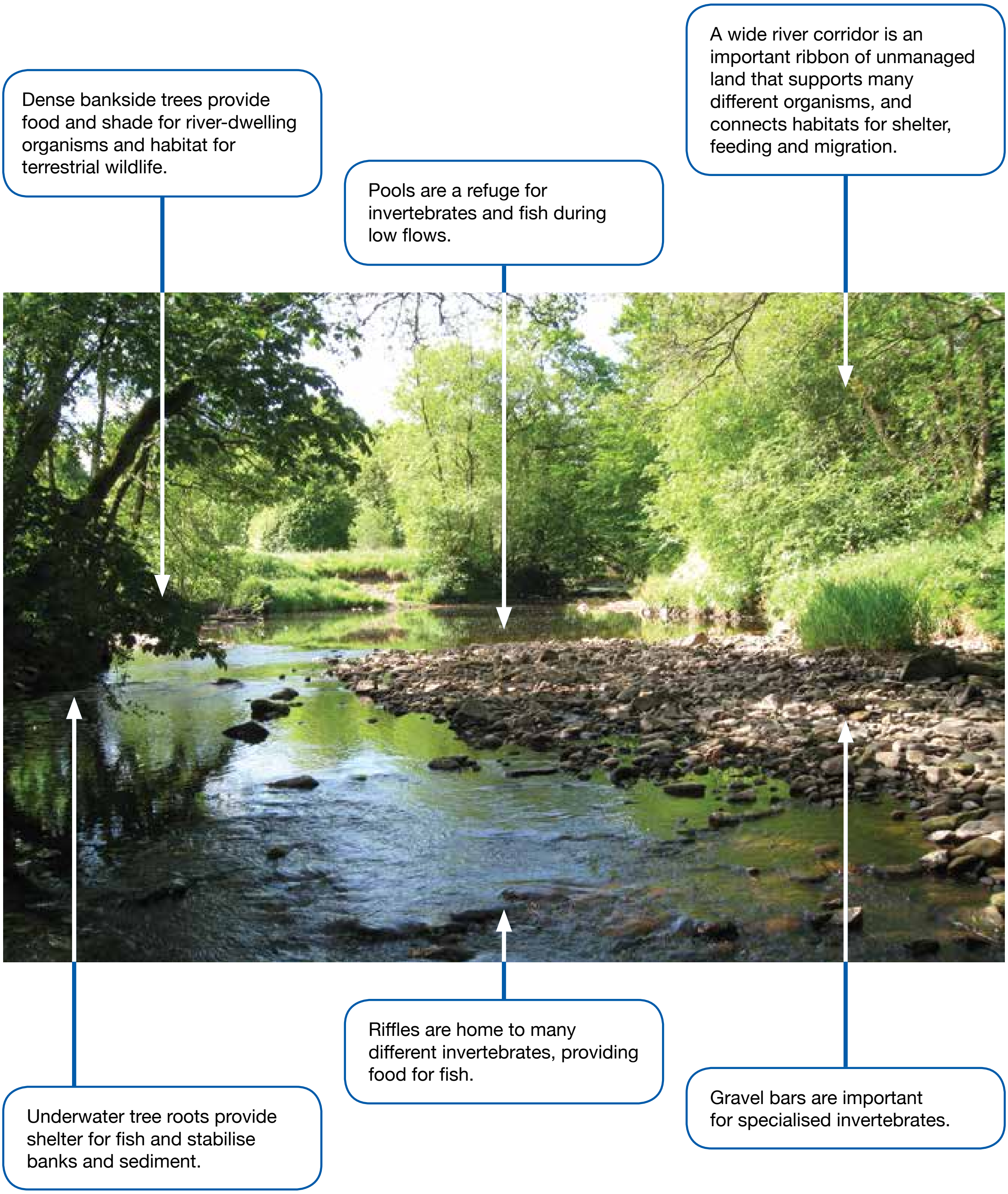


Figure 2.1 The processes at work in a natural river create different habitats for wildlife
(River Nethan, Lanarkshire, © James Hutton Institute).

A river's **flow** and **sediment transport** characteristics determine the distribution of river-bed habitat, for example gravel for spawning salmon. Some areas of the river experience strong fluctuations in current velocity while others provide refuge from high or low flows. Areas such as shingle bars and marginal zones are intermittently dry, especially during summer.
© Graham Eaton, NaturePL

Disturbance (e.g. due to floods) plays a vital role in structuring river communities and maintaining high biodiversity. Disturbance can shift an ecosystem from one persistent state to another e.g. by restructuring an established vegetation community. Healthy ecosystems are generally resilient to disturbance events because they include areas that provide refuge.
© David Woodfall, NaturePL

Vegetation succession is the process by which plant communities develop, from initial colonisation by pioneer species to a complex 'climax' community. Succession in river-bank plant communities typically develops scrub and woodland, and this is critical in linking aquatic and terrestrial habitats and in providing a source of in-stream woody material.
© James Hutton Institute

Nutrient cycling is the reuse, transformation and movement of essential nutrients in the river system. The cycles of phosphorus, nitrogen and carbon are especially important as they are fundamental to the functioning of organisms. This is one of the most significant ecosystem processes because of the importance of nutrients, their relative scarcity in fresh waters and their influence on rates of algal growth.
© Martin Janes, RRC

Plants and animals can **'engineer' habitat** in rivers. Examples include plants that trap fine sediment around their roots and burrowing by chironomids that opens up channels in sediment and so increases oxygenation. As well as local impacts, there can be more widespread effects, for example nest digging by an individual salmon depending on the species and size, can disturb up to 17 m^2 of the stream bed area [18], releasing sediment and nutrients that are deposited downstream.
© Michel Roggo, NaturePL

Figure 2.2 Physical, chemical and biological processes work together to develop different types of river habitat.

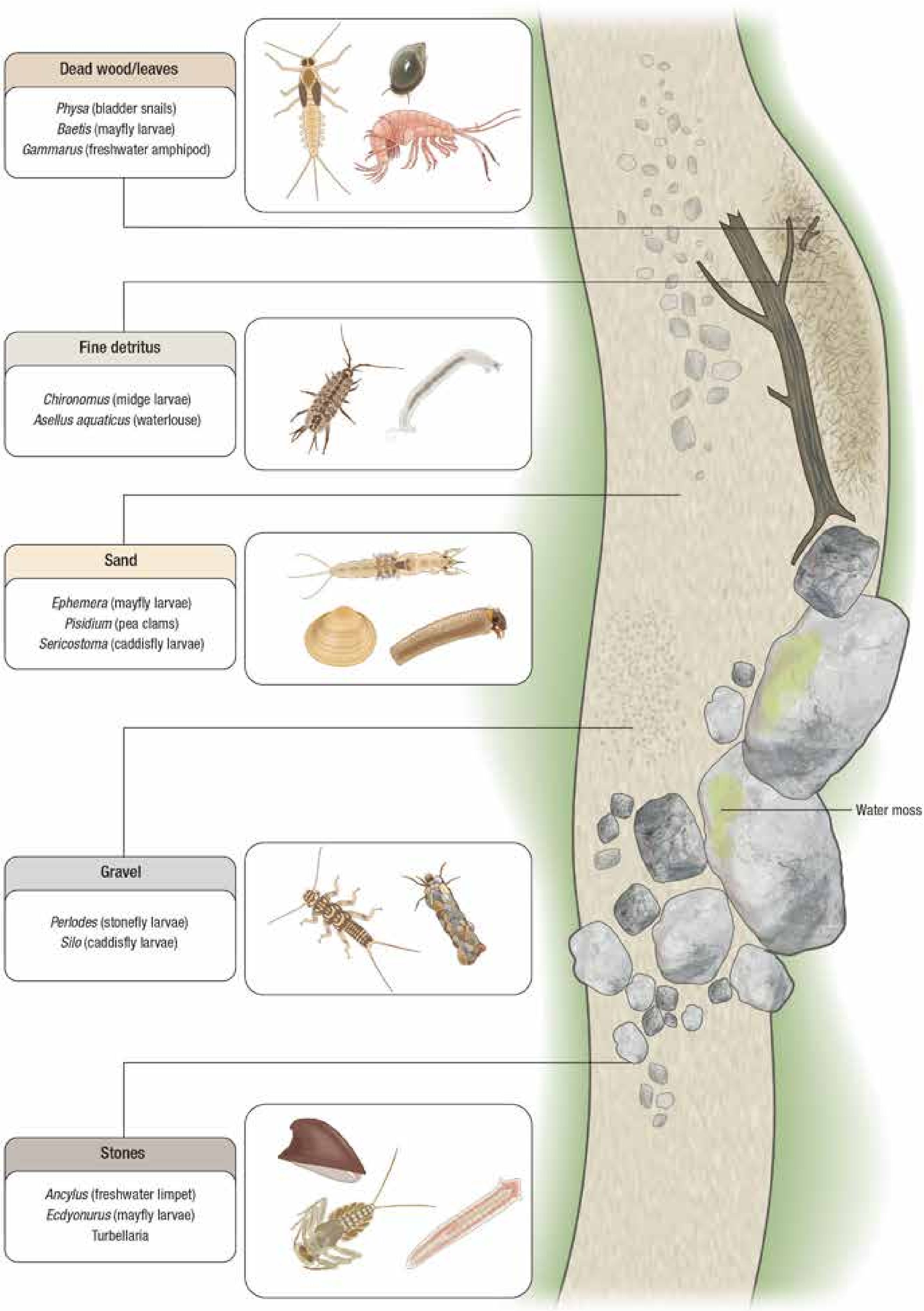


Figure 2.3 Physical, chemical and ecological processes in rivers lead to the development of habitat mosaics made up of medium scale habitat units. Different habitats must be well connected to enable organisms to exploit a range of feeding and sheltering opportunities, adapt to changing conditions within the river, and complete their life cycles (adapted from Bostelmann[d]).

Waterfalls are formed by vertical flow over bedrock, boulder or cobble river beds. Spray creates wetland habitat favoured by organisms that need cool, damp conditions, such as mosses and lichens, as well as specialist beetle, stonefly and caddis species.
© Peter Cairns/2020VISION

Rapids and cascades have a relatively steep gradient, with high water velocity creating torrential conditions. Large boulders provide shelter from high velocities for invertebrates and fish. Blackfly larvae (Simuliidae) favour chute flow, areas in cascades where water hugs the surface of rocks and boulders.
© James Hutton Institute

Riffles form where shallow water with high velocity flows over gravel or cobble material, creating a broken water surface. Riffles are home to animals that cling well and are favoured by fish as a feeding area, for shelter from predators because of the broken water surface, and by salmon, lamprey or trout as the sites of their egg nests (redds) due to the well-oxygenated water.
© James Hutton Institute

Glides are areas of deep water with a smooth surface and intermediate flow velocities, often with gravel or sand river-beds. These areas tend to have lower species richness and diversity than riffles, and are often occupied by aquatic plants.
© James Hutton Institute

Pools are areas of much deeper water and lower current velocities. They provide species with deep-water protection and food owing to the organic matter that accumulates on the river bed.
© James Hutton Institute

Figure 2.4 River habitats and associated communities.

Backwaters are wet areas linked to the main channel but with little or no flow during average weather conditions. They are shelter sites for adult fish, essential breeding habitat for dragonflies and important nursery areas for lampreys.
© James Hutton Institute

Aquatic macrophyte beds create complex habitats by forming physical structures that affect flow patterns, trap sediments, and raise nutrient and oxygen levels. Macrophyte habitats provide food, shelter and spawning sites for a wide range of invertebrates, fish and amphibians.
© Martin Janes, RRC

Tree roots and in-stream woody material improve water quality, stabilise sediments and increase the diversity of physical habitat types within the stream. Accumulations of wood slow the water flow, creating pools and eddies where fish can rest, hide from predators and avoid direct sunlight. They also provide a surface for algae, fungi, bacteria, plants and insects to colonise.
© James Hutton Institute

Exposed sediment is important for plants and invertebrates (notably ground beetles, spiders and craneflies). This habitat is important for conservation because it supports a diverse range of species, including several specialists as well as many that are rare and endangered.
© James Hutton Institute

River banks provide specialist habitats that are scarce in the wider landscape. Steep banks are used by otters for their holts and water voles for their burrows. Nesting sand martin colonies also use eroded river banks.
© Toby Roxburgh, NaturePL

Figure 2.4 (cont'd) River habitats and associated communities.

River-bank (riparian) vegetation communities range from mature woodland to species-rich grasslands. They are an important source of food and shelter for aquatic species and support many terrestrial organisms, including bats and a wide range of bird species.
© Martin Janes, RRC

Floodplain water features provide a diverse range of habitats, favoured by wading birds, amphibians and dragonflies, and provide an important source of food for bats and reptiles. They include oxbow lakes, permanent wetlands, flushes, bogs, wet woodland and reedbeds.
© James Hutton Institute

Floodplain meadows evolved from hay pastures, a previously common feature of river valleys. In the last 50 years they have declined owing to agricultural intensification, building development and lack of management. The few that remain are important flood storage areas, have a high nature conservation value due to their floral diversity, provide nectar for a range of insects, and are important early indicators of environmental change.
© Martin Janes, RRC

Figure 2.4 (cont'd) River habitats and associated communities.

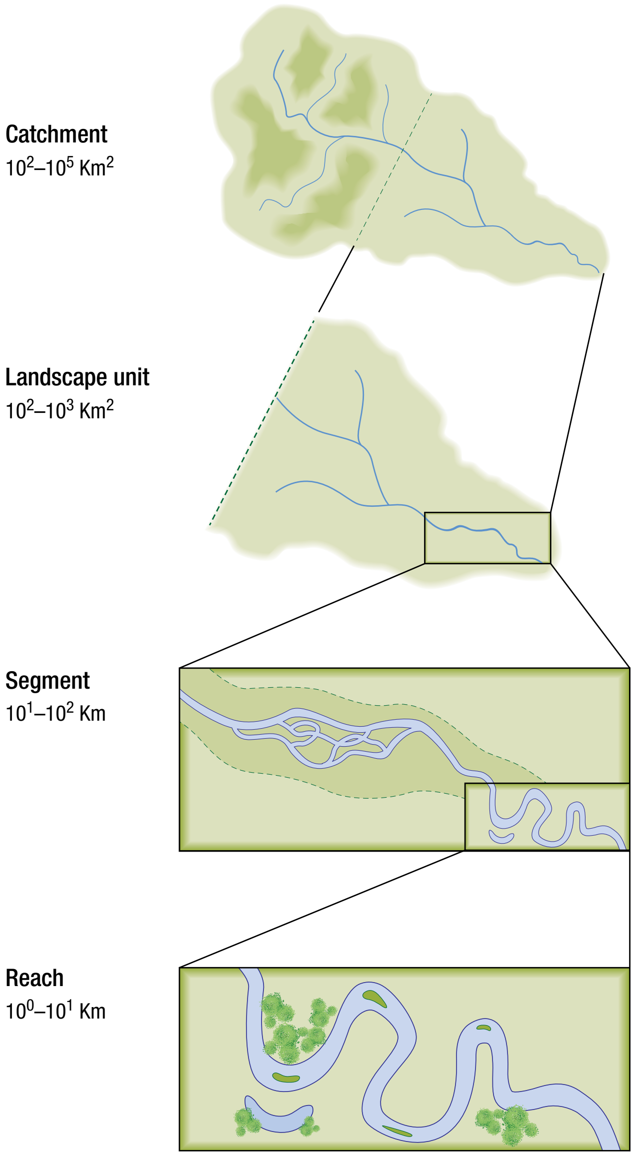


Figure 2.5 Different levels of scale at which river environments can be viewed (adapted from Grabowski *et al*.[19] © 2014 Wiley Periodicals, Inc.).

2.2 River habitat integrity and diversity

Organisms are equipped to make use of different types of available habitat. For example, riffles are home to clinging aquatic insects such as caddisflies and support their plant life that is either well-rooted or restricted to diatoms and small algae. In contrast, the deeper water and less turbulent conditions in pools provide opportunities for animals seeking refuge during low flows, shelter from predators and settled organic debris as a food source. A habitat can be defined by the characteristic community of plants and animals it supports, and its integrity assessed by determining if all of these aspects are present.

The connectedness of habitats is an important aspect of overall habitat integrity. Organisms need to move between habitats as river conditions change (e.g. fish moving to sheltered areas during high flows) and as they progress through their life cycle (e.g. caddisflies have a long larval aquatic stage followed by a brief terrestrial stage). However, the layout of habitats is not fixed in time and place; conditions change continually as water flow, temperature and chemistry alter, ranging from subtle adjustments that take place over many years, to large-scale step changes, for example as a result of a flood.

A river or stream with a greater range of habitats generally supports a greater diversity of organisms because it offers opportunities for different life stages and varied food and sheltering opportunities [20]. Consequently, developing a wide range of habitats is a primary goal of many river restoration projects, ideally achieved by allowing the river to develop naturally its full characteristic habitat mosaic. Organisms themselves can be highly influential in modifying habitats. For example, aquatic plants can trap sediment and spawning fish can overturn river-bed material.

2.3 Connections within river environments

Naturally functioning river corridors are complex, connected pathways, used by organisms to move through the landscape. This dispersal function is relevant to many terrestrial animals and plants, as well as freshwater and amphibious organisms. Examples include the upstream migration of fish to spawning sites, the drift of macroinvertebrates to downstream habitats, seed dispersal by flotation, and the movements of mammals, fish and birds between river, floodplain, backwaters and the riparian zone.

The river and its riparian corridor often constitutes a thread of less altered habitat acting as an informal ‘protected area’ in a managed landscape [16]. River corridors are thus important for a range of terrestrial species not necessarily directly dependent on the river environment but attracted by the shelter and resources they provide. Rivers often link fragmented or degraded areas; lakes and ponds play a similar role by acting as stepping stones for wildlife.

Although longitudinal connectivity from source to sea is a defining characteristic of rivers, they have many other intimate hydrological and biological connections. These include lateral hydrological connections to floodplain habitats and coastal habitats. In particular, river–floodplain connections are widely recognised as important in sustaining natural functions such as nutrient inputs from the terrestrial environment which many riverine species rely on [(6)]. When links are broken this can affect the biodiversity of the entire river. The movement of a river in its corridor influences processes such as river-bank erosion, the exchange of sediment and organic matter and the development of habitat in the floodplain. These processes in turn support a wide range of habitats that can be very biodiverse compared with the main river [(21)].

There is also a less obvious vertical connection, where free-flowing surface water mixes with the groundwater below. The mixing of both types of water within the river bed – in the hyporheic zone – has an important influence on chemistry and nutrient content affecting the small animals that live in the spaces between sediment grains and contribute strongly to overall stream biodiversity [(22)]. The chemical characteristics of the hyporheic zone also influences the extent of temporary habitat for certain macroinvertebrates [(23)] and the development of fish eggs [(24)].

2.4 River habitats and species of the UK and Republic of Ireland

In the UK and Republic of Ireland, the varied climate, geology, glacial history, altitude and land use result in a wide range of river environments [(25)] that support different plants and animals (Figure 2.6). Boxes 2.1 – 2.3 give an overview of three representative types of river environment – headwater streams, high-energy rivers and low-energy rivers – the habitats they support and the species that inhabit them (adapted from Mainstone *et al*. [(16)]).

The Daubenton's bat *Myotis daubentoni* uses its large feet to scoop insects from the water surface. It roosts in trees and buildings near water.
© Dale Sutton/2020VISION

The Atlantic salmon *Salmo salar* needs a wide variety of river habitats for spawning, feeding and shelter.
© Linda Pitkin/2020VISION

The freshwater pearl mussel *Margaritifera margaritifera* lives buried among river-bed sediments for around 100 years.
© Susan Cooksley, James Hutton Institute

Figure 2.6 Many different plants and animals share a common dependence on permanent running water for at least part of their life cycle.

Nymphs of the golden ringed dragonfly *Cordulegaster boltonii* live in pools in acidic streams for 2–5 years before emerging as adults.
© Chris Mainstone, Natural England

The European otter *Lutra lutra* feeds mainly on fish such as trout, salmon and eels. An individual's territory can occupy 20–30 km of river.
© Dave Webb, UK Wild Otter Trust

The dipper *Cinclus cinclus* inhabits fast-flowing rivers. It hunts under water, feeding on insect larvae and freshwater shrimps.
© Richard Steel/2020Vision

Boulders covered by mosses and liverworts are common in steep upland streams.
© Stan Philips, SNH

Macrophytes such as water starworts *Callitriche* sp. take root within slow-moving lowland streams and can create additional habitat.
© James Hutton Institute

Figure 2.6 (cont'd) Many different plants and animals share a common dependence on permanent running water for at least part of their life cycle.

BOX 2.1 Headwater river environments

Headwaters, the smaller tributaries that carry water from the upper reaches of the catchment to the main rivers downstream, are the essential foundation for naturally functioning rivers. They are a major source of water, sediment, energy and nutrients as well as being vital habitats in their own right. Headwaters make up the majority of river length in each catchment.[26]

- Fed by snowmelt, overland flow, springs or lakes, different headwater environments include open marshland streams, cascades draining upland blanket bog and seasonal winterbournes fed by chalk aquifers.

- Some headwaters flow all year round while others dry out in the summer. The permanence of running water has a major bearing on the flora and fauna present, for example ephemeral streams support species that are adapted to an intermittently dry channel.

- The biotic community (food web) is determined by the principal nutrient source. In treeless upland streams, attached algae underpin the food web, favouring invertebrates that feed by scraping or grazing. In tree-lined headwaters, leaf litter is the main nutrient source and creates a food web built on leaf-shredding invertebrates.

- Below the treeline, bankside trees, tree roots and woody material in the channel provide food and shelter, alter flow patterns and promote channel sinuosity. As a result, many different habitats are created and a wider range of species supported.

- Many headwater streams are important for conservation:
  - Flushes of calcium-rich waters form the European protected habitat ‘petrifying springs with tufa formation (Cratoneurion)’ which supports rare and specialist bryophyte and invertebrate communities.
  - Nationally and internationally important invertebrate species found in headwaters include the freshwater pearl mussel (*Margaritifera margaritifera*) and white clawed crayfish *Austropotamobius pallipes*.
  - Headwater environments provide critical spawning and juvenile habitat for brown trout and sea trout *Salmo trutta* and Atlantic salmon *Salmo salar* and are a key habitat for the European protected species brook lamprey *Lampetra planeri* and bullhead *Cottus gobio*, for which parts of the UK are major strongholds. The accessibility of a headwater stream to fish has a fundamental effect on its biological community, for instance by changing the dominant invertebrate predators.
  - Other protected species that can depend upon headwater streams include otter *Lutra lutra*, water vole *Arvicola amphibius*, and kingfisher *Alcedo atthis*.
  - Headwater environments are important for several bird species. For example, the grey wagtail *Motacilla cinerea* is commonly found near fast-flowing upland rivers where it feeds on insects such as ants and midges, and nests in crevices near the water.

- The small size of headwaters makes them extremely vulnerable. As the health of downstream reaches is only as good as that of its headwaters, it is essential that headwaters are fully considered in any restoration plan.

Bankside trees and wood within the River Tat, Norfolk, have created a range of habitats, providing feeding and shelter opportunities for many different species.
© Chris Mainstone, Natural England

BOX 2.2 High-energy river environments

In upland areas, rivers are typically steep with flows driven by heavy rain and snowmelt. These high-energy conditions create river beds made up of bedrock, boulders, cobbles and gravel. The nutrient-poor waters support sparse vegetation mainly of mosses and liverworts, insects that require high oxygen levels including stoneflies, mayflies and caddisflies, fish populations dominated by salmon and brown trout, and birds such as the dipper and grey wagtail.

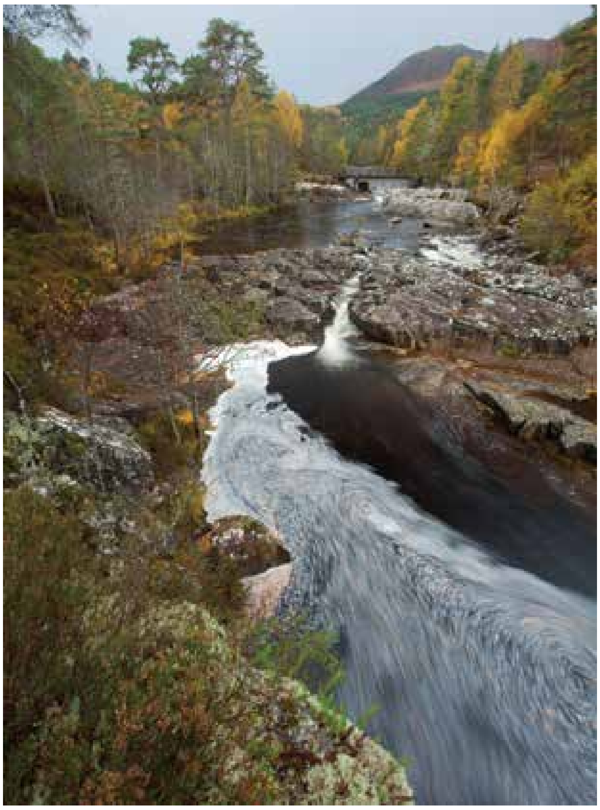
- In high-energy rivers with mobile gravel beds the high levels of hydraulic scour create conditions that are hostile for most plants. Consequently, attached algae are dominant with the larger, more stable, substrates hosting luxuriant growths of mosses and liverworts, particularly in woodland or through ravines where humidity develops. The invertebrates that live in the mosses provide a valuable food source for birds such as dipper and grey wagtail.

- Invertebrates are mostly found on or between coarse river-bed particles and commonly include a rich array of caddisflies, mayflies and stoneflies. Some of these rivers support populations of the white-clawed crayfish and a few are home to the critically endangered freshwater pearl mussel.

- These dynamic rivers create gravel bars, providing habitat for specialist assemblages of invertebrates that are adapted to life in unstable gravels. Gravel shoals are also important for early successional vegetation and birds such as ringed plover and oystercatcher.

- Birds such as dipper, kingfisher and grey wagtail are characteristic of high-energy river reaches where they feed on a variety of aquatic invertebrates including adult flies, mayflies, beetles, crustaceans and molluscs.

- Slackwater refuges, such as pools and backwaters, are an important natural component of high-energy rivers. They provide refuge for species that are not able to withstand high flows and their finer sediments (silts and sands) are essential to some characteristic species: for instance, juvenile lampreys develop in marginal silt beds, and the stonefly *Leuctra nigra* is strongly associated with silty habitats in gravel-bed streams. Riparian trees and large woody material that has fallen into the channel are critical in forming these slackwater areas.



The River Affric flowing through silver birch and Scots pine woodland in Glen Affric, Scotland. Bedrock and coarse sediment dominates this high-energy river environment.
© Mark Hamblin/2020Vision

BOX 2.3 Low-energy river environments

Low-gradient rivers tend to have slow flows and low energy levels. This results in a meandering course and a river bed lined with fine sediments and organic matter. These features are typical of lowland rivers, although low-energy streams are also found in upland areas.

- The accumulated finer sediments favour species that exploit silts and sands, such as pea mussels and unionid mussels. Submerged plants and luxuriant marginal vegetation are features that provide conservation interest in their own right but also create habitat for plant-dwelling aquatic fauna, such as the nymphs of dragonflies, damselflies and some stonefly species.
- The fish community is dominated by species adapted to slow-moving or still water, such as perch, roach and bream. These species lay their eggs on submerged vegetation, which the fry depend on for shelter.
- Fast-moving water and coarse substrates can occur where there is sufficient hydraulic energy and levels of fine sediment supply are relatively low. The critically endangered stonefly *Isogenus nubecula* is a riffle-dwelling specialist of large lowland rivers and would have no habitat if fast-flowing riffles with their coarse sediments were not present.
- Naturally shallow river-bed levels support a high water table on the adjacent floodplain, giving rise to wetland habitats such as fens, wet woodlands and species-rich wet grassland vegetation. These are among the rarest of habitats and support endangered species such as the European protected mollusc *Vertigo moulinsiana*. These habitats are often highly fragmented and are vulnerable to damage.
- Lowland chalk streams are rare habitats that are internationally important. They have extensive stable gravel river beds and characteristic plant communities: river water crowfoot and starworts often inhabit the channel, with plants such as watercress and lesser water-parsnip along the margins. The alkaline waters and extensive gravels support a wide range of invertebrates and are important habitats for fish such as brown trout, Atlantic salmon, brook lamprey and bullhead.
- The water vole is associated with low-energy rivers, living along the marginal aquatic vegetation of slow-flowing rivers, streams and ditches. However, it is also at home in upland, peatland areas where it inhabits small ditches, rivers and lakes.

The River Itchen in Hampshire is a classic example of a chalk river, supporting a range of internationally important plants and animals. Its water quality and the range of physical habitats is crucial to the wide range of species supported.
© Guy Edwards/2020VISION

SECTION 3

How has river habitat been altered by humans?

3.1 Introduction

The rivers of the UK and Republic of Ireland have a long history of alteration by humans for navigation, water and food supply, waste disposal, flood defence, settlement and power generation (Figure 3.1). The first human influences can be traced back to Neolithic times 6,000 years ago when vegetation clearance for agriculture accelerated water runoff and sediment input. Major direct modification caused by drainage, diversion and channelisation began during the Roman occupation in the 1st Century and continued into the late 20th Century. These changes have resulted in direct alteration of river shape and flow. By connecting areas of land, rivers have also been indirectly affected by catchment-scale land-use changes such as urban development, forestry and intensive agriculture [27].

Alteration of rivers has often been carried out with the best of intentions but without knowledge of the potential repercussions. Population growth and technological advance since the Industrial Revolution resulted in extensive alteration of aquatic, wetland and terrestrial habitat within river corridors [28]. Truly natural environments that have escaped both direct and indirect human alteration no longer exist. Based on River Habitat Survey (RHS) data in England and Wales combined, more than 50% of rivers have been physically modified through reshaping and reinforcement whilst in Scotland the figure is 17% [29]. In Northern Ireland more than 50% of lowland rivers have been physically modified. In the Republic of Ireland, channelisation and intensive land use are the main factors likely to place rivers 'at risk' of failing to achieve good ecological status [30].

Identifying the types and impacts of physical alteration is important for developing an effective restoration strategy. Strategies should also incorporate understanding of other pressures; for example, degraded water quality may need to be tackled in conjunction with physical restoration to ensure recovery. Often many types of alteration may be present, collectively increasing the level of degradation. For example, channel siltation could be exacerbated by excessive upstream sediment input from a cattle poached bank upstream of a weir which is already causing silt deposition.

This section gives an overview of the history and impacts of direct and indirect physical change that have affected river habitat and biodiversity.

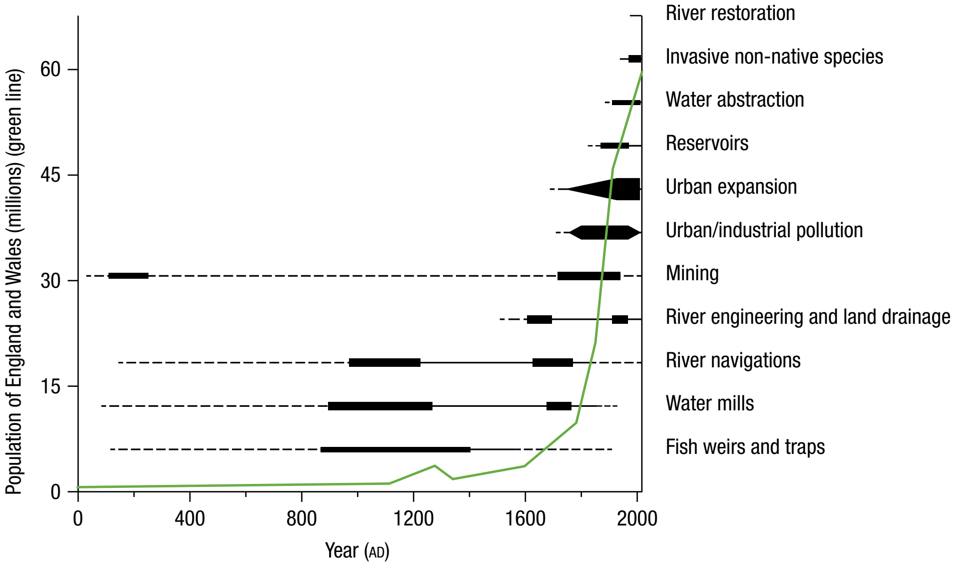


Figure 3.1 A timeline of key human actions that have altered rivers in England and Wales (from Holmes and Raven [15], © British Wildlife Publishing, used by permission of Bloomsbury Publishing Plc. and adapted from Lewin [31], © 2012 John Wiley & Sons, Ltd).

3.2 Direct alteration of rivers

River channelisation and dredging

Figure 3.2 (Left) The Flesk River, Armoy, a straightened channel in Northern Ireland (© Gareth Greer, Rivers Agency, Northern Ireland) **and (Right) a section of the River Medlock in Manchester, England, a Victorian era brick-lined channel with a uniform shape before it was restored in 2014** (© RRC).

Channelisation involves the straightening, diversion and deepening of natural rivers and the creation of artificial channels (Figure 3.2). This aids navigation, and improves drainage of agricultural land and reduces the frequency of flooding locally. Channelisation activities have a long history, but were accelerated in the last two centuries by mandates such as the Arterial Drainage Act (1945) in the Republic of Ireland and the Enclosure Acts of the mid-18th Century in England [15]. Such activity reached its peak during the mid-20th Century resulting in 8,504 km of channelised river network in England and Wales [32]. In the Republic of Ireland, low-lying areas such as the River Shannon basin have been extensively channelised to reduce waterlogging and flood risk [25]. In extreme cases during the 19th and 20th Centuries, streams and rivers were completely lined with concrete or routed underground.

The legacy of widespread channelisation of rivers means that naturally complex rivers have been changed radically; active meandering channels are less common and multi-thread channels are now very rare in England and Wales [33]. Channelised rivers have uniform shapes and river-bed sediment that create a lack of flow variability needed to sustain varied habitat for different invertebrate communities [34] and juvenile fish [35].

Another effect of channelisation is the disconnection of rivers from their floodplains which reduces the frequency of water and matter exchange with the floodplain [36]. Ironically, given the frequent flood defence aim of channelisation, this loss of temporary floodplain water storage, combined with the straight nature of channels that accelerate flow, can exacerbate flooding downstream [37].

Channelised rivers are maintained by regular dredging [37]. Aside from the immediate alteration of habitat, dredging can have longer-term impacts. Increased fine sediment loads generated by destabilised bed and banks lead to the downstream siltation of substrates that can clog the redds (egg nests) of salmon and trout [38] and deprive hyporheic macroinvertebrate communities of oxygen [39].

Gravel extraction

Gravel extraction from rivers to supply aggregate for construction purposes was commonplace between the 1930s and 1960s in Britain [40] but is rare nowadays. However, it is still widely practised to reduce local flood risk. Gravel extraction can alter the natural sizes of sediment and shape of a river. The associated habitat can be slow to recover, depending on the flow and sediment supply regimes. In extreme cases, extraction can create conditions that erode the river bed and banks (Figure 3.3). [41]

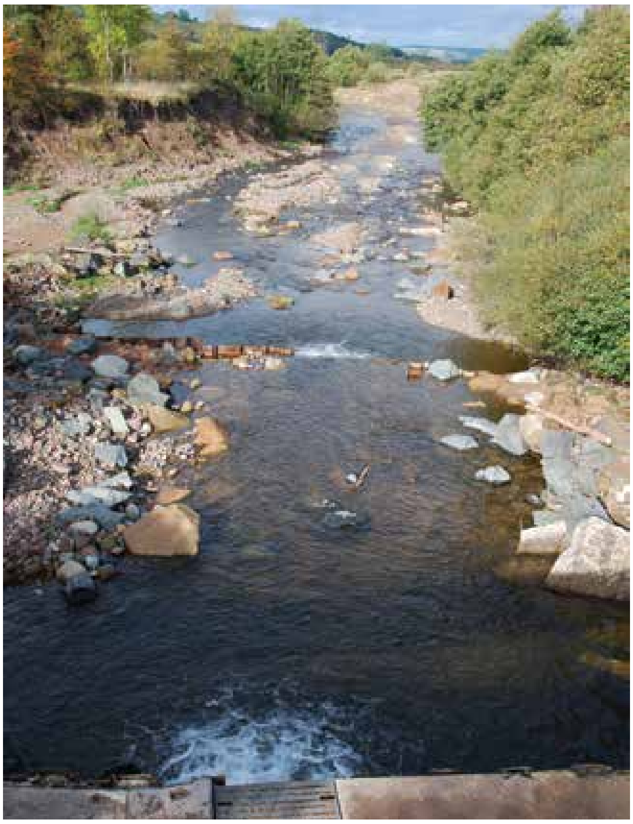


Figure 3.3 The Wooler Water in Northumberland, England. **Owing to historical upstream gravel extraction and the use of weirs (shown), the lower part of the river has been starved of coarse sediment leading to unnaturally severe channel erosion** (© Natural England).

Removal of in-stream wood

Prior to human activity, when riparian forests were much more extensive, large wood accumulations would have been a widespread feature of rivers. Until the late 1990s, when the ecological importance of retaining wood was recognised, the practice of 'de-snagging' was used extensively in order to improve navigation, and because it was thought to reduce flood risk, aid fish migration and assist drainage. Rivers without large wood tend to be wider, straighter and less biodiverse [42]. Although accumulations of wood can increase local flood risk by redirecting water onto floodplains [43], this can reduce flood peaks downstream.

Weirs and locks

Weirs were built to create ponds to supply water for mills, industry and irrigation. Locks that are used to aid river navigation have a similar effect to weirs. The use of sluices and weirs to power mills dates back to Saxon times [15] but the construction of more substantial weirs made from concrete and stone was accelerated by the requirements of the Industrial Revolution. The majority of weirs are now defunct but some are protected as heritage features and many are being modified for micro-hydropower. They significantly alter the natural character of rivers, especially in England and Wales where there are nearly 25,000 impoundments [44]. Although a proportion of the flow is able to pass over such structures, the natural movement of water and sediment are disrupted. Upstream of weirs, uniformly deep water submerges exposed bar and river-bank habitat and can reduce the abundance of certain aquatic plant communities [45]. Weirs also create unnaturally 'flat' or stepped river profiles that lead to silt deposition and attendant problems such as heightened nutrient storage [46]. Another impact of weirs is the obstruction of species movement upstream and downstream. An estimated 5,400 km of Atlantic salmon spawning habitat is inaccessible due to weirs in Scotland [15].

Other in-stream structures

Recognition both of the physically degraded nature of rivers and declining fish stocks has resulted in the construction of structures such as flow deflectors and rubble mats designed to improve habitat for fish. Croys and groynes deflect the flow and alter the natural patterns of erosion and deposition [47] which may degrade habitat and thus are no longer favoured measures. In some cases in steeper rivers with coarse beds, boulders have been removed to construct deflectors leading to a loss of in-channel flow diversity, shelter and range of river-bed sediments important for macroinvertebrate communities and fish.

Bank reinforcement

Artificial reinforcement of banks using boulders, timber, rubble or concrete aims to reduce channel movement to protect land, settlements or infrastructure (e.g. bridges and roads) and to limit sediment input from eroding banks (Figure 3.4). The occurrence of bank protection is extensive; at 63% of all RHS sites in lowland areas of the UK, banks have been reinforced [50]. Effects of bank protection include restricting a river's natural ability to erode and shift in response to floods which in turn can increase local flood risk [48]. Other physical impacts include channel narrowing leading to increased water velocities that can in turn erode river beds. The construction can lead to immediate loss of bankside habitats for example those used by water vole, sand martin, kingfisher and juvenile fish. Potential long-term effects can include a reduction in the channel and floodplain complexity needed to create diverse habitat [49]; this is of particular concern when both banks are reinforced.

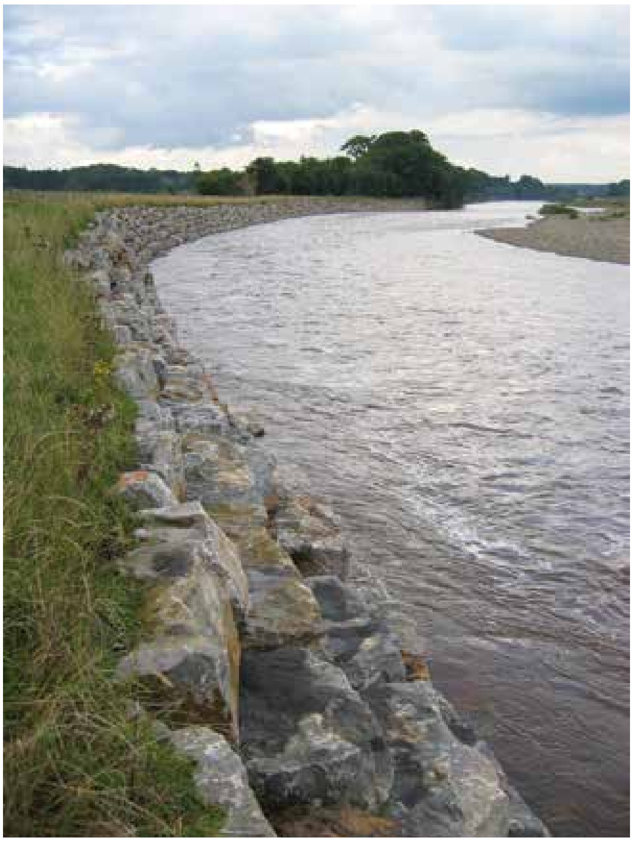


Figure 3.4 (Above) Bank reinforcement to stop natural erosion constructed from boulders on the Ewes Water, Dumfries and Galloway (© Martin Janes, RRC) **and (Below) using corrugated iron and rubble on the River Dee, Aberdeenshire, Scotland. The River Dee bank reinforcement was removed in October 2015 to improve connectivity with the floodplain** (© James Hutton Institute).

Flood embankments

Figure 3.5 A flood embankment next to the Finn River, Clady in Northern Ireland. Flood defences prevent the natural exchange of water and material between a river and its floodplain (© Gareth Greer, Rivers Agency, Northern Ireland).

Flood embankments or levees built using earth or concrete are designed to prevent rivers naturally spilling onto their adjacent floodplains (Figure 3.5). Flood defences have been constructed and maintained for centuries but with increased demand for floodplain development (e.g. urban settlement), the height and extent of flood embankments increased during the 20th Century. RHS data from 5,612 sites surveyed throughout the UK and Isle of Man, showed that 14% were associated with embankments[50]. Embankments confine flow causing further incision and reduced floodplain connectivity and can exacerbate flood risk downstream. For example, a model-based study of the River Cherwell in Oxfordshire estimated that embankments reduced floodplain water storage and increased peak flows downstream by 50-150%[51].

Alteration of riparian and floodplain areas

The development of floodplains for agriculture, urban settlement and industry diminishes the natural character of these areas and is often associated with channelisation, bank reinforcement and flood embankments. The act of removing vegetation on floodplains dates back to Neolithic times. In England, the large-scale draining of floodplain wetlands started during the Roman period but accelerated during the 1600s and peaked during the mid-20th Century[5,15]. Drainage and infilling resulted in the loss of wetlands, backwaters and side channels meaning that these floodplain habitats are now very rare in lowland areas. Owing to vegetation clearance it is estimated that 25% of the total bank length of rivers in England and Wales has no or very little bankside tree cover; floodplain forest dominated by alder is now a very rare habitat. Species-rich floodplain meadows are also a very rare type of habitat with only 1500 ha remaining in England[52]. Riparian vegetation communities, as well as being an important component of river corridor biodiversity, strengthen river banks because of the reinforcement from roots and in turn help to determine the morphology of rivers. When banks are covered by short grass rather than trees, they are relatively less resistant to erosion, increasing the likelihood of rivers to widen and divide[53]. Loss of bankside tree cover also reduces shading needed as refuge for animals during hot weather predicted under climate change[54] and reduces the potential for wood material input to the adjacent river.

3.3 Other causes of river alteration

Land use

Beyond river corridors, the way in which land is used can have a long-lasting effect on the input of water and sediment to rivers (Figure 3.6). Intensive agriculture or urbanisation can reduce evapotranspiration rates and soil water storage leading to accentuated peak flows and reduced baseflows. In extreme cases, especially

Figure 3.6 (Above) Overland water runoff and transport of fine sediment from areas used for agricultural production (© SNH/Lorne Gill) **can (Below) cause problems of siltation in river channels** (© Gareth Greer, Rivers Agency, Northern Ireland).

where there are impervious surfaces associated with urban development, accelerated runoff can lead to river channel erosion and enlargement creating unnatural river morphology and habitat [55]. Although the effects vary between catchments, the diversity of algal, invertebrate and fish communities can be adversely affected owing to degraded water quality and unnatural flow regimes when the area of impervious surfaces approaches 10% of the catchment area [56]. Diffuse sediment input from areas used for agriculture – particularly tillage, or forest plantations with dense drainage networks – increases sediment yields leading to problems of river-bed siltation and altered morphology. In some upland areas of Northern England for example, coal and metal spoil heaps left behind from 19th Century mining have been eroded by rivers leading to dramatic sedimentation followed by erosion [57]. Where there are toxic deposits in these released sediments, they can pollute rivers and reduce the diversity of macroinvertebrate communities [58].

Physical alterations caused by non-native plants and animals

As well as directly harming native plants and animals through competition, predation or the spread of disease, invasive non-native species can directly damage the physical environment. Common invasive plants that inhabit river banks include Japanese knotweed, Himalayan balsam and giant hogweed (Figure 3.7). When these plants die in the winter, bare earth is exposed making it more prone to erosion leading to the excessive deposition of fine sediment in rivers [59]. Invasive aquatic macrophytes are also highly damaging by slowing flows and trapping sediment. Controlling these established plants poses a considerable challenge and the spread of new invasive plants may create further problems in future.

The American signal crayfish was introduced to England in the 1960s and has spread as far north as Inverness, Scotland. As well as damaging native white-clawed crayfish populations, they can alter in-channel habitat by digging burrows that can undermine river banks, loosen substrate and in turn increase sediment loads downstream [60]. The Chinese mitten crab is also highly disruptive and can destabilise river banks through burrowing. It was introduced to England in the 1930s and was found in the south of the Republic of Ireland in 2005 and the River Clyde in Scotland in 2014.

Climate change

Rivers are highly sensitive to altered temperature and precipitation regimes and are therefore vulnerable to the effects of climate change. Potential effects include more frequent extreme flows that could affect physical habitat stability as well as water quality [61,62]. These effects alter habitat, species abundance, composition and distribution [63] and the connectivity between water bodies [64].
Projections of climate change can inform high-level discussion about when or where river habitat and biodiversity may change. For example, reduced summer rainfall and increased evaporation may put stress on river and wetland plant communities and fish. In the UK, rain-fed wetlands and rivers in the south and east have been predicted to be especially affected [65].

Dams and flow regulation

Dam building to create reservoirs for drinking water, electricity generation and flood control accelerated in the 19th Century. Using a minimum height criterion of 15 m, at present there are 596 dams in the UK and 16 in the Republic of Ireland [e]. Dams fragment rivers and disrupt the natural movement of water, sediment and biota [66]. As well as submerging upstream areas, dams and the associated unnatural flow regimes have marked impacts downstream (Figure 3.8). Effects include disruption of the natural flow variability needed to trigger certain ecological behaviour – for example, spates that encourage the upstream migration of fish. In extreme cases, no compensation flow is provided meaning that river health is severely degraded.

Figure 3.7 Giant hogweed is a common invasive plant that as well as directly harming native biodiversity through competition, can degrade river banks and habitat (© Invasive Weeds Agency).

Figure 3.8 Laggan Dam, Highland, Scotland. By altering the pattern of natural flows and sediment movement, dams and associated flow regulation can affect habitat downstream (© James Hutton Institute).

Although impacts on physical habitat depend on the characteristics of each river [67], a reduction of floods able to transport sediment and re-generate habitat is another facet of changed flow regimes. For example, in the upper River Spey, Scotland, impoundment and flow regulation since the 1940s has resulted in channel narrowing, reducing the habitat area available for spawning salmonids [68]. The reduction of floods can also stabilise mobile gravel bars and increase riparian vegetation cover, but with a lower species diversity than an unregulated river [69]. A reduction of sediment supply caused by the trapping effect of dams is another common problem that can lead to the development of 'armoured' river beds [41]. These conditions can reduce habitat for spawning fish [41] and macroinvertebrate communities [70].

What are the benefits of river restoration?

4.1 Introduction

In addition to the rich biodiversity supported by rivers (Section 2), they provide many benefits and services to humans. The benefits of naturally functioning rivers include goods such as clean water for drinking[71] and ecosystem services such as water purification and flood regulation (Figure 4.1) which are crucial for human survival. The essential role of water is reflected in our towns and cities today, many of which originated and developed alongside rivers.

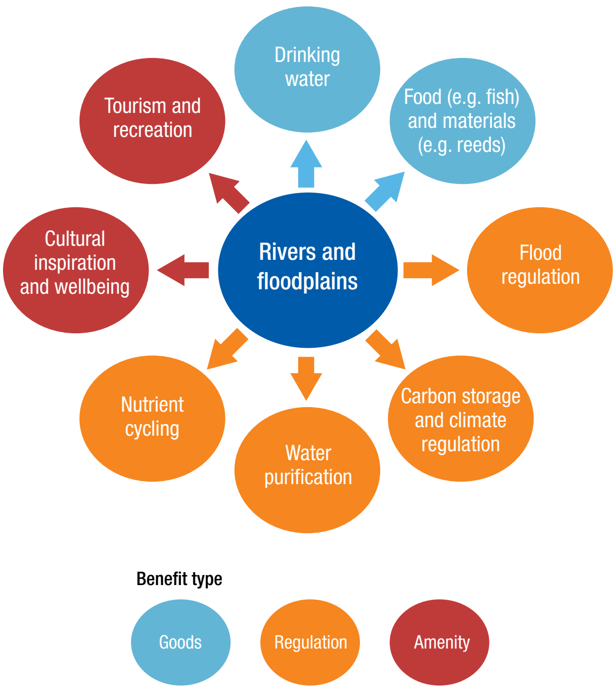


Figure 4.1 **Benefits to society provided by rivers and floodplains. Poor management of our rivers could lead to over-exploitation of some of these benefits causing damage to the health of the river and the biodiversity it supports. Conservation and restoration strategies are needed to protect and reinstate the natural function of rivers to achieve this widespread range of benefits.**

Characterising the 'natural capital' provided by rivers is a useful starting point for devising strategies to safeguard, restore and sustainably use the ecosystem services they provide[72]. Understanding the goods and services provided by rivers and their floodplains also gives an indication of the multiple benefits that their restoration can bring.

Naturally functioning rivers are economically important. A study of recreational angling in the Republic of Ireland commissioned by Inland Fisheries Ireland in 2013, estimated that angling for Atlantic salmon and sea trout was worth €750 million to the economy and supported 10,000 rural jobs[73]. Consequently, the protection and development of sustainable fisheries is a major driver of river management.

The benefits of natural environments – including river corridors – for our physical and mental well-being have also been recognised. The UK Department of Health encourages integration of the environment and health through the 'Confident Communities, Brighter Futures' programme. In 2008, Natural England started the 'Natural Health Service' campaign. Being able to enjoy inspiring natural areas can benefit human health and aid recovery from illness[74]. Realising the potential benefits, the Environment Agency in Wales (now Natural Resources Wales) set up the Splash Fund in 2013 to improve access to rivers and other water environments[f].

4.2 Measuring the success of river restoration

Demonstrating success is integral to any river restoration project. Using sound scientific approaches that measure ecological, hydrological and geomorphic processes enables us to compare conditions before and after restoration, and over longer timescales[75]. Evaluating success and learning lessons are critical to understanding how we can best protect and restore rivers. An overview of monitoring methods is given in Practical Monitoring Guidance[76] which provides advice on commonly used methods (e.g. Figure 4.2). Some of these methods such as mapping of river habitats (e.g. using RHS) and fixed point photography require minimal training and are relatively low cost. Ideally monitoring should be carried out before and after actions are undertaken and over a sufficient length of time to allow the changes to be assessed.

Sharing experiences of river restoration is essential to developing new and better river restoration work and showing the benefits it brings. Knowledge sharing hubs like the European Centre for River Restoration website[g] and the River Restoration Centre's National River Restoration Inventory[h] help to make this information easily accessible and widely used.

By restoring river processes and physical habitat, the expectation is that everything will benefit and the decline of high-profile species such as the Atlantic salmon, kingfisher, water vole, and otter will be halted. These well-known 'indicators' also help to promote the reasons for restoring rivers[12].

Figure 4.2 (Left) Electrofishing to monitor fish (© Judy England, Environment Agency). **(Right) Macroinvertebrates collected in a net from a kick sample** (© Judy England, Environment Agency). **Both monitoring techniques are commonly used to evaluate ecological response to river restoration work.**

4.3 Public perception of river restoration

Rivers are an integral and recognisable part of the local environment. However, over time as they have been damaged by human activities (Section 3), people's perception and connection to rivers has changed. River restoration can play an important role in reconnecting people with rivers and re-establishing the social benefits associated with natural environments (Figure 4.3).

Public perception surveys are a useful means of capturing the social benefits from river restoration. Following restoration of the River Ravensbourne, south London, visitors to Ladywell Fields urban park increased by over 250%, and 78% of visitors felt 'safe' or 'very safe' in the park after restoration compared with 44% before[77]. After the restoration of the River Quaggy, south-east London, 89% of visitors to Chinbrook Meadows thought that the restoration had improved the park[78].

Public perception surveys of the River Skerne restoration project provide a useful long-term study of attitudes towards river restoration[79]. Surveys were carried out in 1995 before restoration to record expectations, in 1997 to capture initial impressions and in 2008 for a long-term view. The after-restoration surveys showed that 82% and 90% of respondents in 1997 and 2008 respectively were satisfied with the project. The project led to an increase in visits to watch wildlife (from <20% in 1995 to >30% in 1997) and an increase in recreational visits. In addition, 40% and 59% in the 1997 and 2008 surveys respectively, felt there was increased recreational value. Among the benefits mentioned by local residents were the improved scenery and the increase in wildlife. This public perception survey highlights the importance of long-term involvement with local communities to create interest in restoration projects and a sense of care for their local environment.

Figure 4.3 (Left) The restored River Quaggy and Chinbrook Meadows, south-east London (© Environment Agency) **and (Right) the restored River Skerne in Darlington, County Durham, England in 2005, 10 years after restoration work began** (© RRC). **Both river restoration projects have been well received by the general public.**

4.4 Case studies of river restoration

The following case studies illustrate the habitat, biodiversity, social and economic benefits from river restoration. All of the case studies show positive habitat responses and some show positive species responses. Combined with the often positive social impact of projects, these case studies show that a high return on investment is possible.

The Rottal Burn, Angus, Scotland [80, 81] [i]

Project summary

The Rottal Burn is an upland, high-energy gravel-bed tributary of the upper River South Esk. The South Esk and its tributaries are designated as an SAC for populations of Atlantic salmon and freshwater pearl mussel. Channelisation of the lower 1.2 km section of meandering river in the 1850s to protect agricultural land from flooding reduced habitat area and floodplain connectivity and steepened the burn, resulting in higher flow velocities. The natural self-recovery of the river was suppressed by the entrenched nature of the channel and repeated dredging that was needed to remove the chronic accumulation of sediment. Although spawning habitat for trout and Atlantic salmon remained, the unnaturally uniform channel conditions limited the extent of juvenile habitat. Electrofishing surveys showed a degraded fish population and the migration of Atlantic salmon returning to sea as smolts from one of the key areas for fish production in the upper South Esk catchment was limited.

With co-operation from a landowner and £100,000 of funding from the SEPA Water Environment Fund, the Esk Rivers Fisheries Trust and specialist consultants devised a plan to restore the channelised section to a meandering course. The main aim was to reinstate habitat for Atlantic salmon and trout in order to bring wider economic benefit through angling opportunities. Using historical maps as a guide to design a natural meandering river, the new channel was constructed in Autumn 2012. The occurrence of high flows led to greater than anticipated river movement shortly after works were completed, creating a diverse habitat.

Biological and habitat benefits

Within weeks of completion, otters were using the burn and in 2013 spawning fish were observed. Increased densities of salmon and trout fry and parr were also recorded. The quality of fish habitat is expected to improve in the long term due to increased shading provided by riparian trees and shrubs; continued monitoring using electrofishing will help to validate this. Although in the short term macroinvertebrate abundance and species richness have been reduced by the ground works, early monitoring results (University of Stirling) indicate a greater diversity of species in the re-meandered channel. The new communities reflect the increase in habitat diversity that include finer sediment and low-velocity depositional areas. A comparison of sample results from 2013 and 2015 shows an increase in the abundance and diversity of invertebrate taxa due to re-colonisation and successional processes.

A future prospect is the natural re-colonisation of the restored section by freshwater pearl mussels. Successful re-colonisation would be a strong indicator of the success of the restoration and achievement of high water quality.

Other benefits

Using economic valuation techniques, prediction of the monetary benefits of the Rottal Burn restoration scheme over a 25-year period suggests a good return on the investment. This includes £198,000 from salmon productivity, £83,000 from flood mitigation and £28,000 from education.

The Rottal Burn before, during and after restoration work was completed to restore the former meandering river in Spring 2012. (Before, During and Immediately After restoration photos © SEPA; After restoration and first flood image © Kenny McDougall, EnviroCentre).

Eddleston Water, Scottish Borders, Scotland[j, k]

Project summary

The Eddleston Water is a tributary of the River Tweed (SAC) in the Scottish Borders. The river was channelised during the early 19th Century and this, together with agricultural intensification, has contributed to increased flood risk in the towns of Eddleston and Peebles. Owing to the historical channelisation and low-energy status of the channel (which limited self-recovery), the river was classified as 'bad' ecological status under the WFD. To address these issues, a partnership led by the participative catchment NGO Tweed Forum, along with the Scottish Government, SEPA and the University of Dundee devised a catchment scale plan to implement river restoration and remedial land management actions to improve biodiversity and reduce flood risk. A second motive was to use the project as a 'flagship' demonstration of the benefits of partnership working and close involvement with landowners to coordinate actions across a catchment while maintaining the productivity of farm businesses. To evaluate hydrological changes and reduction of flood risk, a detailed monitoring network was set up by the University of Dundee in 2011 before works began, alongside groundwater monitoring by the British Geological Survey. Detailed ecological responses to the restoration actions are being monitored through a before-after-control-impact design. Monitoring consists of detailed species-level macroinvertebrate sampling and macrophyte surveys by SEPA and electrofishing by the Tweed Foundation.

Actions on the ground involving 12 farms began in 2013 and are still continuing. Funding for work to date has amounted to £400,000 from a variety of sources including the Water Environment Fund, Scottish Rural Development Programme, Scottish Government, Scottish Borders Council, Carbon Futures and the Woodland Trust alongside voluntary landowner contributions and local businesses. So far in upland areas with lower productivity, 66 ha of native broadleaved trees have been planted with 56 wooden structures installed in streams, to attenuate flood peaks and improve habitat. Lower downstream, on the Eddleston Water itself, three reaches totalling 1.8 km in length have been re-meandered and additional backwater features have been added to improve floodplain habitats and further reduce peak flows. Thirteen 'leaky ponds' have been constructed totalling 5000 m^2 to temporarily store water during intense rainfall events.

Biological, habitat and flood risk benefits

At the Cringletie and Lake Wood restored reaches, the presence of redds indicates the suitability of the new river-bed habitat for spawning trout and Atlantic salmon. Assessment of macroinvertebrate samples taken by the University of Dundee at the two reaches showed tentatively that the diversity and abundance of families has increased, reflecting improved habitat diversity. Continuing monitoring at a species level within both the restored and control reaches will help establish more conclusively any long-term change in macroinvertebrate communities. Hydrological modelling to date shows that the newly recreated meanders can store extra flood water and the wooden structures can delay flood peaks by up to an hour.

Other benefits

Water-body status for the Eddleston Water under the WFD classification system has improved from 'bad' status through 'poor', to 'moderate'. In the region, the project has greatly raised the public profile of using proactive measures that work with natural processes to improve habitat and reduce flood risk.

Recently completed actions in the Eddleston Water catchment photographed in 2014. (Left) Tree planting of a headwater stream to reduce flood risk downstream and improve river corridor habitat and (Right) a restored backwater at the restored meandering reach of the Eddleston Water at Lake Wood (© Ulrika Åberg, RRC).

The River Cole, Thames, Oxfordshire and Wiltshire, England[82] I

Project summary

The River Cole is a lowland tributary of the River Thames with low energy and fine river-bed sediment. The Cole has a long history of modification for milling and agriculture, typical of other rural rivers in the UK. Centuries ago, the river was affected by channel realignment to divert water to a mill. Downstream of the mill the river was straightened and deepened.

The River Cole restoration project was included in an EU LIFE funded urban and rural river restoration demonstration initiative between England and Denmark. The aim of the Cole scheme was to restore the original meandering course of the river to improve its visual appearance, habitat diversity for aquatic species and floodplain storage of flood water. The wider aim of the initiative was to demonstrate the multiple benefits restoration can provide when managing catchments. Completed in 1997 at a cost of £200,000, the river was re-meandered by excavating the old course (where obvious) or a new channel. In addition, backwater features and reedbeds were created by retaining sections of the old channel, and adjacent land management practices were changed to benefit the re-establishment of floodplain grazing meadow. In total 1.3 km of new channel was created and 1.2 km was restored. In 2008, gravel and woody material was added to further restore in-channel habitat.

Biological and habitat benefits

Evaluation showed a rapid positive change to physical habitat diversity and an increased frequency of flood water storage. Ecological responses were also positive. Fish biomass and density returned to pre-restoration levels and there was an increase in plant species richness. In the areas fenced for grazing and arable land use in the lower reach, natural recovery of a complex woody riparian zone developed rapidly. However, for 20 years, cattle grazing (even at the low density specified by environmental stewardship) has prevented the establishment of riparian vegetation in the upper open grazed section. Macroinvertebrates quickly recolonised, and one year following restoration species richness was only slightly below pre-restoration values and rarity of species was significantly lower compared with the pre-restoration channel. In 2009 (12 years following ground work), additional niche-specific macroinvertebrate taxa were found in the downstream reach but fish density showed an overall decline owing to a lack of vegetation, cover and the presence of cattle.

Other benefits

In a public perception survey undertaken in 1997, 70% of residents living in Coleshill were satisfied with the restoration work. In contrast when the survey was repeated in 2008, 50% of residents were satisfied. The reduced support was explained by the lack of local community participation since the start of the project. This emphasises the importance of making communities aware of project aims and including them during decision making to create a sense of pride and ownership in river restoration.

(Left) Flood spillway feature in action to reconnect the floodplain and improve temporary floodwater storage on the River Cole, Oxfordshire, England in 2012 and (Right) a wildflower meadow in 2004 restored by improving land management practices next to the River Cole (© RRC).

River Wensum, Norfolk, England (83) m

Project summary

The River Wensum is a low-energy chalk stream that is designated as an SAC because of its population of white-clawed crayfish and its *Ranunculus* habitat. It is also designated as a river SSSI because of the importance of its chalk river habitat. However, the river network has been altered over time through dredging, the installation of water-mill sluices and siltation caused by intensive agriculture that has degraded the physical habitat. As a result, the river was failing its WFD targets and its SSSI ecological condition was 'unfavourable'. To tackle these issues, the River Wensum Restoration Strategy partnership comprising the Environment Agency, Water Management Alliance and Natural England was formed in 2008 to produce a restoration plan for the whole of the River Wensum. By August 2015, 15 km of channel had been restored through actions including re-meandering, reconnecting old meanders, adding in-stream gravel and wood placement.

One site of significant restoration has been at Great Ryburgh. Previously the meandering river channel here was disconnected by an engineered bypass channel constructed in the early 1950s. Flows in the engineered channel were slow and uniform, resulting in siltation of the river bed. The old meander loop also silted up and became partly obscured by vegetation. A detailed design was developed by specialist consultants to restore natural functioning, form and processes in the meander loop and downstream engineered channel. In Autumn 2010, actions undertaken included reconnecting flow from the main channel and a field drain into the old meander loop, restoring natural channel cross-sections, adding gravel and placing woody material. The new channel was designed to be self-sustaining so that future maintenance would not be required.

In 2014, the River Wensum river restoration project won the England River Prize (now UK) created to reward leading examples of river restoration in the UK.

Biological and habitat benefits

At Ryburgh loop, initial macrophyte surveys completed less than one year after restoration yielded 31 aquatic and marginal plant species including a number associated with chalk streams. Macroinvertebrate sampling indicated the rapid establishment of a species-rich assemblage and a number of the taxa associated with fast to moderate flows and gravel river beds such as *Goerid* caddisflies and the mayfly *Serratella ignita*. Fish surveys recorded the presence of 31 fish in the straightened channel before restoration. In 2011, after restoration, 384 fish were recorded in the re-established meander loop. These included brown trout and target species such as bullhead and brook lamprey. A follow-up survey in 2013 showed a similar improvement in fish populations.

Other benefits

The project has helped to produce multiple benefits of reduced flood risk and increased amenity value for the public. By creating self-sustaining river channels, river maintenance costs have been reduced.


The River Tat, a tributary of the River Wensum, (Left) before and (Right) after bank re-profiling and gravel placement in 2010 to restore channel sinuosity and varied river-bed levels (© Adam Thurtle, Environment Agency).

Kentchurch Weir, River Monnow, between Herefordshire and Monmouthshire, Wales-England border [84, 85] n

Project summary

The Kentchurch Weir was situated in the upper reaches of the River Monnow, a high-energy, gravel-bed river. Redundant since the 1970s, the 2.6 m high weir was the last remaining barrier to fish passage on the Monnow, which had excellent but inaccessible river habitat upstream. The weir was also disrupting the natural movement of sediment and water. A strategic study of fish passage barriers within the River Wye catchment determined that by removing the weir rather than creating a fish pass, there was the potential to reinstate full habitat connectivity in addition to restoring continuity of physical processes and characteristic biodiversity.

The Kentchurch Weir removal project is one of the largest of its kind, costing a total of £75,000 (including weir removal and bank stabilisation). The weir was completely removed in 2011 and excavated material was re-used locally for track construction. Good communication between the project team and the contractor with the local fisheries groups and landowners kept stakeholders informed of the contractors' operations that were likely to disturb sediment.

Biological and habitat benefits

Evaluation by Environment Agency Wales (now Natural Resources Wales) has shown that weir removal has enabled access for fish to spawning grounds within the upper 160 km of river network. Habitat for macrophytes and invertebrates is expected to have been restored and natural processes of erosion and deposition are being allowed to reshape the river. Morphological effects monitored in partnership with Cardiff University over two years have shown the growth of point bars and deposition over the bed downstream due to movement of previously trapped sediment deposits.

Other benefits

The evaluation of the morphological effects of the weir removal has contributed towards better understanding of the processes associated with this type of restoration action. The natural re-adjustment of the channel suggests that future weir removal projects for rivers of this type do not necessarily need to include significant bed and bank re-profiling interventions after demolition. Furthermore pre-intervention assessment of trapped sediment deposits showed that fine sediment release created by the weir removal was less of an issue than anticipated.

(Left) before and (Right) after the River Monnow was restored through weir removal downstream in 2011. This restored natural river-bed levels and a diversity of flow that contrasted with the deep and uniform habitat that previously existed (© Natural Resources Wales).

Mayes Brook, London Borough of Barking and Dagenham, England (86)o

Project summary

The Mayes Brook is a stream that runs through Mayesbrook Park in north-east London. Realigned when the park was built in the 1930s and culverted along much of its length, natural stream functioning was severely limited and the stream was inaccessible due to metal fencing. The Mayesbrook Park Landscape Master plan for the UK's first Climate Change Adaptation Public Park was launched in July 2010 with the aim of creating a multifunctional landscape to produce benefits for people, biodiversity and flood storage within a city environment. The aim of the Phase 1 river restoration was to realign the brook through the park, create more natural bank profiles and reintroduce meanders, backwaters and ponds. Through these actions it was hoped that the Mayes Brook and its restored floodplain and wetlands would become an ecological and community focal point that would contribute to local urban regeneration.

In 2011, 1 km of the Mayes Brook was restored and 1.5 ha of new floodplain created, with riverside wetland creation and woodland planting enhancing habitat and providing an additional 15,800 m^3 in flood storage capacity. The restoration actions were completed in autumn 2011 at a cost of £1,646,000. Other actions included renovating the park facilities and, along with interpretive displays, creating opportunities for the public to learn about the natural environment and adaptation to climate change.

Biological and habitat benefits

Fish, macroinvertebrate, habitat and morphology survey data collected before restoration have provided a baseline for assessing the long-term responses of the project. Follow-up RHS surveys in summer 2012 and spring 2013 have shown an increase in abundance and diversity of habitats and flow types. Continuing monitoring of macroinvertebrate communities will help to assess the ecological response.

Other benefits

The Mayesbrook Park project has shown an alternative to traditional hard engineering approaches to urban channel management and has given priority to the public and biodiversity. The project has successfully achieved its public, private and voluntary sector objectives. An ecosystem services assessment and the ecologically-focused master plan helped build the case for restoration. The ecosystem services assessment suggested a long-term return to society of at least £7 for every £1 spent. Benefits included improvement of resilience to climate change and flood regulation. Extensive public engagement is highlighted as key to the project's success so far and to the future of the park.

Before (Left) and (Right) after restoration in Autumn 2011 of the lower reach of the Mayes Brook (© Nick Elbourne, Royal Haskoning).

River Tolka, Fingal County, West Dublin, Republic of Ireland [p]

Project summary

The River Tolka runs through the north side of Dublin and is the second largest of the three rivers that flow through the city. In the past, parts of the river were straightened to alleviate flood risk and water quality was adversely affected by pollution from industry and urban development. The river is also currently threatened by continued dredging operations and invasive plant species. Within the city limits, work has been undertaken by Dublin City Council to create a park and tackle pollution problems. Further upstream in the suburbs at Castlecurragh, river restoration actions under the direction of Fingal County Council have been undertaken as part of a park development plan for an adjacent housing estate.

At Castlecurragh, a choked old meander was reconnected in 2002 and 2003 as part of the development works. Fisheries enhancement measures were implemented in 2006 by adding gravel to the channel to encourage spawning by brown trout and by excavating some deeper holding pools for mature fish. Landscaping was undertaken to improve river–floodplain interaction, create ponds and improve topsoil conditions for natural plant colonisation.

It is recognised that careful future management of invasive non-native plant species and dredging operations are needed to minimise adverse impacts on biodiversity.

Additional pond enhancement has also been suggested to increase habitat for aquatic vegetation and nesting birds in the future.

Biological and habitat benefits

At Castlecurragh, both adult and juvenile brown trout have been observed using the restored meandering channel. Other key species including otter, kingfisher and different types of bat have been recorded indicating the positive long-term biodiversity response to the restoration actions. Vegetation colonisation in the floodplains has been rapid without resorting to sowing or planting of typical floodplain plants, and the landscaped floodplain is now covered with dense willow scrub as a result of natural succession processes.

Other benefits

In addition to creating greenspace that is attractive to visitors, the amenity value of the park has been enhanced through the construction of pathways around the perimeter and elevated walkways that allow visitors to experience the park without damaging sensitive habitat. The visitors' experience is based around walking, jogging, cycling and fishing all year round. Visitors can look into the park from the higher grounds, while some will walk the informal track along the river.

(Left) a restored section of the River Tolka at Castlecurragh in 2006, four years after restoration and (Right) brown trout caught in the restored meander during an electro-fishing survey in 2003 (© Hans Visser, Fingal County Council).

SECTION 5

How do we restore rivers?

5.1 Introduction

The earliest efforts to restore river habitat date back to the early 20th Century and were mostly motivated by the interests of fishery boards [87]. There are now many examples across the UK and Republic of Ireland that have been undertaken for different reasons (Figure 5.1). This diversity reflects the growing influence of evolving policies and the range of techniques available to achieve different objectives. Earlier projects used techniques that artificially altered river form to rapidly improve physical habitat rather than prioritising natural processes that sustain complex and dynamic habitat [88].

Widely used habitat enhancement structures include flow deflectors, rubble mats, boulder clusters, artificial riffles and fish cover, constructed from stone, concrete and wood. Evidence of rapidly increased physical habitat diversity has been widely shown but diversity and abundance responses of fish populations [89, 90] and macroinvertebrate assemblages [34, 91-93] have varied. These techniques are now less favoured because they:

1. Focus on the requirements of a narrow range of river forms, habitat or species and do not directly tackle the causes of the problem which can limit restoration [27, 34];
2. Are typically constructed on a small spatial scale, meaning that their influence is limited (i.e. typically at a reach scale);
3. Require regular maintenance to prolong their lifespan [94].

Previously these techniques were favoured due to a lack of funds, guidance, and uncertainty over the effectiveness of measures and a lack of catchment-scale planning. Experiences and lessons gained from earlier practice have been used to refine the current favoured approach to restoration: prioritising techniques that encourage the self-recovery of habitat by natural processes [88]. In turn this can restore natural habitat and functioning for the benefit of characteristic biodiversity (Box 1.1).

There are several advantages of restoring river processes [5, 88, 95]:

1. It focuses on tackling the causes of degradation rather than the symptoms of it;
2. It results in conditions naturally more in keeping with a given part of a river and therefore characteristic biodiversity;
3. It results in dynamics and habitat conditions that are more resilient and sustainable than engineered channels or habitats particularly in the face of climate change (Box 5.1);
4. Construction and maintenance costs are reduced as habitat diversity and dynamic processes are accepted as desired traits;
5. It is more likely to achieve wider ecosystem benefits for multiple objectives rather than benefiting limited habitat types or species.

In the long term, restoring natural processes by using minimal intervention is more sustainable and helps to re-establish characteristic high quality habitat.

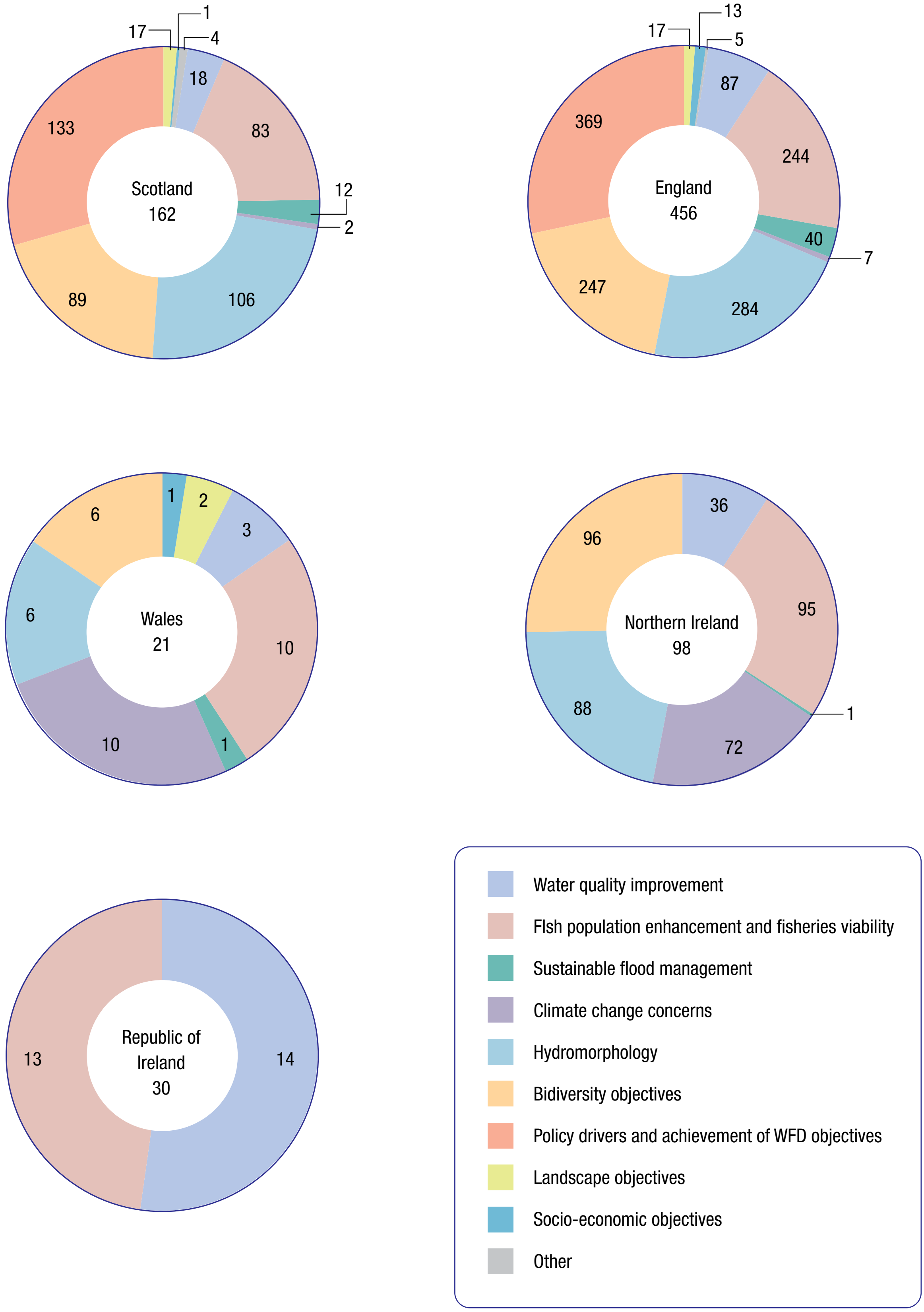


Figure 5.1 Motivations for river restoration projects, by country (adapted from Griffin *et al.* [10]). The number of projects examined is presented in the centre of the charts and the proportions of reported motivations are presented around the outside. Data for the Republic of Ireland are limited and therefore poorly reflect the range of motivations.

BOX 5.1 Restoring river resilience to mitigate the effects of climate change

A resilient ecosystem is one that can freely adjust to accommodate an environmental change. Restoring the resilience of rivers is regarded as a key means of tackling the potential impacts of future climate change. For example, by restoring river corridor woodlands, resilience is enhanced through maintaining the connectivity of biological communities and shading from rising temperatures [96].

Improving the hydrological resilience of rivers through restoration could also help to reduce flood risk [1]. Under climate change, a greater frequency of peak flows is expected [97]. One way to mitigate this would be to reconnect rivers to their floodplains and remove bankside constraints to allow channel movement. Rivers that are connected with their floodplains will help to store water, reducing flood risk downstream. Removal of lateral constraints also allows rivers to freely adjust their size to the prevailing flows and input of sediment [48]

The Insh Marshes in Strathspey, Highland. Flood-water storage provided by the Insh Marshes is estimated to provide an average annual saving of £83,000 in avoided downstream flood damage [98] (© Lorne Gill/SNH).

5.2 Planning and implementing techniques to restore river processes

By considering river processes at the catchment scale, appropriate measures can be implemented in the best locations. This means both local and catchment-scale benefits are possible. Box 5.2 summarises a generic three step approach to planning effective process-based river restoration. The planning process used for the English river SSSIs gives an example of applying these principles in practice[99].

BOX 5.2 Planning river restoration

There are three major steps for planning any effective river restoration strategy[8]:

1. **Achieve a geomorphological, hydrological and ecological understanding of restoration needs within the catchment context.** This requires identifying the causes of degradation to determine which alterations are limiting natural river habitat. Sometimes the causes of degradation may be occurring upstream or downstream of a site of interest or the degradation may extend far upstream or downstream from the source. An assessment also helps to identify the features and processes that would be naturally expected and in turn understand the restoration potential. Identifying 'reference' reaches of the same river type can be a useful approach for gauging the potential outcome of restoration action and setting a restoration target or 'benchmark'[4]. Any overriding problems – for example, poor water quality – that may limit self-recovery also need to be addressed. Together, these considerations contribute to the initial selection of appropriate restoration sites and techniques.

2. **Account for socio-economic constraints and opportunities.** These in turn determine which of the potential restoration sites and techniques identified in the first step are possible[8]. Attempts to introduce novel management can encounter challenges as existing interests, ways of working and understanding need to be overcome[100]. For example, different groups may have different motivations for restoration since it is not a single clearly defined idea; these differences can affect judgement of which activities or measures should have priority, and expectations of how success is measured[101]. Patterns of existing land tenure and rights can also affect the likelihood or ease of restoration. Establishing early dialogue with landowners and communities is vital to overcoming these barriers and gaining support, for without it restoration cannot proceed[102, 103]. Dialogue should also include non-environmental sectors and interests such as hydropower companies or those shaping agricultural subsidy schemes[104]. Explaining the multiple benefits of restoration during negotiation, potentially using the language of ecosystem services (Section 4) may help to stimulate new interest and support. Social and economic assessment should also account for all of the project risks, costs and benefits of proposed actions to ensure an acceptable return on investment.

3. **Define clear goals, timescales for recovery in response to selected restoration actions, and outcomes of any agreed river restoration actions.** These aspects should be based on the understanding of the likely responses to the proposed restoration. These in turn feed into the design, implementation and evaluation strategy of a project[105].

Using a model to involve the public in decision making for restoration plans for the Mayesbrook project, London (© RRC).

Measures to restore river processes include direct actions; for example, removing a structure that is preventing natural processes from occurring, and indirect measures such as managing grazing pressures in the riparian zone. In many cases, depending on the goals and the setting of the project, a combination of techniques will be needed. Not all techniques will be viable or beneficial in all locations and must be tailored to the particular setting using the approach outlined in Box 5.2.

The restoration of characteristic processes, habitat and biodiversity requires a long-term view because of the long timescales needed for full recovery and time needed to plan implementation. There are two ways to ensure support for a long-term approach:

1. Develop projects that can simultaneously produce benefits relatively quickly and ecological recovery in the future [103]. Use techniques that create rapid improvement of habitat and processes in combination with techniques that fully restore processes in the long term and underpin characteristic natural river habitat [87].
2. Take a long-term view of the gains created by river restoration to help spread the cost of action and offset these costs through the improved provision of ecosystem services [5].

Ideally, direct and indirect techniques can be used to satisfy the four main process restoration objectives needed to restore natural river habitat and biological connectivity (Figure 5.2). Interim techniques can be used to accelerate the recovery of processes, and where societal constraints exist, alternative 'last resort' techniques can be used.

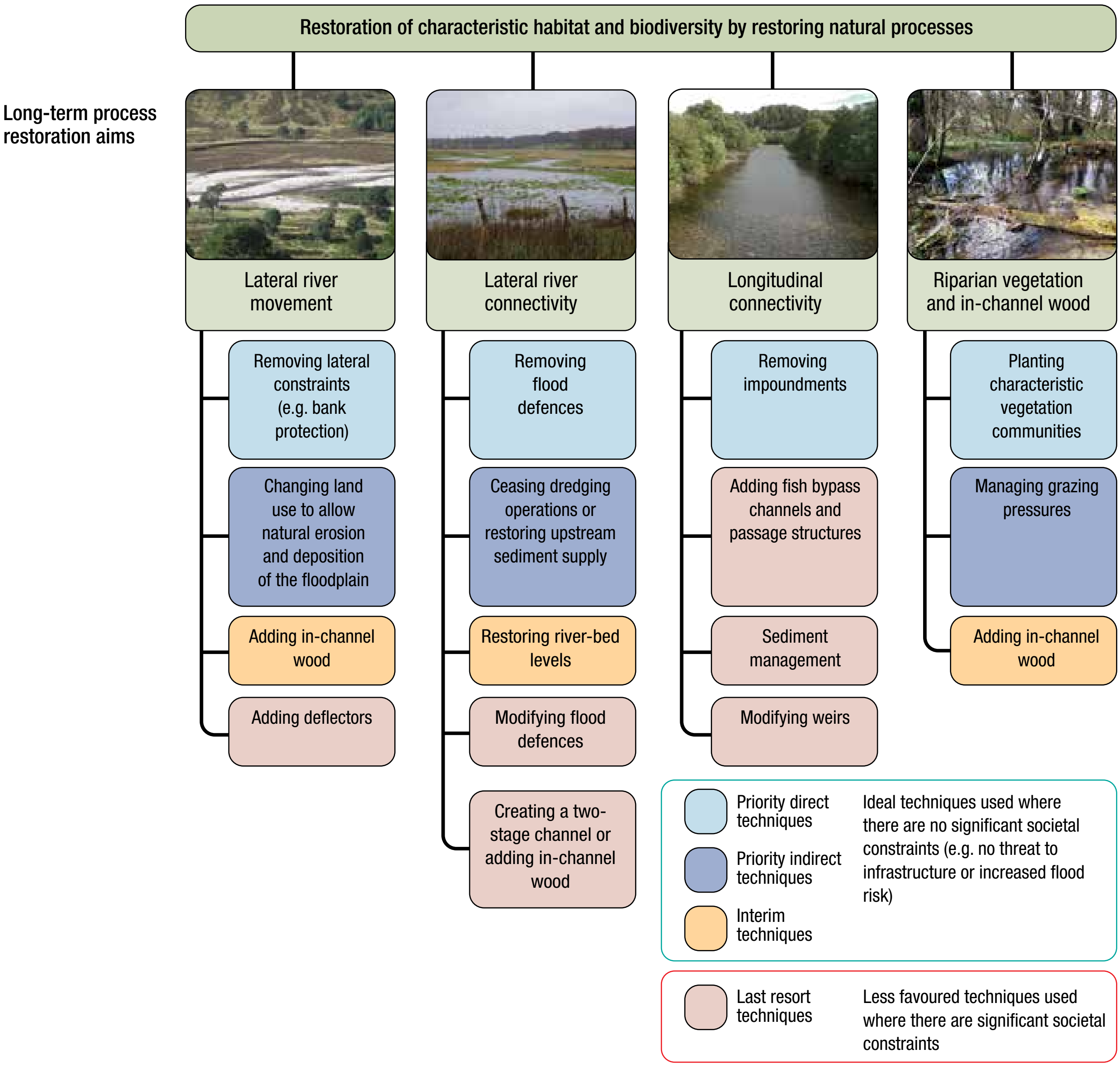


Figure 5.2 The process focused aims of river restoration projects and associated techniques to restore characteristic habitat, biodiversity and connectivity (Images (left to right: © James Hutton Institute, © Chris Mainstone, Natural England, © James Hutton Institute, © Martin Janes, RRC).

5.3 River restoration techniques

Restoring lateral river movement

Allowing rivers to shift their position is essential for creating natural channel shapes. This diversifies flow depths, velocities and river-bed sediment. Restoring lateral river movement is also essential for renewing the natural exchange of sediment between a river and its floodplain and developing complex river, bank and floodplain habitats in the long term. Over time, this may result in the development of a meandering river, development of side channels and abandoned channels that form backwaters. It allows rivers to adjust freely to accommodate changes of hydrology and sediment supply (Box 5.1).

Removing constraining structures (e.g. culverts and bank protection; e.g. Figure 5.3) in high-energy rivers can be sufficient to instigate natural river-bank erosion. When combined with land-use management change to allow erosion and deposition, this can facilitate greater lateral movement across a floodplain [(106)] and the development of complex river and floodplain habitat. Adding in-channel wood as a temporary measure can be used to accelerate bank erosion processes provided lateral constraints have been removed. In small rivers where energy levels are low and societal constraints prevent using the aforementioned techniques, traditional deflector structures can be placed to initiate meanders and a degree of habitat complexity. Such structures need to be planned and installed carefully to minimise potential adverse impacts.

Restoring lateral connectivity

Restoring the free connections between rivers, floodplains and the riparian zone improves the biodiversity of river corridors and allows the temporary storage of water, mitigating downstream flood risk [(107)]. Reconnecting floodplains can reinstate the natural exchange of water, sediment, seeds, organic material and animals between a river and its floodplain.

Removal of flood embankments (Figure 5.4 (Left)) has been observed to result in improvement of wetland floodplain habitat and benefits for fish and riparian vegetation diversity [(108)]. Reduction of flood peaks by reconnecting floodplain wetlands has also been demonstrated [(51)] and tends to be most effective for high frequency, low to medium rainfall events [(109)]. Ceasing dredging and maintenance of flood defences can help to restore the natural form of river channels and lateral connectivity (although it is better that flood defences are removed in a planned way).

When full removal of embankments is not feasible, setting them back to create more space (Figure 5.4 (Right)) or

Figure 5.3 (Left) Before and (Right) five months after removal of a section of a boulder protected bank to restore natural channel movement and river-bank habitat on the White Water, Angus (© Kenny MacDougall, EnviroCentre).

Figure 5.4 (Left) Burn of Mosset in Moray. Breaching a flood embankment has reconnected the channel to its floodplain and led to the development of complex habitat (© Scotavia Images). **(Right) Setting back a flood embankment to allow the River Ribble, in Lancashire more space to spill and interact with its floodplain** (© Environment Agency).

selectively breaching them are pragmatic options[110]. These actions can also be complemented by installing flow gates and culverts to control the influx and outflow of water if there are concerns about water accumulation[87]. Where floodplain habitats have been filled in, backwaters, wetlands and side channels can be restored to enhance degraded floodplains that have been reconnected (Figure 5.5).

Adding sediment with appropriate particle sizes may be needed where the river bed has been dredged and contemporary upstream sediment supply is inadequate (Figure 5.6 (Left)). In low-energy rivers, this is the only way to restore in-channel habitat and connectivity to the riparian zone and wider floodplain by elevating the bed. The low sediment transport rates in these environments means that addition of sediment may generate a lasting solution, restoring characteristic biological assemblages (e.g. benthic macroinvertebrate communities[93]). In contrast, sustainable recovery of characteristic river-bed sediment and levels in high-energy rivers is only feasible by restoring natural sediment supply and avoiding unnecessary dredging (Figure 5.6 (Right)).

Alternatively, where flood risk would be increased unacceptably by raising the river bed, two-stage channels may be considered to partially reconnect riparian habitats[110], with limited in-channel habitat benefit. Woody material can be added carefully to create a similar effect and also improve in-channel habitat.

Restoring longitudinal connectivity

Impoundments can be removed to restore the natural upstream and downstream connectivity of water, sediment, organic material and biota, regenerating a naturally diverse and dynamic river habitat. Removal also helps to restore the natural range of flow depths and velocities in the immediate vicinity.

Although examples of dam removal are rare in the UK and Republic of Ireland, weir removal or modification has been

Figure 5.5 (Left) A newly created wetland 'scrape' in the reconnected floodplain of the River Ribble at Long Preston Deeps, North Yorkshire (© Environment Agency). **(Right) A constructed spring-fed wetland on the River Skerne, Darlington** (© RRC). **Where natural floodplain wetland features have been lost through reduced lateral connectivity and river movement, they can be recreated as part of the restoration of floodplain habitat complexity.**

Figure 5.6 (Left) Adding locally sourced gravel to the River Wylye in Wiltshire. This can restore river-bed levels, floodplain connectivity and flow velocities for spawning fish, macroinvertebrates and plant communities (© Hampshire Aquatic Services). **(Right) The Ben Gill and River Ehen in Cumbria. The Ben Gill was reconnected to the River Ehen in 2014 to restore natural flows and sediment supply** (© Baptiste Mareau, Northern Rivers Institute).

widespread (Figure 5.7). Redundant deflector structures that attempt to enhance habitat can act as partial impoundments and have also been removed (Figure 5.8). Removing impoundments requires management of sediment upstream and assessment of the social and economic impacts of such interventions [44]. The removal of structures becomes most viable when the structures fall in to disrepair or no longer serve a useful function. Removing impoundments creates rapid habitat changes both upstream and downstream [111]. The recovery of flow regimes may be rapid, and there are examples of positive changes in macroinvertebrate assemblages [112, 113] in areas previously impounded by weirs. Complete biological recovery, however, may considerably lag as river-bed sediment is reworked over time [114].

When full removal of a weir is not possible owing to societal limitations, alternative solutions exist to mitigate their effects. Notches can be cut in the weir crest to allow the partial re-naturalisation of biota, sediment and water fluxes and habitat [44]. Accumulated sediment in impounded areas can be excavated and placed downstream to restore onward sediment movement provided there is sufficient flow. Where reinstating migration for fish is the main objective – fish pass structures can be installed (e.g. ladders, locks and lifts). Bypass channels that are designed to mimic natural river conditions and improve habitat connectivity are favoured over conventional fish pass structures. Well-designed fish passes and bypass channels result in rapid improvements to migration of certain species meaning that previously blocked habitat becomes accessible. However, these measures may have limited wider ecosystem benefit as, unlike barrier removal, they do not restore the natural fluxes of water, sediment, organic matter and biota or characteristic river habitat. Indeed weir removal can be more cost-effective [44].

Figure 5.7 Before and after removal of the redundant Prestolee Weir, on the River Irwell near Manchester in 2013. Weir removal can restore the natural movement of water, sediment, plants and fish and characteristic river habitat (© Oliver Southgate, Environment Agency).

Figure 5.8 Removal of a 'croy' structure (deflector) by using hand winches on the River Dee, Aberdeenshire to restore the continuity of water flow, sediment movement and river-bed habitat (© River Dee Trust).

Restoring riparian vegetation communities and in-channel wood

Restoration of characteristic riparian vegetation can increase shade to reduce water temperatures, bring back wooded wildlife corridors and reduce river-bank erosion by reinforcing banks with roots [87]. Other benefits include tree root encroachment into water margins and, in time, sustained input of leaf and wood material to rivers. Together these changes can further enable the self-recovery of physical habitat and provide nutrients for the benefit of fish and macroinvertebrate communities. However, given the long timescales for full recovery of vegetation, the benefits may take time to appear.

Planting of native trees, grasses and shrubs can be used to reinstate characteristic riparian vegetation communities (Figure 5.9). Care needs to be taken to ensure that native and appropriate species for the given environment are planted. In some cases where local seed sources are sufficient, grazing management techniques (e.g. reducing stocking densities and setting water points away from riparian areas) can be sufficient to allow riparian vegetation to re-establish without fencing or planting. Riparian vegetation restoration initiatives may require maintenance to ensure that grazing pressures are dealt with effectively (e.g. regular fence maintenance) and where necessary, to remove invasive vegetation species that may rapidly colonise these protected corridors [87]. Furthermore, to prevent excessive shading that can harm the productivity of an adjacent watercourse, selective tree removal or coppicing may be needed.

Studies have shown that restored mixed vegetation riparian corridors in farmland can have a positive effect not just on water quality but also riparian habitat complexity that can benefit in-channel macroinvertebrate assemblages [115] and woodland beetle species [116]. Restoring riparian vegetation communities can also increase the capacity of floodplains to slow and store flood waters, thus reducing flood risk downstream [117, 118].

Restoring indigenous riparian tree communities that can naturally supply wood material is the long-term process-based solution for restoring the supply of in-channel wood. As an interim measure before trees establish, wood material can be placed to mimic the effects of naturally occurring wood accumulations in streams (Figure 5.10). Unlike static in-stream structures, wood installation is a more natural technique requiring minimal maintenance and their flexible nature means they are less likely to be displaced [87]. The positive effect of engineered wooden structures on physical habitat for fish and especially salmonids is well documented [119] and they can also increase the abundance of invertebrates [120, 121].

Figure 5.9 (Left) Trees planted as part of a river corridor restoration project on the River Lyvennet in Cumbria. Note the pump fitted for livestock watering to prevent disturbance by cattle (© Daniel Brazier, Eden Rivers Trust). **(Right) Trees planted along the River Gairn, Aberdeenshire to reduce river-bank erosion and increase shading** (© James Hutton Institute).


Figure 5.10 (Left) Wood placement in the River Wensum catchment, Norfolk to diversify river habitats (© Adam Thurtle, Environment Agency). **(Right) One year after the placement of wood to diversify river habitats on the Allt Lorgy, Highland** (© Liz Henderson, Spey Catchment Initiative).

Reconnecting and reconstructing channels

Restoring meanders can create a rapid improvement in physical habitat and 'kick-start' processes that will sustain habitat in the long term (Figure 5.11). Abandoned meander and side channels blocked off during river channelisation can be reconnected by removing artificial obstructions to restore the extent and complexity of river habitat (Figure 5.12). This requires less excavation than constructing a meandering channel but may involve the removal of any accumulated fine sediment and re-grading to fully re-connect the abandoned channel. Where the potential


Figure 5.11 (Left) Aerial view of the River Lynvennet and Howe Beck, Cumbria in Autumn 2014 after re-meandering and diversion from the previously channelised rivers resulting in nearly 2 km of new river habitat (© Oliver Southgate, Environment Agency). **(Right) The Howe Beck nine months after excavation and diversion along the course of an old channel** (© Daniel Brazier, Eden Rivers Trust).

Figure 5.12 Excavation to reveal and reconnect the old meander loop at Shopham on the River Rother, West Sussex in 2004 (Left) and (Right) the newly reconnected meander (© Damon Block, Environment Agency).

for self-recovery of river habitat is limited – for example, due to low energy levels[122] – diversion into an excavated channel course may be preferred. It is sometimes possible to restore a meandering course by using historical maps or the remaining traces of a previous course in the floodplain as a guide. This approach means that river morphology will be restored to a natural condition that is sustainable in the long term provided upstream pressures have been dealt with (e.g. alteration of sediment supply caused by land-use change).

The main aims of re-meandering are to reinstate natural bar, riffle and pool sequences, increase habitat area and lateral connectivity. Past studies have shown that meander restoration projects successfully improve characteristic processes and habitat[123, 124] but species abundance and diversity responses vary. Monitoring of Danish re-meandering schemes has shown small, short-term increases of invertebrate, fish and aquatic vegetation abundance[125] but other studies show that the effects on fish are limited[126, 127].

5.4 Addressing other causes of physical river alteration

Reducing the impacts of land use

To mitigate the effects of altered flow and sediment supply regimes created by land-use change, a range of management solutions can be used alongside physical restoration of rivers and their floodplains. For example, 'hot spot' problems such as soil erosion can be tackled by using alternative tillage regimes to reduce overland runoff and sediment input to rivers[128] [q]. Land-use change and alteration of artificial drainage networks in headwater settings can also be effective. At Pontbren in upland mid-Wales, tree belts planted on grazed hillslopes were found to reduce flood peaks by 40% at the field scale[129]. In Northern England, the positive effects of blocking drains and restoring peatlands on water quality and river-bed macroinvertebrate communities has also been demonstrated[130].

Removing invasive plants and animals

Controlling invasive plant and animal species is very challenging and complete eradication is often impossible. However, control measures can improve native biodiversity and reduce the detrimental physical effect of certain species. Non-native terrestrial plants in riparian zones are most commonly controlled through mechanical removal or herbicide spraying but can also be removed by altering environmental conditions, for example by shading and manipulating water levels[87]. Invasive animals such as signal crayfish and Chinese mitten crab can be controlled to some extent through trapping and chemical treatments. In two tributaries of the River Thames, removal of signal crayfish increased the abundance and richness of the local macroinvertebrate communities[131].

Mitigating the effects of dams and flow regulation

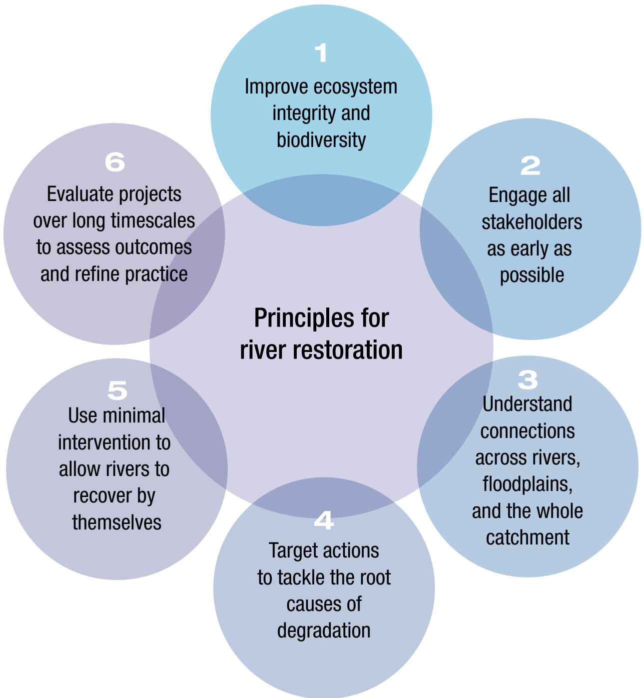
River habitat affected by large dam infrastructure and flow regulation cannot be restored unless these constraints are removed. Removal of redundant large dams has been practised in the USA to completely restore natural fluxes of water and sediment[132]. Where dams cannot be removed, some of the adverse effects can be mitigated while maintaining infrastructure and operating regimes. Rewetting dry channels and recreating variable flow regimes by altering operational procedures can be used to improve hydrology. The assumption of reinstating flow regimes is that improvement of the range of depths and velocities will benefit biota as a result[133]. Environmental flows can be designed to have wide ecological benefit. For example, flushing flows can be released to cleanse river-bed sediment of silt, loosen compacted sediment and remove algae[134]. Designing appropriate flow regimes requires understanding not only of hydrology and the flow requirements of biota but also appreciating the social and economic effects of such actions on water supply[135]. Where sediment supply has been cut off by a dam, gravel replenishment downstream can be used to restore the natural flux of sediment and create river habitat[41].

SECTION 6

Recommendations for restoring rivers

This section provides recommendations to improve the undertaking of river restoration projects across the UK and Republic of Ireland. Six key principles should underlie the efforts of all initiatives to promote restoration (Box 6.1).

BOX 6.1 Key principles for river restoration



The six key principles to guide effective river restoration are:

1. Improve overall ecosystem integrity and biodiversity, rather than focusing on the status of single species, by using process-based techniques such as floodplain reconnection.
2. Engage with the interests and motivations of different stakeholder groups as early as possible. Discuss objectives, and identify opportunities and barriers, before planning activities.
3. Understand the connections between natural processes upstream and downstream: work beyond the scale of individual reaches to consider riparian areas, floodplains and the wider catchment.
4. Target measures at the root causes of degradation – not the symptoms – and at the scale at which the pressures exist.
5. Use minimal intervention wherever possible to reinstate natural processes so that rivers can recover by themselves.
6. Evaluate restoration projects using robust monitoring techniques over long timescales (>5 years) to determine outcomes and inform future restoration.

Twenty recommendations to promote and improve the implementation of river restoration aimed at both policy makers and practitioners of restoration are listed below. These are based on the principles given in Box 6.1, the messages that arose from the November 2014 Liverpool workshop (Box 1.2) and our understanding of river restoration summarised in this report.

Create policies that support restoration

1. Ensure long-term (i.e. 5–30 years) provision of government funded resources to facilitate planning, implementation and evaluation of river restoration projects.
2. Streamline regulations and permission processes to aid implementation of small-scale, low-risk restoration projects [13].
3. Consider innovative approaches to compensating landowners, such as land purchase, land swapping, conservation covenants and easements, and payments for alternative land use [104].

Provide funding for restoration

4. Encourage greater uptake of voluntary (self-funded or in-kind) work by showing the long-term benefits of river restoration that allows self-recovery of processes such as reduced maintenance costs and flood risk.
5. Promote different sources of funding. These include (in 2016):
   a. Agri-environment schemes (e.g. Scottish Rural Development Plan in Scotland and Rural Development Programme for England) provide funding to cover the costs of some measures, such as riparian tree planting.
   b. The Water Environment Fund and the Environmental River Enhancement Programme fund river restoration in Scotland and Republic of Ireland respectively.
   c. Large grants like the Heritage Lottery Fund, Landfill Tax Scheme, EU Integrated Projects, EU Climate Change Adaptation funds and EU LIFE projects provide considerable sums of money towards restoration.
6. Consider alternative sources for funding restoration planning and actions [104]. These include:
   a. Payment for ecosystem services (PES) approaches. Projects involving Water Companies have recently piloted this approach, providing incentives to land managers to adopt measures that improve rivers and catchments and so reduce water treatment costs [136].
   b. Developer contribution schemes. A water quality improvement example is the River Mease Developer Contribution Scheme [137].
   c. Persuading companies (e.g. food producers and suppliers such as supermarkets) to invest in restoration projects to enhance the reputation of their brands and to address their needs for Corporate Social Responsibility.

Devise effective plans for restoration

7. Assess processes and causes of degradation at the catchment scale to target the right restoration measures in the right places and at the right scale.
8. Adopt frameworks such as the REFORM protocol [4] and the designated river restoration strategies in England [104] to aid decision support for planning at large scales.
9. Encourage a long-term commitment to planning and undertaking restoration.
10. Balance 'top-down' strategies with 'bottom-up' initiatives to use and increase existing interest and enthusiasm. Grasp 'easy-win' opportunities e.g. on lower-value land led by supportive communities and landowners, especially where it can be demonstrated that they will contribute towards the aims of wider catchment restoration.
11. Assess the level of risk associated with project actions for individual cases to ensure that it is commensurate with the cost of each project [4].
12. Involve all of stakeholders (landowners, river trusts, NGOs, voluntary groups and communities) at the earliest opportunity, including those that may not already be engaged in restoration, to gain support and maximise use of local knowledge [128]. Effort should be made to:
    a. Recognise the skills and time needed to build relationships with stakeholders [138].
    b. Acknowledge and discuss different potential motivations and expectations for restoration.
13. Set clear and measureable project goals. The following should be considered:
    a. Understand the social and economic constraints when setting goals. For example, consider setting back or selectively breaching levees to reinstate a degree of floodplain connectivity, rather than completely removing them if there are social constraints that cannot be overcome.
    b. Set goals that provide benefits to society, to help gain wider project support and funding [13]. For example, explicitly link river restoration to reducing flood risk and mitigating hydrological extremes caused by climate change.
    c. Use reaches at reference state or existing restoration priority plans such as the Priority River Habitat Plan for England [139] to help set goals.

Gather evidence and evaluate projects

14. Invest in selected existing or new 'flagship' restoration sites for detailed monitoring in the long term (i.e. >5 years) to improve confidence in the evidence base [4,13]. A number of considerations should be given to these sites:
    a. Encompass a geographical range of restoration projects, including sites outside lowland and urban areas (addressing the current trend to work in these areas [11]).
    b. Undertake monitoring before restoration work is carried out and afterwards for a sufficient length of time to detect both rapid and longer term changes. Ideally, control sites should also be incorporated in monitoring programmes.
    c. Concentrate on river restoration that focuses on assisted self-recovery through allowing natural processes to function.
    d. Monitor, using rigorous scientific approaches, physical habitat, biological, economic and social responses over wider scales that include rivers and their floodplains and at the catchment scale [4].
    e. Determine if river restoration benefits the characteristic biodiversity that would naturally be expected in the absence of physical habitat damage.
    f. Investigate multiple benefits; how does river restoration reduce flood risk, improve climate change resilience and mitigate diffuse sediment pollution?
15. Promote and carry out simpler and cost-effective monitoring methods that can be applied across all sites (e.g. fixed point photography) and add to the evidence base [13]. Consistency in these methods is vital for ensuring comparability between projects. This is possible through following the RRC Practical Monitoring Guidance [76].
16. Use citizen science to provide useful information while also reconnecting people with their river environments [103].
17. Use all monitoring evidence to evaluate projects objectively and help contribute to the design of others.
18. Understand how different projects are carried out so that opportunities and barriers can be identified to help refine future practice.

Communicate the benefits

19. Communicate the principles (Box 6.1) and benefits of river and floodplain restoration. In particular:
    a. Tailor the content and presentation of messages to the audience (e.g. policy-makers, river users, land managers). Interaction (e.g. via field site visits and visualisations) can be more effective than relying on written reports [140].
    b. Promote the vision for catchment-scale restoration using natural processes and self-recovery as much as possible.
    c. Highlight the long-term potential benefits of restoration to address any concerns over the costs and long timescales of projects.
    d. Share knowledge of project performance to assist 'learning by doing' and the successful completion of future projects [13].
20. Promote river restoration as an activity that overlaps with other conservation, landscape restoration and policy drivers to reinforce its added value. For example, river and floodplain restoration complements natural flood management approaches [1-3].

SECTION 7

The future of river restoration

Reversing a long history of alteration and bringing back the features characteristic of naturally functioning rivers is a considerable challenge, but the arguments for achieving it are compelling. Alongside biodiversity conservation and enhancement, there can be considerable benefits to society. These include:

1. Improved resilience to climate change impacts of increased hydrological extremes of drought and flood risk by improving water storage and attenuating peak flows;
2. Reduced river maintenance costs by reinstating natural processes and physical habitats;
3. Improved human well-being through improved opportunities for amenity, tourism and leisure;
4. A renewed sense of stewardship by communities towards their local river environment.

The vision of restoration is to give rivers more freedom to adjust naturally and to support more natural habitat and functions (Figure 7.1). There is now a much better understanding of how different restoration techniques can produce positive changes in physical habitat and their biological communities[141, 142].

The case for restoration is strengthened by its contribution to a range of policies and landscape restoration agendas. It helps to address the need to manage floods by restoring natural storage features such as floodplains. Restoring the natural vegetation communities of river corridors contributes to wider woodland restoration that improves resilience to climate change and provides other benefits.

The ongoing Eddleston Water, River Wensum and River Eden catchment projects show how multiple restoration measures can create long-term catchment-scale benefits. Knowledge gained from these and other ‘flagship’ projects will help promote river restoration in the UK and Republic of Ireland, Europe and beyond. Wherever possible we should consider the wider benefits that might accrue from restoring rivers and their floodplains at a catchment scale, and tackle the barriers that prevent us from doing so.

We must also learn from past experiences, good and bad, and celebrate those examples that can help to promote restoration. For example, the UK River Prize (similar to the European River Prize) was created in 2015 to encourage partnership working and reward successful restoration projects.

Partnership working is particularly important because successful restoration requires the involvement of many different people. Engineers, planners, conservationists, scientists, local communities, local authorities, farmers, landowners and politicians can all play a vital part. Developing inclusive approaches will be challenging but worthwhile, and following the recommendations outlined in this report will help. The reward will be not just natural rivers that function freely with improved biodiversity but also benefits for a society that is re-engaged with rivers[103].

Figure 7.1 Some examples of recently competed river restoration projects: (A) the Rottal Burn, Angus (© RRC), **(B) the River Tat, Norfolk** (© Adam Thurtle, Environment Agency), **(C) the Blackwater, Hampshire** (© Martin Janes, RRC) **and (D) the Braid Burn, Edinburgh** (© AECOM).

Glossary

Abstraction	The extraction of water from lakes and rivers for human purposes – for example, irrigation and drinking.
Backwater	Area of low velocity or static water under dry-weather flows, most commonly former river channels or flood channels within the alluvial floodplain, connected to the river channel at least in periods of high flow [143].
Bar	An elevated region of channel bed that has been created by sediment deposition. Types of bars include lateral, mid-channel, riffle and point bars [144].
Benthic zone	The surface of a submerged substrate or habitat. Benthic fauna are animals that live within this zone [144].
Biodiversity	'The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems' (Convention on Biological Diversity, 1992 [a]).
Biological processes	Natural processes that plants and animals use as part of their life cycle – for example, nutrient cycling and vegetation succession.
Boulder	A particle larger than a football in size (specifically with an intermediate axis in excess of 256 mm) [144].
Cascade	A chaotic, white-water flow type associated with boulder-bed streams [144].
Catchment	The area upstream of a given point on the river network from which water contributes to the flow of the river [144].
Channelisation	The straightening, diversion and deepening of natural rivers and the creation of artificial channels.
Characteristic biodiversity	Biological communities and associated habitat that would be expected for a given environment that is not adversely affected by human pressures.
Coarse sediment	River-bed material that is greater than 2 mm in diameter. Includes gravel, cobbles and boulders.
Cobble	A particle approximately between the size of a tennis ball and a football (specifically with an intermediate axis ranging between 64 mm and 256 mm) [144].
Community	A distinctive group of living organisms that interact with each other in a common location.
Deposition (river)	The settlement of sediment or organic material on a river bed or floodplain.
Diffuse pollution	The generation and movement of pollutants over a wide area – for example, the movement and input of fine sediment from many small sources into a river network.
Disturbance	The disruption of an ecosystem – for example, by a flood causing it to change its character.
Dredging	The excavation of gravels, sand or silt from the bed of a river or stream often undertaken mechanically to increase the flood capacity of the channel [144].
Ecological status	Expression of the quality of the structure and functioning of aquatic ecosystems, expressed by comparing the prevailing conditions with reference conditions. As defined by the European Water Framework Directive [143].
Ecosystem	A concept in ecology linking the many interacting components of the environment to the organisms that live within it. An ecosystem includes both living organisms including animals, plants and bacteria, and non-living components such as water, rocks and sunlight [144].

Ecosystem services	The benefits provided to humans by ecosystems. Examples of ecosystem services include flood mitigation, water supply and energy production.
Electrofishing	A technique of monitoring fish species composition and abundance using electric shocking and netting. Sometimes called electric-fishing.
Embankment	An artificial bank built to raise the natural bank level thereby reducing the frequency of flooding of adjacent land [143].
Fine sediment	Sediment that is less than 2 mm in diameter. Includes sands, silts and clays [144].
Floodplain	The area of the valley bottom that is or was historically inundated periodically by flood waters [143].
Flow type	A sub-reach scale unit of a channel (i.e. less than 10–20 channel widths long) characterised by a particular type of flow and morphology. Examples include riffles, glides, cascades and pools [144].
Food web	A network of links that show the feeding relationships among species in a community.
Geomorphology	The study of land-forms and the processes that create and rework them [144].
Glide	A flow type characterised by smooth, slow and laminar flow. Faster flowing and shallower than a pool [144].
Gravel	A particle approximately between the size of a tennis ball and a pea (specifically with an intermediate axis size ranging from 2 mm to 64 mm) [144].
Habitat mosaic	A patchwork of linked habitats created by physical, chemical and biological processes.
Habitats Directive	European legislation adopted in 1992 to conserve habitats and species.
Hydrology	The study of the water cycle: water evaporation, precipitation, storage, distribution and run-off. Also used to refer to the flow characteristics of a river [144].
Hyporheic	An aquatic zone beneath the bed of the river thought to provide an important refuge and nursery habitat for aquatic organisms [144].
Impoundment	The blocking effect on water and sediment movement created by a weir or dam.
Invertebrates	Animals without backbones. In river environments includes fly larvae, beetles, snails, freshwater mussels and leeches, among others. They form an important source of food for larger animals and can be a useful indicator of stream health [144].
Lateral connectivity	Freedom for water to move between the channel and the floodplain [143].
Lateral river movement	Freedom for a river channel to move across a floodplain [143].
Longitudinal connectivity	A measure of the freedom of upstream and downstream ecological, hydrological and geomorphological linkages in a river.
Macroinvertebrates	Invertebrates that can be seen with the naked eye.
Macrophyte	Larger plants of fresh water which are easily seen with the naked eye, including all aquatic vascular plants (plants with vessels), bryophytes, stoneworts (Characeae) and macro-algal growths [143].
Meander	A curve in the course of a river [144].
Morphology (river)	The size and shape of a stream or river [144].
Natural capital	'Natural Capital can be defined as the world's stocks of natural assets which include geology, soil, air, water and all living things. It is from this Natural Capital that humans derive a wide range of services, often called ecosystem services, which make human life possible' (Natural Capital Forum [r]).
Nutrient cycling	The reuse, transformation and movement of nutrients in a river system.
Overland flow	The flow of water over the ground surface. This occurs when infiltration is impeded due to saturated soil, impermeable geology or during heavy rainfall when the rainfall exceeds the infiltration rate [144].
Physical habitat	River corridor environments created by the interaction of the flow of water and morphology.

Physical modification	The artificial alteration of a river's shape or flow due to human actions – for example, by dredging or damming.
Physical processes	Processes that shape physical habitat involving the movement of physical material such as water and sediment.
Pool	A deep, very low velocity flow type associated with areas of low river channel topography [144].
Process-based	An approach to planning and implementing river restoration that allows natural processes to do the restoration work.
Rapid	A steep river type (but less steep and turbulent compared with cascade river types) with a river bed made up of boulders and cobbles [145].
Reach	Major sub-division of a river, defined by physical, hydrological, and chemical character that distinguishes it from other parts of the river system upstream and downstream [143].
Redd	An egg nest made on the bed of a river by a fish.
Reference conditions	Conditions representing a totally undisturbed state, lacking human impact, or near-natural with only minor evidence of distortion [143].
Resilience	A measure of an ecosystem's ability to adjust to accommodate an environmental change, for example climate change.
RHS	River Habitat Survey.
Richness (species)	The number of species in an ecological community.
Riffle	A shallow steeper section of river characterised by higher water velocities and unbroken standing waves appearing as ripples on the water surface [144].
Riparian zone	Area of land adjoining a river channel (including the river bank) capable of directly influencing the condition of the aquatic ecosystem (e.g. by shading and leaf litter input) [143].
River corridor	The area including the current active river channel and its adjacent land [144].
River restoration	Definition used in this report: The re-establishment of natural physical processes (e.g. variation of flow and sediment movement), features (e.g. sediment sizes and river shape) and physical habitats of a river system (including submerged, bank and floodplain areas).
SAC	Special Area of Conservation. A protected area of conservation interest included in the Natura 2000 network of sites under the European Habitats Directive.
Sand	Fine sediment that feels gritty when rubbed between thumb and forefinger. Specifically with an intermediate axis size that ranges from 2 mm to 0.0625 mm [144].
Sediment	A particle of any size [144].
Sediment supply	A measure of the delivery of sediment load to a section of river from external sources (e.g. hill slopes) or internal sources (e.g. river bed and bars) [144].
Sediment transport	The movement of sediment by flowing water in a river.
SSSI/ASSI	Site of Special Scientific Interest in Scotland, England and Wales. Area of Special Scientific Interest in Northern Ireland. A nature conservation designation defined by the statutory conservation agencies.
Silt	Fine sediment that feels smooth when rubbed between thumb and forefinger. Specifically with an intermediate axis size that ranges from 0.0625mm to 0.001 mm [144].
Siltation	The deposition of silt material on a river bed which can clog up the spaces between coarser river-bed sediment.
SPA	Special Protection Area. A protected area of conservation interest included in the Natura 2000 network of sites under the European Birds Directive.
Substrate	The material of which the bed of a river channel is composed [144].
Succession (vegetation)	The process by which plant communities develop, from initial colonisation by pioneer species to a complex 'climax' community.

Suspended sediment	Fine sediment that is transported in suspension by a river.
Tributary	A stream or river that joins the main stem of a river network [144].
Two-stage channel	A type of channel modification sometimes used in artificially straightened rivers when there are constraints on achieving full river restoration. Two stage channels consist of a strip of land cut into a river-bank below the floodplain which is often disconnected.
Water quality	The character of water – for example, its temperature, clarity and chemistry.
Weir	Structure used for controlling flow and upstream surface level, or for measuring discharge [143].
Wetland	Habitat (e.g. marsh, fen, shallow temporary water) occupying the transitional zone between permanently inundated, and generally dry, environments [143].
WFD	European Water Framework Directive (2000).

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