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River Restoration Works – Science based Guidance centred on Hydromorphological Principles in an Era of Climate Change

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River Restoration Works - Science based Guidance centred on Hydromorphological Principles in an Era of Climate Change

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Dedication

This document is dedicated to the memory of our friend and colleague Martin O' Grady (RIP) who spent over 40 years working as a fishery biologist with Inland Fisheries Ireland. Much of his interest was related to the river corridor concept and brown trout and he encouraged many young fishery scientists in this area. Some of his work contributed to the foundations for this guidance document.

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Executive Summary

- The policy context and legal obligations provided by the EU Water Framework Directive (WFD), other Directives as well as on-going climate change indicates that those considering undertaking any river works should be increasingly cautious. It is important to consider potential direct and indirect effects of any project that would have traditionally been undertaken to "restore" river habitat for sectoral purposes.
- River channel behaviour is complex and any intervention in natural processes may result in unexpected adverse impacts. Alteration of the natural form of a river channel should be approached with caution. Rivers can generate substantial power in high or flood flows. This stream power interacts with the bed and bank of the channel to create a stable channel form. Anthropogenic interference with this stability may lead to instability and outcomes that cannot be predicted. It is important that project planners are aware of all the risks.
- If a project is aimed at a particular sector, e.g. improving fish stocks or fisheries, it is essential that the habitats of other river corridor species, such as invertebrates and birds, are not lost. Therefore, all measures require careful planning.
- The term 'restoration' in this guidance document is used for convenience as an umbrella term to cover a range of active and passive projects. The term does not imply precise ecological restoration as it is recognised that conditions, such as landuse and climate, have changed over time. The principle for river restoration (human intervention) in this guidance document is:
  Any intervention must be environmentally sensitive, justifiable and measurable. Works must be sustainable and acknowledge a river's diverse physical and ecological process, forms of connectivity, physical-biotic interactions, place-specific history, complexity and ecosystem services. It should improve a rivers' ecological potential resulting in a more self-sustaining, resilient, ecologically functional system.
- This guidance document is designed to assist any public sector agency or private parties in the planning and design of river restoration projects and to encourage best practice based on international recommendations. The document outlines a phased approach to planning and design of river restoration works to ensure that projects are sustainable, resilient and include climate proofing protocols and to achieve objectives without causing detrimental ecological impacts. This is not a detailed manual or a technical engineering design guide but describes measures that are compliant with the EU Water Framework Directive (WFD), other EU Directives and State regulations.

- The document supports recommendations that are consistent with the natural hydromorphology of the river. It is recommended that projects should be planned at a catchment (watershed) scale. A fully integrated approach to river restoration is required in Ireland, tackling all stressors, the underlying drivers of river degradation, climate change associated impacts, but also taking important biological aspects into account as per the requirements of the WFD and other legislation.
- Proposals are centred on addressing the root cause of perceived river system problems rather than observed symptom(s). Passive restoration, i.e. allowing the natural river recovery process to take place, is discussed. A step-by-step evidence-based process for river restoration works is described, comprising three phases that should be followed when considering and planning any river restoration project:

  Phase 1 - Assess the problem

  Phase 2 - Design and implement

  Phase 3 – Monitor, evaluate and adjust

- Phase 1 requires clear measurable objectives for each project to be agreed and identified. Desktop and field assessments should be carried out. The data should be compiled and analysed to determine if there are any human activities that are exerting detrimental pressure(s) on key ecosystem elements such as biota (e.g. fish stocks) and the hydromorphology (i.e. identifying the cause and the symptoms). The impacts (if any) these pressures are having on ecological state must be clearly specified.
  - Conclusions of the desk and field studies should be clear and identify if there is a problem, what the cause of the problem is and the impacts on the biota.
  - If there is no clear evidence of negative impacts on the state of relevant ecosystem components, then there should be no need to progress to phase 2. However, other works could be considered, such as riparian measures for improving climate resilience, if shortcomings have been identified during the field survey programme or because of analysis of field datasets.
  - Where clear anthropogenic pressure-state relationships exist, the APSR (Activity, Pressure, State, Response) framework should be invoked to define pathways by which specific restoration activities will mitigate pressures and drive the desired improvement in state. Achievement of measurable objectives can be monitored by using appropriate ecological indicators.

- Three works strategies or options (diagnosis) are recommended:
    1. Passive restoration
    2. Riparian measures only (if water quality the main cause)
    3. Riparian and instream measures.
- Phase 2 is the design and implementation phase and involves prioritising areas for works, identifying remedies, seeking relevant permissions and carrying out works. Numerous risks and mitigation measures are listed, covering topics such as timing of works, inappropriate materials, alteration to hydromorphology, damage to the instream and riparian habitat, bank protection works, de-tunnelling, species-specific works, barriers, stakeholder objectives and alteration to the current form of a river. This phase requires clear specification of a restoration pathway, i.e. the mechanism by which proposed works will achieve desired improvements in ecological state.
- Phase 3 is the monitoring, evaluation and adjustment phase. It is important to define *a priori* what will constitute restoration success and how this can be measured. Monitoring and evaluation of restoration works is essential for determining the effectiveness of measures and 'value-for-money'. It allows the success of a programme to be assessed and to adjust or update relevant policies. It also allows partial successes or failure of any measures to be assessed. It can also help identify which restoration methods work best for on-going and future initiatives and contribute to developing best practice in a changing environment (adjustment). The key steps for developing a monitoring and evaluation programme are outlined:
    1. Determine the objectives
    2. Determine the key questions and hypotheses
    3. Select appropriate monitoring design (e.g. BACI) and indicators
    4. Determine sampling scheme for collecting supporting data
    5. Implement the monitoring programme.
- The monitoring strategy will depend on the initial objectives of the projects, seasonal conditions from year to year, river type, hydrological regime and the ecological communities present. IFI recommends monitoring 12 months post-works, in same season/calendar, in similar water conditions (check water level gauge), and annually thereafter (or two-yearly) for 5-6 years and at 5-year intervals thereafter. Costs of post-work monitoring should be built in at the funding stage or a commitment received to ensure funding is available in the future.

1. Introduction

This guidance document is designed for all parties - public sector, private or voluntary - across Ireland who may be considering undertaking works in a river or watercourse. The guide aims to assist groups in determining whether restoration works in a river are required (evidence-based) and appropriate and to encourage best practice in the planning, design, implementation and monitoring of projects. The document contributes to the development of a national policy relating to all restoration works in rivers or river corridors. Such a policy is considered essential in the context of compliance with the EU Water Framework Directive (2000/60/EC) (WFD), other Directives and State regulations, in line with hydromorphological processes and climate resilience.

There is developing awareness of the nature and complexity of river processes (Rinaldi *et al*., 2013b) and the habitat requirements of fish. Increased understanding has highlighted the sensitivity of river processes, the way they underpin the biodiversity and amenity value of rivers (SEPA, 2002) and their vulnerability to adverse impacts. Therefore this guidance is centred on the ideas of river complexity and habitat robustness - the principles of hydromorphology and climate resilience - with the aim of being WFD and EU Habitats Directive (HD) (1992/43/EC) compliant and achieving the fundamental goals of restoration and preventing deterioration. The legislative and policy context provided by the WFD and other EU Directives, as well as on-going climate forcing indicates that river restoration programmes should be increasingly careful when planning and considering the potential effects of any activities that would traditionally have been undertaken in order to enhance river habitat for specific sectoral purposes (e.g. improve angling or fish habitat). In Ireland, such planning must also take into account (a) the EU Floods Directive (2007/60/EC) and CFRAMS determination, (b) the requirement to confer with the Office of Public Works (OPW) Drainage Division, where any works are proposed in channels that have been arterially drained by OPW, and (c) other relevant legislation.

A phased process is outlined to determine if, based on available evidence, any works are necessary or desirable. If works are required, the document recommends appropriate planning and design so that works are sustainable, resilient and have a strong likelihood of achieving defined objectives without causing any detrimental impacts. Works should be planned and implemented at a catchment (or watershed) scale (Roper *et al*., 1997). This change in practice to a more sustainable approach may be challenging. It will require educating interested parties to become increasingly familiar with how rivers function as an integrated system within the landscape so as to ensure that a range of habitats for all fish species and other freshwater species are protected, while also ensuring that the work undertaken is consistent with the natural hydromorphology of the river in question.

This document is not a detailed manual or a technical engineering design guide, but it provides a framework to plan, design, implement and monitor river restoration projects. It also lists the key issues that fishery managers and others should be aware of. It lists best practice measures to ensure projects are undertaken in a way that addresses all environmental concerns. It promotes identification of any perceived problems and recommends addressing the root cause of the problem rather than apparent symptoms. The guide also encourages passive restoration where possible – this concept concentrates on eliminating damaging land management practices and allows the natural recovery process to take place (Keating, 1996).

There are many different definitions of restoration in the literature and many practitioners and scientists disagree as to what it constitutes (Roni *et al*., 2005). In the most formal sense, the definition of restoration is "*returning an ecosystem to its original pre-disturbance state*" or to a "*close approximation of its pre-disturbance condition"* (US National Research Council, 1992). The Australian Society for Ecological Restoration (SER, 2004) defines restoration as "*the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed*". Addy *et al.* (2016) describe it 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*)." The term restoration has been used to refer to all types of habitat manipulations including enhancement, improvement, mitigation, habitat creation and rehabilitation (Roni *et al*., 2005).

For the purposes of this document the phrase "restoration" is used as a convenient umbrella term to cover a range of active and passive projects. It does not imply precise ecological restoration to some "pristine" state, as it is recognised that conditions such as landuse (Roni *et al*., 2005) and climate may have changed over time. The principle for river restoration (human intervention) in this policy is:

Any intervention must be environmentally sensitive, justifiable and measurable. Works must be sustainable and acknowledge a rivers' diverse physical and ecological process, forms of connectivity, physical-biotic interactions, place-specific history, complexity, ecosystem services (e.g. water supply, recreation, biodiversity, etc.). Any restoration programme should improve a river's ecological potential resulting in a more self-sustaining, resilient, ecologically functional river.

1.1 River degradation

Rivers are by their very nature ever-changing features of the natural landscape and have been exploited by humans since the dawn of agriculture. Landscape changes due to farming, grazing, deforestation, peat harvesting and water abstraction have directly degraded watershed characteristics with additional indirect impacts imposed by anthropogenic effects on climate (Gilvear *et al*., 2013). Attempts to control the flow of rivers also date far back in time and over human history there has been a continuous increase in the variety of ways and intensity with which humans have modified the physical, chemical and biological nature of rivers (Allan, 1995). Since the 1800's many rivers in Ireland have been subjected to major schemes for navigation, flood control, utilization of floodplains, land and hydropower (Fig. 1.1). This work has led to the degradation of their natural character resulting in a loss of habitat and biodiversity (including fish).

Fig. 1.1 Examples of different levels of river channel modifications and degradation in Irish rivers (for farming, navigation, land drainage and urban development)

Our rivers are surrounded by terrestrial environments that experience impacts from multiple pressures. Many scientists have pointed out that worldwide declines of fishes and other aquatic species in freshwaters are partly a result of trying to manage individual species and certain habitat characteristics for sectoral goals rather than managing whole ecosystems (Roni *et al*., 2005). Large decreases in structural habitat complexity are detrimental to fish diversity and can change species composition (Smokorowski and Pratt, 2006). Rivers are also the systems most at risk with one third of all freshwater species assessed by the International Union for Conservation of nature (IUCN) threatened with extinction. Freshwater vertebrate populations are undergoing declines at a rate more rapid than those in terrestrial and marine environments (Darwall *et al*., 2018).

Any man-made structure in a river has the potential to interfere with fish movements and migration. These structures may include bridge floors, culverts, sluices, dams and weirs (Fig. 1.2). Migratory or diadromous fish species (e.g. sea lamprey, salmon and eel) are the most affected, spending part of their life cycle at sea and part in freshwater, but potamodromous species (e.g. brown trout, bream and pike), whose entire life cycle is completed within fresh water, are known to make extended movements for feeding or to spawning grounds, and must also be considered. It is vital that the migratory pathways of these species are not impinged by man-made structures and that there is free passage between nursery, recruitment, feeding and breeding habitats. These structures interrupt and alter the natural flow and physical properties of river water as it flows from headwaters to estuary. In Ireland, the fish species that make extensive migratory journeys outside of freshwater are Atlantic salmon, sea trout, sea lamprey, river lamprey, Twaite and Allis shad and European eel.

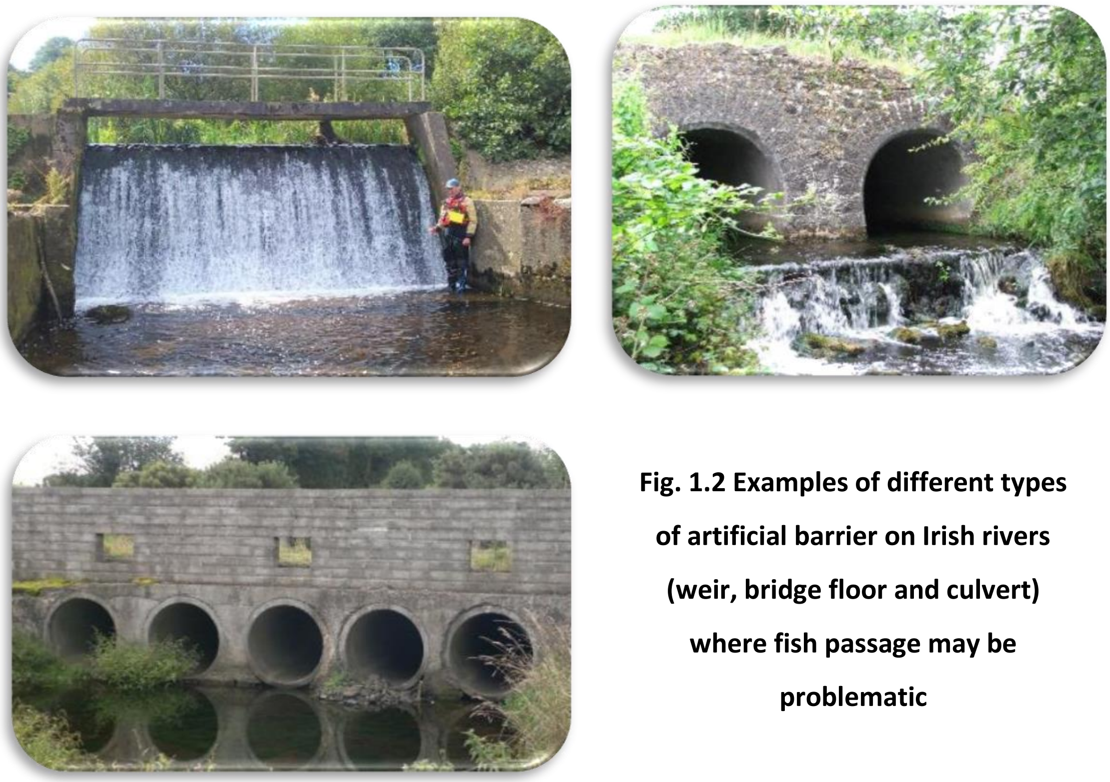

Fig. 1.2 Examples of different types of artificial barrier on Irish rivers (weir, bridge floor and culvert) where fish passage may be problematic

Dams and weirs can directly and/or indirectly hinder progress towards WFD and HD objectives by creating habitat degradation, fragmentation and pollution. Such structures directly impact on the biological (fish, plants and aquatic insects), chemical status (phosphates, nitrates and dissolved oxygen), physical-chemical status (temperature, dissolved oxygen) and hydromorphology (depth, width, flow and structure) elements of the WFD.

1.2 Hydrology, geomorphology and hydromorphology

Hydrology is the study of water and all the physical processes involved at all stages in the water cycle in terrestrial environments, including both surface and sub-surface flows. It is a field that is strongly relevant to scientists spanning many disciplines, from ecology to engineering. Geomorphology encompasses the study of the physical earth surface and the processes which shape that surface. The largest sub-discipline of geomorphology is fluvial geomorphology which relates specifically to riverine investigations (Wohl, 2014). The roots of this sub-discipline stretch back to the late eighteenth century with more recent research continuing to bring together concepts from geology, geography and hydrology (Wohl, 2014). 'Hydromorphology' is a term coined in the early 2000's in response to the WFD requirements for rivers to be assessed in terms of their ecological status, with hydromorphology acting as a supporting element. It is, in essence, applied fluvial geomorphology, bringing hydrology together with geomorphology for water managers, often for the purposes of river rehabilitation (Newson and Large, 2006). There is a growing field of research on the link between physical habitat and ecology within rivers, promoting cross-over research between hydromorphology and ecology, relevant for both scientific and management perspectives (Vaughan *et al.*, 2009).

1.2.1 Water Framework Directive (WFD) and hydromorphology

The main environmental aims of the WFD are to protect all water bodies, prevent deterioration and restore them to at least good ecological status or good ecological potential. For surface water bodies, including rivers, the WFD also demands good chemical status. The ecological status of a river is determined holistically by examining numerous aspects of water quality and the interlinkages between them. This framework includes the biological quality elements (BQE's): fish, macrophytes and macroinvertebrates and phytoplankton and the supporting elements of physico-chemical parameters and hydromorphological elements (including hydrology, lateral connectivity (floodplains) and longitudinal continuity (natural and man-made barriers).

In all cases the WFD looks at channel condition and its deviation from "normal" conditions. The general agreement worldwide is that if hydromorphological conditions are good, habitat can be created and maintained, which in turn can support good ecological status (Quinlan, 2020).

The risk assessment for freshwater morphology, undertaken as part of Ireland's groundwork for WFD implementation, identified channelization and barriers to passage as significant pressures placing Irish rivers at risk of failing to achieve appropriate ecological quality (SHIRBD, 2008).

Arterial drainage programmes have been carried out on many of Ireland's riverine catchments over the last century (O' Grady and Curtin, 1993). Most schemes have been undertaken since the 1950's by the OPW under the Arterial Drainage Act (S.I. No. 3 of 1945) and involved dredging of channels, both vertically and horizontally to achieve the desired objectives (mainly land drainage). The trapezoidal channel form was used in most projects (Fig. 1.3). This approach involves straightening and deepening the natural channel to create a larger, more efficient cross-section that will contain flood flows without over-spill onto the floodplain – reducing natural floodplain connectivity. However, this form throws the stream out of equilibrium (Nunally, 1978) because the increased depth and uniform slopes diminish the resilience imparted by diversity in physical habitat.

Fig. 1.3 Examples of arterially drained rivers in Ireland

Straightening can promote erosion of both bed and bank materials that were previously in equilibrium, during high discharges, possibly leading to bank collapse. Unless constantly maintained the trapezoidal channels can lose their design efficiency (Nunally, 1978; Newbury, 1994). The enlargement of channel cross-sections can result in a reduced sediment flux through the fluvial system and more deposition of fine substrate within the channel, often leading to substantial vegetation growth instream. This, in turn, can lead to a cycle of repeat maintenance and of repeat vegetation growth. In arterially drained channels the riparian zone often consists of a narrow corridor along the margins of the bank full channel and a small area at the top of the bank. This is a radically different state to the structural diversity of the natural system, in which dynamic riparian zones contribute material including large woody habitat. Woody habitat impeding water flow adds a 'roughness factor' with potential to reduce the rate of water conveyance downstream (Fisher and Dawson, 2003).

Under the WFD, the presence of artificial barriers is considered to impose impacts on river hydromorphology; to achieve "high status", a river must have no discontinuities in its flow regime. As stated in the Directive "*the continuity of the river is not disturbed by anthropogenic activities and allows undisturbed migration of aquatic organisms and sediment transport*". As such, weirs and dams are identified as a hydromorphological pressure (creating a reduction of waterbody status) impacting on Irish watercourses. Structures will require mitigation under a programme of measures to meet the environmental objectives of the WFD.

For the purposes of the WFD hydromorphological status should be assessed based on criteria expressing hydrological regime, river continuity and morphological conditions (Fig. 1.4).

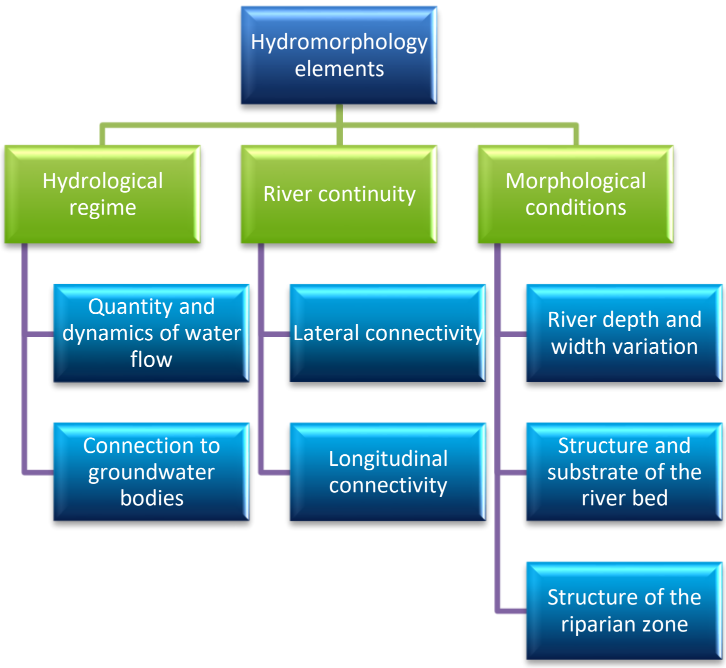

Fig. 1.4 Hydromorphological elements of the WFD

One of the assessment methods employed currently in Ireland is the River Hydromorphology Assessment Technique (RHAT) (Murphy and Toland, 2014) which is a visual assessment of the physical habitat, resulting in a score outlining deviation from reference conditions. Hydromorphological quality is assessed by looking at various parameters including water flow, channel morphology, sediment composition, lateral and longitudinal connectivity and structure of the physical habitat, including instream and riparian vegetation and land cover. The Environmental Protection Agency has recently adopted the Morphological Quality Index (MQI) for use in Ireland (the MQI Ireland assessment tool, Quinlan, 2020). Currently, the MQI is being used at river reach scale for heavily modified waterbody designation and considers the cumulative impact of multiple pressures within a reach. Ultimately, the outputs will be at waterbody scale.

In more recent years, there has been a move towards combining morphological and hydrological methods, conducive to restoration projects focussed on catchment-wide scales and those which employ process-oriented approaches (Belletti *et al*., 2015). IFI believe this catchment-wide and process-oriented approach is most appropriate for all future river restoration works in Ireland.

1.3 Climate change

Climate change has been identified by Inland Fisheries Ireland (IFI) as one of the greatest threats facing fish populations and the wider aquatic environment in the medium to long-term (IFI, 2019). Average air temperatures in Ireland have already increased by 0.8°C since 1900 and changes are projected to increase over the coming decades (Desmond *et al*., 2017). Climate change will have widespread effects on Ireland's environment including impacts on aquatic habitat and the biota within. It is now necessary to improve resilience to climate change impacts from associated increased hydrological extremes of drought and flood risk.

Riverine ecosystems are particularly vulnerable to climate change because (1) many species within these habitats have limited dispersal abilities as the environment changes, (2) water temperature and availability are climate-dependent, and (3) many systems are already exposed to numerous anthropogenic pressures (Woodward *et al*., 2010; Connor and Kelly, in prep.). Many of the effects of climate change are already occurring, including an increase in surface water temperature of rivers and lakes (Arvola *et al*., 2010; Desmond *et al.,* 2017; George *et. al.,* 2007; Woodward *et al.*, 2010). Changes in flow regime of streams and rivers (Fig. 1.5), associated with projected changes in precipitation and storm events, may cause an increase in the transport of sediments, pollutants and nutrients downstream. Changes in precipitation, evaporation and flooding dynamics will cause changes in water levels, habitat structure and water residence time in lakes and wetlands. Small intermittent streams and small lakes may disappear while flow in permanent streams and rivers may become intermittent (Arnell *et al*., 2015; Desmond *et al*., 2017: Stagl *et al*., 2014; Whitehead *et al*., 2009;). Drier weather, increasing temperatures and periods of drought can lead to reductions in the dilution of contaminants in waterbodies and a reduction in wetted habitat area for fish and their invertebrate prey. High temperatures contribute to drying of peat lands and can result in a reduction of natural pollution attenuation and flood prevention, the leaching of nitrogen, ammonia and peat slides (when followed by heavy precipitation) (DHPLG, 2019).

Fig. 1.5 River Erriff at Aasleagh Falls (left) drought conditions, summer 2018 and (right) normal summer levels, summer 2006

Changes in water temperature are primarily influenced by volume discharge, the depth of the water and the amount of solar radiation received at a site. Water temperature plays an important role in almost every aspect of fish life and adverse levels can affect fish behaviour, growth, survival and disease resistance (Wood and McDonald, 1997; Mohseni *et al.,* 2003; Barange and Perry, 2009; Cochrane *et al*., 2009). High water temperatures, low flow and low dissolved oxygen in combination can cause fish kills. Increased temperatures cause changes in fish species distribution, abundance, phenology, behaviour, reproductive triggers, species composition and community structure and dynamics, including native, non-native and invasive species (Hershkovitz *et al.,* 2013). Ireland's native cold-water fish populations such as salmon, brown trout and Arctic char are more vulnerable to climate change and warming of our waterbodies than those fish species that have been introduced over the last 100 years (Chu *et al.,* 2005; Kovach *et al.,* 2019; Morrissey-McCaffrey *et al.,* 2019). Some of these latter species (e.g. roach) have a higher thermal tolerance than the native cold-water species and therefore, will have a higher tolerance of increasing climate pressure (Hein *et al*., 2012; Connor *et al.*, 2019). Floods and high water levels associated with climate change events may enable invasive species to move upstream and surmount barriers, if present, but they can also facilitate the movement of diadromous lamprey and other species (Jonsson and Jonsson, 2010; O' Keeffe *et al*., 2018).

It is recommended that any future river restoration projects must include appropriate protocols for climate proofing waterbodies and should focus on preserving or re-establishing the hydromorphological processes that create habitat complexity and buffer water temperature (O'

Briain, 2019; O' Briain *et al*., 2019). Resilience of rivers can be enhanced by restoring river corridor woodlands through maintaining the connectivity of biological communities and by increasing shading (keeping rivers cool) from rising temperatures. Shading from riparian trees and shrubs can help reduce local stream temperatures with summer mean and maximum water temperatures on average by 2-3°C (EA, 2016).

1.4 River restoration

Rivers by their very nature are unusual in that their throughput is unusually high and this property provides a natural cleansing ability (Hynes, 1970). This natural recovery capability facilitates the restoration of riverine ecosystems (Gore, 1985). A review of more than 150 case studies of recovery in freshwater systems established that resilience varies with the type of disturbance, with biological attributes of the community and with degree of isolation from a source of colonists (Niemi *et al*., 1990). Rivers have considerable ability to recover from pulse events of limited and defined duration (e.g. chemical inputs, e.g. King, 2015), but recovery from more serious events such as habitat degradation or alteration (channelization) can take several years (e.g. Kennedy *et al*., 1983) or decades. Habitat mitigation measures can, in some cases, reduce these recovery periods (Niemi *et al*., 1990).

River restoration can involve active or passive strategies (Roni and Beechie, 2013). Active or structural restoration involves direct interventions to modify the river system. The adverse impacts of channelization and of barriers may act as a stimulus to undertake river restoration works. Such works may be initiated through a broad (e.g. a community-based interest group with a number of stakeholder interests represented) or a narrow sectoral view (e.g. a project led by a local angling club) of the river. Active restoration (mainly instream restoration structures) has been used internationally for over 80 years in an attempt to increase abundance of fish (Foote *et al*., 2020) and billions of dollars have been spent worldwide (Whiteway *et al*., 2010; Roni, 2018). Active restoration of habitat for fishery purposes is the principal category of stream restoration that has been implemented for many decades in Ireland, mainly in drained catchments (e.g. O' Grady, 2006), similar to the UK and US experience (Addy *et al*., 2016; Roper *et al*., 1997). The Irish work mainly targeted salmonids (e.g. Kelly and Bracken, 1998; O' Grady, 2006; Kennedy *et al.*, 2014). Many of the projects aimed to increase fish holding capacity, create easy access for anglers, ease fish passage and improve flow, etc. Some projects were localised and involved addressing specific problems such as an eroding bank or the local degradation of spawning habitat. River restoration measures for fisheries have also been implemented in many other countries, but numerous projects only considered small scale measures and solutions, and neglect that river ecosystems are strongly governed by catchment scale processes (Roper *et al*., 1997; Palmer *et al*., 2010).

A shortcoming with such a single-view or sectoral-driven approach is that the works may inadvertently impact adversely on other elements in the channel (physical or ecological) and river corridor. Some of these types of works can have negative as well as positive results (SEPA, 2002) due to inappropriate design for the channel type or as a result of adjacent land management practices (Keating, 1996) or they have been implemented on a small-scale or site-specific basis or have not addressed the ecosystem processes that originally led to the loss of habitat (Roper *et al*., 1997).

It is unclear how effective active restoration measures (e.g. instream structures) are in achieving their objectives. This is partly due to the lack of project monitoring and variation in results (Whiteway *et al*., 2010; Roni, 2018; Foote *et al*., 2020). Several literature reviews concluded that salmonid abundance increases following restoration (e.g. Roni *et al*., 2002 and 2008). However, Pretty *et al*. (2003) found little evidence of any general benefit to fish of small-scale instream structures in assessed low-gradient river restoration projects in England; this may have been due to projects being inappropriate in design and scale, poor water quality and schemes being isolated within longer sections of degraded river. Stewart *et al*. (2006) carried out a systematic review of 137 studies to assess the impact of engineered instream structures on salmonids and found no ecologically significant impact on salmonid population size or habitat preference, although they may provide preferential habitat where discharge is high (>$6m^3s^{-1}$). More recently Whiteway *et al*. (2010) and Foote *et al*. (2020) undertook meta-analyses on data from 211 and 100 stream restoration projects respectively to estimate the effect of instream structures on salmonid abundance and biomass. These authors found there was a significant increase in salmonid density and biomass following the installation of structures, but the scarcity of long-term monitoring is still problematic. Whiteway *et al*. (2010) and Foote *et al*. (2020) also recommended that the structures be used as a temporary tool while larger scale watershed changes are made. Roni (2018) concluded that river restoration may lead to either increased survival, abundance or both, but fish response varies greatly depending on typology, location, type of restoration works as well as life history.

These contrasting findings highlight that the outcomes of instream restoration programmes are difficult to predict and can be ineffective. Badly planned or inappropriate work may lead to waste of investment in time and money and may have drastic downstream or local effects if structures are dislodged and lead to bank damage or channel or bridge blockages. Restoration for sectoral purposes (e.g. specific fish populations) should be secondary to the goal of restoring the ecosystem that supports multiple species. If all restoration actions are consistent with the overriding goal of restoring high-level ecosystem processes and functions, then habitats for multiple species will likely recover (Roni *et al*., 2005).

A divide exists between restoration science and practice and this has been a known factor contributing to the inefficiency or failure in restoration works in past studies (Wyborn *et al.,* 2012). Therefore, both must work together if any works are to be sustainable and effective. Combining science and practice ensures that the river will respond positively to mitigation works in ways which maintain their diversity over time (Wohl *et al.,* 2015). Increasingly the concept of integrated management is being advocated for rivers and their catchments (Roper *et al*., 1997; SEPA, 2002; Rinaldi *et al*., 2013b). Management interventions which seek to alter or restore original channel characteristics such as width, depth, flow velocities, sediment characteristics or modify the structure of the riparian corridor – all valid WFD criteria for the appropriate river scenarios - will need to ensure that the ecological status of a river is maintained, that protected species are not damaged and that climate resilience is also addressed (Johnson *et al*., 2019).

Presently, there is a requirement for all river restoration proposals and projects to be compliant with EU and State legislation including but not limited to Habitats Directive, Water Framework Directive, Fisheries Acts (e.g. S.I. 14 of 1959, No. 10 of 2010) (and any forthcoming Irish legislation in the fisheries area), Wildlife Acts (e.g. No. 39 of 1976, No. 38 of 2000), relevant planning legislation (S.I. No. 30 of 2000) and 1945 Arterial Drainage Act or National Monuments Act (S.I. No. 2 of 1930) (in regard to bridges, culverts and weirs).

Best-practice restoration projects should consider the “passive” approach. As with active management this involves examining the stressors in each catchment (or watershed) to get an understanding of what is interrupting the natural processes that rivers undertake (Keating, 1996). Understanding what is failing is the first step to be undertaken before any mitigation measures can be introduced. Passive restoration can also involve changing the way human systems operate with the goal of reducing their impact on river ecosystems. It can involve regulatory measures to restrict or mandate certain behaviour (policy change), education to encourage voluntary changes in behaviour or market measures to provide economic incentives (Keating, 1996). Passive restoration concentrates on eliminating damaging land management practices within a catchment and allowing the natural restoration process to take place; many rivers will recover if left alone, restoring natural channel dynamics (Keating, 1996; O’ Grady, 1991). This approach offers a less expensive option and can often be a more successful long-term alternative to active restoration (Keating, 1996). Passive restoration projects will likely provide more long-term benefits to rivers than the more expensive active manipulation (Keating, 1996; Groll, 2017). Many authors have found that fencing out grazing animals provided significant improvements in riparian vegetation, bank stability and overall channel conditions (e.g. Platts and Nelson, 1985; Hunt, 1993) and hydromorphology (Groll, 2017) at a very low cost. In many cases natural recovery can be assisted by planting or reintroduction of native flora. Fencing that completely excludes livestock eliminates the introduction of nutrients and pathogens from animals and allows for riparian vegetation to colonise free of grazing pressures, assisting in bank stabilisation (O' hÚallacháin *et al*., 2020).

It has been shown that improving river hydromorphology has positive impacts on habitat composition and on biota, including fish (Haase *et al*., 2013). Reach-scale restoration may not result in improvement of the overall ecological status, and therefore catchment-scale (or watershed) measures examining wider scale stressors such as point and diffuse source pollution are required. Whatever the geographical scale, process-based restoration principles such as those suggested by Beechie *et al.* (2010) and Rinaldi *et al*. (2013b) are more conducive to self-sustaining systems, without further need for management or intervention. Scientists and practitioners have also recognized that restoration actions are more likely to be successful at restoring individual or multiple species and preventing the demise of others if they are considered in the context of the surrounding watershed or ecosystem (Doppelt *et al.,*1993, Muhar *et al.,* 1995, Reeves *et al.,* 1995, Roper *et al*., 1997, Beechie and Bolton, 1999; Habersack, 2000).

As recommended by many authors (e.g. Boon, 1992; Boon, 1998; Roni *et al*., 2005), a fully- integrated approach to river restoration is required in Ireland, consistent with the requirements of WFD and including climate change-associated impacts. Boon (1992) recommended that activities should take account of five dimensions; the longitudinal, lateral, vertical connections that rivers have with their environment, a temporal dimension (rivers change with time) and a conceptual dimension (reason for the work). The title for the works carried out - be it restoration, improvement or rehabilitation - all relate to the action of improving the ecological condition of rivers to ensure good ecological functioning.

1.5 Objectives

- The restoration of water courses, where necessary, should be a long-term goal that will take time to implement correctly. It is not something that should be rushed into and requires compilation of a comprehensive baseline data set and careful planning (getting the balance right) (Boon, 1998).

- To describe an evidence-based process for how river restoration works should be carried out by any party. The procedure takes account of natural river processes, system or sub-catchment scaling and climate change associated impacts on sensitive habitats and species.
- Measures must be environmentally sensitive, sustainable and take the entire ecosystem into account. They should also include appropriate protocols for climate proofing waterbodies. Any measures to be implemented should be considered as a long-term change designed to operate in sympathy with "natural" river processes. Proposed measures should demonstrate how they will mitigate existing pressures to aspects of ecological state, where this outcome is measurable by accessible and well-understood ecological indicators.
- To encourage passive restoration, i.e. where it is possible to allow the rivers' natural processes to re-occur (rivers and their fish populations can often recover naturally). In areas where this is not possible a combination of active and passive restoration measures could be employed (see case study 1).
- This is a live guidance document, as IFI (and others) learn more about the practices and practicalities and their long-term effects (particularly related to climate change) the guidance will be adapted and changed through knowledge sharing processes.
- These objectives are consistent with requirements and obligations imposed on the State in the context of the relevant Directives, primarily the Habitats Directive, the Water Framework Directive and the Floods Directive and are consistent with relevant national legislation (e.g. 1945 Arterial Drainage Act; 1959 Fisheries Consolidation Act, etc.).

Fig.1.6 Rivers support a large number of plant and animal species (examples of some of the biodiversity in Irish rivers)

2. Evidence-based assessment process for river restoration

2.1 Introduction

The approach to river restoration needs to be systems-based, responding to those underlying drivers of river degradation that may be present within a catchment. Success of projects should be judged against reference or control sites (Geist and Hawkins, 2016) and using appropriate sets of monitoring indicators. Hunt (1993) recommended 12 guiding principles for management of trout habitat in streams in the USA and many of these can be applied to Irish rivers, for example:

- Learn from nature
- Work *with* not *against* the inherent capacity of streams and watersheds
- Focus on the limiting factors at work in each catchment
- Tailor works to the catchment and stream
- There is no "one size fits all" approach
- Encourage native vegetation and trees
- Integrate habitat rehabilitation of the river, its riparian zone and its watershed to achieve synergistic benefits.

River channel behaviour is complex and any intervention in natural processes may result in unexpected adverse impacts. If the project is aimed at improving fish stocks or fisheries it is essential that the habitats of other river corridor species, such as invertebrates and birds, are not impaired. Therefore, all measures need careful planning, hydromorphological principles should be applied and potential climate change impacts recognised during the process. Those tasked with planning any project should ensure that the cause of the problems is addressed and not just the symptoms.

The best way to ensure the highest level of positive influence is to adopt a strategic approach to the planning and implementation of restoration works. Angelopoulos *et al*. (2017) reviewed 663 publications and identified that 'poor or improper project planning due to inadequate guidance' was the most common and major constraint found throughout. This poor planning subsequently led to a variety of issues across a large sample size. Some of the most reoccurring issues included:

- Not addressing the root/main cause of habitat degradation
- Failure to identify long-term achievable goals prior to works
- Incorrect identification of what level of restoration is required
- Potential flood risk for those living within a restored river's floodplain
- Risk of isolating stakeholders or local members of the public due to lack of involvement or poor communication (Speed *et al.,* 2016)
- Failure to plan the project at a catchment scale by focusing solely on individual reaches and rivers (Roper *et al*., 1997; Jansson *et al*., 2007).

2.2 Process for river rehabilitation works

A stepwise process, comprising six steps spread across three phases, should be followed when considering and planning any river restoration project (Figs. 2.1 and 2.2). Each of the three phases is described in detail below.

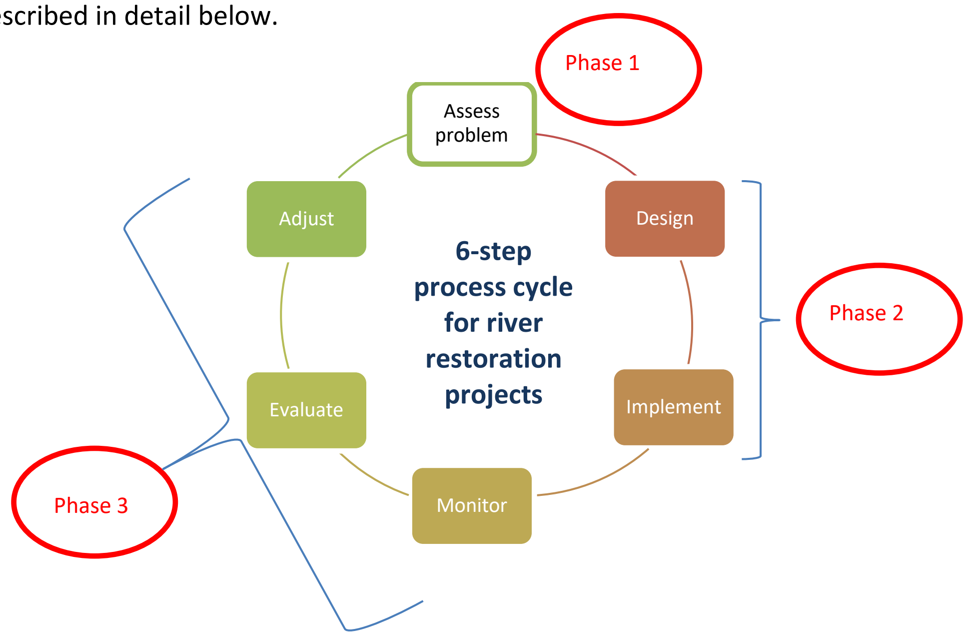

Fig. 2.1 Six step process for river restoration projects (adapted from http://www.for.gov.bc.ca)

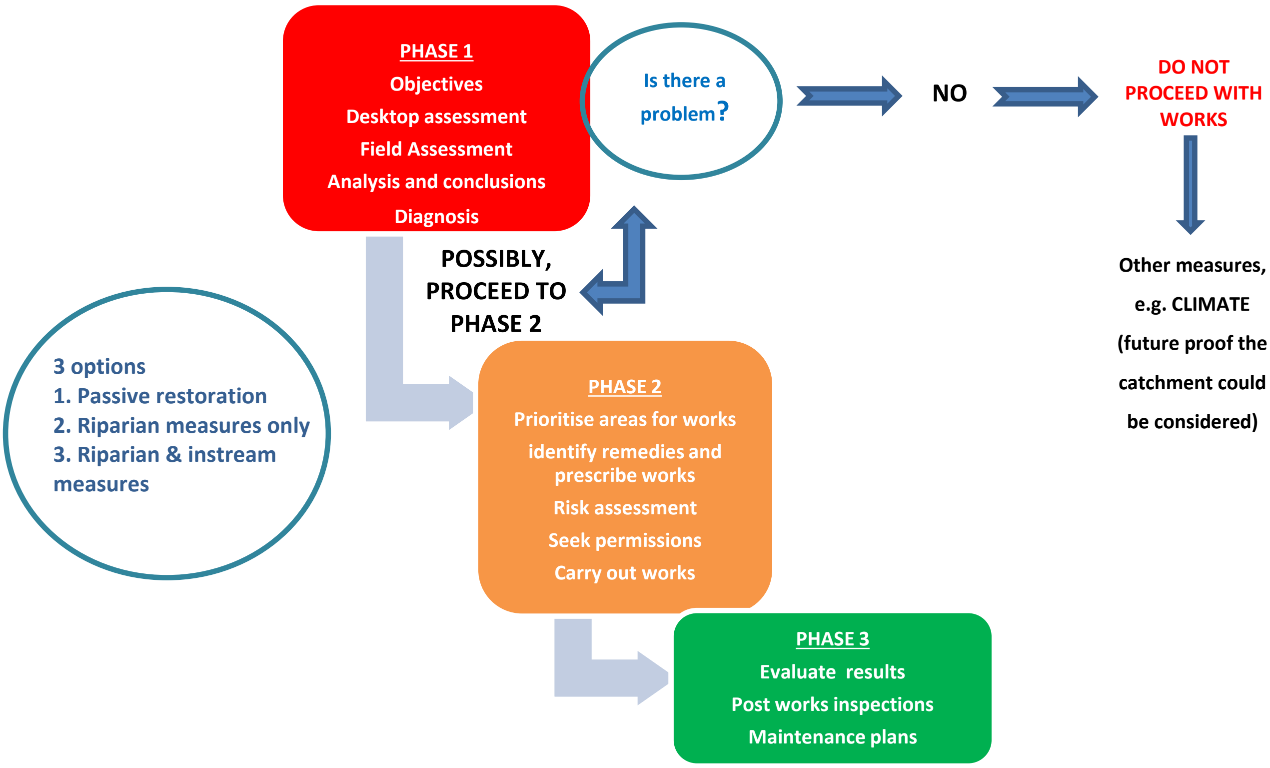

Fig.2.2 Process chart for river restoration projects in Ireland

2.2.1 Phase 1 – Assess the problem

2.2.1.1 Objective of works

The success of a project relies on clearly identifying aims and objectives at the outset and defining a clear pathway from restoration works to system recovery. Objectives should be measurable using accessible indicators and an *a priori* definition of "success". Political (at whatever scale) and other factors can drive management responses/objectives that are not supported by the underlying science, for example improving the amenity values of rivers for fisheries has been a major driver for many river restoration projects. However, focussing on this driver can lead to restoration approaches that focus on superficial and/or aesthetic elements of the river system (e.g. "gardening"/aesthetic improvements) and ignore the underlying natural river processes (Woo and Choi, 2013).

Setting goals and objectives that are achievable over the short to medium term along with identifying a long-term vision for the river basin is the best way to minimise the risks associated with planning (Speed *et al.,* 2016). Implementing the process of project identification is suggested by Angelpoulos *et al.,* 2017. This can be broken down into two parts:

1. Identify the current status of the waterbody and identify goals and objectives specific to this
2. Identify the policy objectives at both a regional and national level

Primary aims may consist of improving ecological status (WFD) or restoring natural river processes (hydromorphology - also WFD) with fish or other biota as one of the beneficiaries. Consideration should be given to identifying the scale of the project. This includes the scale of assessment works and the restoration works (e.g. river basin district, catchment, sub-catchment, waterbody or reach). Aims should be SMART (specific, measurable, achievable, realistic and timely) to help with the assessment/ evaluation of the success of the project; can you deliver and prove it? Aims should also highlight potential costs required, ensure that funding is available to complete and monitor works for a fixed period afterwards.

2.2.1.2 Desktop Assessment

Comprehensive catchment-scale desktop and field assessments should be undertaken in the first instance. The outcome(s) of these exercises will be the key support for any catchment-based plan; they will identify any underlying problems (specific anthropogenic pressures and degraded ecosystem state) and highlight potential catchment based solutions (defined restoration responses that mitigate observed pressure-state relationships). Subsequent work can be undertaken at a smaller scale and in stages but must be cognisant of this overall catchment plan.

The goal of desktop assessments is to identify pressures (e.g. there are several artificial barriers present) and corresponding effects on ecological state (e.g. fish passage is impeded). It is important that information on the baseline or current status of the biota (e.g. fish stocks or other biological elements), water quality, hydromorphology (including presence of barriers to fish passage and ecosystem function) within a catchment is analysed. This assessment will establish a baseline dataset against which to develop a restoration project and monitor improvement if required.

In certain cases, there will be no need to progress past phase 1 (see case study 1). For example, in the case of a proposed fisheries project, if expected fish densities and age classes of species are present then the habitat is already at high to good ecological status as identified by the WFD fish ecological classification tool, FCS2-Ireland (SNIFFER, 2011). Any proposed works will not improve the ecological status. If there is no problem with the hydromorphology of the river and the fish stocks are in high to good status, then the project should not proceed. However, it may be appropriate to look at allied actions such as climate resilience measures (see chapter 3) to future-proof the catchment and contribute to enhancing the condition of the riparian corridor. This latter work should be done using a risk-based approach (e.g. IFI will begin roll-out of the national river temperature model and interactive risk maps in late 2021/2 and could be considered) (*Kelly, F., IFI, pers. comm*.).

Where clear anthropogenic pressure-state relationships exist, the APSR (Activity, Pressure, State, Response) framework (e.g. Shephard *et al*., 2015) should be invoked to define pathways by which specific restoration activities will mitigate pressures and drive the desired improvement in state. Achievement of measurable objectives can be monitored by using appropriate ecological indicators.

Anthropogenic pressure (e.g. agricultural run-off, overgrazing) should be identified, and corresponding aspects of impaired ecological state located and described (e.g. water quality/eutrophication, poor or degraded habitats, etc.). Remedial measures should be tailored to mitigate those specific pressures (address the cause and not the symptom). If the water quality in a catchment is less than good and is the root cause of the decline in for example fish stocks, instream works will not mitigate the high-level pressure and should not be undertaken. This situation could be reviewed if the water quality issue is rectified. Pressures relating to infrastructure problems, e.g. bank damage adjacent to buildings, bridges, roads clearly require immediate action (O' Grady, 2006 and see case study 1).

Criteria to include in desktop assessments are listed in Table 2.1.

Table 2.1: Parameters to include in desktop assessments

Criteria	Comments
Catchment/ sub-catchment/ waterbody	GIS based (boundary delineation, etc.) Historic Maps (http://map.geohive.ie/) Check for barriers
Drivers, processes and forms in a catchment	Include gradient; land-use; sediment type and supply, transfer and deposition; channel form and habitat. (refer to the EPA documents on pressures, etc. in specific catchments)
River/stream order/reach typology in the catchment	Classifying river types is important as there is no "one size fits" all when it comes to restoration measures, e.g. in deeper lowland rivers it may be more appropriate to engage in marginal vegetation management and construction of fishing stands for anglers rather than undertaking instream works such as creating pools and introducing rock to make instream structures. Under natural conditions a river will vary in character and in type as a result of passage through the landscape (Leopold, 1994). Stream order (e.g. Strahler) is one method for classifying stream types. River reaches can be classified in many different ways, e.g. Rosgen (1996) river classification system describes individual reaches, but does not describe a whole drainage system; Murphy and Toland, (2014) classified four types of rivers for WFD purposes (bedrock channels, cascade step-pool, riffle, glide, pool and lowland meandering).
Channel gradient and bed type	These are particularly significant considerations in any proposed river restoration project. A low gradient lowland channel is likely to have marginal and instream weed growth, deep water and low velocity facilitating a habitat suited to a range of coarse fish and to adult brown trout. In contrast, an upland stream is likely to contain high levels of cobbles, gravels and sands with little instream vegetation and a preponderance of habitat suited as spawning and nursery water for salmon and brown trout. There is little point in trying to create salmonid spawning habitat in a flat, lowland channel and, equally, little point in creating coarse fish angling water in shallow upland streams.
Inland Fisheries Ireland (IFI) data	WFD fish ecological status (www.wfdfish.ie) Catchment wide surveys (qualitative e.g. TEF_{10} or quantitative fish stock surveys) have been carried out. Establish if there is any imbalance in the fish stocks e.g. absence of age classes, etc. Identify the presence of barriers in the catchments and their assessment status (assessed or not assessed) Catchment-wide habitat surveys – RHAT surveys Check life stage and habitat requirement and timings, see Appendix 1 and 2 Assess spawning effort in the waterbody and estimate carrying capacity (maps of spawning areas, redd counts, electrofishing data) IFI will have interactive water temperature risk maps available – late 2021-2022 Invasive species records
Environmental Protection Agency (EPA) and LAWPRO data	Water quality data (Q-values), hydrometric data, chemical/nutrient data, pressure data, etc. (https://www.catchments.ie/maps/), location of WWTPs, etc. Check if an area is listed as 'priority area of action' by EPA (or LAWPRO) for WFD purposes
National Parks and Wildlife Service (NPWS) data	Location of SACs and SPAs, NHAs, pearl mussels, etc. https://www.npws.ie/maps-and-data), Check specific species in the catchment and in the area of interest
National Biodiversity Data Centre (NBDC) data	Invasive species distributions, etc. (https://maps.biodiversityireland.ie//),
Geological Survey of Ireland (GSI) data	Groundwater, Bedrock, Geochemical (siliceous/calcareous). Information on quarries, landslides, soil types, etc. which can often indicate sources and types of sediment. (https://www.gsi.ie/en-ie/data-and-maps/Pages/default.aspx)
Office of Public Works (OPW) data	https://maps.opw.ie/) (http://waterlevel.ie/) OPW hold a comprehensive record of pre-drainage engineering drawings in the form of longitudinal and cross-sections that can give baseline information (information includes natural channel base widths, pre-drainage bed levels, bed type, channel planform and cross-sectional form, etc.). These records should be consulted prior to any proposed works. Check CFRAMS reports - flood risk, etc. – any structural work in some flood-prone areas may be off-limits
Forest Service (DAFM)	Forestry documents, wetlands – re-watering initiatives. (https://publicapps.agriculture.gov.ie/gispublic/rpfms/pages/workspace/public.jsp) (https://www.agriculture.gov.ie/forestservice/forestservicegeneralinformation/foreststatisticsandmapping/forestcovermaps/)
Abstractions	Reviewing water discharge regimes and water abstraction practices on resident salmonid stocks to ascertain if improvements can be made.
Other	Check local navigation (e.g. Waterways Ireland), non-OPW drainage works (e.g. Local Authority) and check national monuments database (https://www.archaeology.ie/archaeological-survey-database)

2.2.1.3 Field Assessment

The main goal of the field assessment is to fill in any gaps identified during the desktop assessment, e.g. assess the local fish stock, water quality, available habitat, climate resilience, etc. There are different field assessment methods that can be undertaken (e.g. WFD assessments) including surveys on fish species, macroinvertebrates, habitat/hydromorphology and barrier assessments (Table 2.2). Using standardised assessment techniques in line with WFD methods allows for comparative studies in the future.

The data gathered during the desk and field assessment can be used as a suitable baseline against which 'restoration objectives' can be measured.

CASE STUDY 1
Crana River, Co. Donegal

Examples of damage to infrastructure (bridges) caused by a severe flooding event on the Crana River, Co. Donegal, August 2017

Note: A severe 100-year flood event occurred in the Crana River catchment in August 2017 causing substantial bank erosion on exposed banks, movement of marginal bed material and displacement of materials within the watershed, impacting on local communities and farmland. Mitigation works were carried out to protect infrastructure. However, no instream restoration works were recommended for fisheries by IFI in this case after a UAV habitat survey and associated fish stock surveys were completed one year post-flood. The Crana River is a high gradient catchment with good levels of gravel recruitment. Fish populations compared favourably with previous data one-year after the flood event. Riparian cover along the river corridor served to stabilise the riverbanks and limit the potential for excessive bank erosion – the recommendation was to allow the system to repair itself by natural processes – passive restoration (Millane et al., 2018 and 2019).

Table 2.2. Field assessment methods to assess status of rivers in Ireland

Group	Element	Information	Recommended method of assessment
Biological	**Fish**	Their greater longevity allows fish to be witnesses and indicators of historical alterations and impacts to water bodies, even when drivers have already disappeared. Fish are indicators at the meso-habitat scale (river segments); while some other biological elements represent the micro-habitat scale. The composition and structure of the fish community integrate the information from the lower trophic levels (phytobenthos and zoobenthos) and reflect the quality status of the entire aquatic ecosystem.	TEF (timed electrofishing) e.g. 10-min electrofishing (see *Matson et al. 2018*). and/or ADEF (area delineated electrofishing) and Fish Ecological Status determined using FCS2 Ireland tool (Sniffer, 2011) Fish Habitat Assessment – e.g. LCU (subjective assessment of each habitat element of the fish life-cycle) (e.g. O' Connor and Kennedy, 2002)
	Macroinvertebrates	They represent an extremely diverse group of aquatic animals sensitive to stressors such as organic pollutants, sediments, and toxicants. They are regarded as being ideal indicators as they are continually exposed to any changes that occur in the environment. It is these responses to change that can be used to establish any impacts on the water body.	Kick sample, EPA Q-Value System (the Irish National assessment system) (Toner *et al.*, 2005) SSRS (Small stream risk score) (WRBD, 2005). In the absence of Q-value data this is a useful rapid assessment method in tandem with 10-min electrofishing and RHAT surveys.
	Macrophytes	Macrophyte communities in rivers respond directly to physical and chemical conditions but are subject to variation because of differences in composition of substrata, shading and flow regimes.	CBAS (Canonical Correspondent Analysis (CCA)-Based Assessment System) (see Dodkins *et al.*, 2005) or Classification and dynamics of aquatic macrophytes in some Irish rivers (Caffrey, 1990) or An Irish national vegetation classification system for aquatic river macrophytes (Weekes *et al.*, 2018) See also: A river vegetation quality metric in the eco-hydromorphology philosophy. (O' Briain *et al.*,2018)
Hydromorphological	**Hydromorphology (Hydrology & Morphology)**	Hydromorphology considers the physical character and water quantity of water bodies. Hydromorphological elements such as water flow and substrate provide physical habitat for biota.	RHAT survey - developed specifically for the WFD (see Murphy and Toland, 2014) Or Morphological Quality Index (MQI) Assess, classify and monitor the current morphological state of a river (Rinaldi *et al.*, 2013a)
	Barriers (continuity assessment)	Barriers have a profound effect on hydromorphology. Identification of barriers may indicate reasons for species presence/absence or sediment regimes.	IFI barrier assessment tool (for baseline) and/or SNIFFER assessment (see SNIFFER, 2010) for detail IF planning a removal or mitigation works
	Fish Habitat	Fish habitat modelling, comprising habitat mapping, assessing flow and hydromorphology and habitat suitability	e.g. Mesohabsim (Parasiewicz, 2011)
Invasive macrophyte species	**Riparian and instream**	Invasive species are considered a major anthropogenic threat to biodiversity	Mapping all invasive species in the catchment, using walkovers, drones, aerial photography, etc.

2.2.1.4 Data analysis

All desktop and field assessments should be analysed to determine any underlying pressures and the impacts they are having on the state of hydromorphology and biota (e.g. fish stocks) in the catchment. Conclusions of the desk and field studies should be well-defined and identify clearly what the cause of the problem is and the impacts on the biota.

If there is no problem with the hydromorphology and the biota (e.g. fish stocks) there should be no need to progress to Phase 2. However, other appropriate works could be considered, such as riparian measures for improving climate resilience, if shortcomings have been identified during the field survey programme or as a result of analysis of field datasets (or based on national river temperature model - IFI's interactive maps – roll-out to begin late 2021).

2.2.1.5 Diagnosis

The results of both field and desktop assessment are used as an evidence base to identify the cause(s) of any perceived problem (anthropogenic pressures) and the symptoms (impaired ecological state of habitats or biota). Appendix 3 lists examples of physico-chemical and hydromorphological pressures that can affect biological quality elements and their response. It is then necessary to define clear pathways, by which suitable works can mitigate observed pressures and drive ecosystem recovery.

Options for intervention need to be carefully considered, as do the risk of adverse impacts from any intervention; however, in many cases intervention should be a last resort or may not be required at all (SEPA, 2002). SEPA (2002) lists a number of questions which should be posed during this phase of the decision making process for Scottish rivers; these are listed below as they are appropriate to the Irish situation and project managers should consider each point carefully:

- What is the problem or issue of concern?
- What are the causes of the problem?
- What are the aims of the planned intervention?
- Are they realistic (e.g. is it feasible to restore habitat in a degraded heavily modified catchment?)
- Are they legal (permission pursued, landowner and other consultation, environmental screening assessments, etc.)?
- Have they been approved by the appropriate bodies?
- What are the likely negative impacts of the proposed intervention (e.g. intervention in one location usually has impacts elsewhere that may be difficult to predict)?
- What are the chances of the aims being successfully achieved with minimal additional impacts?
- After consideration of the above questions, is the intervention still necessary and/or desirable?

- If so, how can management maximize benefits to other rivers users (number of different objectives?

Identifying the real cause of a perceived problem is essential. For example, traditional work such as raking spawning gravels to clear out fine sediments might only have short term benefits if the source of the fine sediments is overgrazed land upstream that will continue to deposit on gravels during the next flood (Bašić *et al,.* 2017). Recent literature shows that the natural "raking" done by spawning fish (e.g. sea lamprey) creates habitat niches and that invertebrate diversity and quantity is enhanced by this natural "raking" (Hogg *et al*., 2014). Therefore, instead of addressing the symptom, the cause of the problem should be addressed, e.g. fencing and creating a buffer strip alongside the affected land.

If there is no problem with the hydromorphology and the biota (e.g. fish stocks) there should be no need to progress to phase 2. However, if proceeding to Phase 2, there are three options/actions to choose from:

- **Option 1** – **Passive restoration** - allowing the river to recover naturally, is being actively examined and used in the last few decades (e.g. O' Grady, 1991; Groll, 2017); and should be considered for relatively natural unmodified channels. Groll (2017) found this was most suitable in channels free from man-made barriers/impoundments. Results from two passive restoration case studies in Germany show a high spatial and temporal diversity and dynamic for all measured hydromorphological features, e.g. riverbed sediments, organic structures such as woody habitat and macrophytes, microhabitat types.

- **Option 2** - **If water quality the limiting factor – No instream works** - Recommend riparian actions (e.g. fencing to exclude livestock with off-line drinking facilities, planting buffer strips, etc.)

- **Option 3** – **Riparian and instream measures.** Instream measures should be a last resort in many cases – any intervention must address the cause of the problem and not the symptoms (SEPA, 2002.

2.2.2 Phase 2 – Design - Implement

Once it is established that some works or measures are appropriate, six steps should be followed:

a) Areas for works should be prioritized.
b) Appropriate measures identified (prescribe remedies) (initial engagement with NPWS through the Developments Applications Unit (DAU).
c) Risk assessments carried out.
d) Monitoring programme designed, including accessible indicators with defined targets that constitute restoration "success"
e) Relevant permissions should be sought, e.g.it may be necessary to carry out Natura Impact Screenings or full Natura Impact Statements (NIS) as required for the EU Habitats Directive in some catchments (see IFI environmental process: (https://www.fisheriesireland.ie/NSAD/environmental-assessment-process.html), etc.).
f) Restoration works are carried out.

2.2.2.1 Prioritise areas for work

Prioritising areas for works should be based on ecology and/or hydromorphology. Additional factors may influence the final decision (i.e. landowner agreement/project synergies /resources). Several different approaches can be used to prioritise sites, ranging from simple scoring procedures to complex models (Beechie *et al*, 2008). A common strategy and cost beneficial strategy for restoration projects in a catchment is to:

- **Prioritise moderate sites** – based on WFD classification. Sites classified as POOR or BAD are likely to have serious water chemistry issues that will not respond to any physical works programme; however some moderate sites could also have significant water quality problems and these must be identified and flagged in advance.
- **High and Good sites should not be a priority** for river restoration works (already reached WFD target)

Documentation of each step and the decisions made is critical for providing a transparent prioritisation process.

RHAT or MQI surveys are a useful tool for assessing the conditions of rivers. Diaz-Redondo *et al*. (2019) used a method to assess sites using RHAT surveys and prioritised sites that had fewer failing attributes (e.g. good substrate condition but poor riparian habitat), availing of the individual attributes within the overall RHAT score. Sites could be upgraded or downgraded based on additional information such as species presence, barriers or synergies. Sites that can maximise the use of assisted natural recovery were preferred.

Prior to any implementation of restoration works the area of planned works must be visited. Site specific issues must be identified relative to the works that are proposed. This allows for site specific risks and mitigation measures to be identified and implemented coinciding with the restoration works themselves.

2.2.2.2 Identify remedies

As part of the assessment process a list of proposed measures needs to be outlined for the system dependent on the stressors highlighted in the assessment process above. It is important to demonstrate clearly how any proposed measures (restoration responses) can mitigate observed pressure-state relationships, i.e. problems and symptoms, identified above. A risk assessment must then be completed and appropriate and low-risk mitigation measures identified. Plans for proposed works can then be developed. A list of candidate appropriate measures, all situation-dependent, is provided and described in detail in chapter 3.

2.2.2.3 Risk assessments

Risk assessment is a term used to describe the process or method where issues are identified that have the potential to cause harm. Associated risks are analysed and evaluated and sensible measures to control risk are identified and introduced. A risk assessment will need to be carried out once the remedies/restoration measures for each project have been identified. The idea of Risk Assessment is to identify "what might happen if…" and to protect all parties from any potential adverse effects of carrying out the proposed works plan.

There are obvious health and safety risks in undertaking any construction works and those works adjacent to water have additional risks (e.g. IFI, 2016). Plant and machinery for use on site must be handled with all care and planned works should be awarded to competent professional contractors with expertise in the topic area and with appropriate insurances, etc. Well-intentioned local volunteer undertakings may lie exposed to a range of risks. Clients, designers, contractors, employees and project supervisors involved in construction projects all have obligations under Health and Safety at Work (Construction) Regulations of 2013. All parties involved in these projects should be aware of their duties and ensure that they carry them out.

Importation of materials on-site generates further risks related to biosecurity that must be analysed in advance. Machinery and plant should be power-hosed and fully cleaned, particularly regarding wheels and tracking, excavator buckets, etc., prior to entry on any works site. The machinery should remain on-site until the works are completed. Importing of stone, and particularly of any soil filling, is fraught with risk of inadvertently importing fragments or seeds or propagules of nuisance plants, particularly invasive terrestrial plants that can be dispersed by water e.g. Giant Hogweed, Himalayan

Balsam, Japanese Knotweed. Evidence of the spread of these invasives is visible on many national roads, where re-alignments and planting along road margins used imported soils that contained unwanted invasive plants (NRA, 2010). All proposed restoration projects will outline the risks that the works will have of introducing or increasing the spread of invasive species. Mitigation measures should be identified and put in place to address these.

Additionally the aim of the risk assessment should be to capture the pros and cons of carrying out the restoration works as some works have the potential to cause negative or harmful effects to the waterbody itself (IFI, 2016) (Table 2.3). Many significant challenges are faced when attempting to restore river ecosystems and therefore river channels should not be interfered with lightly. River channel behaviour is complex and any intervention in natural processes may result in unexpected adverse impacts. Some of the challenges include: the complexity and scale of the task, the uncertainty of future conditions within the river basin itself, balancing the multiple roles of the river and the acceptance that it is not feasible to return most rivers back to a 'natural' state (Speed *et al.,* 2016).

Works undertaken in one area have the capacity to impact adversely both up- and downstream; they can significantly impact upon flora and fauna, e.g. fish populations and the overall status of a waterbody if not carried out in a careful and environmentally responsible manner (IFI, 2016). Inappropriate works, particularly instream works, can cause local ponding or impounding effects that may back-up or impede flow and thereby raise the water levels sufficiently upstream that land drain outfalls or drains of an upstream landowner may become water-logged or may not function as efficiently. Likewise, works may impact downstream by altering velocity of water and contributing to adverse impacts on riverbanks, including causing bank erosion or localised flooding.

Removal of barriers in rivers has a range of positive impacts for natural river processes but the approach to removal must be examined and planned carefully to ensure no adverse up- or downstream impacts. A river's response to weir removal is strongly dependent on local conditions and variables and assessments for impacts of weir removal should be undertaken by an experienced geomorphologist, although minimal input may be needed for small weirs and low risk sites (Kitchen *et al.,* 2016). The removal of a weir from a water course will have several upstream and downstream effects. Upstream there may be improved land drainage, reduced flood risk, reduced saturated zone and the drying out of backwaters/ponds. Sediment dynamics will also change with upstream sediment deposits eroding. The eroding upstream sediments may also temporally infill downstream pools and create a more dynamic downstream system potentially encouraging the river to meander. The removal of a barrier could also cause the unintentional movement of invasive species upstream to new areas. Therefore a GIS risk assessment framework should be developed to assess management options within a catchment (King and O' Hanley 2016) so that the spread of invasive species may be mapped and limited adequately (e.g. create a biota pass rather than remove the barrier (Tummer and Lucas, 2019).

Some of the risks associated with various types of restoration works are listed below. Mitigation measures are also listed (Table 2.3).

Table 2.3. Examples of risks and mitigation measures associated with restoration works

<table>
<tr><th>Risk</th><th>Description</th></tr>
<tr><td>Timing of works</td><td>• Timing of instream works negatively impacting on the fisheries resource of the river.
• Interference with the migration of fish species: either migration within the freshwater system itself or anadromous species which migrate great distances to spawn in freshwater (salmonids, eels, lamprey)
• Many fish species are sensitive to siltation. Siltation from in stream works would negatively affect them.</td></tr>
<tr><td colspan="2">Mitigation
Care must be taken to ensure that the timing of works minimises adverse impacts to the spawning activity, migration and juvenile development of the species present (see Appendix 1 for migration times of fish species).
Ensure adequate fish passage is present at any permanent or temporary structure constructed within the river channel.</td></tr>
<tr><td>Poor choice of materials or inappropriate materials introduced</td><td>• Introducing alluvial material of incorrect size or introducing Large Woody Habitat (LWH) where there are no LWH/trees.
• Some instream works introduce stone of a large size to ‘stabilise’, for example gravel beds introduced or as part of a ‘forcing structure’ (low weir type structure) to allow for long-term scouring of a pool excavated.
• Some such structures create a low-level barrier to fish movement with a clear hydraulic jump at low/moderate flow conditions. Some of these pool formation structures can be ‘constructed’ at very low cost by bed excavation, without any rock introduced, as per agreed OPW/IFI strategies.</td></tr>
<tr><td colspan="2">Mitigation
Encourage the use of soft works over hard stone where possible, for example the use of trees in bank reinforcement works.
Materials removed from the river itself should be incorporated back into proposed works; this reduces waste and reduces the risk of invasive species introduction.</td></tr>
<tr><td>Alteration to hydrology or hydromorphology of the waterbody</td><td>• This can result in a significant negative alteration to the characteristics of the flow resulting in scouring, potential, erosion or deposition either upstream or downstream of works
• Could also lead to very shallow depths during low flow</td></tr>
<tr><td colspan="2">Mitigation
Adequate pre-planning and understanding of the river basin and overall catchment prior to work implementation.</td></tr>
<tr><td>Damage to the instream and riparian habitat</td><td>• This includes removal of gravels, removal of instream vegetation, bankside damage, tree/shrub/root system removal, undesirable ‘extra’ work e.g. over-widening, over-deepening, lack of adherence to restoration guidelines.
• Alterations to spawning gravels through in stream works can negatively impact upon lamprey spawning success. This may occur by removing necessary substrates, disrupting spawning activity in March/April (Brook and river lamprey) or May/June (sea lamprey) or damaging developing larvae within the spawning gravels directly after the spawning event has occurred.
• Removal of silts and sediments in low velocity sheltered areas and backwaters can be detrimental to larval lamprey development.
• Removal of gravels and overall disruption to spawning sites will hinder the success of spawning populations of salmon, trout, lamprey and shad.
• Without appropriate mitigations in place, regular instream maintenance work can have adverse impacts on larval lamprey populations and habitat (King et al., 2015).
• Excessive removal of instream and marginal vegetation can impact adversely on spawning and nursery habitat for coarse fish species.</td></tr>
<tr><td colspan="2">Mitigation:
Do not remove gravel or stone from the river, only when specified to do so: retain all vegetation or vegetation at water’s edge (depending on channel type); adhere to pre-planned works</td></tr>
<tr><td>Bank protection works</td><td>• Some bank protection works can push or drive the situation/adverse impact downstream onto someone else; bank protection works that merely serve to address symptoms and not causes should be avoided) (Gilvear et al., 2002; SEPA, 2002)</td></tr>
</table>

<table>
<tr><td></td><td>Some measures are too ‘controlling’ – they FIX a situation so that they prevent natural processes (e.g. natural channel braiding) and force natural processes to do something different
Trees used as bank protection can become dislodged, travel downstream and cause a blockage at a bridge or other infrastructure. This could lead to increased scour and structural failure with significant consequences.</td></tr>
<tr><td colspan="2">Mitigation:
No bank armouring (large stone) should be carried out unless erosion is impacting on important infrastructure, e.g. dwellings, roads, railway lines – softer measures required (see case study 1 and chapter 3). Use of trees to be agreed with OPW in drained channels, appropriate anchoring to be identified.</td></tr>
<tr><td>“De-tunnelling”</td><td>The traditional practice of “de-tunnelling” rivers requires careful consideration considering expected climate change impacts.
In general removal of trees on unconsolidated riverbanks will lead to a loss of bank strength when the roots die, increasing erosion risks.
Changes in water temperature caused by excessive vegetation removal may affect fish spawning migration behaviour.
Reduced tree cover along the spawning migration route can leave fish species exposed to predation.
Trees are one source of “cover” for fish, particularly brown trout</td></tr>
<tr><td colspan="2">Mitigation:
As a general guide trees should be retained and only LIGHT pruning undertaken. Pollarding can be considered in some cases. DO NOT OVERPRUNE.
The aim for all projects should be to “cool” the river or keep the river “cool”.</td></tr>
<tr><td>Species-specific works</td><td>Works specifically designed for salmonids could have a detrimental impact on habitats of other species.
The negative impacts need to be carefully considered, for example de-silting operations could have a negative effect on lamprey populations; vegetation removal impacts adversely on coarse fish species as they use this for spawning and for cover/feeding.</td></tr>
<tr><td colspan="2">Mitigation
Works should not be species focused. By working with the local hydromorphology, the works could benefit those species appropriate to the site. This is consistent with a holistic approach. This should be done at the planning stage.</td></tr>
<tr><td>Barriers</td><td>The construction of barriers to migration and alteration to flow and water levels will have negative impacts on resident and migratory fish populations and their spawning migrations.
Alterations to natural river systems, which may restrict natural lateral and longitudinal connectivity, may either, damage, remove, or prevent access to these habitats by fish.
Barriers impact adversely on natural flow patterns and on sediment transport and create artificial impoundments in the river. This is contrary to the Water Framework Directive requirements.
Removal of barriers may cause the un-intentional spread of invasive species upstream
Unless managed properly, removal could lead to downstream spread of sediments or pollutants that may have built up upstream of the barrier.
The removal of barriers can lead to an increase in peak flows downstream which can give rise to an increased flood risk.
Weirs may be protected structures and may require archaeological assessments
Weirs may have a recreational or cultural value; removal may impact negatively on certain groups (e.g. kayakers)</td></tr>
<tr><td colspan="2">Mitigation
No new construction of barriers (unless on the rare occasion where an isolation barrier may be required for invasive species). Barrier removal prioritized. Modern fish friendly barriers and fish passes to be designed only where absolutely necessary. Appropriate sampling to be undertaken (e.g. sediment). GIS based risk assessment to map invasive species and assess risks. Flood risk assessment to be undertaken. Appropriate consultations to be carried out. Check national monuments database. Assess the ecosystem services provided by the structures.</td></tr>
<tr><td>Stakeholder objectives</td><td>Managing stakeholder objectives is imperative. It is likely that the initiative for a project may come from a well-intentioned local group anxious to undertake work for general benefit.
The objective may be very local in outlook and in geographical extent and may encompass a perceived shortcoming in the river and how it might be addressed.</td></tr>
</table>

	• It may be a significant challenge to harness this goodwill and re-direct it to goals and ambitions that satisfy some degree of the initial local interest and concern while also satisfying larger or more holistic catchment-based issues. • Acceptance of natural river processes can be difficult for riparian owners, e.g. sediment loss is balanced naturally by gain elsewhere and vice versa
Mitigation Education, effective communication, compromise, soft-works, adaptive management, etc.	
Alteration to the current form of a river	• This type of work should be approached with caution and avoided if possible. • Rivers can generate substantial power in high or flood flows. Stream power interacts with the bed and bank of the channel to create a stable channel form. Interfering with this stability may lead to instability and outcomes that cannot be predicted. The form of a river is a composite of bedrock and surface geology, of catchment size and topography and location in a catchment. The form is also impacted by human influence, such as that caused by drainage works on a large or small scale and by introduction of barriers or weirs.
Mitigation Avoid this type of work	

2.2.2.4 Seek relevant permissions, etc.

The requirement for consent will be dictated by the type of work to be carried out. It is important, however, that a thorough examination of the authorizations required is conducted and obtained prior to any works commencing. A comprehensive description is included in IFI (2014) and includes fishery owner, operator, landowner, IFI, NPWS, Local planning authority, Waterways Ireland, OPW, angling clubs, etc. For example, permission from OPW is required to work in OPW channels; permission from OPW is also required regarding modification of weirs, dams, etc. (1945 Act). The ownership of land parcels can be examined on-line via the Land registry website (www.landdirect.ie). This will provide Folio numbers and landowner names for all parcels adjoining a channel where works are proposed. Landowner permissions can be quite controversial as many landowners will be supportive, some will not, and some will barter to get what they want. Works might be asked for where there is a real or perceived need for same or not. A decision on how to proceed in these circumstances is required (e.g. walk away or compromise to do things that might not be appropriate (e.g. hard vs. soft engineering)) as this can delay projects substantially. Having an education package available for landowners is important. Local IFI staff, teams from LAWPRO (local community officers and ASSAP officers) can provide advice locally.

Under the 1959 Fisheries Consolidation Act all weirs constructed post August 1842 are obliged to incorporate a fish passage solution to facilitate the "the free run or migration of all fish at all periods of the year". In a detailed survey of 30 fish passage solutions Barry *et al*. (2018) demonstrated the unsuitability of many of these structures on the Irish river network with only one fish passage solution providing unhindered upstream access for adult salmon. Salmonids, due to their strong swimming/jumping ability, are more successful than non-salmonids at using fish passage mitigation options (Bunt *et al*. 2012). Most fish passage options are designed to accommodate anadromous salmonid species. Barry *et al*. (2018) also showed that 100% of the fish passage solutions examined impacted adversely on sea lamprey passage. Although the authors examined a limited number of fish passage solutions in their study, it does point to a high degree of inadequacy to perform the required legal function in historic structures.

2.2.2.5 Carry out works

Works should be carried out as per the detailed plans drawn up and in compliance with all relevant legislation (e.g. Fisheries legislation – closed season, Wildlife act – close season for tree cutting, Health and Safety Construction Regulations), guidance documents (e.g. IFI, 2016, etc.) and permissions.

The instream works window is July to September. However, it may be necessary to delay works in certain cases, e.g. crayfish are carrying eggs from May – Mid July and therefore works should be delayed to end of July in sites where crayfish have been recorded in the initial desk and field surveys.

Works may have to be undertaken using a two-stage approach in certain situations. For example, instream works should be carried out from July to September, but riparian works/tree management should be undertaken during winter. Fencing should be the last operation to be undertaken in a site project.

There may be different contractors doing the work. This needs to be sequenced to minimise damage/disruption to landowner property. Lands will require re-instatement following completion.

If the work is put out to tender to external contractors, there are precise rules and regulations to be aware of regarding advertising and award. More detail and reference documents are available on the IFI website in relation to the Environmental Assessment procedure, screening, etc. (https://www.fisheriesireland.ie/Angling-Information/national-strategy-for-angling-development.html)

2.2.3 Phase 3 – Monitor - Evaluate

The diagnosis stages of the process above require that candidate projects address observed ecological pressure-state relationships in a river system. Clear recovery pathways need to be specified for any proposed restoration works, i.e. this intervention will mitigate this problem in this way. An appropriate quantitative evaluation of restoration works should be conducted (e.g. hydromorphological and fish stocks) post-works to assess the success or otherwise of projects. This should include both short-term and long-term assessments. Monitoring should use accessible ecological indicators that are known to capture the state of those ecosystem components that are specifically targeted for restoration, e.g. fish population state can be monitored by electrofishing, while change in hydromorphological state is captured by RHAT surveys. It is important that indicators have associated targets which express restoration success, i.e. restoration has been achieved when ecological status of the fish population reach good or high status and a desired RHAT score is recorded. Long-term monitoring might be defined as having sufficiently long life span that permits an overview assessment of the works, as the altered river and processes may take periods of years, in many cases, to achieve a full physical impact. The changes in impact over time will, in turn, impact on biological elements, including the fish species and life stages for whom the initial works were designed (see chapter 4 for more detail).

Plans may also be required for regular or on-going inspections/audits/maintenance checks depending on the type of works implemented. On-going maintenance plans may also be required (e.g. for fishing stands). This evaluation phase is dealt with in more detail in Chapter 4.

The monitoring process must commence IN ADVANCE of any works at sites, in order that a ‘beforehand’ scenario can be compiled. The monitoring should follow the BACI model – Before, After, Control, Impact. Put simply, the monitoring should have a set of sites (Control replicates) where no works are done and a further set of sites (experimental or Impact replicates) typical of the specific works that will be done. Both sets of replicates should be surveyed BEFORE (B) works and then AFTER (A) works, on an agreed timescale. This timescale should include data collection in more than one year BEFORE any works, to consider the extent of natural fluctuations in fish, invertebrate populations etc.

Fig. 2.3 Monitoring in rivers – e.g. electrofishing and kick sampling

3 Best Practice Measures

3.1 Introduction

This chapter includes a list of measures that may be appropriate for certain scenarios in river restoration projects in Ireland and that have been researched and published in the scientific literature. These measures have a focus on natural hydromorphological processes and climate resilience, in line with current holistic land management perspectives and with EU directives. The list of measures is divided into four areas and not just confined to undertaking instream works (Fig. 3.1). Measures for the riparian zone to improve its interaction with instream habitats are also recommended. It also includes measures appropriate for drained and undrained ("natural") catchments. Many of the proposals are also consistent with positive action for river corridor climate resilience.

Drained channels are those channels that have been arterially drained (see Introduction and Fig 1.3). Undrained channels are those which have not been arterially drained; however, some may have been modified in various ways by anthropogenic activity, which would affect their hydromorphology. For example, floodplains have been encroached on for agriculture and urban settlement. Both activities limit the extent of riparian vegetation and large-scale removal of woody habitat was common throughout history (Addy *et al.*, 2016). When considering restoration projects, measures must be appropriate to the hydromorphology and type of channel or catchment being examined. Fish life cycle and habitat requirements must also be considered if proposing fish species-specific measures. These are described in Appendix 2 and 3.

Fig. 3.1 *Best practice* measures are examined under four main headings with, in each case, issues identified, and overall strategies proposed.

3.2 Riparian scenarios and measures

The riparian zone is the strip of land area lying between the normally wetted channel of a river or stream and the normally dry terrestrial landscape adjoining the river or stream (Fig. 3.2). Riparian zones provide important chemical, physical and biological functions within a river catchment, including processing nutrients, delivering woody habitat (Fig. 3.3) and organic matter, providing shade (Fig. 3.4), stabilizing soils, regulating microclimate and many other important functions (IFI, 2020; Roni *et al*., 2005). They also provide important habitat for both terrestrial and aquatic biota. Riparian vegetation is a crucial component of fluvial systems and serves multiple socio-ecological functions (i.e. protects banks, alter flow conditions, supplying woody material, etc.) (Dufour and Rodriguez-Gonzalez, 2019; IFI, 2020). In arterially drained channels the riparian zone often consists of a narrow corridor along the margins of the bank full channel and a small area at the top of the bank while in un-drained channels there is a wider corridor (Fig. 3.2). Riparian zones in many river basins have been impacted by agriculture, forestry, recreation, building of infrastructure (e.g. roads), and residential and industrial developments. Work is required to restore many riparian areas and improve river habitat quality which in turn will improve habitat for aquatic biota such as fish (Roni *et al*., 2005).

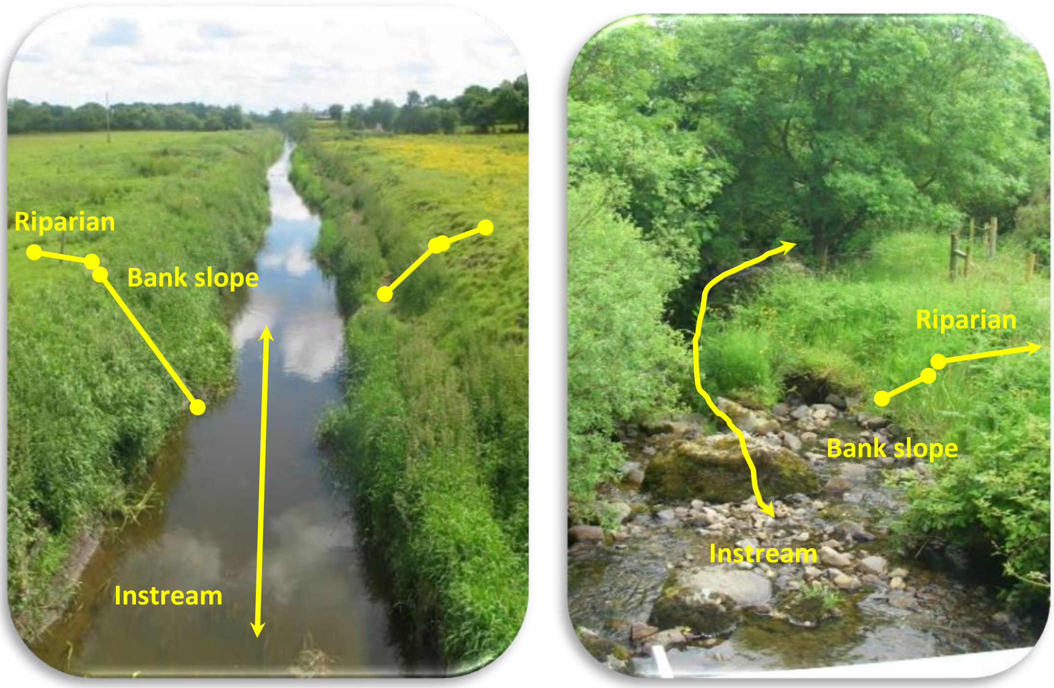

Fig. 3.2 Examples of the river corridor in a drained (left) and undrained river (right) (instream, bank slope and riparian areas)

Fig. 3.3 Examples of instream woody habitat

Fig. 3.4
Riparian tree cover is essential (provides cover for fish, bird and mammal species, source of prey items for fish, roots anchor bank soils, root wads provide habitat for fish - sediment for lamprey. Native deciduous trees are recommended

Riparian measures described here are common for both undrained and drained channels or are type-specific (Table 3.1), they include:

- Fencing – complete livestock exclusion and provision of off-line drinking water; eliminates nutrient, pathogen and sediment input from livestock and damage to bank slopes (Fig. 3.5)

(Note: From 1st January 2021, farms with an allowance to farm at a grassland stocking rate over 170kg/HA are required to prevent cattle from accessing watercourses (fencing must be 1.5m from top of watercourse bank), locate livestock drinking points >20m away from watercourses and prevent direct runoff from farm roads (4th Nitrates Action Programme (NAP) requirements (Teagasc, 2020b)).

- Encouraging natural colonisation of vegetation (Fig. 3.6).
- Planting trees- native broadleaf trees, particularly those adapted to wet conditions and inundation e.g. alder and birch.
- Creation of buffer strips – in line with landowners; agreement of drainage authorities; possible grant-aided in new EU CAP programmes (Fig. 3.7).
- Measures to address riverine impact on bank slopes – erosion, deposition and slippage.

IFI in conjunction with the OPW developed environmental guidance for river maintenance (King *et al.*, 2011; Brew and Gilligan, 2019). The OPW advocate a balanced approach between their remit for water conveyance and environmental management (Brew and Gilligan, 2019). Many of their environmental procedures with implications for the riparian zone are listed in Table 3.1. The Department for Infrastructure (DfI) (formerly Rivers Agency) in Northern Ireland have also developed a series of environmental strategies to address maintenance issues, in general, as well as specific guidance for particular issues relevant to retention of habitat and biodiversity opportunities (Rivers Agency, 1999).

Given that there is no remit to manage undrained channels for flood conveyance by the OPW, there may be more scope for establishing large riparian zones in these waters. Moreover, the proposed EU CAP reform may incentivise landowners to do so. In some cases, the channels may be naturalised, so it would be more appropriate not to interfere (passive restoration). Riparian zone measures such as fencing, vegetation management and tree management have clear positive implications for climate change mitigation in addition to their habitat enhancement and WFD compliance impacts.

Fig. 3.5 Fencing and livestock exclusion: Unrestricted livestock access can damage the bank and bed of the river (photos top and left) and may cause a significant decline in water quality. Damage of the banks may exacerbate erosion and/or flooding and result in loss of productive land. Fencing and livestock exclusion allows the banks and bed to recover. Locate livestock drinking points >20m away from watercourse.

Fig. 3.6 Retain tall emergent vegetation on bank slopes

Fig. 3.7 Example of buffer strips, beside a tillage field (left) and rough pasture (right)

Table 3.1: Riparian and climate change measures (consult IFI prior to undertaking any works)

<table>
<tr><th></th><th>Drained channel options</th><th>Undrained channel options</th></tr>
<tr><td rowspan="7">Riparian margins (vegetation and tree planting and management)</td><td>Fencing on both banks is recommended (retain corridor for track machine for maintenance inside fence line if possible).
Fencing reduces poaching by livestock, protects existing or newly planted trees and protects against other landuse activities. Fencing can also allow natural regeneration to take place.</td><td>Fencing on both banks is essential.
Fencing reduces poaching by livestock, protects existing or newly planted trees and protects against other landuse activities. Fencing can also allow natural regeneration to take place. retain riparian vegetation.</td></tr>
<tr><td colspan="2">Stock watering – encourage the use of pasture pumps, and other devices (e.g. solar powered water trough and pump). Place water points at least 20m away from the riparian zone/watercourse (as per NAP from 1st January)</td></tr>
<tr><td>Retain as much riparian natural vegetation as feasible during any maintenance activities (except invasives).
Ensure a band of natural vegetation along the river, to reduce runoff and promote shading</td><td>Retain all riparian vegetation (except invasives).

Ensure a band of riparian natural vegetation is present along the river, to reduce runoff and promote shading</td></tr>
<tr><td>Retain canopy cover where feasible.

Shade moderates water temperature and instream productivity, nutrient sources, uptake of nutrients, creates habitat and cover for wildlife and thermal refugia.
Trees and woody habitat can help to slow flood flows
If necessary, a selective approach to tree management is encouraged, e.g. branches impeding flow removed, remove overhanging branches to known flood level using a saw
DO NOT OVERPRUNE
Consider pollarding to encourage re-sprouting above flood level rather than within flow areas</td><td>Retain canopy cover.

Shade moderates water temperature and instream productivity, nutrient sources, uptake of nutrients, creates habitat and cover for wildlife and thermal refugia.
Trees and woody habitat can help to slow flood flows</td></tr>
<tr><td colspan="2">Tree planting is essential and should be encouraged in open areas (southern bank most appropriate). Tree planting should be carried out between October and March.
Mosaic of tree planting/dappled shade to be created on at least one bank
Keep rivers cool or cool rivers by creating riparian shade (e.g. EA, 2016; Sparrow, 2018)

The most common and cost-effective formula is planting one to two-year old trees (30-60cm in height) at 2-2.5m centre spacing). A width of at least 2-5m is recommended although greater widths are preferable.
Mixed vegetation assemblages (native and deciduous) are recommended</td></tr>
<tr><td colspan="2">IFI, as part of their climate change research monitoring programme will produce a series of interactive maps identifying areas most at risk to high water temperatures in both drained and undrained channels (roll out on a phased basis will start end of 2021).

NOTE: ADVICE WILL BE REVIEWED WHEN NEW EVIDENCE BECOMES AVAILABLE</td></tr>
<tr><td colspan="2">Remove invasive species</td></tr>
<tr><td></td><td>Preserve and re-establish hydromorphological processes that create habitat complexity and buffer water temperature where possible</td><td>Preserve and re-establish hydromorphological processes that create habitat complexity and buffer water temperature

Review concept of “making room for the river” or erodible river concept (ECC). Landuse planning and develop long-term strategies

Removal of lateral constraints</td></tr>
</table>

		Integrated approach to include both the river and the floodplain (e.g. Climate Adapt, 2019) -
RISKS Increases in riparian vegetation will not benefit all organisms and care must be taken to avoid detrimental impacts (NPWS to advise on certain plant communities, birds, etc.) Flood risk must be considered (risk assessment)		
Adjoining land (area adjoining the riparian zone)	Buffer strips – Woodland, shrub and field vegetation – a natural barrier/buffer zone could be created to slow surface run off leading to uptake of nutrients and retention of sediment and provides habitat for wildlife Requires landowner support.	
	Remove invasive species	
RISKS Buffer zones may not always improve the runoff from agriculture and other activities when groundwater or field drainage by-pass the buffer Zones.		
Bank slope/bank stabilisation (bank erosion)	Eliminate direct stressors - causes of erosion	
	Protect bank slopes, retain riparian vegetation - as much as feasible	Protect bank slopes, optimize and retain grassy vegetation on bank slope. Plant grasses and shrubs (native species)
	Fencing - grazing management – livestock exclusion fencing (as per NAP from 1st January). Allow natural colonisation of vegetation, (preferably native)	
	Promote retention of native herbaceous vegetation – this provides shade at stream margins, erosion control, sediment retention and a nutrient source	
	Consider planting and/or use of organic material to encourage plant growth, e.g. hessian matting has achieved good results where steep sided banks require seeding.	
	Retain tree roots <u>where possible</u> – this provides thermal refugia and shelter and stream bank erosion control.	Retain tree roots – this provides thermal refugia and shelter and stream bank erosion control.
	Consult with OPW – soft engineering is preferred option, e.g. Christmas tree revetments, live willow planting, etc. See Brew and Gilligan (2019) for recommendations	Consider environmentally sensitive soft engineering solutions If works are absolutely necessary, e.g. Christmas tree revetments, live willow planting, root balls of trees, or other soft solutions
	Remove invasive species	
	Restrict maintenance to channel, leave margin of vegetation at foot of each bank slope during maintenance	N/A
	Spoil heaps to be placed on bank top not on bank slopes	N/A
RISKS Bank stabilisation interventions could exacerbate an erosion problem or transfer it elsewhere (SEPA, 2000). Bank stabilisation measures are river specific, e.g. Christmas tree revetments may not be suitable in rivers that carry a heavy silt load (Brew and Gilligan, 2019). Trees used for bank protection can give rise to damage to bridges and other infrastructure if they are not securely bound in place. On-going maintenance may be required as erosion is a natural process and will always occur. Requires careful planning. Soft engineering approaches may not achieve the same longevity as hard engineering, but they are preferred. Slumpage of rock armour can lead to further problems of scour behind the revetment.		

3.2.1 Vegetation in the riparian zone

The benefits of vegetated riparian zones in buffering the effects of nutrient input into streams and rivers has long been recognised in the literature (Osborne and Kovacic, 1993). Other benefits that the riparian zone provides are reducing peak flows in certain watercourses and the ecosystem services that they provide (Riis *et al*., 2020). It is notable that relative to its extent in the landscape, riparian vegetation has the capacity to generate a high return on ecosystem services (Riis *et al*., 2020). Riparian vegetation increases shade which has the effect of reducing water temperatures, as well as stabilising riverbanks with tree root systems (Florsheim *et al*, 2008). Moreover, trees can encroach into the river itself forming diverse habitat features and contributing woody habitat and leaf litter to the river load (e.g. Fig. 3.6). These reach-scale processes influence the physical form of the river and channel-floodplain interactions (Beechie *et al.*, 2010; Gurnell, 2012). At the basin scale the riparian corridor will intercept nutrient and sediment run off from agricultural, industrial land and roadways (Talmage *et al*., 2002).

Water quality, impacted on by diffuse and point source pollution, is one of the biggest stressors on watercourses (European Commission, 2019b). In an Irish context agriculture and wastewater have been identified as substantial contributors of excess nutrients to watercourses (EPA, 2019). Buffer strips of riparian vegetation are one way to mitigate this problem. The options are to fence an area (e.g. Fig 3.8) and let the vegetation re-establish or alternatively fence the area and plant native species.

Incentives to protect and promote the biodiversity and buffering potential of the riparian zone fall under the remit of new Common Agricultural Policy (CAP) reform proposals, for the period beyond 2020. Three of the nine CAP objectives (European Commission, 2020a) include:

- Climate change action.
- Environmental care.
- Preserve landscapes and biodiversity.

Environmental Directives such as the WFD may enter the scope of conditional payments (European Commission, 2019a). Moreover, opt-in eco-schemes (e.g. Pearl Mussel Project - PMP) may reward environmental stewardship with direct payments for farmers. The new CAP reform proposals are designed to enable member states to show more ambition for the environment and climate change action agendas which, if enforced, would have positive impacts on the riparian zone and watercourse biodiversity. Specific examples mentioned to protect water could potentially include 5m wide buffer strips along watercourses (European Commission, 2019a).

Fig. 3.8 River Dee (left) pre-works and (right) two (top) and four (bottom) years post-stock exclusion

To date the removal of instream woody habitat has been commonplace among all channel types. Undrained channels are more likely to have wide riparian woodland corridors and therefore more potential for woody habitat contribution to the channel. However, as with drained channels, woody material tends to be removed, with the aim of avoiding damage to infrastructure such as bridges. If riparian zones along undrained channels are lengthened and widened as part of the CAP reform, instream woody habitat will follow and take some time to re-establish as part of the river channel morphodynamics.

The use of riparian/buffer zones should be encouraged and be mandatory in some areas (in the correct location) depending on topography to prevent the input of excess/additional sediment and nutrients into watercourses.

Protection of riparian zones, (Broadmeadow and Nisbet, 2004), optimizing grassy vegetation (Sparrow, 2018), fencing back livestock and the planting of trees (Poole and Berman, 2001; Lenane, 2012; Kalny *et al.*, 2017; Johnson *et al*., 2015; O' Briain *et al.*, 2017a; Dugdale *et al.* 2018; Marine Scotland, 2018; Sparrow, 2018) along river watercourses to provide bank stability and shading are important measures to consider in any future river restoration project to protect against the impacts of climate change. Complete livestock exclusion serves the multiple purposes of eliminating nutrient and pathogen release to water as well as the 'poaching' and sediment disturbance associated with livestock in watercourses. Such exclusion does require provision of drinking water off-line for livestock and such measures should be integral to any river works plan (O' hÚallacháin *et al*., 2020).

3.2.3 Tree planting and management

As mentioned above, riparian vegetation, particularly native trees, can bring many benefits. Canopy cover provides natural protection from erosion (SEPA, 2002), shade for fauna within the channel (Crook and Robertson, 1999), moderates the effects of higher water temperatures (O'Briain *et al*., 2017), provides sources of nutrients and instream cover under tree roots. The canopy itself provides "cover" for resident brown trout. Removal of trees to provide access for anglers is not recommended.

Historically most (approximately 80%) of Ireland was covered in trees (Teagasc, 2020a) and woody habitat would have been a common feature in river channels (e.g. Fig. 3.3 and 3.4). Much of this native tree cover has been lost and many rivers now lack shade (e.g. Fig. 3.2). Riparian woodland can help reduce thermal exposure and these zones can also reduce lateral transport of nutrients and sediment from land to watercourses, with multiple benefits for water quality and instream habitat (DAFM, 2018; Swanson *et al*., 2017; Nisbet *et al*., 2011; Broadmeadow and Nisbet, 2004). Some scientists have found that summer mean and maximum temperatures are on average 2-3°C lower in shaded than in open rivers (Bowler *et al*., 2012; Caissie, 2006). IFI (2019) found that water temperatures exceeded ideal temperature thresholds for salmon and brown trout across surveyed catchments during summer drought in 2018 and on many occasions achieved lethal water temperatures for brown trout. These results mean that usable habitat for trout was greatly reduced in certain catchments during summer 2018 and this may contract further in the coming decades without intervention; therefore, measures are required to "cool" and keep rivers "cool". Increasing tree and shrub cover in the riparian zone has additional benefits by providing a natural source of instream woody habitat which is beneficial for many species of plants, invertebrates, fish and mammals. Leaf litter from native broad leaf trees that falls into channels is a valuable food source for a wide range of invertebrate animals. Both the adult and immature life stages of the invertebrates are a key element in the food chain for fish, aquatic birds and bats.

Shading (Fig. 3.9) is critically important with regard to cooling rivers in light of climate change impacts in Irish rivers (e.g. O' Grady 1993; O'Briain *et al*. 2019(b)) and elsewhere (Kalny *et al.*, 2017; Johnson *et al*., 2015; Dugdale *et al.,* 2018). Published recommendations on the amount of canopy cover required to moderate river temperature varies from 30% in chalk streams in England to at least 42% in Ireland (O' Briain *et al*., 2017a) to 50% in non-chalk UK rivers (Broadmeadow *et al*, 2010) and up to 60% in Scotland (Garner *et al*., 2017). However, these latter authors also state that the channel must be shaded almost entirely to generate the greatest reductions in water temperature. Researchers in Denmark found that a 100m stretch of riparian forest can reduce water temperature by up to 1°C, but that greater lengths (up to 500m) can reduce temperature by 2-3°C at canopy covers between 75-90% (Kristensen *et al*., 2013). The ideal percentage varies depending on river typology, modifications, depth and velocity (Lenane, 2012; Kristensen *et al*., 2013; Garner *et al*., 2017) and channel orientation (EA, 2016; Garner *et al*., 2017). O' Briain *et al.* (2017a) found that the effect of tree cover also changes annually, such that greater tree cover is required in "warmer" summers. Climate scientists have predicted that, by mid-century, mean air temperatures will increase by 1-1.6°C, the number of hot days will get warmer by up to 2.6°C and the number of heat waves is also predicted to rise up to ten fold (Nolan, 2015). This will cause associated increases in stream water temperature and therefore there is a requirement to keep rivers cool or to "cool" rivers using various measures, including riparian tree cover. In view of the above findings any de-tunnelling activities undertaken in Ireland must be reviewed in the context of climate change – enough tree cover must be retained to ensure a cooling effect, as the risk of climate change impacts on the fish population may outweigh any disadvantages of tunnelling).

There is no one size fits all, but riparian planting of native broadleaf trees should create a mosaic of tree cover producing dappled shade (Fig. 3.9) over at least half the channel surface (SEPA, 2002 Lenane, 2012; EA, 2016). Many authors recommend planting on the southern bank in rivers running east to west (EA, 2016; Brew and Gilligan, 2019). Rivers running north to south will require a higher density of overhanging trees than those running east to west, and planting should be targeted in slow flowing (low gradient) reaches where flow retention times are long (Garner *et al*., 2017; Marine Scotland, 2018). This targeting will also serve to reduce the growth of nuisance levels of instream vegetation and thereby the requirement for maintenance in drained rivers. Recommendations for Irish rivers will be made by IFI over the coming years (Kelly, F., IFI, *pers. comm*.).

Fig. 3.9
Example of deciduous canopy cover providing dappled shade over a stream

3.2.3 Bank stabilisation: erosion, deposition and slippage

Bank erosion is a natural and complex process in river channels (SEPA, 2002) and is integral to the functioning of river ecosystems (Florsheim *et al*., 2008). A natural channel migrates laterally by erosion of one bank, maintaining, on average, a constant channel cross-sectional area by deposition on the opposite bank, so there is an equilibrium between erosion and deposition (Leopold, 1994). Therefore, the shape of the cross-section can change, but the cross-sectional area remains stable, while the actual position of the channel may change over time. This process can be extremely slow or long-term, in human life-span terms. Acceleration of erosion rates is often associated with upstream land use changes in the catchment (SEPA, 2002). The traditional response to bank erosion has been bank protection (e.g. Gilvear *et al*., 2002) and this has been a common measure used in river restoration projects to protect farmland, fishery beats, reduce sediment inputs and allow access. But this measure can potentially be damaging to stream ecosystems (Gilvear *et al*., 2002). The cumulative effect of bank stabilisation structures is to limit riparian function and diminish habitat for riparian species (Florsheim *et al*, 2008). Ecologically functioning riparian zones provide a variety of resources and are important areas for biodiversity (NRC, 2002).

Traditional engineering techniques (e.g. use of large rock/riprap, bank armouring, gabions) are no longer appropriate (SEPA, 2002) as they can have a negative effect on riparian areas (Florsheim *et al*., 2008). Exceptions arise in certain urban settings and locations adjacent to dwellings or infrastructure. Piégay *et al*. (2005) noted that traditional policies for managing bank erosion are not sustainable and have been reassessed in certain countries since the 1990’s (Piégay *et al*., 2005). Alternatives to traditional techniques include elimination of direct stressors and non-structural approaches (no hard materials such as large rocks, gabions, concrete blocks) such as planting native vegetation and fencing

(Florsheim *et al*., 2008). Some countries (or States) are applying the erodible corridor concept (ECC). This concept recognises the many advantages of erosion (e.g. ecosystem services – the highest ecological diversity and values are found in actively migrating rivers and their floodplain) and allows the river to migrate freely within a "defined" fluvial corridor within which future flooding and erosion is anticipated to occur (Piégay *et al*., 2005; Kondolf, 2012).

Terminology for this concept varies, but it is espoused in several countries and continents:

- France = Éspace de Liberté or space of freedom
- Spain = Fluvial Territory
- Bavaria, Germany = Elbow Room for the River
- Netherlands = Room for the River Programme
- USA = Channel Migration Zones (CMZ)
- Quebec, Canada = Freedom Space for Rivers (FSR) (Kondolf, 2012; Biron *et al*., 2014; Kondolf, 2016).

Some countries have enshrined the concept in legislation. In France, legislation indicates that bank protections must not significantly reduce the "space of mobility" of the channel (Piégay *et al*., 2005)). Biron *et al*. (2014) proposed three levels of "freedom space" for rivers in Quebec, Canada, based on the magnitude of floods (1. frequent flooded areas or minimum space, 2. space for floods of larger magnitude and 3. space for exceptional floods). However, this concept requires the development of long-term strategies and landuse planning by central governments so that riparian land can be acquired and requires the cooperation of multiple agencies and private landowners (Florsheim *et al*., 2008). It also requires that the concept be included in river management legislation (Biron *et al*., 2014). Additionally, the application of this concept is not appropriate for all channel types (Piégay *et al*., 2005).

More environmentally sensitive measures are required to support geomorphological functions (Piégay *et al*., 2005). The cause of erosion must be understood first and then removed (if possible), e.g. high livestock densities and overgrazing, and therefore grazing management and fencing could do much to limit erosion. Sometimes the cause is difficult to pinpoint and solve, e.g. land drainage for forestry in the upper catchment leading to rapid run-off. SEPA (2002) recommends three measures for bank stabilisation: do nothing, enhance natural vegetation or use of environmentally sensitive engineering (e.g. planting and/or organic material, hessian matting has achieved good results where steep sided banks require seeding). Christmas tree revetments (see example - Case Study 2), live willow planting or other soft solutions are also recommended for drained channels (Brew and Gilligan, 2019; Table 3.1, River Restoration Centre, 1999).

CASE STUDY 2

Example of a log/Christmas tree revetment project on the Castlehill stream, Co. Mayo

1995

Pre-works - An eroded bank on the Castlehill stream.

In 1996 a log/Christmas tree bank revetment operation was carried out. Fencing (stock exclusion) and planting (willow slips) programmes were also completed

1997

One year post-works. Three changes are evident:

A) Bank stabilization and revegetation on the previously eroded bank has commenced

B) Width of the river has narrowed due to stock exclusion and bank stability

C) The berm (right of picture) is starting to vegetate.

2014

A tree line has developed and bank stabilisation is evident (left of picture). The trees growing on the right were "self-seeded"

Bank slippage represents another scenario where the bank slope/riparian area can change over time. Slippage is more likely to be a feature in channelized or arterially drained rivers and streams. It is a situation where an area of bank top splits away from the cohesion of the surrounding soils and slips or slumps into the cross-section (Fig. 3.10). The result is a change in cross-sectional form, possibly narrowing the wetted width, without any change in cross-sectional area. The slippage can "pull" or carry fencing and riparian tree cover with it. In channels managed by the OPW, locations of slippage are commonly left to stabilise as the alternative, a re-instatement of cross-sectional form, may simply lead to further slippage. DfI Rivers (NI) have developed specific environmental measures to address slippage issues and their focus is on retaining the diversity of physical form created by the slippage (Rivers Agency, 1999).

Fig. 3.10 Examples of bank slippage

Both erosion and slippage can create areas of vertical bank profile and, where the bank materials are of appropriate texture, these banks can be colonised by bird species, e.g. kingfisher and sand martins, for nesting. Erosion and deposition are natural processes and in many circumstances erosion control may not be in the best interest of the river environment (Brew and Gilligan, 2019). Therefore, in undrained channels the "do nothing" approach is recommended. This approach may seem illogical, but any intervention could exacerbate the problem or transfer it elsewhere (SEPA, 2002). Alternate measures such as fencing are recommended.

3.3 Instream scenarios and measures

Instream processes and forms are defined within the morphology element of the WFD under the umbrella "structure and substrate of the riverbed" as well as "river width and depth variation". Like the riparian zone morphology, the processes driving instream form can be considered at a reach-scale (Beechie *et al.*, 2010). Any proposed instream measures must be considered within the context of broader catchment integrity and the local ecotype. Any intervention should aim to mitigate a defined ecological problem, rather than a sectoral aspiration.

Several instream measures that may be appropriate for certain types of river restoration scenarios are described below and in Table 3.2. Measures cover four areas:

- Instream vegetation
- Channel bed
- Channel substrate
- Instream cover

Instream works on all channels must only take place between July and September to avoid adverse effects on fisheries (Inland Fisheries Ireland, 2016).

3.3.1 Instream vegetation

Instream vegetation is an important component of aquatic ecosystems providing habitat and food for a range of aquatic organisms (e.g. Fig. 3.8). Instream macrophytes can play an important role in initiating and driving the physical changes that underlie hydromorphological recovery. It has been shown that macrophytes have a strong relationship with habitat complexity and can manipulate mechanisms such as flow, sediment interception and sorting (O' Briain *et al*., 2017b). A range of coarse fish species and pike use instream vegetation during spawning and attach eggs to plant material (Appendix 2). When nutrient levels increase, for example due to fertiliser run-off from agricultural land, vegetation can become excessive, particularly in shallow, wide channels with no riparian tree cover.

Mechanical cutting or removal is not recommended as this may cause downstream accumulations and/or colonisation and establishment in new areas. In addition, mechanical cutting is highly season-dependant for success, may require repeat cutting in any year and the cutting process tends to lead to a synchronised re-growth of the nuisance weed (Baattrup-Pedersen *et al*., 2018). Decomposition of cut vegetation can also occur if left to decay in the channel (SEPA, 2002). Chemical treatment is also not recommended in any river channel. This practise was discontinued by the OPW over 25 years ago.

In drained channels Brew and Gilligan (2019) recommend selective vegetation removal by retaining as much in stream as possible, e.g. retain a band of emergent vegetation on both sides at the water's edge, retain one third to one half of instream floating type vegetation such as *Ranunculus* sp. (EP7 and EP8 –OPW/IFI guidance – Fig. 3.10) (Brew and Gilligan, 2019)).

In undrained channels retain all vegetation (e.g. Fig. 3.11) and introduce riparian measures. In small channels riparian trees and the shade they cast can be used to limit growth of instream macrophytes when excessive (SEPA, 2002). It is important to determine the cause of excessive macrophyte growth if present in a channel, as it may be caused by excess nutrients and therefore instream works to remove vegetation would not be appropriate until the cause is eliminated. In this case, riparian measures, such as fencing and buffer strips would be more appropriate.

Fig. 3.11 Retain instream floating vegetation (TOP LEFT – undrained channel) and retain margin of vegetation (TOP RIGHT and BOTTOM – drained channels)

Table 3.2: Instream and climate change measures (consult IFI prior to undertaking any works)

	Drained channels	Undrained channels
Instream vegetation	Selective vegetation removal – retain as much as possible – e.g. a band of vegetation on both sides at water's edge Some vegetation traps silt and creates valuable habitat for larval lamprey. Other measures if excessive vegetation growth present include: buffer zones to limit nutrient input, planting trees in the riparian zone can limit instream growth in small channels	Retain all vegetation – identify cause if excessive and not natural. Some vegetation traps silt and creates valuable habitat for larval lamprey. Other measures if excessive vegetation growth present include: buffer zones to limit nutrient input, planting trees in the riparian zone can limit instream growth in small channels
RISK Impact on biota (e.g. nesting birds), reduce shade and cause increase in water temperature, essential cover removed, loss of habitat attributes for coarse fish, etc. Timing of works is critical (consult IFI and NPWs in advance for advice on appropriate scheduling of works)		
Channel bed and substrate	Holistic approach required Over deepen the channel along one side and place spoil on opposite side Excavate bed to form deeper pool areas and shallow riffles Manage berms to form two-stage channel Replace stones and boulders from spoil heaps Reinstate gravels removed during maintenance Silt management – skip sections during maintenance as these will act as buffers to d/s transport, minimise all new diggings, other measures = soft bank stabilisation measures, fencing and buffer zones	Holistic approach required Retain any berms Retain all substrate - identify cause if excessive siltation Riparian measures to reduce siltation (e.g. buffer zones, fencing, etc.) Other measures (once the source of the pressure is addressed): it may be necessary to carry out one off work to improve physical habitat, e.g. gravel compaction- a one-off gravel raking exercises may be needed to reduce compaction if natural "flushing" doesn't work – all work must be justified, sustainable and risk assessed with appropriate mitigation measures). Retain natural channel bed profile.
RISK Silt management/gravel raking, etc. can cause siltation downstream and a resultant deterioration in WFD status. Silt management/removal can also have a negative impact on biota such as lamprey. Appropriate mitigation measures should be put in place (e.g. silt traps) if implementing any measures related to silt.		
Instream cover	Placement of substrate or woody habitat (where appropriate) - Use existing boulders to form simple low-level structures to provide cover Scope for experimental work using woody material (e.g. deflectors – see example)	Retain vegetation and all substrate Retain woody habitat
RISK Introducing material can accelerate erosion if placed too close to riverbank, expert advice required		
Invasives	Remove/control invasive species where possible	
RISK Removal and control measures come with an element of risk and can cause unforeseen consequences, particularly when an invasive is well-established. There must be a demonstrable ecological and social benefit and any other environmental problems should be addressed in parallel. A comprehensive risk-benefit assessment of control programmes should be prepared (Kopf *et al*, 2017)		

3.3.2 Channel bed

Deep pools are natural features of certain river channel types and are used by adult fish. They provide resting areas and refuges for adult fish from high water temperatures and are often important areas for angling (Elliott, 2000; SEPA, 2002). Deposition of sediment in pools is part of the normal functioning of a river and is a response to catchment and local influences (SEPA, 2002). It is also normal for pools to move position over time (SEPA, 2002). Any work relating to restoring or managing pools must be carefully designed and planned as it could destabilise the river channel and accelerate erosion rates.

In drained channels of appropriate bed type Brew and Gilligan (2019) recommend modifying the uniform longitudinal profile of the riverbed by over-digging the channel bed on alternating sides to create a non-trapezoidal cross section and generate a degree of meander within the wetted channel. An alternative is to over dig the bed locally and deposit the excavated material downstream to create a riffle – pool sequence to replace uniform glide habitat along the channel long section (Fig. 3.12a and b). No measure is recommended for undrained channels because the number and extent of pools is likely to reflect natural ecotype rather than anthropogenic pressure.

Fig. 3.12 (a) Before and after photos showing the riverbed excavated to form deeper pool areas and shallow riffles in a drained channel.

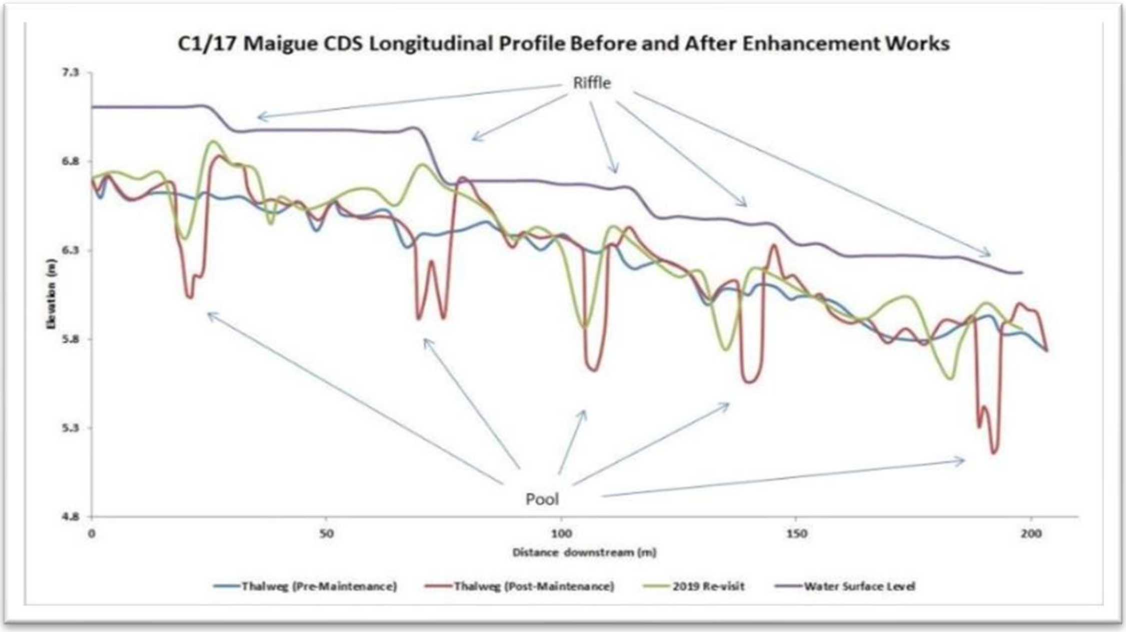

Fig. 3.12 (b) Before (blue line) and after (brown line) longitudinal profile showing the riverbed excavated to form deeper pool areas and shallow riffles in a drained channel in 2007. The green line shows the channel bed in 2019, twelve years later, indicating the persistence of the excavated pools. Upper purple line is water surface level.

Both O' Grady (2006) and Brew and Gilligan (2019) also recommend the formation of a 2-stage channel in over-wide channels. The manipulation of berms to retain narrowing features of fisheries benefit also enhances conveyance requirements in drained channels (EP7 OPW/IFI guidance; King *et al*., 2011; Brew and Gilligan 2019) (Fig. 3.13).

Fig. 3.13 Example of berm management by OPW during maintenance with retention of mature tree cover on the non-working bank (Cor River - Catchment Care Project).

3.3.3 Channel substrate

Stream substrate plays a key role for many species in rivers (e.g. fish, macroinvertebrates, etc.).

3.3.3.1 Siltation

Fine sediments can impact river biota. Egg and larval stages of some fish species are particularly sensitive to deposition of "fines" in spawning gravels and this can cause mortalities through suffocation (SEPA, 2002; Bašić, *et al*., 2017). However, silt and fine sediments in low velocity areas of rivers (e.g. Fig. 3.14) is often an important habitat for the juvenile stage of all three lamprey species found in Ireland for up to 6 years prior to maturation (Maitland, 1980; Maitland, 2000), therefore monitoring should be carried out prior to any silt manipulation or removal works.

Fig. 3.14 Examples of lateral silting areas used by lamprey (low velocity and silty habitats are important to the development of larvae of all three lamprey species found in Ireland for up to 6 years prior to maturation)

Manipulating stream substrate has been a theme in many restoration projects to date (e.g. O' Grady, 2006; Pander *et al*., 2014; Bašić, *et al*., 2017). Researchers in Germany and the UK examined the effectiveness of different substratum restoration techniques (e.g. gravel introduction, substrate raking and gravel jetting) and found that improvements were short term (Pander *et al*., 2014; Bašić, *et al*., 2017). In addition, Pander *et al*. (2014) found that substrate raking caused a six-fold increase in fine sediment deposition on downstream sites compared to other measures. Silt can travel at least one kilometre downstream when disturbed (Brew and Gilligan, 2019). Therefore, the traditional method of raking or cleaning gravels is no longer appropriate as it is an unsustainable short-term solution requiring continual maintenance if fine sediment continues to be a problem (SEPA, 2002; Pander *et al*., 2014).

Increased fine sediment loads in river catchments are commonly associated with intensive land management practices such as agriculture and forestry, where tilling, etc., may be practised right up to the edge of the river bank, facilitating washing of clays due to overland flow after heavy rainfall. Consequently, only catchment-scale initiatives will solve the causes of such problems rather than treat their symptoms (SEPA, 2002). It is essential that a holistic approach is adopted, considering catchment and natural substrate dynamics (Pander *et al*., 2014; SEPA, 2002). Reducing fine sediment delivery to rivers such as through changes in agricultural practices is more sustainable for managing excessive river sedimentation (Bašić, *et al*., 2017) particularly in the context of the WFD. However, once the source of the siltation is removed or the problem rectified it may be necessary to carry out “one-off” work in certain areas to improve physical habitat, e.g. if gravel continues to be compacted after restoration measures are introduced a one-off gravel raking exercise may be required to reduce compaction if natural “flushing” doesn’t work. All work must be justified, sustainable and risk assessed with appropriate mitigation measures to prevent any downstream migration of silt. In drained channels, Brew and Gilligan (2019) recommend such measures as skipping sections during regular channel maintenance as these will act as buffers to downstream transport, minimise all new diggings and use of soft bank stabilisation measures, fencing and buffer zones to minimise siltation (EP 10 OPW/IFI guidance – Brew and Gilligan, 2019)

3.3.3.2 Spawning habitat (gravel-based – for salmon, trout and lamprey)

In natural river channels spawning habitat is usually unevenly spread throughout and is found where suitably sized gravels accumulate (SEPA, 2002). This is a natural process that cannot be “forced”. Often spawning habitat is not the limiting factor and other issues may be putting pressure on the overall fish abundance (SEPA, 2002). Not all river channels have an abundance of spawning gravels, some will have a natural bedrock base, and in these cases, an artificial introduction of spawning gravels is not appropriate (e.g. Fig. 3.15). This case is an example of the potential tension between appropriate catchment-scale mitigation of a defined anthropogenic pressure and sectoral aspirations for a river reach. Restoration is not aimed at ‘enhancement’ but at recovery of a system to a healthy state appropriate to the region and ecotype.

Plate 3.15 Examples of natural bedrock channels where gravel introduction would not be appropriate

If there is an apparent absence or scarcity of fish spawning habitat, it is essential that a holistic approach is adopted, considering catchment and natural substrate dynamics (Pander *et al*., 2014). Additionally, spawning effort and carrying capacity should be assessed across the catchment as the perceived problem may not actually be an issue and any measures solely to increase fish spawning effort may not benefit the channel or the biota. There may not be the adult population big enough to use additional spawning habitat and the additional juvenile fish produced may not have enough habitat for their life needs and well-intended efforts may be completely in vain.

SEPA (2002) recommend that creation of spawning habitat should only be considered in seriously degraded channels where spawning habitat is absent; however there may be scope to carry out such works in less- or non-degraded channels where justified and sustainable. Again, the reason for any degradation must be examined as well as the question as to whether the investment will remain stable or whether further degradation will occur. This "creation" option is expensive and requires careful design related to substrate type, where and how they should be placed if they are to remain stable. Channel gradient is also important to retain the new substrate. Expert geomorphological advice and design is required for this measure.

In drained channels gravels, stones and boulders removed during maintenance operations should be reinstated (Brew and Gilligan, 2019) (Fig. 3.16; Table 3.4).

 

3.16 Retain all stone and gravel material (Do not remove). In drained channel, gravels, stones and boulders should be reinstated if removed during maintenance operations.

3.3.4 Instream cover

Three main elements of instream cover for brown trout have been identified – overhead canopy cover from trees (e.g. Hubert *et al*., 1994; see previous section 3.3.1), water depth within the channel (e.g. Kennedy and Strange, 1982; - see 3.3.2 above) and the nature and size of alluvial material on the channel bed (Heggenes, 1988; Kondolf, 2000). As part of a more extensive programme, fish cover in degraded rivers can be increased by boulder or woody habitat emplacements (see case study 3) - if such features form part of the natural hydromorphological regime, e.g. in high gradient cascade step-pool channels. However, boulder placement needs to be carefully sited to avoid bank erosion or excessive bed scour (SEPA, 2000). If they are located too close to a riverbank, they could deflect flows and accelerate erosion, but conversely, they can also deflect flows away from vulnerable banks. Expert geomorphological advice is required for this measure. Brew and Gilligan (2019) recommend using boulders, of appropriate size for the channel, that may be present in existing spoil lines in drained channels to form simple low-level structures.

Along with clearing the riparian corridor of vegetation, removal of woody habitat from within the channel has been commonplace with the intention of maintaining channel capacity, avoid blocking instream structures, improving navigation and fish passage (Piégay and Gurnell, 1997). However, the presence of instream large woody habitat has impacts on flow, sediment storage and transport, which in turn influence channel dimensions and riverbed structure (Piégay and Gurnell, 1997). These factors indicate that the presence of large woody habitat is conducive to the creation of diverse riverine habitat, which has direct implications for ecology. Woody habitat has also been shown to have positive impacts on fish populations (Stewart *et al*., 2006; Howson *et al.*, 2012). As well as the overhead shade given by canopy cover, instream wood provides pool refuges for fish from predation and high velocities (Crook and Robertson, 1999) and can serve to ‘sort’ bed materials, forming gravel shoals for spawning salmonids and lateral silting areas used by larval lamprey (Torgersen and Close, 2004). Addy *et al.*, 2016 (and other authors) recommend added woody instream structures before vegetation re-establishes. Woody habitat has a significant impact on salmonids resulting in increased population abundance (see woody habitat installation example - case study 3).

CASE STUDY 3

Photos of the various steps required to install timbers and completed pair of deflectors using trees that were cut down during routine drainage maintenance work (Eignagh River, Co. Mayo), July 2019 (photos taken at low water levels).

3.4 River connectivity – longitudinal and lateral

Connectivity, as considered by WFD, covers three spatial dimensions – longitudinal, lateral and vertical (Seliger and Zeiringer, 2018). Longitudinal connectivity is the upstream to downstream flow route from headwaters to the confluence with the sea; lateral connectivity is the overspill linkage of the river to its natural floodplain, and vertical is from the river downward in to the hyporheic zone and groundwater (Seliger and Zeiringer, 2018).

Poor connectivity can have a significant impact on the hydrology and water level of a river for considerable distances upstream and downstream. It can also interrupt sediment supply and conveyance and interrupt fish migration patterns as well as cause habitat loss and impact on natural flood mitigation capacity (Griffin *et al*., 2015; Gough *et al*., 2018). Where river restoration is being considered for a channel or catchment, it should be remembered that the catchment is likely to contain many artificial barriers in the channel, that many or most are disused and that removal of barriers provides a rapid and substantial re-instatement of natural river processes and is very beneficial for a range of migratory fish species and transport of sediments. Many artificial structures are of a size or are in a channel of size or flow capacity where removal or modification of the structure may be an option for community groups. As a first-off action where little overall catchment or sub-catchment knowledge is available, the barrier inventory available from the National Barriers Programme (NBP) in IFI can be consulted. If the catchment has not been assessed by the NBP community groups could undertake a comprehensive walkover survey and compile a detailed inventory and photolog of all stream crossing structures and barriers in the overall catchment or sub-catchment. This data coupled with a NBP sub-catchment assessment could form the basis of a priority listing for river restoration action and for discussion with relevant public authorities.

River connectivity and additional climate change measures include (Table 3.3):

- Longitudinal measures such as artificial barrier removal, fish passage solutions and measures for small structure (fords, bridges, etc.)
- Lateral connectivity measures (e.g. reconnect the floodplain)

Table 3.3: River connectivity, including climate change, measures

<table>
<tr><th></th><th>Drained</th><th>Undrained</th></tr>
<tr><td rowspan="8">Longitudinal connectivity measures</td><td colspan="2">Artificial barrier removal</td></tr>
<tr><td colspan="2">RISK
Removal could cause the spread of invasive species (risk assessment required prior to removal)
Removal could cause silt to be released downstream – mitigation measures to include silt traps, etc.
Pollutant material could be present in silt deposits upstream of artificial barriers (e.g. weirs); when disturbed could flow downstream in harmful concentrations. Mitigation could include: prior excavation of any contaminated sediment, sampling material upstream and downstream prior to any project planning (part of environmental impact assessments)</td></tr>
<tr><td colspan="2">Fish passage measures - Rock ramps are the preferred option</td></tr>
<tr><td colspan="2">RISK
Some designs may not work for all fish species – consider alternate measures in certain situations, e.g. bypass channels</td></tr>
<tr><td colspan="2">River crossings, bridges, culverts – preferred option is clear span “bridge type” structures: the alignment or orientation of a channel should not be altered if installing a new bridge or culvert structure – rather the new structure should accommodate the existing alignment of the channel. This will offset any adverse impacts of the structure.

Bridge floor - use rock of suitable size to form a series of low stepped structures to impound water downstream of the structure, enabling a gradual backwatering from down- to upstream, can be similar to the functioning of a rock ramp.</td></tr>
<tr><td colspan="2">RISK
Potential damage to bridge structures, requires engineering design, etc.</td></tr>
<tr><td colspan="2">Remove/control invasive species and pathogens where possible</td></tr>
<tr><td colspan="2">RISK
Risk of spread of aquatic invasive species upstream – consider intentional fragmentation options – Barrier assessment is a key tool to determine the distribution and risk of spread of IAS -</td></tr>
<tr><td rowspan="2">Lateral connectivity measures</td><td>Creation of riparian zones and strategic management of the incised channel form</td><td>Review an integrated approach to include both the river and floodplain – concept of reconnect floodplain
“Make room for the river” and remove lateral constraints
Natural water retention measures</td></tr>
<tr><td colspan="2">RISK
Potential for infrastructural flooding – must be reviewed in connection with CFRAMs (consultation required, OPW, landowners, etc.)</td></tr>
</table>

3.4.1 Longitudinal connectivity

3.4.1.1 Artificial barrier removal

The removal of derelict artificial barriers in rivers is a viable solution for river restoration (Gough *et al*., 2018); however it is important to note that not all artificial barriers can or should be removed as some are still performing a function required by society (e.g. water supply). Removal of artificial structures (e.g. weirs or dams) restores local hydromorphology, can result in the return to a natural functioning reach for sediment and fauna and flora and contribute to the objectives of the WFD and water quality improvement (Gough *et al*., 2018). Complete removal of artificial barriers (e.g. dams and weirs) has several important implications for river management. Weir removal increases the number of adult fish able to successfully migrate and disperse widely upstream to spawn, by removing impassable structures and by reducing the incidence of injuries at obstacles and decreasing energy expenditure to attain spawning grounds (Castro-Santos and Letcher, 2010). Furthermore, weir removal may increase reproductive output through successful egg emergence (i.e., unhindered by sedimentation, better available habitat), which would then lead to an increased recruitment rate and an increased output in the following years. Weir removal may also make fish more successful in their downstream migration via reduced predation at ponded zones (Jepsen *et al*., 1998) and decreased delays (Schilt, 2007).

Key hydromorphology benefits of removing artificial dams and weirs under the WFD are: (Armstrong *et al*., 2010; IFI, 2014):

- Reducing artificial barriers to natural migration and movement to all aquatic organisms allowing upstream escapement and whole catchment colonisation by migratory species
- Re-establishing a self-sustaining river system with natural continuity of hydromorphological processes, without the need for further maintenance
- Re-establishing natural habitat diversity and continuity in temperature, oxygen balance, pH
- Every barrier removed in Ireland will contribute to reaching the EU goal of 25,000km of free-flowing channels under the EU Biodiversity Strategy 2030 (European Commission, 2020b).

Other benefits of in-channel structure removal may include:

- Avoidance of health and safety risks associated with the existing structure.
- Reduced costs and manpower associated with day-to-day maintenance and repair of the structure.
- Reduced flood risk upstream of the existing structure.
- Reduce adverse thermal impact – removal of barriers eliminates the increased water temperature within the previously impounded water upstream of the barrier (Coghlan, B., IFI, pers. comm)

3.4.1.2 Fish passage solutions

Fish passes or 'fish passage solutions' are structural elements incorporated into artificial barriers to facilitate fish migration through the structure. They are important for the improvement of free passage for fish and other aquatic species in rivers in situations where the barriers cannot, for whatever reason, be removed (FAO, 2002). However, the most consistent messages from the reviews on fish passage solution performance (Bunt *et al*., 2012) indicate high variability in successful fish passage and the reality that fish passage solutions often do not perform as intended (Silva *et al*., 2018). This points to the need to monitor and evaluate fish passage effectiveness after construction and to modify and learn from projects as needed. The dominance of fish passage studies focusing on salmonids is problematic. As the focus has increasingly turned to non-salmonid fishes and catering for multispecies assemblages in fishways, evidence of failures in the current fish passage solution paradigm continues to mount (Birnie-Gauvin *et al*., 2017; Lennox *et al*., 2019). As of spring 2020, IFI's National Barrier Programme (NBP) had rated 2385 weir/dam structures as impassable in those catchments examined to date. The vast majority of these were less than 2m in height.

Fish passage solutions should achieve the following objectives (Armstrong *et al*., 2010; IFI, 2014; Franklin *et al*., 2018):

- Efficient and safe upstream and downstream passage of resident and migratory aquatic organisms and life stages with minimal delay or injury.
- Provide a diversity of hydraulic and physical conditions, thereby providing a high diversity of passage opportunities.
- The structure provides no greater impediment to fish movements than adjacent stream reaches.
- Structure has minimal maintenance requirements.

These objectives can be achieved by seeking to realise the following principles of good fish passage solution design (Franklin *et al*. 2018):

- Maintaining continuity of instream habitat, avoiding vertical drops.
- Minimising alterations to stream alignment and gradient.
- Maintaining water velocities and depths within a range equivalent to adjacent stream reaches.
- Provide an uninterrupted pathway along the bed of the structure.

Over the last couple of decades understanding of the impacts of instream structures on fish movements has increased considerably. Despite this, the bias towards salmonid-centric upstream movement infrastructure design largely continues to prevail (Birnie-Gauvin *et al*., 2019). This outlook must be replaced with a more WFD-centric view, where the river catchments are viewed as a whole and the hydromorphology, natural process and biota of a system are placed on par with the fish populations utilising it.

Rock ramps or "close to nature" style fish passes or fishways (e.g. bypass channels, fish ramps) imitate as closely as possible natural river rapids and the construction material chosen corresponds to the substrate normally present in rivers under natural conditions (FAO, 2002). A rock ramp presents as a gently sloping channel section, composed of rock, providing an alternative route to the existing barriers. The rock ramp may occupy part or the whole width of the channel and appears as a semi-natural part of the riverbed. The hydraulic step or jump associated with the barrier is replaced by a more gently sloped river section with a continuum of flowing water that can be used by all fish life stages for both up- and downstream movement. Ramp design aims to maintain fish passage during low-flow conditions and maintain hydraulic conveyance during high-flow conditions (USDI, 2007; Kapitzke, 2010) and does not require maintenance or require fish to find a narrow bottleneck – as in a fish passage solution. One of the main benefits is that ramps provide a chance for many species to use it rather than just salmonids. Resting pools and a wide range of velocities are a feature of rock ramps. The construction of rock ramps, as a solution to mitigate fish passage problems, is one of the best measures to cover most requirements (e.g. Hanover weir rock ramp fish pass 2017, Burren River, Co. Carlow (https://www.youtube.com/watch?v=0g-FPG6Eyaw) (Fig. 3.17); Lacken Weir Rock ramp, River Nore, Co. Kilkenny and Castletown weir rock ramp, River Nore, Co. Laois 2016), (https://www.youtube.com/watch?v=dZnERMczHTw); Tuckmill stream rock ramp, tributary of the Slaney River, Co. Carlow (Fig. 3.18).

Fig. 3.17. Hanover weir 2014 (left) and post mitigation 2017 (right) after installation of rock ramp, Burren River, Co. Carlow

Fig. 3.18. Examples of rock ramps constructed on Irish rivers: (top left) Lacken Weir rock-ramp constructed by the Office of Public Works (OPW) on the River Nore, Co. Kilkenny; (top right) Tuckmill stream rock ramp, tributary of the Slaney River, Co. Carlow; (bottom) Castletown weir rock ramp, River Nore, Co. Laois (constructed in 2016 by Inland Fisheries Ireland)

3.4.1.3 River crossings, bridges, culverts

The progression of modern road infrastructure has advanced from wading shallow riffles, to fords to bridges, thus enabling crossings in all flow conditions. As bridge technology developed larger structures may have created a "gradient break" in the river's longitudinal profile, with an increased slope or discontinuity between up- and downstream. In some circumstance's bridges impound water upstream and/or a steep drop may be created between the bridge floor and the downstream riverbed (see example Fig. 3.20). These discontinuities and steep drops remain a common element in river crossings and create a migration and movement issue for fish and sediment in various flow conditions.

It may not be feasible to intervene in a bridge floor without major engineering safeguards. Mitigation in such a scenario can be achieved by using rock of suitable size to form a series of low stepped structures to impound water downstream of the structure, enabling a gradual backwatering from down- to upstream. The low head height between steps and the open spaces between the rock material enable up- and downstream movement of fish species, similar to the functioning of a rock ramp.

IFI's 2016 document "*Guidelines on protection of fisheries during construction works in and adjacent to waters*" sets out *inter alia* requirements in relation to bridges and culverts (Figs. 3.19 to 3.21) and the need for such structures to allow for unhindered upstream and downstream movements of fish and aquatic life. The preferred option for all river crossings is clear span "bridge type" structures. Alternatively, the floor of any structure, such as a culvert, could be designed to be approximately 500mm below the normal river bed level so that the floor ends up being covered with natural bed material and is in line with bed levels upstream and downstream. IFI (2016) recommends that contact should be made with IFI at the earliest possible stage in the planning and design process where works such as road construction, installation of culverts, pipeline crossing and works on or in the water are planned. This consultation will allow the concerned parties to comply with the provisions of the Fisheries Acts and Habitats Regulations.

Fig. 3.19 Examples of bridges where a drop has been created between the bridge floor and the downstream riverbed causing fish passage issues

Fig. 3.20 Example of a ford where fish passage is an issue

Fig. 3.21 Examples of culverts where fish passage is an issue

3.4.1.4 Artificial barrier - pre- and post-mitigation assessment

Several follow up surveys are required once a structure has been assessed as a barrier to fish migration (IFI, 2014). A decision tree matrix is required to identify if the structure will be removed or if mitigation measures (e.g. fish passage solutions such as a rock ramp) are required. There are several published guidance documents available for barrier removal (Bowman, 2002; Saldi-Caromile *et al.,* 2004; Garcia de Leaniz, 2008; EA, 2010; Kitchen, 2016). Additionally, the EU Horizon 2020 AMBER project outlined steps involved in the adaptative management of barriers in Europe and produced a series of relevant publications and policy documents (https://www.amber.international/). The next step is to determine whether the artificial barrier can be removed. If it cannot be removed (i.e. the structure is determined to be essential for a specified use, e.g. for water abstraction, navigation, protecting infrastructure) then mitigation measures should be evaluated and explored. Design by a competent person is required for barrier mitigation measures (developing a fish passage solution). A risk assessment is also required prior to all barrier removal works/fish passage solutions to assess the impacts of silt, impact on other species, etc. A range of surveys, permissions, etc., are required in advance of any removal and some of these are detailed in IFI's barriers working group report (IFI, 2014).

An outline of the information requirements and steps involved prior to undertaking any barrier removal or mitigation project is detailed in Table 3.4. Post project monitoring will also be required in certain situations (see Chapter 4).

Table 3.4 Information required prior to any barrier removal or mitigation works in Ireland (not in any specific order) (from Bowman, 2002; Graber *et al.*, 2015, Tonitto and Riha 2016, Cullagh, A. IFI, pers. comm)

Category	Description
Barrier assessment, ownership and legal rights	Evaluate the structures passability in the context of its location in the catchment (see Table 2.2)
	Determine ownership of structure and secure agreement for works
	Determine ownership of any milling/ water rights associated to structure
	Determine ownership of land around the structure and secure agreement for works
	Assess scientific and engineering challenges and conceptual approaches
	Determine if structure is obsolete or has a role in navigation, water abstraction, flood relief etc. ○ Is structure protecting infrastructure (Bridge, road, retaining wall)
Environmental Impact assessment	A Natura impact statement (NIS) will be required in certain situations for the EU Habitats Directive in some catchments (see IFI environmental process, etc.).
(GIS assessment and monitoring)	Identify length of channel upstream of structure that is currently impounded and extent of catchment that will be opened up
	Identify species present upstream and downstream of structure ○ Native and invasive fish species ○ Invasive plant/ invertebrate species
	Highlight any potential contaminants of the sediment by identifying land use upstream of structure ○ Take sample for analysis (heavy metal and organic nutrients?)
	Identify if additional structures are present upstream & downstream of structure in question
Planning	Determine if planning permission is required
Funding	Secure funding for barrier removal or mitigation project (e.g. IFI advertise a number of funding opportunities annually – www.fisheriesireland.ie)
Stakeholder engagement	○ Apply adaptive management measures as outlined from the AMBER project ○ Recreational/ leisure such as angling clubs, canoe, kayak ○ Local landowners ○ Articulate potential ecological benefits of the project
Ecosystem services	Identify cultural significance of structure ○ Can the cultural importance be captured while ensuring the river processes are no longer impeded?
Risk assessment	Undertake risk assessment (include invasives, see section 3.5.2)
Archaeology	Check national monuments database (https://www.archaeology.ie/archaeological-survey-database)

3.4.2 Lateral connectivity

Many European rivers have been significantly modified to serve one dominant function (e.g. navigation) but a one-sided approach to managing rivers is no longer optimal in the context of WFD requirements and of climate change issues (i.e. more droughts and extreme floods). Permitting rivers to change their position laterally is important for creating channel shapes, diversifying flows, depths, riverbed sediment, improved biodiversity of river corridors and allowing the temporary storage of water, mitigating downstream flood risk (Addy *et al*., 2016). Restoring lateral connectivity is also important for the natural exchange of sediment between a river and its floodplain (Addy *et al*., 2016).

In Europe and elsewhere this one-sided management of rivers is currently being replaced by an integrated approach to include both the river and the floodplain (e.g. Climate Adapt, 2019) and the concept of "making room for the river" or "freedom space for rivers" (e.g. Piégay *et al*., 2005; Biron *et al*., 2014). Buffin-Belanger *et al*. (2015) found that "freedom space" limits would be robust in future climate scenarios over a 50 year period with ratios of benefits to costs ranging from 1.5:1 to 4.8:1. This concept essentially requires a recognition of the "floodplain" as an area that does normally flood over or becomes inundated in flood flow conditions and that this natural response has been 'constructed out' by human activity and that, for some form of future-proofing, it needs to be 'constructed in' again. It will be challenging for this basic reality to gain traction but, in a climate change scenario, it is impossible to fund or to construct engineering solutions to offset all potential flood risks. This is particularly so in agricultural scenarios. Re-allowing flood plains to function as normal can provide seasonal aquatic habitats, create corridors of native riparian forests, create shaded riverine and terrestrial habitats, store sediment, provide food and supply woody material (Griffin *et al*., 2015). It also helps to retain and slowly release discharge from waterbodies (natural flood management) as well as facilitating groundwater recharge and improving water quality. River and floodplain restoration can contribute to improving the hydrological regime and cope with climate change effects (Roni *et al*., 2005; Climate Adapt, 2019; Connor and Kelly, *in prep*.). It is an important measure to create larger, more interconnected areas within catchments that are climate proofed against flooding, drought and warming conditions (Kondolf, 2012; Diaz-Redondo *et al*., 2018 a and b). Any overland flooding in spring/spawning period onto the floodplain can benefit some coarse fish species that may spawn in these areas. This could be a benefit of enhanced floodplain connectivity (Górski *et al*., 2010). Some authors recommend floodplain habitat restoration over instream habitat improvement in larger river channel (>12m bankfull width) and low gradient channels (<2%) (Dominquez and Cederholm, 2000; Roni *et al*., 2002; Pess *et al*., 2005).

Removal of lateral constraints (e.g. bank protection and embankments) allows rivers to freely adjust their size to the prevailing flows and input of sediment (Addy *et al*., 2016). This can reduce flood risk downstream especially in small-sized to medium-sized streams and rivers where degradation is severe, if investments are made strategically (Addy *et al*., 2016). Removal of flood embankments has been observed to result in the improvement of wetland floodplain habitat and benefits for fish and riparian vegetation diversity. Such approaches are severely constrained in the case of channelized or arterially drained rivers or in urban areas. However, creation of riparian zones and strategic management of the incised channel form is possible in the case of these rivers. Addy *et al*. (2016) recommend setting flood embankments back from the river to create more space or selectively breach embankment in certain situations (Addy *et al*., 2016). A complete return to the pre-drainage condition in such channels would require a major political and land-management conversation that is outside the remit of this guidance document.

3.5 Issues with invasive aquatic species

Invasive alien species are defined as having been introduced to habitats outside of their native range(s) and where their introduction damages environments, economies or is detrimental to human health (CBD, 2009). They are considered a major anthropogenic threat to global biodiversity, prompting efforts to enhance the effectiveness of invasive species management (e.g. Caffrey *et al*., 2014; Piria *et al*., 2017). The presence of a truly invasive species is evidenced by a demonstrable adverse impact on native communities or habitats.

Aquatic Invasive species (AIS) may be plant or animal. The plant species observed in riparian areas in Ireland commonly include species such as Giant hogweed, Japanese knotweed and Himalayan balsam (Fig. 3.22). These are not specifically 'aquatic' or 'riparian' plants but they can be dispersed by river flow as seed or vegetative fragments and, where present at aquatic sites, commonly establish a riparian corridor that can rapidly exclude other plant species. The dispersal of invasive aquatic plants tends to be largely in a downstream direction. Animal invasives (e.g. fish species such as dace and roach) have the capacity to disperse 'actively', unlike 'passive' plant dispersal, and can move both up and downstream and also into tributary channels.

The threat of AIS lies in competitively excluding or outcompeting our less robust native species, by preying on native species or by altering the natural aquatic or riparian habitat in which they reside. Food web studies in Colorado have also shown that non-native fish cause niche displacement in native species by inducing resource shifts toward lower trophic positions (Rosgoch and Olden, 2020). In addition to their biological effects, invasive species can adversely impact the recreational and amenity use of infested watercourses by restricting angling, boating, swimming and other water-based leisure pursuits, e.g. the invasive plant, *Lagarosiphon major* (or curly waterweed) in Lough Corrib. They can impact on industry by clogging engines, turbines and water intake pipes, e.g. the Zebra mussel (*Dreissena polymorpha)* in the Shannon lakes and other water bodies (Fig. 3.22). These adverse effects have resulted in significant costs to the economy. Non-native invasive species are commonly introduced by human action, either accidentally (e.g. hull fouling or ballast water) or intentionally (e.g. water garden planting or illegal import and transfer of fish species from water to water). Spread within the country is often mediated by water flow in river catchments.

Preventing the introduction of non-native species of plants and animals (and pathogens) and the control of existing populations to reduce their negative impact on the water environment is essential in the context of climate change.

3.5.1 Management of aquatic and riparian invasive species during restoration works

Management (prevention, control and removal) of invasive species should be an important aspect of any riverine restoration or rehabilitation effort. Legislation does exist in Ireland (e.g. S.I. 477 of 2011; see Appendix 3) but responsibility for enforcement requires sufficient resourcing.

- Any management or removal action, however well-intentioned, may be of little avail unless the invasive issue is addressed on a 'whole-waterbody' basis.
- To be effective, measures should commence at the most upstream point of the channel, of whatever size, where the invasive species is known to be. The control/management should continue downstream to include the proposed works area and an additional downstream perimeter.
- It is imperative that any instream or riparian work carried out on Ireland's rivers does not result in the inadvertent spread of these species.
- Any works must only be conducted in line with recognised best practice guidelines for biosecurity (e.g. Early *et al*., 2009; IFI 2010; NRA, 2010; National Biodiversity Centre, 2020).
- It is imperative that all machinery and equipment is checked to ensure that it is clean, dry and disinfected both before and after any works are conducted.
- Management of certain species has Health and Safety implications, e.g. Giant Hogweed.
- Soils should not be introduced onto a site and any materials for planting should be native species and native-sourced. Invasive species have been spread widely by viable plant parts hitch-hiking in soil or plants themselves escaping cultivation (Kelly, 2012).
- Biosecurity measures alongside increasing public awareness campaigns, educating contractors, heavier fines, stricter border control and stronger legislation for transporting these species internally in Ireland are required.

Guidance documents generally include the following advice:

- Learn to identify invasive species and prevent their introduction.
- Be aware of infested areas and incorporate invasive species management into land-use plans. Contain and if possible, remove unestablished or poorly/newly established invasive species.
- Ensure zero transport of invasive species from infested to non-infested locations.
- Follow the "check-clean-dry-disinfect" or "inspect-remove-clean-dispose-notify" protocols (check/visually inspect for any invasive material, remove plant fragments and any other visible material, clean equipment, drain water, disinfect and dry (e.g. IFI, 2010; National Biodiversity Data Centre, 2020) .
- Maintain desirable species to discourage invasive species establishment.
- Refer to the IFI's and other protocols for biosecurity (IFI 2010; www.fisheriesireland.ie)
- Also refer to OPW biosecurity (Brew and Gilligan, 2019)

Fig. 3.22 Examples of invasive species in Ireland – Asian clam, zebra mussels, rhododendron, giant hogweed, Himalayan balsam and Japanese knotweed

3.5.2 Risk assessment, invasives and connectivity projects

There is one major caveat to barrier removal or fish passage solutions that must be recognised, and risk assessed and that is when aquatic invasive species (AIS) are present in a catchment. When barriers are constructed, novel habitat is created, which can be beneficial for invasives to colonize (Liew *et al*.

2016). Upstream of barriers, the conversion of natural lotic segments into artificial lentic habitat will impact rheophilic species which are intolerant of drastic habitat alterations and invasive species may fill these new niches (Vitule *et al*., 2012). Indeed part of the argument made for removal of barriers in the restoration of rivers with non-natives is that it can restore conditions closer to which native species are adapted and increase their ability to compete favourably with non-natives (Fausch *et al*., 2009). However, with an increasing frequency of invasions by AIS to river systems comes the requirement to control the spread of these species. Construction of barriers to isolate non-invaded portions of rivers or the decision to not remove existing ones ("concept of intentional fragmentation" or "management by isolation" or "selective passage") may be needed to control AIS when eradication is unfeasible (Fausch *et al*., 2009; Clarkson *et al*., 2012; Tummers and Lucas, 2019). Within an invaded catchment, the distribution, type and permeability of existing barriers form a key tool for the management of within-catchment invasion.

As recommended in chapter 2 a GIS risk assessment framework should be developed to map AIS in each catchment, assess impacts of their spread on native species and assess management options within a catchment (King and O' Hanley, 2016) so that the spread of invasive species may be mapped and limited adequately. This represents a significant aspect in the adaptive management of barriers in rivers, and should form part of the decision-making process for removing barriers, constructing new ones, installing multi-species fish passes or installing selective passage solutions (Tummers and Lucas, 2019).

4. Project evaluation

Monitoring and evaluation of restoration works is essential for determining the effectiveness of measures aimed at improving habitat and increasing fish numbers and conditions (FAO, 2008). The evaluation of restoration activities is concerned with determining the physical and biological effectiveness of various restoration actions (FAO, 2008). Project evaluation, including monitoring and maintaining a river, allows the success of a programme to be assessed and to update relevant policies. It will also help identify which restoration methods work best and in what types of situations for on-going and future initiatives and contribute to developing best practice in a changing environment. The absence of post-project monitoring limits the development of valuable information which could be used to improve restoration efforts (Roni *et al*., 2005). Therefore a well-designed monitoring programme must be an integral part of the project process and should not be an afterthought (Pretty *et al*., 2003; Roni *et al*., 2005; Hammond *et al*., 2011) and in the long-term will contribute to better cost effectiveness. It should be conceived during the design stage of the project (Roni *et al*., 2o05). Associated costs for monitoring will also need to be allocated at the funding stage or a commitment received to ensure funding is available in the future.

4.1 What should be included in the monitoring programme

Prior to monitoring, geo-referenced mapping and recording of all works and cataloguing data in a central location is recommended so that on-going monitoring and evaluation can be facilitated. Software programmes to capture field data, such as Arc GIS Collector could facilitate this work. The key steps involved in developing a monitoring and evaluation programme are shown in Fig. 4.1. The priority when developing a monitoring programme is to determine the objectives and define key questions (Weber *et al*., 2018). This is followed by selecting the monitoring design, monitoring parameters, spatial and temporal replication, selecting sampling methods, implementing the programme and analysing and communicating the results (Roni *et al*., 2005). According to these authors the most difficult part and the biggest shortcoming of many evaluation programmes was the study design. The absence of pre-project data, adequate treatments and controls, reference sites, and various management factors limited the ability of many studies to determine the effects of rehabilitation actions.

Monitoring should be appropriate to the type of work that is undertaken, i.e. assess the impact of the "work that was done". For example, if tree management is undertaken e.g. large-scale removal, then assessing canopy cover before and after is relevant, alongside fish and other biota if necessary, (e.g. periphyton and macroinvertebrates may also be important to include). Decisions on which elements of a project to evaluate may also be influenced by pre-existing long-term data sets (e.g. EPA data, IFI fish data, etc.), resources and timescale. The initial objectives of the restoration project will often indicate which elements to monitor, but could cover ecology, fisheries, macrophytes, and hydromorphology (hydrology and geomorphology) depending on the level of skill of those carrying out the assessments (Hammond *et al*., 2011). If not, all aspects can be monitored then a prioritisation of monitoring methods should to be carried out. A list of potential monitoring methods is compiled in Table 4.1.

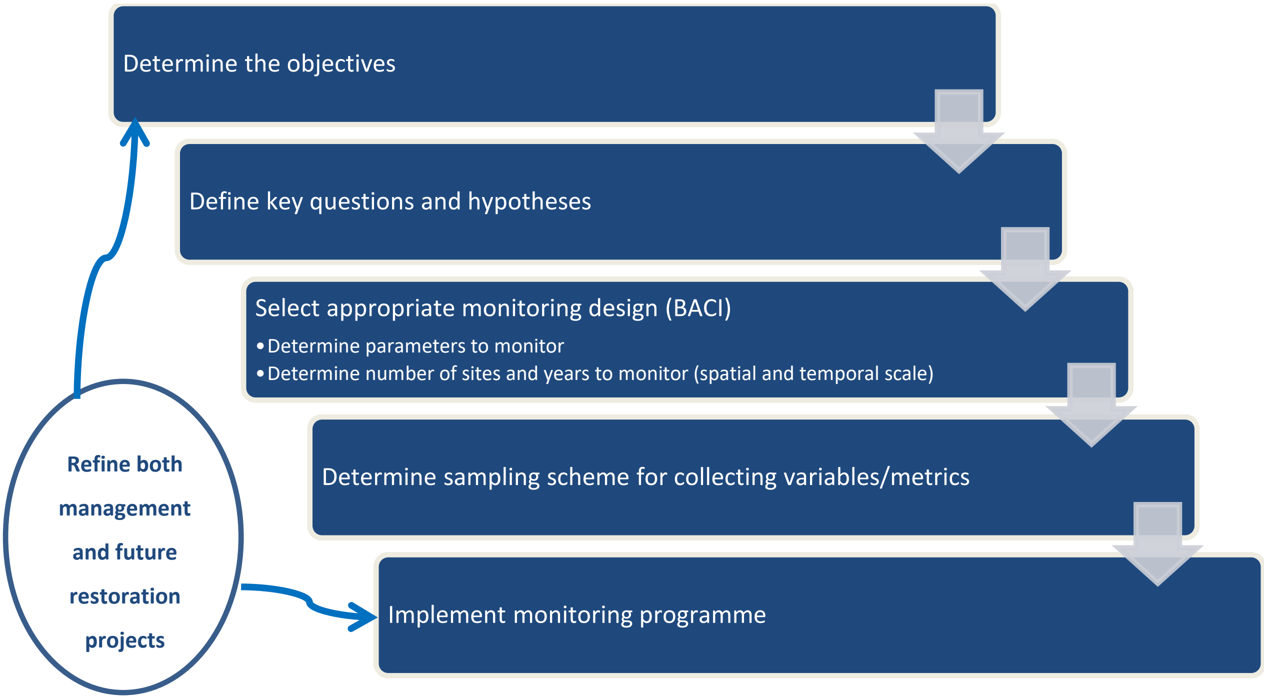

Fig. 4.1. Keys steps for developing a monitoring and evaluation programme for restoration actions (adapted from Roni *et al*., 2005).

4.2 BACI (Before-After-Control-Impact)

To evaluate the success of projects, monitoring should be carried out before and after works. The BACI (Before-After-Control-Impact) assessment is a commonly used approach and is the method recommended here (e.g. Geist and Hawkins, 2016 Friberg *et al.*, 2016; Mahlum *et al.*, 2018). Monitoring takes place before and after in the 'experimental' site (where works have been carried out) and the control site (where no work was carried out and which is not affected directly or indirectly by the works). In order to carry out such an assessment, clear objectives/hypothesis must be identified, a combination of qualitative and/or quantitative monitoring needs to be completed, but determining what set of surveys to undertake is dependent on the objectives of the rehabilitation works. Designing robust study designs to include both reference sites and pre-treatment data is critical to accurately determining the success of restoration project (Mahlum *et al*., 2018). Current best practice identified that pre-works monitoring should be undertaken for three successive seasons/years prior to commencement of works. This is to ensure that any positive outcomes from the works programme are a consequence of the works programme and not a consequence of natural fluctuations in population size or physical variables.

The Control and Experiment sites should be as similar as possible in terms of the sites' "physical" attributes, e.g. gradient, bed type, width, depth, velocity regime and their biological attributes, e.g. same suite of plant, invertebrate and fish species in both sites. There should be no "confounding elements" that might undermine any project outcomes. For example, the Control site should be at a distance upstream from the Experimental so that it does not impact on the experiment. Similarly, there should be no 'features' intervening between the two sites e.g. physical migration barrier; tributary channel that would alter flow regime etc.; discharges of any sort; water abstraction of any sort; any adverse habitat issue such as major animal encroachment, with fouling and poaching.

4.3 Timescale and frequency

Evidence suggests that many river restoration projects fall short of their objectives because of failure to focus on appropriate time scales (Speed *et al*., 2016; Foote *et al*., 2020). Generally, three years post-works was often a rule of thumb, but this was mainly due to funding availability (Hammond *et al*., 2011). Rivers experience natural variability on a seasonal and annual basis (e.g. stream flows) and evaluation needs to take account of this. Monitoring needs to take account of short and long-term time frames based on the type of work undertaken in order to determine if a project is a success as some processes take time to establish, e.g. bank stabilisation requires the trees to establish. Recovery periods can vary between species, river types and geographical locations (Hammond *et al*., 2011). The rate of recovery will also vary depending on local weather conditions (e.g. a drought year may limit or delay recovery) and therefore multiple years are recommended.

IFI recommends monitoring 12 months post-works, in same season/calendar, in similar water conditions (check water level gauge), and annually thereafter (or two-yearly) for 5-6 years and at 5 year intervals thereafter; however not all elements need to be monitored in the same year and flexibility is required, as it will not be possible to collect the same detail for every project.

4.3 Audits/maintenance checks

In some projects regular post-works maintenance checks or audits will be required (e.g. assessing the status of fishing stands). IFI have an electronic form for assessing fishing stands/infrastructure and will have an electronic form for electrofishing surveys in late 2020.

Table 4.1. Potential evaluation techniques for river restoration works.

	Method	Resources	Timescale	Remarks
Visual	Fixed location photography (Skinner and Thorne, 2005)	Camera	High resolution (every season) to low resolution (5+ years)	Low cost. Only captures ground level, limited information. Needs same camera (high quality is important)
	Aerial photography	Drone or Satellite data	High resolution (every season) to low resolution (5+ years)	Captures larger scale. Links to GIS and links to use of MESOHABSIM
	RHAT survey	Camera, RHAT data, expertise.	Annually to 5+ years.	Comprehensive. Subjective, requires similar level of expertise for consistency. Intercalibration among experienced users is essential. It gives replication of variables and in-site over 500m reaches. Individual components can be analysed.
Physical	Physical survey (cross sections/ longitudinal profiles) (Skinner and Thorne, 2005)	GPS. Measuring staff, measuring tape, camera, PPE.	Annually to 5+ years. Once prior to works and one year after works. After that, a more widely spaced frequency is adequate, e.g. after 5 and 10 years. EREP returned to repeat cross-sections after 20 and 25 years on some midland streams.	Cross-sectional and long-section data is useful and highly informative in short and long-term time scales. This may also be useful where extensive instream works are done – such as rubble mats if appropriate
	Habitat mapping	e.g. Mesohabsim, Electrofishing, Drone, flow meter, Arc GIS Collector app, etc.	Pre- 1 year post 5 years post	Good scope here – expertise available in IFI Particularly relevant in larger channels especially where MAJOR actions planned e.g. barrier removal and exposure of drowned habitat, etc.
	Flow regimes	Flow meter, measuring tape, PPE.	Annually to 5+ years. Pre- 1 year post 5 years post	Useful. Two strategies required (A) Overall transect approach where more 'generalist works done – W-D-V (B) Detailed: at specific structures; inlet, mid-

				point and outlet flow past structures…
	Sediment analysis	Granulometry equipment sieves and sieve stack; Surber sampler with quadrant and fine mesh bag; shovel for downward excavation, sampling equipment. Alternative is the pebble count method.	Suggest pre- One year post and 5 years	Strategy depends on what you are looking for or want to demonstrate using 3 samples across any transect (e.g. EDM project 1996-2000) Alternative might be pebble count method – may give a broader picture, depends on what you want to demonstrate, etc
	Topographical survey.	Geophysical survey equipment, expertise.	Pre, one year post, 5+ years.	This is dependent on the objective and what you want to demonstrate, so not to be used in all situations. Do pre and 5 year post if planning same.
Biological	Macroinvertebrate	Kick sample net, Q-value, SSRS/expertise, GPS, PPE.	Annually to 5+ years, ideally late spring/summer samples	If no EPA data available, consultants may be appropriate for standardisation and QC purposes
	Fish	E-fishing equipment, netting, expertise, PPE.	Annually (June- Sept) to 5+ years. Then at 5- year intervals until no change	Ideally 3 years pre to allow for natural fluctuations (IUCN UK strategy)
		Anglers catch		May be very relevant for coarse fish or where it's difficult to deploy normal fish sampling methods. For example - Survey lakes or large river waterbodies using (a) CEN netting and (b) angler competition data – for comparison.
	Vegetation surveys (Macrophytes/ Marginal/ Riparian)	ID guide, expertise, PPE.	Possibly use drones to get good aerial coverage and digitise images for species discrimination and accurate % cover etc.	Ideally 3 years pre-works to allow for natural fluctuations – this is the IUCN UK strategy (Addy *et al*., 2016)

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Appendix 1 – Physico-chemical and hydromorphological pressures

Physico-chemical and hydromorphological pressures affecting biological quality elements and their response

<table>
<tr><th>Indicator</th><th>Physico-chemical pressures</th><th>Hydromorphological pressures</th></tr>
<tr><td rowspan="3">Macrophytes</td><td>• Reduction of water transparency
• Variations of mineralization conditions (conductivity and salinity)
• Eutrophication</td><td>Variations of the flow regime, river continuity and morphological characteristics of the riverbed</td></tr>
<tr><td>Response</td><td>Response</td></tr>
<tr><td>They are indicators of changes in the medium and long term reflecting the quality conditions existing during the last months or even years. The disappearance of a species from an aquatic system (especially those of small size) can be highly significant.</td><td>Their response to flow stabilisation is usually the increase in the coverage of the species.</td></tr>
<tr><td rowspan="3">Diatoms (phytobenthos)</td><td>• Eutrophication
• Increases in organic matter
• Salinity
• Acidification</td><td rowspan="3">Diatoms are not very sensitive to hydromorphological pressures (alterations of the hydrological regime, river continuity and morphological conditions of the bed), so their use is not recommended for the detection of these pressures.</td></tr>
<tr><td>Response</td></tr>
<tr><td>They are short-term indicators and respond to the increase of nutrients (mainly N and P) in the water through changes in their composition that, in some cases, suppose the decrease in diversity and the increase in biomass.</td></tr>
<tr><td rowspan="3">Macro-invertebrates (zoobenthos)</td><td>• Thermal pollution
• Increases in organic matter
• Variations of mineralization conditions (conductivity and salinity)
• Pollution by metals or other pollutants</td><td>Variations of the flow regime, river continuity and morphological characteristics of the riverbed</td></tr>
<tr><td colspan="2">Response</td></tr>
<tr><td colspan="2">Benthic invertebrates indicate alterations in the medium and long term since their species have life cycles between less than a month and up to more than a year. Their intermediate temporal scope complements that of other biological elements with shorter response times, such as phytobenthos, or longer ones, such as fish.</td></tr>
<tr><td rowspan="3">Fish</td><td>• De-oxygenation of the water
• Water contamination
• Eutrophication and appearance of toxicity due to algae</td><td>• Alteration of habitat with changes in:
- Depth and width of the river
- Water velocity
- Granulometric composition
- Morphology of the riverbed
- Riparian vegetation
• Variations in the continuity of the river</td></tr>
<tr><td colspan="2">Response</td></tr>
<tr><td colspan="2">Their indicator value lies in being predictors of change over a larger spatio-temporal scale, even when drivers of alterations have already disappeared.</td></tr>
</table>

Appendix 2 – Fish migration times in Ireland

Table A2.1 Downstream migration

Downstream migration																																				
Species	**Jan**			**Feb**			**Mar**			**Apr**			**May**			**Jun**			**Jul**			**Aug**			**Sep**			**Oct**			**Nov**			**Dec**		
Salmon smolt								X	X	X	X	X	X	X	X	X	X																			
Salmon kelts																																				
Sea trout smolt																																				
Adult trout																																				
Trout smolt								X	X	X	X	X	X	X	X																					
Silver eel																																				
Yellow eels																																				
Sea / River Lamprey																																				
Smelt																																				
Allis shad																																				
Twaite shad																																				
Perch (adult)																																				
Perch (juvenile)																																				
Roach (adult)																																				
Roach (Juvenile)																																				
Pike (adult)																																				
Bream (adult)																																				
Bream (Juvenile)																																				
Tench (Adult)																																				
Tench (Juvenile)																																				
Rudd (adult)																																				
Gudgeon																																				
Flounder (Adult)																																				
Pollan																																				
Dace																																				

NOTE/KEY

Main migration period

Lower migration period

Smolt generation elver pass operation & silver eel trap and truck-based information XXXXXXXXXXXX

Table A2.2 Upstream migration

Upstream migration																																				
Species	**Jan**			**Feb**			**Mar**			**Apr**			**May**			**Jun**			**Jul**			**Aug**			**Sep**			**Oct**			**Nov**			**Dec**		
Wild salmon																		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
Hatchery salmon																									X	X	X	X	X	X	X	X				
Adult trout																									X	X	X	X	X	X	X	X	X	X		
Trout smolt																																				
Elvers & Bootlace eels							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X												
Glass eels																																				
Yellow eels																																				
River Lamprey																																				
Sea Lamprey																																				
Smelt																																				
Allis shad																																				
Twaite shad																																				
Perch																																				
Roach																																				
Pike																																				
Bream																																				
Rudd																																				
Tench																																				
Gudgeon																																				
Flounder (Adult))																																				
Flounder (larvae)																																				
Flounder (Juveniles)																																				
Pollan																																				
Dace																																				

NOTE/KEY

Main migration period

Lower migration period

Smolt generation protocol, elver pass operation & silver eel trap and truck-based information XXXXXXXXXXX

Appendix 3 - Habitat requirements of fish species in Ireland

When considering measures for fish species, appropriate to the hydromorphology of the channel or catchment being considered, their life cycle and habitat requirements must be considered and these are described below.

A2.1 Salmonids

The two species of native salmonid present in Irish rivers are Atlantic salmon (*Salmo salar*) and trout (*Salmo trutta*). Trout are principally divided into anadromous sea trout or freshwater brown trout and different varieties of the latter have been further described (e.g. ferox, gillaroo, sonaghan) (Ferguson and Taggart, 1991). Freshwater brown trout may be potomadromous or more locally resident in a catchment (O' Grady *et al*., 2008; Ferguson *et al*., 2019). Both species require a diverse array of connected habitat types with variable requirements at different life stages (reviewed in O' Grady *et al*., 2008 and NASCO, 2010). Spawning and nursery habitat requirements are very similar for both, with spawning typically occurring during autumn-winter on gravel substrates in riffle zones with sufficient oxygenated and cool water flow for egg development. Salmonids have three key life cycle stages (fry, juvenile and adult) which all have their own habitat requirements or habitat niche. Rivers or streams that do not provide this full set of conditions (depending on type, e.g. not all spawning streams will retain adult fish all year round, but this is natural) or the correct amount of these resources pose a problem for resident salmonids and will lead to habitat bottlenecks that constrain the viability of wild salmonid populations (Armstrong *et al*., 2003). Given the current climate change era and increasing water temperatures being observed in our rivers there is a need to identify restoration works which will build salmonid resilience to climate change effects by regulating temperature and improving habitat complexity.

Excess siltation/sedimentation can negatively impact adult spawning areas by limiting access to spawning substrates. Well-oxygenated flowing channels are also required for juvenile fry and parr development and are typically diversely structured habitats principally comprising of gravels, cobble and boulder substrates. Adult salmonids typically occupy glide and pool areas in river channels. Pools are an important holding and resting area for returning anadromous salmonids and act as a refuge when there are extended periods of low water or warm conditions. Salmonids are pollution-sensitive and are susceptible to higher water temperatures relative to coarse fish species. In this regard, they are likely to be particularly under threat in future climate change scenarios which predict higher mean water temperatures and sustained periods of drought in summer (Desmond *et al*. 2008; O' Briain *et al*. 2019).

Conservation measures could include enhancing fish cover (boulders/woody debris), native broadleaf planting in the riparian zone and removal of artificial barriers.

A2.2 Lamprey (brook, river and sea)

Adult brook, river and sea lamprey require clean gravels, sand and small stone substrate with flow through the sediment when spawning (Maitland, 2003; Rooney *et al*., 2013)). Sea lampreys require larger substrate than the other species when spawning (comprising of sand, gravel and cobble) (Joint Nature Conservation Committee, 2015).

In Ireland spawning of brook and river lamprey occurs usually in March/April with brook lamprey migrating only short distances to spawning sites when water temperatures reach 10-11ºC (Kelly and King, 2001; Rooney *et al*., 2013). River lampreys commence their spawning migrations from the sea in September-October period prior to spring spawning. This upstream migration continues throughout the winter and early spring months with movement occurring mostly at night, during the day these adults hide under rocks and in stream vegetation (Maitland, 2003). Adult sea lampreys enter freshwater systems usually in April to begin their spawning migration. They can travel long distances in order to reach preferable spawning grounds, this is dependent on their routes being clear of migratory barriers (Maitland, 2003). Spawning of sea lamprey occurs in May-June when water temperatures reach at least 15ºC (Maitland, 2003; Rooney et al 2015)); however they have been observed spawning as late as July in the lower reaches of some Irish rivers (Kelly, IFI, pers. comm.). Sea lampreys require a migration route that is free from obstacles both natural and man-made to ensure minimal effort and delay en-route to spawning sites and their progression into Irish rivers is impacted by large weirs (Gargan *et al*., 2011; Rooney *et al*., 2015; Barry *et al*., 2018). The spawning event may take place over several days, it is therefore essential that spawning locations have a diverse range of habitat that consists of adequate spawning gravels and nearby resting areas such as pools, eddies and sheltered areas of low velocity.

Hatching occurs 2 weeks after egg deposition and the larvae can remain within the spawning gravels for another 1-3 weeks (Kelly and King, 2001). Larval lamprey will then migrate downstream in search of sheltered areas comprising of silt, mud and sand substrata, low velocities and high organic matter content (Maitland, 2003). Dawson *et al.* (2015) reviewed several studies indicating that sea lamprey larvae were most abundant in substrate consisting of 90% sand particles less than 0.5mm in diameter. Other suitable larval habitats can include organic detritus overlaying coarse sediments, submerged tree roots and submerged silt banks (Joint Nature Conservation Committee, 2015). As the larvae develop, they construct burrows in these areas where the current velocity is below that of the main channel and where organic material can accumulate (Kelly and King, 2001; Torgersen and Close 2004). These low velocity and silty habitats are significant to the development of larvae of all three lamprey species found in Ireland for up to 6 years prior to maturation (Maitland, 1980; Maitland, 2000).

A2.3 Twaite Shad (*Alosa fallax*)

The presence of twaite shad in Ireland is predominantly limited to the rivers Suir, Nore, Barrow, Munster Blackwater and Slaney (King and Roche, 2008). Spawning migration of the twaite shad into freshwater commences in April and usually extends for 2-3 months (Aprahamian *et al.,* 2003). The timing of this migration has been associated with water temperatures reaching 10-12ºC and can also be influenced by estuarine tides and river flows (Maitland, 2000). A migration route free of obstructions and barriers is crucial if shad are to reach their preferred spawning sites. Twaite shad have been recorded up to 100km upstream in the River Severn, UK. Shad spawning sites have been identified as fast flowing, shallow and clean gravel/cobble beds (Maitland, 2000). Depths required for spawning have been found to range between 0.15 to 1.20m (Aprahamian *et al.,* 2003). The habitat at shad spawning grounds should remain diverse with a mixture of deep pools and overhanging vegetation to provide shelter prior to the spawning event (Aprahamian *et al.,* 2003). Once spawning has occurred the fertilized eggs sink to the bottom of the river with incubation taking 72-120 hours (Aprahamian *et al.,* 2003). Upon hatching the juveniles enter backwaters and areas of low current velocity to use as nursery habitat (Maitland, 2000). They will feed and develop in these low velocity sheltered areas of the river from June- October and will migrate downstream as they develop during their first year. This migration coincides with the declining water temperatures of the autumn months. The juvenile shad will then utilise estuarine habitats to feed and grow prior to their sea migration (Maitland, 2000).

A2.4 European Eel (*Anguilla anguilla*)

The European Eel is listed as critically endangered by the IUCN Red List since 2010 and with the introduction of the Eel Regulation in 2007 is subject to management plans to protect the species and promote the recovery of the stock. The eel is a catadromous species, spawning in the Sargasso Sea and migrating into our transitional and freshwater systems. The upstream migration is undertaken predominately in the elver stage with a downstream migration undertaken by silver eel; however numerous upstream and downstream migrations are undertaken during the yellow eel life-stage as documented by acoustic telemetry and microchemistry analysis (Arai *et al*., 2006; Harrod *et al*., 2005;

Barry *et al*., 2016). The longitudinal connectivity of our river systems impacts on this migration journey and while eels can pass some structures with suitable bank side vegetation the delay and increased risk of predation are factors to be taken into account.

A2.5 Coarse fish

Colloquially coarse fish are considered to include all freshwater species except the salmonids and eel. In Irish fisheries legislation coarse fish are specifically protected under Bye Law 606 (2009), where they are defined as any freshwater fish other than pike, salmon, trout, eels or minnow. Together, pike and coarse fish support socially and economically important recreational fisheries in Ireland (IFI 2015a, IFI 2015b).

Roach, dace, chub and common carp are listed in Regulations 49 and 50 of the European Communities (Birds and Natural Habitats) *Regulations 2011* [*SI. 477*] as invasive (see Appendix 3).

The riverine habitat requirements of Ireland's coarse fish species (excluding chub and carp) are presented in Table A2.1. In common with the salmonids, habitat requirements and preferences vary between species and within species depend upon life stage. However, several common themes are apparent. Most species are found predominantly in lowland, slow flowing rivers, and rely upon sheltered and vegetated backwaters or off-channel ponds and lakes at various life stages. Migrations to and from these habitats can be important to ensure healthy populations. Restoration, or recreation of these features, may, therefore, be expected to benefit populations of resident coarse fish. Where present, these features should be retained, if in stream works are planned. In most instances, improving the overall health of the ecosystem, rather than targeted enhancement for specific species (FAO, 2008) is recommended.

Any overland flooding in spring/spawning period onto the floodplain can benefit some coarse fish species that may spawn in these areas - as occurs in the floodplain of many large rivers in mainland European countries (Górski *et al*., 2010). This could be a positive aspect of enhanced floodplain connectivity.

Table A2.1: Habitat requirement of salmonids, lamprey, shad, eel and coarse fish species in Ireland. (Note: orange shading highlights species identified as invasive, as per sections 49 & 50 of the European Communities (Birds and Natural Habitats) *Regulations 2011* [*SI. 477*] Birds and Habitats Regulations; Distribution/prevalence; C=common, L=Localised; W=widespread, R=rare, A = abundant)

Common Name	Scientific Name	Distribution/ Prevalence	Angling Species	Spawning Period Ireland	Spawning Migration	Spawning Habitats Rivers	Spawning Substrate	Larval	Juvenile	Adult	Overwinter/ Refuge Habitats
Brown trout/sea trout	*Salmo trutta*	C/A	✓	Oct-Jan	✓	Riffle areas, shallows	Gravels	Riffle	Glide, runs	Pool areas close to riffle/glide	✓
Salmon	*Salmo salar*	C/A	✓	Oct-Jan	✓	Riffle areas, shallows	Gravel, cobble	Riffle	Glide, runs	Pool areas	✓
Brook lamprey	*Lampetra planeri*	C/A	x	Mar-May (≥10°C)	✓	Riffle areas, shallows	Sand, gravel	Silt beds,backwaters	Silt/sand/ gravels	Slow flowing rivers & Backwaters	✓
River lamprey	*Lampetra fluviatilis*		x	Apr-Jun	✓	Riffle areas, shallows	Sand, gravel (small stones0	Silt beds,backwaters	Silt/sand/ gravels	Moderate - fast flowing river	✓
Sea lamprey	*Petromyzon marinus*		x	May-Jul	✓	Riffle areas, shallows	Sand, gravel, cobbles	Silt beds,backwaters	Silt/sand/ gravels	Fast and slow flowing rivers and streams	
Twaite shad	*Alosa fallax*		✓	May-Jun	✓					Fast and slow flowing rivers and streams	✓
Eel	*Anguilla*		x	N/A (marine)	✓	N/A (marine)	N/A	N/A	Cobbles/river margins lower reaches	Slow flowing rivers & backwaters	✓
Bream	*Abramis brama*	W C/R	✓	May-June (>15°C)	✓	River backwaters, margins, floodplains	Submerged vegetation	Low velocity back waters and margins	River margins & Low velocity Backwaters	Slow flowing rivers & Backwaters	✓
Dace*	*Leuciscus*	L/ A	✓	March-April (>7°C)	✓	River channels, tributary streams	Gravels	River margins & shallows / low velocity back	River margins & Low velocity backwaters	Moderate - fast flowing river	✓
Gudgeon	*Gobio*	W/C	x	June (>14°C)	x	Shallows	Gravels, sand, vegetation	Low velocity back waters and margins	River margins & low velocity backwaters	Fast and slow flowing rivers and streams	
Minnow	*Phoxinus phoxinus*	W/A	x	April-July (>10°C)	x	Flowing water	Sand, gravels	Low velocity back waters and margins	River margins & low velocity backwaters	Fast and slow flowing rivers and streams	✓

Perch	*Perca fluviatilis*	W/A	✓	April-May(>8ºC)	✓ (short)	Flooded margins, backwaters, tree roots, submerged vegetation	Aquatic plants, submerged objects & structures[1]	Low velocity back waters and margins	River margins & low velocity backwaters	Slow flowing rivers & backwaters	✓
Pike	*Esox lucius*	W/C	✓	Feb-April (>7-9ºC)	✓	Flooded margins, backwaters, submerged vegetation	Submerged vegetation	Low velocity back waters and flooded margins. Requires vegetation	River margins & low velocity backwaters. requires vegetation	Open water/slow flowing rivers	✓ (following prey fish)
Roach*	*Rutilus*	W/A	✓	April-May (>12ºc)	✓	Backwaters/margins/over gravels or weed in faster runs	Submerged vegetation, gravel	Low velocity back waters and margins	River margins & low velocity backwaters		✓
Rudd	*Scardinius erythrophthalmus*	W/C	✓	May-July (>15ºc)	✍	River backwaters, margins	Submerged vegetation	Low velocity back waters and margins	River margins & low velocity backwaters	Slow flowing rivers & Backwaters, weeded habitats	✓
Tench	*Tinca tinca*	L/C	✓	June-July (>20ºc)	✓	River backwaters	Submerged & emergent vegetation	Low velocity back waters and margins	River margins & low velocity backwaters	Slow flowing rivers & backwaters	✓
Nine-spined stickleback	*Pungitius pungitius*	L/C	x	April-July	X	Sand/gravel		Low velocity back waters and margins	River margins & Low velocity Backwaters	Fast and slow flowing rivers and streams	-
Three-spined stickleback	*Gasterosteus aculeatus*	W/A	x	March/August	X	Sand/gravel		Low velocity back waters and margins	River margins & low velocity backwaters	Fast and slow flowing rivers and streams	-
Stone loach	*Noemacheilus barbatulus*	W/C	x	April-August		Sand, stone and vegetation		Low velocity back waters and margins	River margins & Low velocity Backwaters	Fast flowing rivers and streams	-

Appendix 4 – Invasive species legislation

Legislation

Potentially invasive species are subject to legal regulation on a national and EU level. In Europe, Commission Implementing Regulation (EU) 2016/1141 (adopting a list of invasive alien species of Union concern pursuant to Regulation (EU) No 1143/2014 of the European Parliament and of the Council) adopts a list of invasive species of member concern

(https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016R1141&from=EN).

Regulation (EU) No 1143/2014 (on the prevention and management of the introduction and spread of invasive alien species) sets out measures which member states must adopt to manage invasive species

(https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R1143&rid=5.)

In Ireland, several aquatic invasive species of particular relevance to any parties undertaking works in waterbodies are listed under Regulations 49 and 50 of the European Communities (Birds and Natural Habitats) *Regulations 2011* [*SI. 477*]

(http://www.irishstatutebook.ie/eli/2011/si/477/made/en/print).

Relevant species from S.I. 477 of 2011 are listed in Table A4.1. Regulation 49 prohibits, except under licence, the introduction or dispersal of several specified (listed) invasive plant and animal species. Regulation 50 (which has not yet been enacted) prohibits trade or possession of listed invasive plant and animal species. Soil or spoil taken from areas infested with knotweeds (Japanese, giant and their hybrid) is also listed as a vector material under Regulation 50 of the same legislation. In Ireland, horizon scanning has also identified potentially invasive species of concern (Table A4.2) (Lucey *et al.*, 2020).

Table A4.1. Invasive species associated with rivers in Ireland

Name	Common name	Environment	Impact
Allium triquetrum	Three-cornered garlic	Terrestrial	Medium
Anguillicoloides crassus	Swimbladder parasite of eels	Freshwater	High
Aphanomyces astaci	Crayfish plague	Freshwater	High
Azolla filiculoides	Water fern	Freshwater	Medium
Corbicula fluminalis	Asian Clam	Freshwater	High
Corbicula fluminea	Asian clam	Freshwater	High
Corophium curvispinum	Caspian mud shrimp	Freshwater	Medium
Crassula helmsii	New Zealand pigmyweed	Freshwater	High
Cyprinus carpio	Common carp	Freshwater	Medium
Dreissena polymorpha	Zebra mussel	Freshwater	High
Elodea canadensis	Canadian waterweed	Freshwater	High
Elodea nuttallii	Nuttall's waterweed	Freshwater	High
Eriocheir sinensis	Chinese mitten crab	Freshwater	High
Fallopia japonica and hybrids	Japanese knotweed	Terrestrial	High
Fallopia sachalinensis and hybrids	Giant knotweed	Terrestrial	High
Fallopia x bohemica	Bohemian knotweed	Terrestrial	High
Gammarus pulex	Gammarus shrimp	Freshwater	Medium
Gammarus tigrinus	Gammarus shrimp	Freshwater	Medium
Gunnera manicata	Giant rhubarb	Terrestrial	Medium
Gunnera tinctoria	Chilean rhubarb	Terrestrial	High
Hemimysis anomala	Bloody red shrimp	Freshwater	High
Heracleum mantegazzianum	Giant hogweed	Terrestrial	High
Hydrocotyle ranunculoides	Floating pennywort	Freshwater	High
Impatiens glandulifera	Himalayan balsam	Terrestrial	High
Lagarosiphon major	Curly waterweed	Freshwater	High
Lemna minuta	Least duckweed	Freshwater	Medium
Leuciscus cephalus	Chub	Freshwater	High
Leuciscus	Dace	Freshwater	Medium
Lysichiton americanus	American skunk cabbage	Terrestrial	Medium
Myocastor coypus	Coypu	Semi-aquatic	High
Myriophyllum aquaticum	Parrot's-feather	Freshwater	High
Neovison vison	American mink	Terrestrial	High
Nymphoides peltata	Fringed waterlily	Freshwater	High
Oncorhynchus gorbuscha	Pink salmon	Freshwater/marine	High
Oxyura jamaicensis	Ruddy duck	Freshwater	High
Persicaria wallichii	Himalayan knotweed	Terrestrial	Medium
Rhododendron ponticum	Rhododendron	Terrestrial	High
Rutilus	Roach	Freshwater	Medium

Adapted and modified from Kelly *et al*. (2013), www.biodiversity.ie & www.invasivespecies.com

Table A4.2. Watch list of potentially invasive riverine species

Name	Common name	Environment	Impact
Alytes obstetricans	Midwife Toad	Freshwater	High
Astacus astacus	Noble Crayfish	Freshwater	High
Astacus leptodactylus	Turkish Crayfish	Freshwater	High
Batrachochytrium dendrobatidis	Frog Chytrid Fungus	Freshwater	High
Carassius auratus	Edible Goldfish	Freshwater	High
Cercopagis pengoi	Fishhook Water flea	Freshwater	High
Dikerogammarus villosus	Killer Shrimp	Freshwater	High
Dreissena bugensis	Quagga Mussel	Freshwater	High
Egeria densa	Brazilian waterweed	Freshwater	Medium
Gyrodactylus salaris	Salmon fluke	Freshwater	High
Ludwigia grandiflora	Water primrose	Freshwater	High
Ludwigia peploides	Water primrose	Freshwater	High
Mesotriton alpestris	Alpine Newt	Semi-aquatic	High
Ondatra zibethicus	Muskrat	Semi-aquatic	High
Orconectes limosus	Spiny-cheek crayfish	Freshwater	High
Orconectes rusticus	Rusty crayfish	Freshwater	High
Orconectes virilis	Virile Crayfish	Freshwater	High
Pacifastacus leniusculus	Signal crayfish	Freshwater	High
Pimephales promelas	Fathead minnow	Freshwater	High
Procambarus clarkii	Red Swamp Crayfish	Freshwater	High
Procambarus marmorkrebs	Marbled crayfish	Freshwater	High
Pseudorasbora parva	Topmouth Gudgeon	Freshwater	High
Rana catesbeiana	North American Bullfrog	Semi-aquatic	High
Salvelinus fontinalis	Brook trout	Freshwater	High
Sander lucioperca	Zander	Freshwater	High
Trachemys scripta	Common slider	Freshwater	Medium

Adapted and modified from Kelly *et al.* (2013), www.biodiversity.ie and www.invasivespecies.com

Plant and fish species references

- An Bord Pleanala: Appendix 4.1, Outline Invasive Species Management Strategy: http://www.pleanala.ie/publicaccess/EIAR-NIS/JA0038/Douglas%20FRS%20EIS/EIS%20Individual%20Appendices/234335_Appendix_4.1_Issue_080517.pdf
- Invasive Species Ireland: https://invasivespeciesireland.com/
- Field Guide to invasive species in Ireland: https://invasivespeciesireland.com/wp-content/uploads/2010/11/Field_guide_to_invasive_species_in_Ireland_booklet.pdf
- Guidance for drafting best management practices for invasive alien species: Adriaens *et al*. (2018):https://pdfs.semanticscholar.org/8ee2/a24e222cdad54b8f74ae29e7151881adc25b.pdf
- Forest* A *Syst (USA), Best Management Practices: https://www.forestasyst.org/invasive_species.cfm

Invasive Species Risk Assessment

In 2013, an invasive species prioritisation risk assessment ranked 48 species as having a *High* impact and 78 as having a *Medium* impact (Kelly *et al*., 2013). In 2014, 41 species were subject to a more detailed and comprehensive risk assessment (**N**on-native species **Ap**plication based **R**isk **A**nalysis (NAPRA, 2014).

In Ireland, several invasive species have established themselves in, and along our river corridors. These are mostly aquatic and terrestrial animals and plants. Table A4.1 shows invasive species that have been found in Ireland that pose a high or medium risk. Table A4.2 shows a list of species, not yet recorded in Ireland but comprising a watch list of potentially high-risk species.

- Risk analysis and prioritisation: http://invasivespeciesireland.com/wp-content/uploads/2013/03/Risk-analysis-and-prioritization-29032012-FINAL.pdf
- NAPRA 2014, detailed risk assessment: http://nonnativespecies.ie/
- High risk invasive species: https://www.biodiversityireland.ie/wordpress/wp-content/uploads/Invasives_taggedlist_HighImpact_2013RA-1.pdf
- Medium risk invasive species: https://www.biodiversityireland.ie/wordpress/wp-content/uploads/Invasives_taggedMediumImpact_2013RA-2.pdf

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