Upper Bealnabrack Habitat Restoration Plan

IFI/2023/1-4633

Iascach Intíre Éireann
Inland Fisheries Ireland

Version Number	Date	Section(s)	Page(s)	Summary of Changes	Approved by
1.0	26/01/2023	All	All	First draft for review	

Project reference: SCF 22 0159

Date of issue: January 2023

Citation: Ó'Briain, R., Keane, S., Donovan, S. & O'Leary, C. (2023). Upper Bealnabrack Habitat River Restoration Plan. River Hydromorphology Research Programme. Inland Fisheries Ireland. Citywest, Dublin.

Summary

The Bealnabrack river on the west side of Lough Corrib is typical of many rivers found draining the mountains of the west of Ireland. It is a relatively natural system with no significant artificial barriers or arterial drainage and has good-high water quality. It is an important salmonid river within the Lough Corrib catchment/lake complex but is underperforming in part due to impaired physical habitat quality and other stressors such as elevated water temperature that are related to surrounding land use pressures. The upper Bealnabrack is failing to meet the minimum requirement of Good WFD status because its fish community is degraded. Hydromorphology and thermal regime assessments have identified these as likely pressures impacting the fish community. This situation is likely to worsen without intervention to mitigate the documented pressures and buffer the river ecosystem against shocks associated with climate change. Therefore, a Programme of Measures (PoMs) is required to address fish habitat deficits and improve overall habitat for biota in and around the Bealnabrack river, now and into the future

The Bealnabrack river also presents a unique opportunity to undertake large scale landscape restoration on account of a single landowner in the upper catchment that is amenable to nature-based restoration approaches. Restoration projects that work with, rather than against, natural processes are more likely to be self-sustaining into the future and will not require the continuous energy, time and labour inputs, often required in other restoration schemes.

The restoration strategy outlined in the document offers a long-term vision for Bealnabrack river and the catchment in general.

The high-level goals are to:

- Improve habitat quality for salmonids and other stream biota in the short-medium term (5-10 years) by implementing a nature-based approach
- Meet the WFD environmental objective of Good Ecological status
- Create a self-sustaining river ecosystem in the longer term (+10 years) by re-establishing the ecological and hydromorphological processes that underpin healthy rivers

The evidence led approach completed during the comprehensive baseline assessment has been used to set clear and realistic goals for the restoration strategy, that target documented habitat deficits and are appropriate to the river setting.

The restoration measures intended to manage the Bealnabrack over the long term include:

- Riparian woodland establishment to normalise erosion rates and regulate water temperatures
- Online wetland creation to increase habitat biodiversity and create refugia for fish
- Instream habitat creation through addition of large woody habitat to enhance physical habitat diversity
- Soft engineering to manage bank erosion threatening road infrastructure
- Sympathetic management of surrounding terrestrial habitats to buffer and support the river system and increase ecological resilience to landscapes pressures and the broader impact of climate change

Introduction

1.1 Project context

As part of mission its statement and through legislation such as the Water Framework Directive (WFD), the Habitats Directive (HD) and other national and international agreements, Inland Fisheries Ireland (IFI) is actively engaged in improve and protect the aquatic environment. A core focus of IFIs corporate plan (2021-2025) is to "to develop and improve fish habitats" to meet the overlapping IFI high level objectives (1. Habitat, 2. Fish, 3. Stakeholders) and Water Framework Directive (WFD) environmental objectives.

The Bealnabrack River and its main tributaries, the Joyce and Failmore rivers, is an important salmonid system on the west side of Lough Corrib , County Galway. This river catchment has been earmarked for rehabilitation measures that aligns with broader plans for longer term management of the Great Western Lakes and their feeder rivers. IFI require a river restoration plan for the upper Bealnabrack River. Specific requirements include:

- The identification of salmonid habitat rehabilitation options for the upper river section that are appropriate to the river setting and form part of landscape approach
- Options and an outline restoration plan
- Options for erosion control and management to protect critical road infrastructure, while mitigating any negative environmental impacts
- Liaison with stakeholders, including local landowners and National Parks and Wildlife.

1.2 Report aims and objectives

The aim of this report is to highlight opportunities for salmonid habitat restoration and, more generally, measures to improve habitat in the river landscape in the upper Bealnabrack river. To achieve this overall aim, the following objectives were set for this phase of the project:

• Establish the current ecological and hydro(geo)morphological condition of the upper Bealnabrack River, including landscape and reach-scale pressures that may be impacting natural processes and functioning.

• Identify rehabilitation options that could enhance river process and function in the upper Bealnabrack River and, consequently, lead to improvements in both salmonid habitat and overall biodiversity

• Prioritise the most appropriate nature-based restoration measures from landscape to reach-scale, in the form of a list that can be applied to the outline plan and taken forward to the detailed design stage

1.3 Report Structure

River restoration refers to a number of different strategies and techniques applied to enhance the natural state and functioning of rivers and catchments. Several terms are used to describe works aiming to improve the riverine environment - such as rehabilitation, re-naturalisation, enhancement, re-creation, and mitigation - and the term river restoration is used as an umbrella term to account for these in this report.

The report describes the process that were followed to identify habitat restoration options for the upper Bealnabrack River. The report is structured as follows:

Section 1-2 – Introduction & Catchment overview

Section 3 – Methods

Section 4 – Desk study assessments

Section 5 – Field survey and ground truthing results

Section 5 – Options, Restoration recommendations

Section 6 - Outline plan proposal

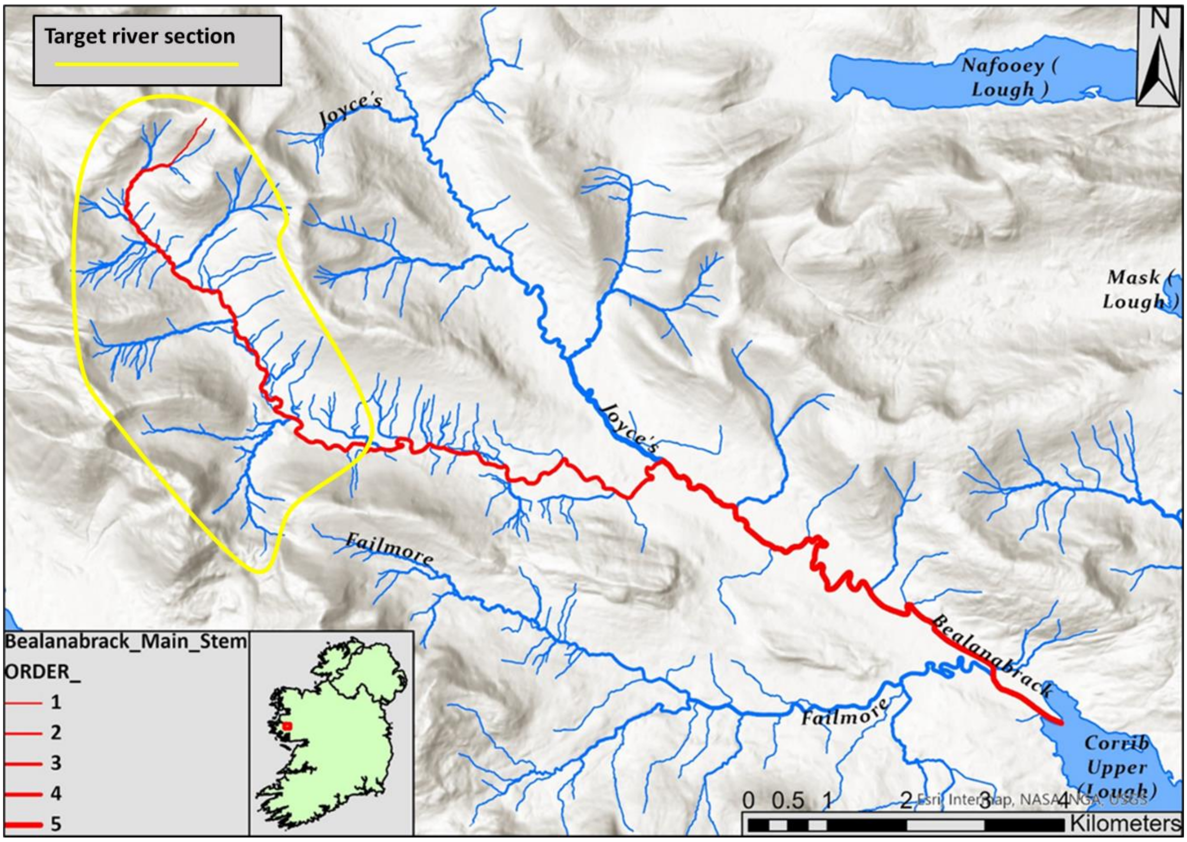
Section 7– Next steps

In summary, after a vison for the target river was developed after preliminary consultation with IFI WRBD and local landowners, a desk and field assessment was undertaken help establish and understand the current condition of the upper Bealnabrack River and to identify key constraints on natural processes. The results were then assessed against potential restoration options to develop an outline plan. This is intended to inform the subsequent detailed design in consultation with key stakeholders.

2 Catchment Overview

The Bealnabrack River (Map 1) is part of the Corrib catchment (WFD Hydrometric area 30) on the west coast of Ireland and falls within. It has a catchment area of approximately ? km^2 and flows in a predominantly eastern direction for approximately ? km from its headwaters in the Maamturks Mountain range to the northwest corner of Lough Corrib. The two main tributaries are the Joyce River that joints with the Bealnabrack in its middle reaches and the Failmore that joins just upstream of Lough Corrib. The Bealnabrack River is typical of rivers on the west side of Lough Corrib and known to be an important Atlantic salmon (*Salmo salar)* feeder river. Land cover in the catchment is dominated by peatlands, with rough pasture and forestry constituting the other major catchment land cover types.

This current IFI habitat restoration project will focus on target river section within the Bealnabrack_SubCatchment_010 (Map 1). This includes approximately 7km of main channel.



Map 1. the Bealnabrack catchment and target river section.

3 Methods

A function-based framework for developing and accessing river restoration projects was applied to this project. The framework breaks down river function into a hierarchy of five categories (Figure 1). High-level functions are supported by lower-level functions. Level 1 (hydrology) underpins all other functions, whereas level 5 (biology) depends on all other functions (Figure x). A primary goal of the framework is to help those undertaking restoration activities to understand that stream functions are interrelated and generally build on each other in a specific order. Functions should be addressed in the order shown. For example, reintroducing a species of fish (level 5), is unlikely to be successful if limitations related to supporting functions such as hydrology (e.g. sufficient flows), geomorphology (e.g. physical habitat),and physico-chemical (e.g. water quality) have not first been addressed. The combined desktop and field assessment sought to evaluate elements within each of levels as they related to Bealnabrack river in the Glenosh valley. The baseline assessment was intended to provide an understanding of both the status of the river system, as well as how that system works.

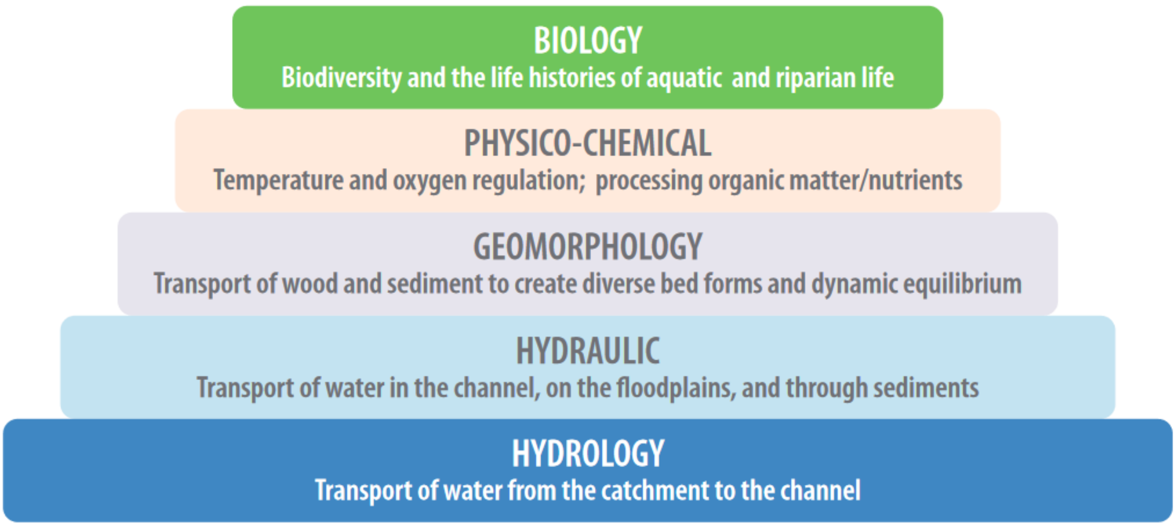


Figure 1. River functions pyramid framework (Adapted from Harman *et al.,* 2012)

3.1 Desk study

A desk study was conducted to collate relevant data for the Bealnabrack River catchment with the purpose of establishing current target section characteristics, including likely reference (unmodified) conditions and the nature and extent of anthropogenic pressures, so that appropriate restoration measures could be identified. The desk study involved liaison with IFI WRBD local staff and focused on review of information available from online sources, available GIS layers, technical reports and literature available from IFI or elsewhere.

The desk study comprised review of the following catchment characteristics:

- Water Framework Directive (WFD) status

- The presence of designated sites and protected species (based on data from National Parks and Wildlife Services (NPWS))
- Hydro(geo)morphological form and function (based on review of maps of catchment topography, geology, hydrogeology and quaternary geomorphology features available from Ordnance Survey Ireland (OSi) and Geological Survey Ireland (GSI), and satellite imagery.
- Catchment land cover, with a focus on peat and forestry (based on review of land cover maps and satellite imagery, Teagasc soil maps).

3.2 Field study

Field surveys were conducted in the target river section in July-August 2022 by the IFI R&D hydromorphology/ecology team and WRBD operations staff to:

- Generate baseline data and characterise the fish community and associated fish ecological status together with previous IFI surveys. A single-pass, semi-quantitative, and timed method (10 minutes) was employed for electro fishing surveys at all sample sites. As part of WFD assessment, fish ecological status was assigned to each of the 13 fish survey sites. The status was calculated utilizing the Fish Classification Scheme 2 for Ireland (FCS2-Ireland). This is a statistical model developed to assign an ecological status to fish in Irish rivers (Kelly and Harrison, 2016). The model compares the observed fish community of a site with the expected community under favourable conditions. An Ecological Quality Rating (EQR) from zero (Bad) to one (High) is produced, which relates to one of the following five WFD status categories: Bad, Poor, Moderate, Good and High
- Undertake hydromorphological assessments to ground truth the desk top study and further characterise physical habitat condition and pressures. The River Hydromorphology Assessment Technique (RHAT) (Murphy and Toland, 2012) metric was used to assesses hydromorphological condition and any associated pressures. The RHAT metric provides a visual assessment of departure from hydromorphological "naturalness" and allows for the assignment of a morphological classification directly related to the EU Water Framework Directive (WFD) status that is, from "bad" (heavily modified) to "high" (natural). To derive the RHAT score, data were gathered along extended reaches (up to 400m) that were representative of the main channel and overlapped with electrofishing sample sites. As part of the scoring process, the field data was then combined with a desktop study assessing river typology (e.g., underlying bedrock, valley form and channel planform) and historical management (e.g., channelization, impoundment or land use change) to evaluate the extent of river modification present at the study sites and calculate the overall RHAT score. Explanatory criteria used for RHAT scoring were based on eight attributes (Channel Form & Flow Type, Channel vegetation, Substrate Condition, Artificial Barriers to Continuity, Bank Structure and Stability, Bank vegetation, Riparian Land Use, Flood Plain Connectivity) and alterations to these attributes. Components scored in units of 1 on a scale from 0 to 4 included; channel form and flow type, channel vegetation, substrate condition, and barriers to continuity. Components scored in units of 0.5 on a scale from 0 to 4 included bank structure and stability, bank vegetation, riparian land use and flood plain connectivity. Overall RHAT score is the ratio of the sum of the 8 individual components to potential maximum score (max = 32) and assigns WFD classes as listed in Table 1.

Table 1: RHAT WFD classes by total attribute score

WFD Class	∑ Attribute scores	Description
High	≥26	Near Natural
Good	≥19.5 to <26	Slightly Modified
Moderate	≥13 to <19.5	Moderately Modified
Poor	≥6.5 to <13	Extensively Modified
Bad	< 6.5	Severely Modified

- Characterise the summer thermal and flow(depth) regime: Depth/Temperature data loggers (Onset HOBO) were deployed in discrete sample sites including the upper and lower reaches of the main channel target river section and at a terrestrial location to record air temperature. Each logger was secured to the riverbed inside a PVC tubing ,shielding it from direct sunlight. Loggers recorded stream temperature every 30 min, to derive a measure of hourly water depth and temperature.
- Perform drone surveys to provide a visual record of the target river section and monitor changes to river morphology as a response to restoration measures

Outputs of the field assessments were used to develop an understanding of the target river fish community, habitat pressures and its landscape setting. This information was the used to identify appropriate restoration measures that will support a long-term approach to habitat and species management in the target section and elsewhere in similar rivers systems.

4 Desk study assessments

4.1 Water Framework Directive

The environmental legislation underpinning management of Irelands water bodies is the European Union (EU) Water Framework Directive (WFD; Directive 2000/60/EC). The EU WFD establishes a framework for the protection of inland surface waters, transitional waters, coastal waters, and groundwater. It aims to prevent and reduce pollution, promote sustainable water use, protect and improve the aquatic environment and mitigate the effects of floods and droughts. This is achieved through the development and implementation of strategic long-term River Basin Management Plans (RBMPs), which includes a Programme of Measures (PoMs) outlining the on-going monitoring and management actions required for water bodies to achieve future objectives.

Under the WFD, surface water body status is classified based on ecological and chemical status or, in the case of Heavily Modified Water Bodies (HMWBs), Potential, and the overall objective is to achieve Good Status or Potential for all waters by 2027.

As well as setting an objective to achieve Good Status for all water bodies, the WFD further stipulates that there should be no deterioration in water body status between RBMP cycles, thereby constraining impacts of development even when these may operate within currently enforceable positions as set by environmental constraints. Deterioration constitutes a reduction in class of any element at the water body scale, or a worsening within the lowest class.

Bealnabrack_SC_10 WFD status was rated as High by the EPA. The main tributaries, the Joyce (Joyce's_SC_010) and Failmore (Failmore _010) wererated as Good and High, respectively. None of the sub catchments, including the target river section were regarded as 'At risk' of not achieving their WFD environmental objective of Good or High Ecological Status in the latest EPA assessment, 2016-2021.

The EPA monitor the water quality status of the Bealnabrack catchment through macroinvertebrate surveys, including three stations on the Bealnabrack main channel (Hydometric area code 30B01) upstream of its confluence with the Joyce's river. The EPA's annual macroinvertebrate community rating are presented in Table 2 to show the annual status from 1982 to 2021 for the Bealnabrack main channel. The biotic indices (Q-Value) used to assess macroinvertebrates primarily reflect the impact of nutrient enrichment through the presence and/or absence or pollution sensitive taxa. The Bealnabrack River met its environmental objective of ≥Good with an improvement to High (4-5) condition at the downstream boundary (station 0050) of the target river section.

Table 2. Biological Quality Rating (Q-Values) for the Bealnabrack main channel, 1982-2021 (EPA. 2022)

Station Code	1982	1985	1989	1994	1996	2000	2003	2006	2009	2012	2015	2018	2021
RS30B010050							Good	Good	Good	Good	Good	Good	High
RS30B010100	High	High	High	High	High	High	Mod	Good					
RS30B010200	High		High	Good	High	High	Good	Good	Good	Good	Good	Good	Good

4.2 Designated sites and protected species

The Bealnabrack catchment is located within the Maumturk Mountains SAC (site code: IE0002008) and borders the Lough Corrib SAC (site code IE0000297). As part of the Natura 2000 network, the river's maintenance and restoration to favourable conservation status is mandated by the European Union's Habitats Directive. A qualifying interest for the Maumturk Mountains SAC is Atlantic salmon. One target related to the species, listed in the SAC's conservation objectives, is the maintenance or exceedance of current salmon fry abundance (NPWS, 2017). Other migratory species, brown/sea trout (*Salmo trutta*), and European eel (*Anguilla anguilla*) were also previously recorded in the Bealnabrack catchment (Gordon et al, 2021).

Atlantic salmon and European eels are listed under the Convention for the Protection of the Marine Environment of the North-East Atlantic (the OSPAR Convention) which specifies that necessary measures must be put in place to protect and preserve ecosystems and natural diversity in the north-east Atlantic. EU legislation (EC 1100/2007) also specifies major conservation actions for European eels which is overseen by the Irish Eel Management Plan.

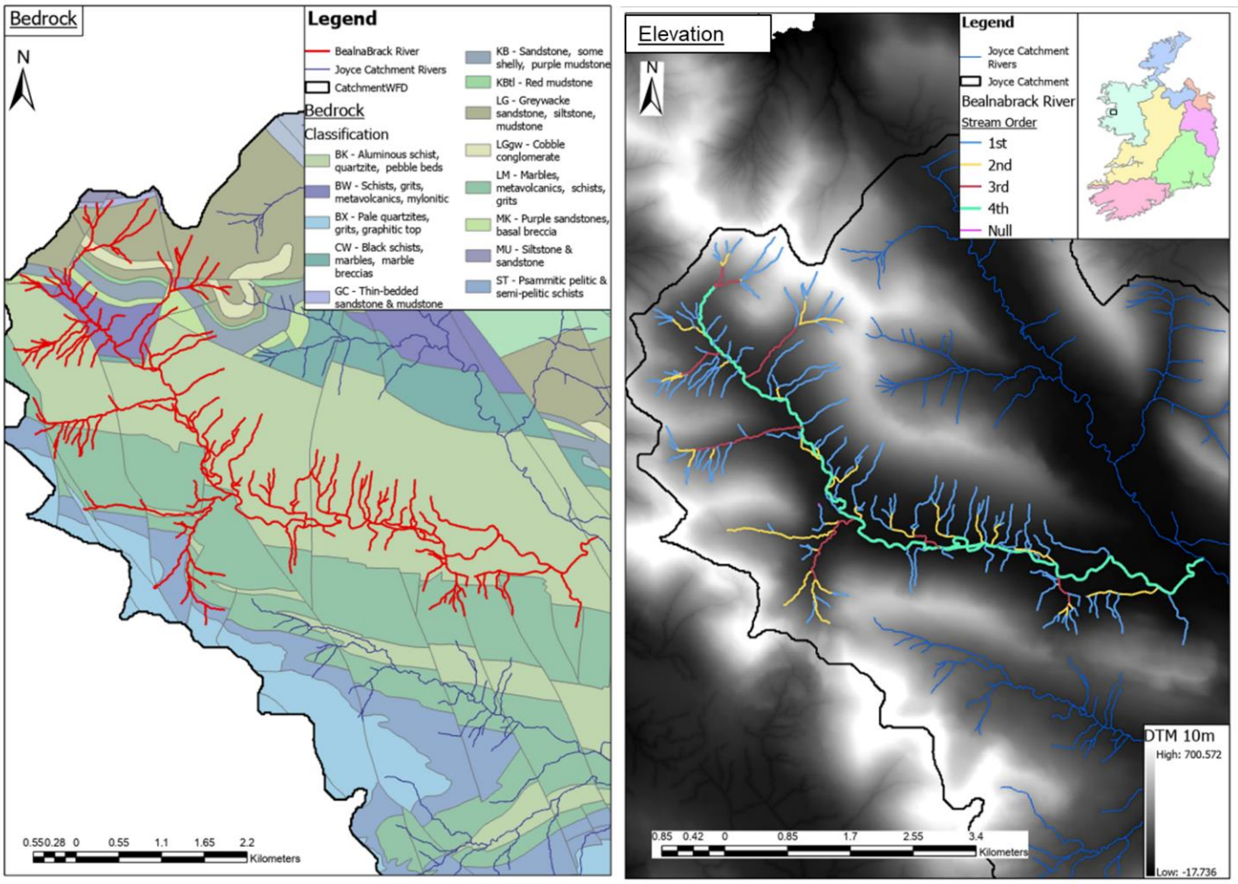
4.3 Hydro(Geom)orphology

4.3.1 Lithotopographic record and landscape context

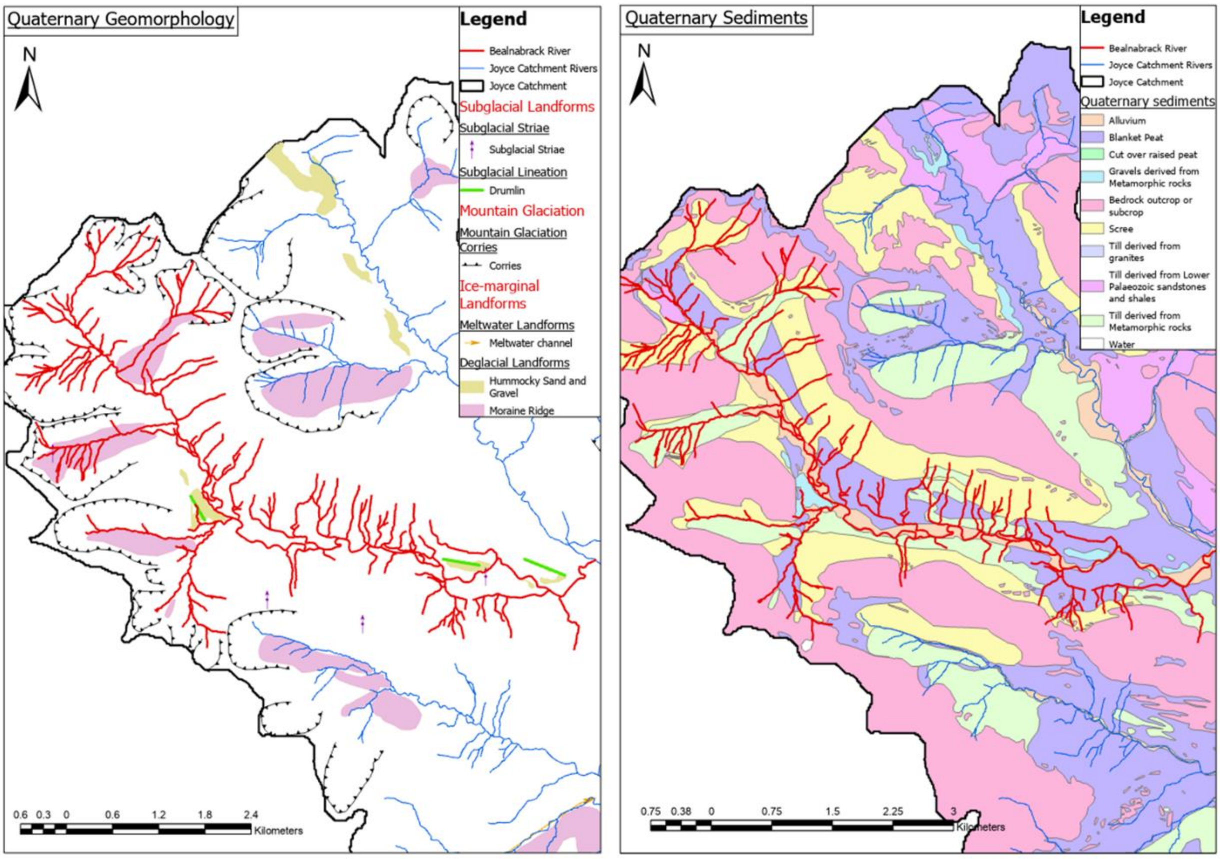
The Bealnabrack catchment is predominantly underlain by metamorphic rocks of the Connemara Metamorphic Complex (CMC), including quartzites, gneisses, schists and marbles (Map 2). The geological composition of the CMC, which is erosion resistant, provides a large-scale (regional) control on the topography of the Bealnabrack River catchment by maintaining high elevations and relief which is evident in the target river section with elevation ranges from 17m on the valley floor to 700m in the surrounding mountains (Map 2). Weathering and denudation of these hard rock types yields predominantly coarse sediment (gravel, cobble and boulder).

The valley-scale topography of the Bealnabrack River catchment has largely been shaped by glacial and post-glacial processes operating during the Quaternary period. Upland areas exhibit numerous corries, which would have formed at the heads of small valley glaciers, and moraine ridges (till composed of cobble, gravel and sand) on the valley sides (Map 3). Other fluvio-glacial deposits of sand and gravel, including drumlins, are present on the Glenosh valley floor and in lower areas of the catchment.

The very upper Glenosh valley includes a deposit of glacial till. Scree is frequent on steep valley slopes. Alluvium deposits consisting of cobble, gravel and sand is abundant along the valley floor Map (3). Much of this material has likely been recruited from the glacial till deposits in the very upper valley and moraine features located in the valley via flash floods and the via rivers natural migration along the valley floor to form the river bedload composition. For example, three tributary rivers in the upper Glenosh valley intersect moraine features (Map 3) are which likely to contribute significant sediment to the Bealnabrack main channel.



Map 2. Bedrock geology of the Bealnabrack catchment (left) and elevation/altitude map of the target river section (right) in the Glenosh valley



Map 3. Quaternary geomorphology and sediments in the Glenosh valley

4.3.2 Hydrology/Hydrogeology

The aquifer type underlying the Bealnabrack river was predetermined using the classification assigned by the Geological Survey of Ireland. Aquifer types in Ireland are sub-divided into three categories within the nine major aquifer classes and are intended to describe both resource potential (Regionally or Locally important, or Poor) and groundwater flow type (through fissures, karst conduits or inter-granular fractures). The aquifer type is uniform along the Glenosh valley and classed as a "Pl: Poor Bedrock Aquifer". This is a class of bedrock aquifer and is generally unproductive except for local zones where it may be moderately productive. Overall permeability, storage capacity, recharge acceptance, length of flow path and baseflow are likely to be low-intermediate, with groundwater discharge to river channels potentially decreasing significantly in the drier summer months leading to low base flows during periods of low rainfall.

The bedrock geology in the Glenosh valley consists of largely impermeable rock except where fractures, fissures and joints may exist in the surface bedrock. Together with the poor bedrock aquifer, surface flows in the Bealnabrack are heavily influenced by run off from the surrounding land. Surrounding mountains, steep valley sides and high annual precipitation found on the Atlantic west coast mean the Bealnabrack can be classed as spate river. Spate river is a term used to describe a river where the flow is very quickly affected by rainfall (i.e. flashy regime that rises and falls quickly) and these rivers are typically found in wet, mountainous regions with impermeable bedrock. In this environment, falling precipitation is collected in streams along the valley sides and flows quickly down into the main channel along the valley floor.

The temperature of spate rivers fluctuates greatly in comparison to rivers with a significant groundwater component e.g. spring-fed rivers, that can buffer against high levels of solar radiation and air temperature to stabilise water temperature. The Bealnabrack was expected to be very responsive to solar radiation and air temperature, particularly during warm dry summer periods, when high temperatures together with low flows could lead to high water temperatures.

4.3.3Near natural or Reference Hydromorphic Conditions

Based on the geomorphic context described above, the river section in the Glenosh valley were expected to exhibit characteristics typical of upland rivers under reference (unmodified) conditions. On steep slopes along the valley sides bedrock and cascade typologies are likely to be the reference type where they are not overlaid by glacial deposits. Where streams flow through moraines and glacial till deposits that yield unconsolidated sediment, channel typologies (ranging from step-pool channels on steeper slopes to braiding/ wandering and actively meandering and channels as gradient decreases downstream along the valley floor) are be expected under reference conditions.

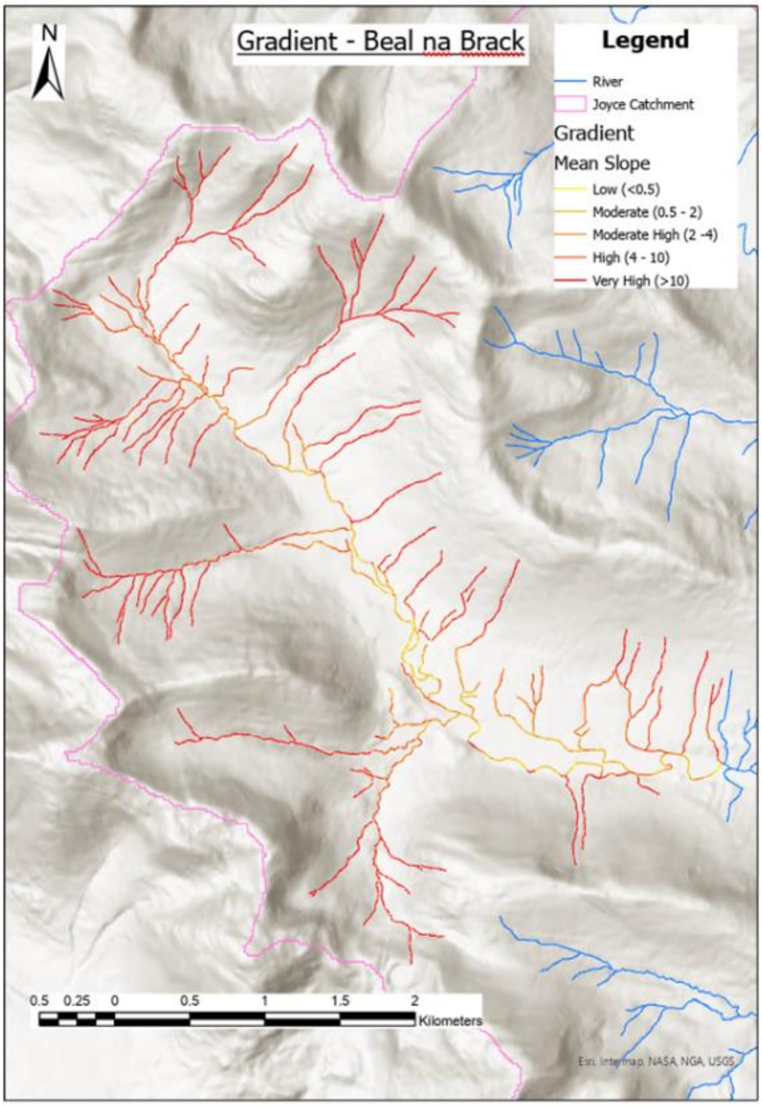
Having set the landscape-scale context of the Bealanabrack River, above, review of aerial imagery largely aligned with expected river form. The target river section has been delineated by slope and classed into river typologies/forms typically associated with that gradient (Table 2). Most of the channel length in the tributaries in the target river section are high gradient, first order streams flowing off the steep valley sides. Consequently, they tend to have low sinuosity and most likely exhibit bedrock, cascade or step-pool morphologies (Map 4). These streams are likely to be efficient at transporting coarse sediment derived from, firstly, processes of weathering and bedrock erosion, and, secondly through recruitment/entrainment of coarse unconsolidated material by those streams that intersect glacial deposits e.g. moraines, and deliver them downstream.

Table 2. Classification of river typology as it relates to the predominant slope/gradient

Slope %	Features
Very high (>10)	Upland. Very steep, deeply entrenched, torrent streams. High shear stress. Cascades with waterfalls and associated deep scour pools
High (4-10)	Upland. Steep entrenched, bedrock or cascading. Frequently spaced deep pools with associated step/pool morphology and boulder-cobble substrate are typical of cascade forms
Mod-High (2-4)	Middle-Upper. Moderate entrenchment. Narrow, gently sloping valleys with occasional rapids and infrequently spaced pools that grades into pool-riffle-glide morphology as slope decreases. Gravel is the dominant bed type. Braided river morphology may also occur in rivers where there is a spat/flashy flow regime and high, mobile sediment load. Typically suited for salmon spawning and as nursery habitat.
Mod (0.5-2)	Middle-lower. Meandering form, point bars on depositing bends, lateral pools on eroding bends, may have pool-riffle-glide at gradient breaks. Broad floodplain with alluvium. Mixed bed load, but gravel still dominant. Instream vegetation may include streamlined macrophytes such as aquatic buttercup (*Ranunculus* species). Typically suitable for trout spawning and as salmonid nursery habitat.

Low (<0.5)	Lowland. Flat, low gradient valleys with fine alluvium. Very sinuous with stable, well vegetated banks and bars that include stands of tall reed species. Mixed bed load, but fine material dominates. Often associated with adjacent wetlands. Typically suited for adult salmonids and other lowland fish species.

In the upper Glenosh valley, the main channel of the Bealnabrack river has moderate to high gradient and largely exhibits a form that transitions between braiding and wandering. In the lower valley, the river changes to a more regular meandering planform as gradient moderates, evidenced by sediment storage, typically in the form of point bars, throughout (Plate 1).



Map 4. Classification the target river section in the Glenosh valley according to gradient.

Plate 1: example of active meander form and sediment storage through regular point bar formation on depositing bends on the Bealnabrack river, Glenosh valley

There is evidence of channel migration along the valley floor driven by sediment deposition and bank erosion (Plate 2). This is a natural process that is responsible for creating and maintaining habitat diversity, but the rate may be accelerated by altered land use such as riparian vegetation loss and heavy grazing that accelerate erosion rates.

Plate 2. example of channel migration where the channel has moved circa 25m (yellow arrow) between 2017 (top) and 2020 (bottom) on the Bealnabrack river, Glenosh valley

4.3.4 Hydromorphological pressures

Morphological pressures are alterations made to river channels by anthropogenic activity that impact on geomorphological processes and river form. In broad terms, they include channel realignment and deepening/widening, sediment removal, impoundments, embankments, bed and bank protection, and crossings and culverts.

GIS layers including those for historic channel drainage, current OPW arterial drained rivers and IFIs National Barriers Programme indicated no evidence of substantial modifications to the Bealnabrack river and its tributaries stream in the Glenosh valley. River planform appears largely unaltered, there are no significant impounding structures or flood embankments. There are a small number of road crossings that intersect some the tributaries on the road into the Glenosh valley, but these are assumed to have a negligible impact on geomorphological processes. Bed and bank protection is typically not visible in aerial imagery and is assessed through site visits.

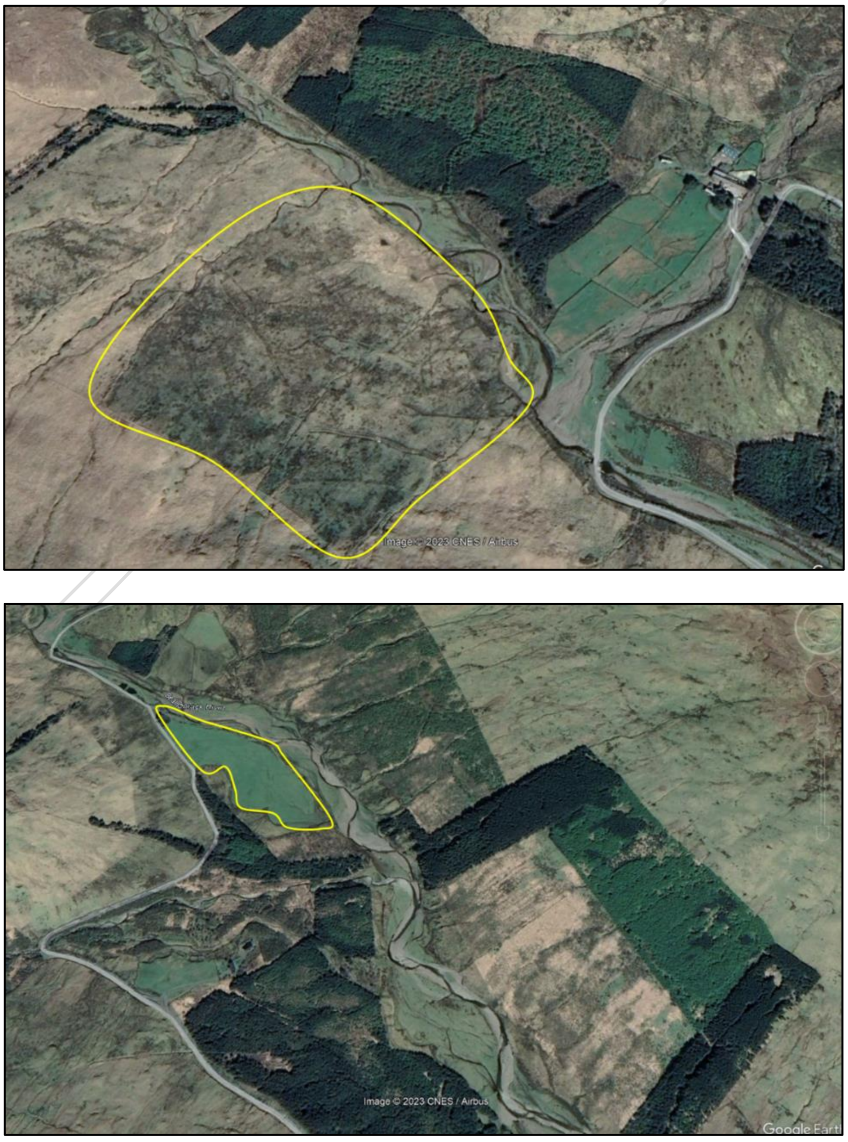


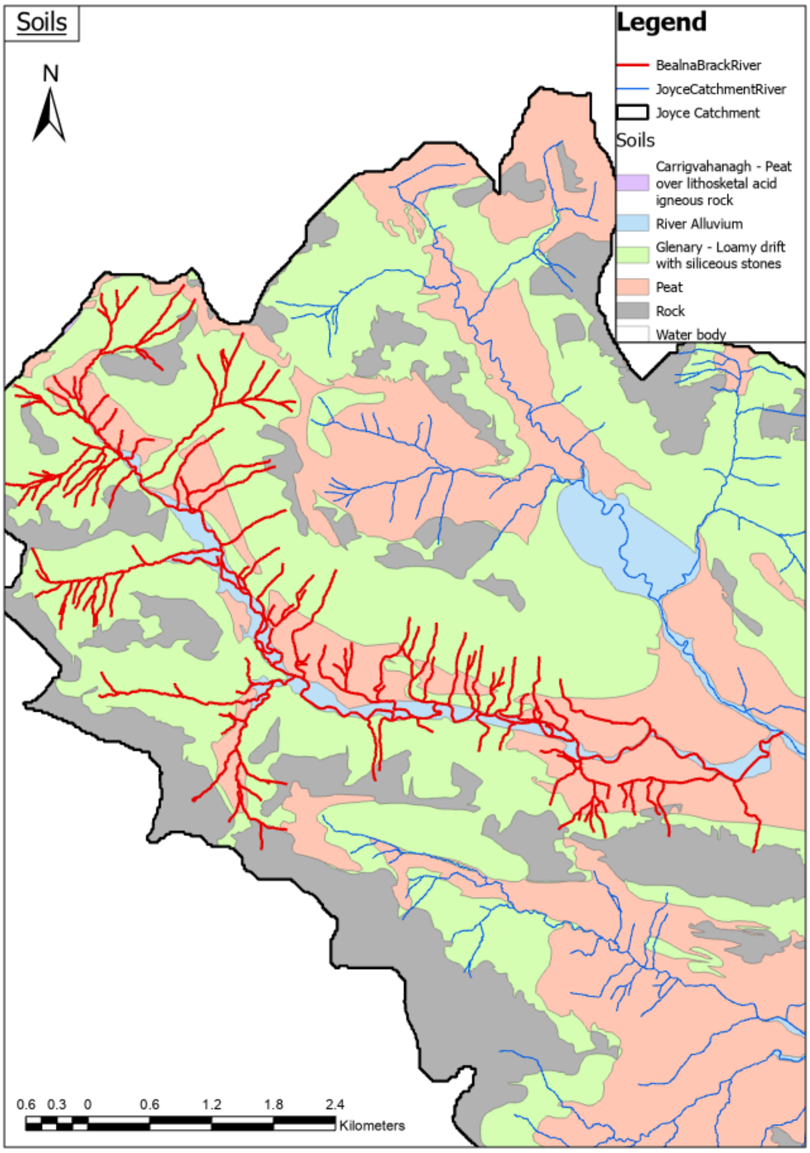
Plate 3 : example of previously clear-felled forestry (yellow line) and related field drains (top) and reclaimed land (yellow line) (bottom) in the Glenosh valley.

Aerial imagery suggests the most significant anthropogenic pressure in the Glenosh valley is likely to be land use related, specifically loss of native vegetation and land drainage to facilitate agricultural activities (predominantly sheep grazing), and planting of coniferous forestry (Plate 3). Land drainage and native vegetation loss is likely to alter the hydrological regime of the Bealnabrack River and its tributaries by increasing runoff rates. Aerial imagery also revealed the absence of a functioning riparian zone. Loss of riparian vegetation also makes channel banks more susceptible to erosion and reduces the supply of organic allochthonous material such as leaves and insects to the channel. Forestry activities such as those already present in the valley may also contribute to increased rates of runoff through drainage and the simplification of ground-level vegetation, while fine sediment generation may increase substantially during felling, preparation, planting and in the early stages of growth when soils are loose and exposed. However, these phases are relatively short compared with the growth phase during which very little forestry activity occurs and sediment inputs may be minimal.

4.4 Land cover

4.4.1 Peatlands

An analysis of Teagasc soil maps indicates that the Glenosh valley side are largely composed of blanket peat and podzols; interspersed with stagno-podzols and surface-water gleys, on loamy drift with siliceous stones. Stagno-podzols and surface-water gleys promote waterlogging due to presence impermeable horizons that impede the downward movement of water. The lower southern slopes are dominated by blanket peat, also a waterlogged soil, which becomes more abundant in the lower catchment. As previously revealed in in the quaternary sediments (Map 5), alluvial soils are prevalent at low elevations along the valley floor.



Map 5. Soil map of the Bealnabrack (Glenosh valley) and Joyce river valley.

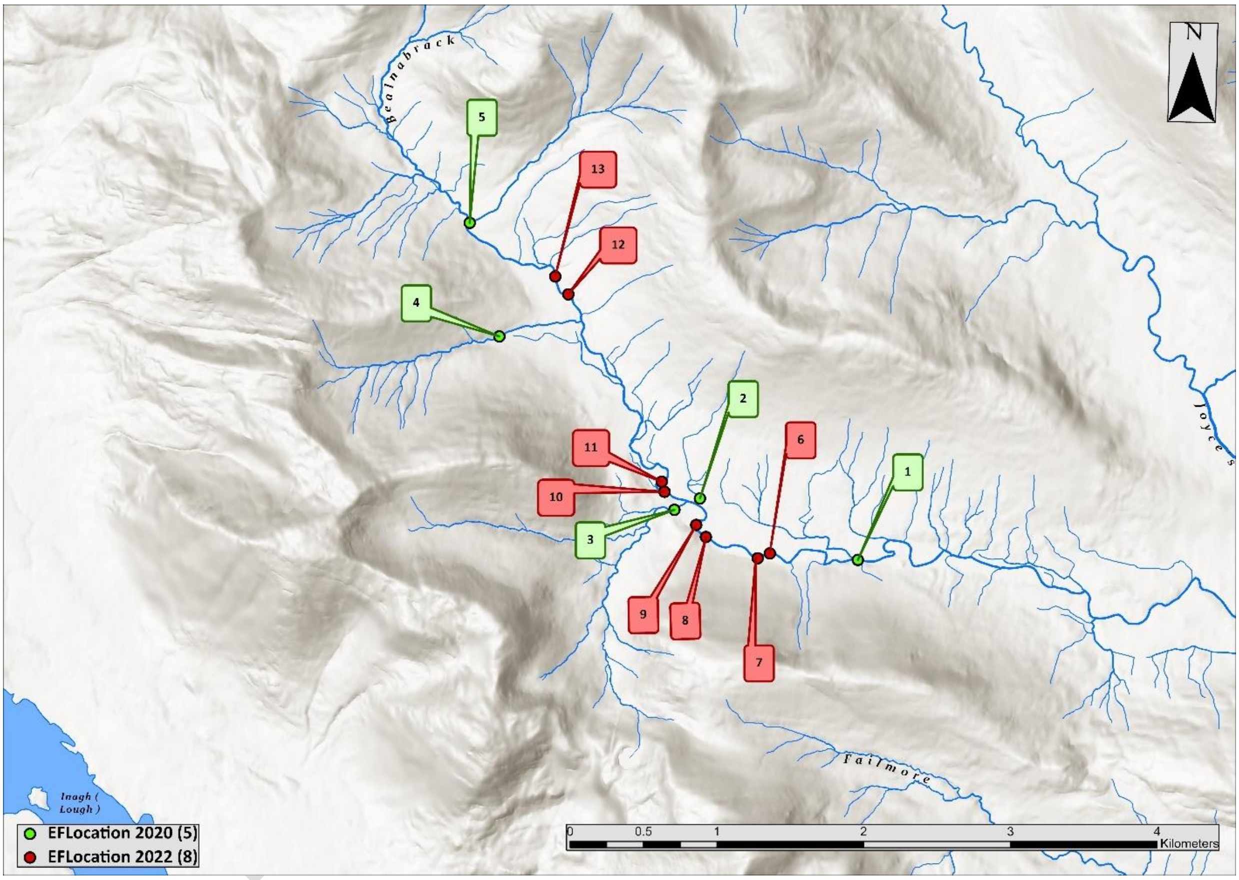
4.4.2 Forestry

In the Glenosh valley, there is significant forestry cover. The forestry is largely coniferous but also interspersed with some areas of deciduous broadleaf forest. Most forestry is within 200 m of the watercourse. Conifer forests can contribute to fine sediment delivery and acidification of surface waters and must be considered a potential pressure on the Bealnabrack river in the Glenosh valley.

5 Field assessment and ground truthing results

5.1 Fish community assessment

A series of fish surveys and habitat assessments were conducted on the upper reaches of the Bealnabrack River to generate baseline data set. Electro-fishing surveys were conducted on 13 sites in the upper Bealnabrack River (Map 6). Five sites were surveyed in August 2020 by IFIs National Research Survey Programme (NRSP) Rivers team (Gordon *et al.*, 2021). The remaining eight sites were surveyed in July 2022 by the IFI Hydromorphology/Ecology Team.



Map 6. The 13 electric-fishing survey sites on the upper reaches of the Bealnabrack River. The green surveys (1 to 5) were conducted in August 2020 and the red surveys (6 to 13) in July 2022.

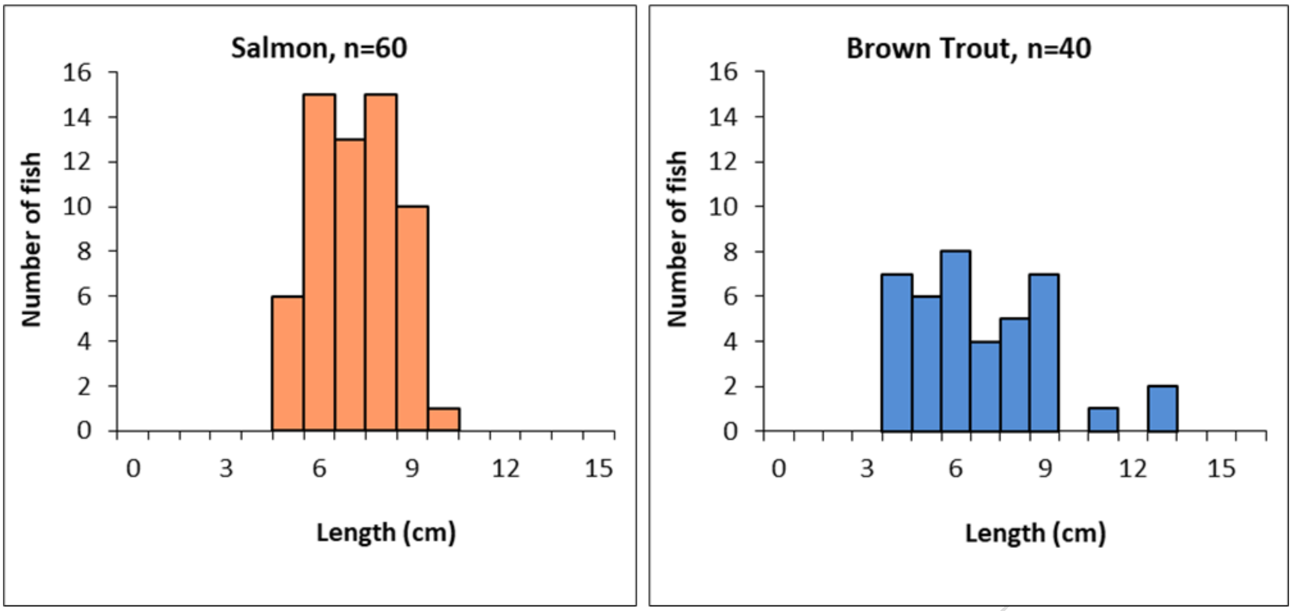


Figure 2. Length frequency graphs for fish recorded in the 2020 survey (sites 1 to 5).

Two species, brown trout and salmon were recorded in 2020, with the latter being most abundant (Figure 2). Similarly, salmon were the most abundant species in 2022, followed by trout (Figure 3). A single Minnow (*Phoxinus phoxinus*) and single stoneloach (*Barbatula barbatula*) were also recorded in 2022 (Figure 4). Juvenile salmonids were the dominant cohort with moderate numbers of parr (≥9).

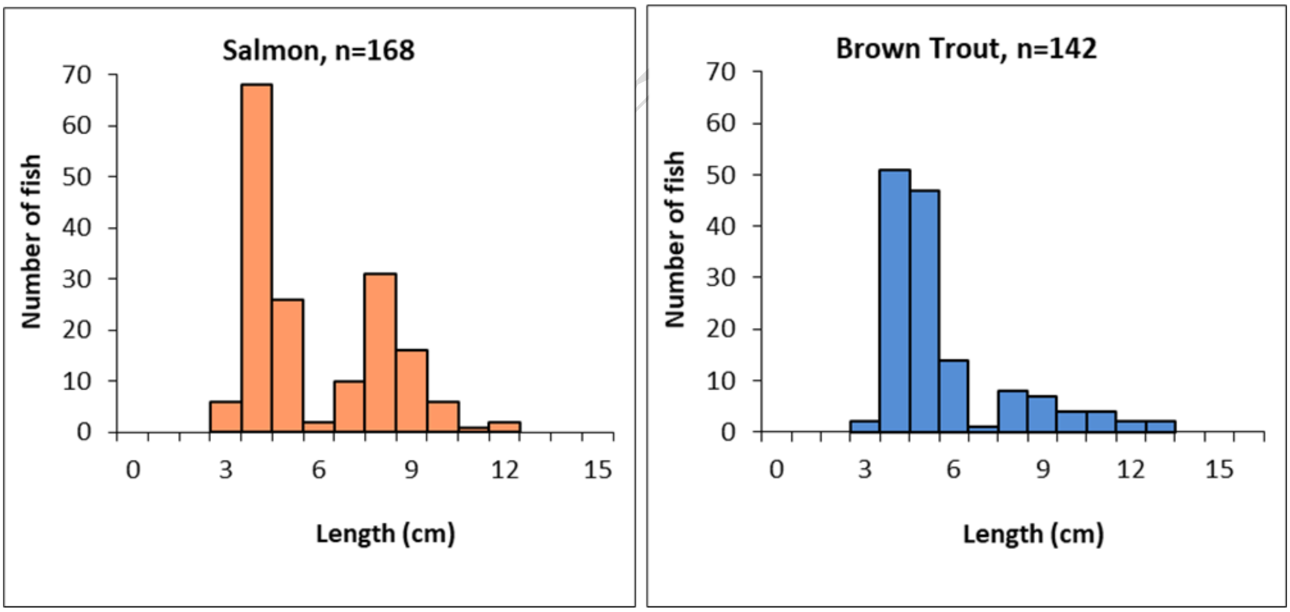
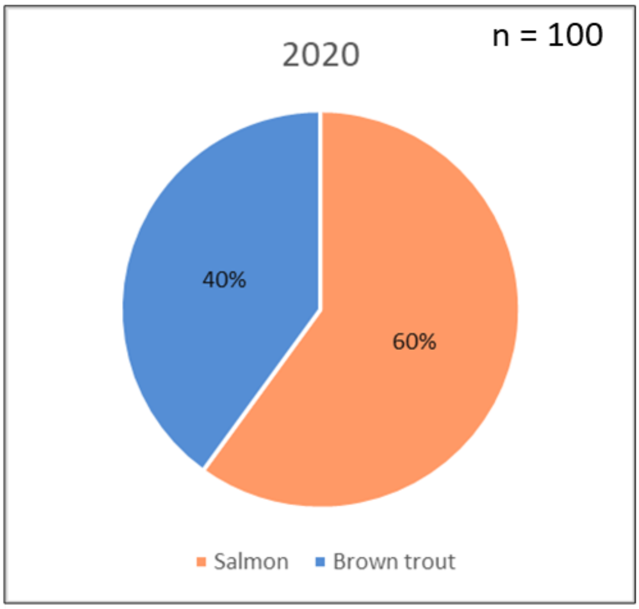


Figure 3. Length frequency graphs for fish recorded in the 2022 survey (sites 6-13).



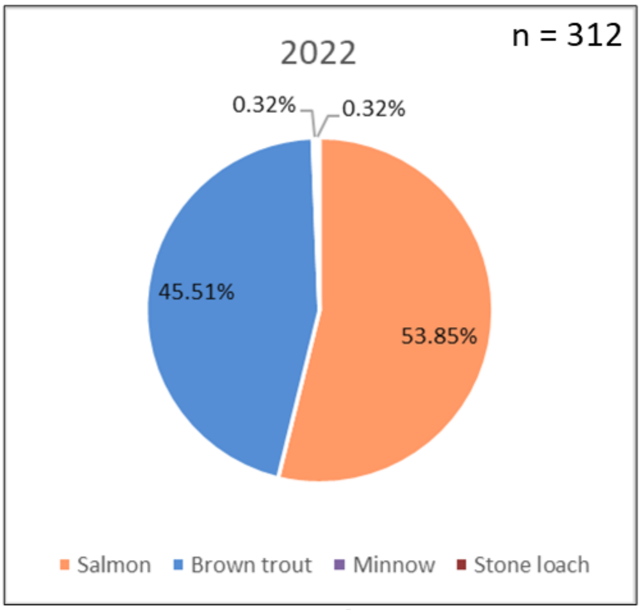


Figure 4. Fish Species Composition (%) for the 2020 survey (sites 1 to 5) and the 2022 (sites 6 to 13).

5.1.1 Fish Ecological Quality Rating (EQR)

Only sites 2 and 4 met their environmental objective of Good fish status, with six sites classed as moderate and five sites as poor (Table 3). Failure to achieve Good status reflects absence of expected fish species or life stage cohorts.

Table 3. Fish ecological status for the electro-fished sites in the Bealnabrack River.

Site No.	Year	Status
1	2020	Poor
2		High
3		Moderate
4		Good
5		Moderate
6	2022	Moderate
7		Moderate
8		Poor
9		Poor
10		Poor
11		Poor
12		Moderate
13		Moderate

5.2 Hydro(geo)morphology

5.2.1 Channel Geomorphology

Field visits confirmed the findings of the desk study in that the river exhibits many characteristics typical of dynamic, montane river in the upper reaches before transitioning to a meandering form as it enters the lowlands. Specifically, stream son the upper valley sides have a bedrock typology with cascading/step-pool form becoming more prevalent on the lower slopes and with increased accumulation of boulders and cobbles. Along the valley floor, the channel form transitions between braiding and wandering in the upper reaches to a more regular meandering planform as gradient moderates, with regular meander bends that are actively eroding on the outside bend and have pronounced point bars that store sediment on the inside bend (Plate 4). Channel width and depth varied along the channel, but generally increases in a downstream direction as discharge increases. A variety of flow types were present and associated habitats including pools, riffles, and glides were also recorded.

Plate 4. examples of main channel typologies moving downstream from A-D: braiding (A), transition to wandering (B), active meandering (B) and a vegetated point bar at the bottom of the Glenosh valley

Exposed bank faces reveal that the channel is flowing through a mixture of alluvium (sand, gravel, cobble) and peat that ensures delivery of an abundant and mixed sediment load (Plate 5). Moreover site visits and conversations with local IFI staff confirm that streams on the valley sides passing through moraines and other glacial till deposits are a significant source of course substrate such as large gravels to the main channel. The channel bed is dominated by coarse gravel and cobbles (16 – 256 mm) and fine sediment (<2 mm) deposition such as sand is generally limited to exposed bars.

In general, these characteristics imply that there is both a relatively high sediment load delivered to the channel from both in-channel (bank erosion and longitudinal transport) and hillslope sediment production processes, and high sediment transporting competence (i.e., stream power, which is the product of slope and discharge), as is usual in montane settings such as this. This combination results in a highly dynamic river channel with frequent mobilisation of bed material.

Floodplain land use in the study reach is dominated by rough pasture and forestry on the periphery of the valley floor. Access to the channel for livestock (and deer) is not controlled by fencing and, consequently, riparian vegetation is dominated by short grasses and no/few trees are present in the riparian zone.

Plate 5: example of coarse alluvium recruited via bank erosion (left) and extensive alluvial deposits (right) that contribute to the mixed bedload observed in the river.

5.2.1 Hydromorphological Condition Assessment

In general, the channel is not significantly modified by anthropogenic pressures with survey sites 1 and 2 falling just below the WFD environmental objective of Good (score of ≥19.5) and the site 3 achieving good status in the RHAT assessments. The main modifications were to bank structure, bank vegetation, riparian land use and to a lesser extent, channel vegetation (Figure 5). Unobstructed access to the channel by livestock and deer and the absence of a functioning riparian zone represents the greatest modification to the river.

This pressure is likely responsible for increased rates of bank erosion, channel over widening and reduced habitat provision at some location. For example, the channel has 'unravelled' in the main channel upper reaches beyond what is expected and severe erosion associated with degraded bank vegetation has led to large turf sods being eroded and washed downstream (Plate 6). This process is also contributing to some local siltation. These conditions also lead to a highly mobile bed and overly active channel migration that impedes macrophyte establishment on the margins or instream through excessive scour. Presence of instream vegetation such as streamlined macrophytes like aquatic buttercup (*Ranunculu*s species) are expected in the middle and lower reaches of the Glenosh valley but are absent. Patches of plant species such as aquatic buttercup are important as salmonid nursery habitat and as foraging locations.

Riparian land use is another modification affecting hydromorphological condition. It consists of short cropped, rough pasture that is bordered by coniferous forestry and provides none of the habitat benefits associated with a functioning riparian zone. These include organic material delivery to channel which is important for aquatic food webs, shading to regulate water temperature and interception of fine sediment/nutrient run off before it enters the river.

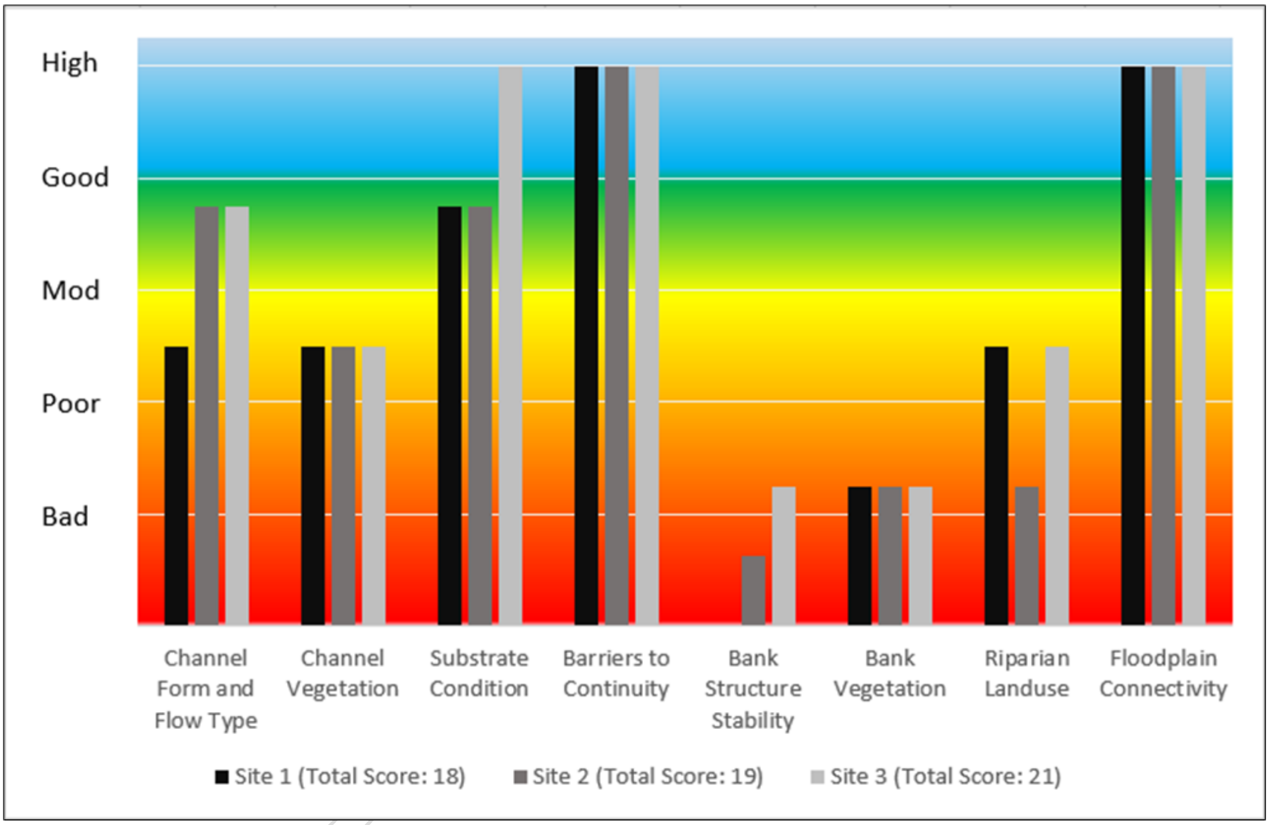


Figure 5: The results from three RHAT sureys at representative locations in the target river section. The bottom axis shows the attributes assessed and used to calculate the overall score. The vertical axis shows the WFD class and related scoring of the attributes.

Plate 6. Example of channel over widening (left) and eroded turf sods (right) that are associated with overgrazing of the riverbanks.

5.2.2 Flow and thermal and regime

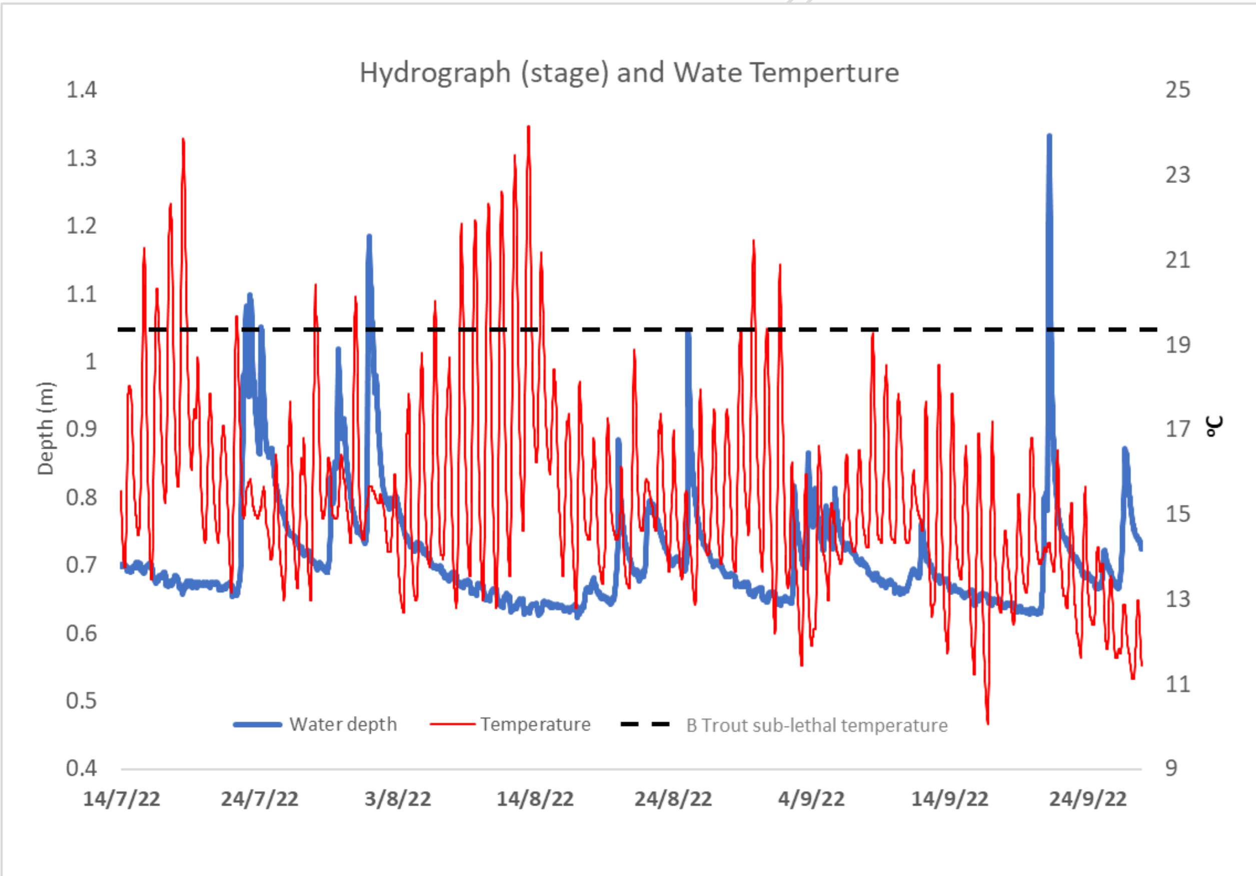


Figure 6. depth and water temperature recorded in a pool feature in the Bealnabrack main channel the Glenosh valley at one logger location.

As expected, results from the depth and water temperature monitoring confirm that Bealnabrack river has a flashy flow regime and is very responsive to weather conditions . This is evident from the rapid increase and decrease in water depth following rainfall in late July-August (July 24^{th}-August 3^{rd}, 2022), again in late August (24^{th}) and late September (24^{th}) and extended intervening periods of low flow during dry weather (Figure 6). Concomitantly, there is an inverse relationship between water flow (using the depth data as a proxy) and water temperature with low flows associated with high summer water temperatures and high flow events related to lower summer water temperatures.

5.3 Invasive non-native species (IAS)

Knotweed (Fallopia spp.) was identified in the Glenosh valley including locations along the road into the valley that are close to the target river section. The infestation appears to be limited to these areas as none was located beside the river or in its floodplain.

6 Restoration strategy and options

6.1 Legislative drivers

The Bealnabrack_subcatchment(SC)_10 waterbody, covering much of the Glenosh valley including the target river section was assigned High (overall) WFD status by the EPA in their 2016-2021 assessment. At the time, the Fish Ecological Quality Ratings (EQRs) were not available for the inclusion in the final assessment by the EPA. Fish surveys from 2020 and 2022 and subsequent EQR (section 5.1) calculation show that 11 of the 13 survey sites failed to meet the minimum requirement of Good fish status. The net effect of this result means the Bealnabrack_SC_10 fails to meet the minimum requirement of Good WFD status under the 'one out-all out' rule that is applied when calculating status (the three biological elements used in WFD assessment, plants, macroinvertebrates and fish must all have a minimum EQR of Good for the waterbody to be meet its environmental objective. Moreover, hydromorphology and thermal regime assessments (sub section 5.2.2 and 5.2.2) have identified pressures that may be impairing fish community success. Therefore, a Programme of Measures (PoMs) is required to address fish habitat deficits and improve overall habitat for biota in and around the Bealnabrack river.

6.2 Strategic considerations

The Bealnabrack river is a relatively unmodified system with no significant artificial barriers or arterial drainage and good-high water quality. It is an important salmonid river within the Lough Corrib catchment/lake complex but is underperforming in part due to impaired physical habitat and other stressors such as elevated water temperature that are related to land use pressures. This situation is likely to worsen without intervention to mitigate the documented pressures and buffer the river ecosystem against shocks associated with climate change. The river also presents a unique opportunity to undertake large scale landscape restoration on account of a single landowner in the upper catchment that is amenable to nature-based restoration approaches that will be sustainable into the future without continuous energy, time and labour inputs, often required in other restoration schemes.

There is a wide range of measures that can assist with improving river condition. Measures may focus directly on any one or more of the elements of the river ecosystem, while recognising that there will be implications for other parts of the system. While the ultimate goal of a river restoration project might be to improve instream habitat and restore riverine biodiversity, the restoration measures should target other aspects of the river system and surrounding landscape – such as the riparian zone, the flow regime, or the floodplain – with a view to achieving that goal.

Strategic river restoration planning requires consideration of how these measures are nested within the broader strategy, including the appropriate scale for addressing different issues, and the way that one measure may support or hinder other measures. Goals and objectives should be framed, as much as possible, in terms of measurable changes to hydromorphic and ecosystem function, the provision of ecosystem services, and desired socio-economic benefits. Developing a strategy for action requires an iterative process of considering potential goals together with options for action and agreement with stakeholders (Figure 7).

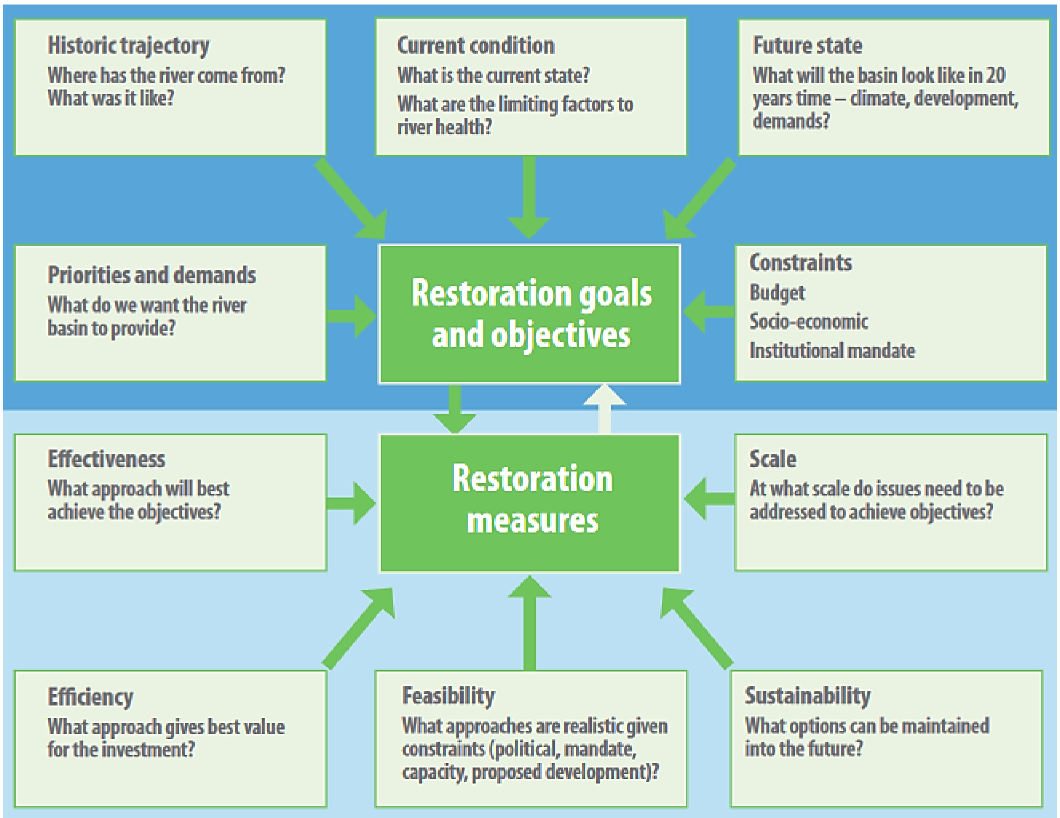


Figure 7. Considerations in selecting restoration goals, objectives and measures

This requires a consideration of:

- the current condition of the river system, its historical trajectory, and the likely future state of the system
- priorities for, and demands on, the catchment, including those related to socio-economic development and ecosystem conservation
- feasibility of different options and potential constraints, such as limitations related to budget or stakeholder conflict
- the appropriate scale at which to intervene
- the effectiveness of different measures
- the approaches that are more likely to be sustainable over the medium to long term

The guiding principle underpinning nature based or process base restoration is to identify, understand, and work with the catchment and riverine processes. Restoration projects that work with, rather than against, natural processes are more likely to be self-sustaining. Understanding the complex physical and ecological processes that affect river condition is critical to understanding the causes of declines in river condition, the loss or reduction in biodiversity, and for identifying the most effective and efficient restoration measures. Therefore, restoration planning needed to be informed by a robust assessment of the current status of the river ecosystem, existing issues and threats, and the future scenarios. For this reason, a comprehensive assessment of the Bealnabrack catchment with a focus on the Glenosh valley was undertaken to characterise the landscape context, hydromorphological condition, water quality condition and fish community status (sections 4 and 5). The evidence led approach has been applied to set clear and realistic goals for the restoration approach, that target the observed ecological deficits and are appropriate to the river setting. This understanding is vital to ensuring that the potential benefits of the restoration programme and associated habitat improvements are fully realised.

6.2 Proposed restoration measures for the Glenosh valley

The desk study and field study (Section 4 and 5) has established that the Bealnabrack river within the Glenosh valley supports a fish community dominated by salmonids, but is largely failing to meet its WFD environmental objective of Good fish status despite good water quality. It can therefore be assumed that physical habitat for salmonids is impaired, and this assertion is largely supported by pressures identified in the RHAT surveys and thermal regime assessment.

The overriding pressures are associated with simplification of riparian and bank vegetation, both of which are likely to increase erosion, leading to artificial channel widening and fine sediment generation and delivery via enhanced bank erosion and overland flow pathways. Furthermore, the absence of tree canopy cover and channel widening exacerbate water heating during warm/low flow summer condition. Elevated water temperature can have a range of negative impacts on resident cold-water salmonids including reduced feeding and growth, disease susceptibility, poor competitive ability, and potential replacement by more thermally tolerant species such as minnow and stone loach (O'Brian et al, 2019).

As such, the desk and field study indicates that options for salmonid habitat restoration within the Glenosh valley should focus on ensuring that rates of sediment production and delivery and thermal regime are within the naturally occurring range for catchments of this type. Planning and implementation needs to also consider likely changes in the landscape over time, including to the climate, land use and hydrology, the river corridor. Given the gross uncertainty over future conditions, river restoration should aim to provide resilience to a range of scenarios by adopting restoration strategies that are sustained over the long term.

A list of high-level restoration options is provided in Table 4. Based on the assessment (Section 4 and 5), the restoration measures highlighted in yellow in Table 4 are considered appropriate for mitigating documented pressures, addressing current habitat deficits and re-establishing processes that are sustainable as part of a long term restoration strategy.

Table 4. list of high-level river restoration options

River element	Restoration measure	River restoration objective
Catchment	Catchment management	Alter the water, sediment, and other matter that enters the river channel
Flow regime	Flow modification	Change the volume, timing, frequency, and duration of flows
	Stormwater management	Alter the flow pattern of water running off from urban areas, e.g. altering flood peak
	Dam removal/ retrofit	Improve flows and ecological outcomes, including improving the movement of sediment and fish
	Floodplain reconnection	Reduce flood risk by increasing the capacity of the river system to store and release floodwaters
		Allow for the movement of biota, sediment and other matter between the channel and floodplain

		Increase assimilation of pollutants and groundwater recharge
Habitat (riparian)	Riparian management	Alter the water, sediment and other matter that enters the river channel; provide habitat; regulate water temperature through shading; and support migration along the river corridor
	Land acquisition	Acquire riparian lands to control land use and/or allow for restoration works
Habitat (instream)	Instream habitat improvement	Promote or create habitat that supports aquatic biodiversity e.g. macrophyte establishment
	Bank normalisation/stabilisatio n	Reduce erosion/slumping of bank material into the river
	Channel reconfiguration	Altering the channel plan form or the longitudinal profile, increasing hydraulic diversity and habitat heterogeneity
Water quality	Water quality management	Protect or improve water quality, including chemical composition and particulate load
Biodiversity	Species management	Protect or improve number/diversity of important specie, eradicate or control inavaisve alien species
Socio-ecological	Aesthetics/recreation/ education	Increase community value, such as by improving appearance, access, or knowledge

Building on section above, Table 5 describes the proposed restoration measures as they may apply to the target river section and the pressure(s) addressed.

Table 5: proposed restoration measures for target river section in the Glenosh valley

Option	Restoration measure	Measure description	Pressure addressed
1	Creation of a riparian broadleaf buffer zone	Broadleaf woodland planting within a 20-50m buffer zone, whereby it would intercept overland flow, reduce sediment and nutrient inputs, stabilise soils and riverbanks, provide shading and add lead litter and insects to the channel. This measure can also be co-located with measure 2 to create wet woodland features	Excess bank erosion, high water temperatures, fine sediment delivery, water quality
2	Create online wetlands	Strategically placed large wood structures at natural channel pinch points effect upstream storage of water during high winter floods and create online wetland features	Provision of refuges for fish, reduced erosion and enhanced fine sediment storage. Reduced downstream flood risk. High value biodiversity feature.
3a	Large wood addition to create habitat	Adding large wood to create habitat features such as pool and riffles and provides cover from predators for fish.	Lack of cover, erosion control, provision of sufficient habitat for fish and deep/slow-water refuges

3b	Undertake erosion management using soft engineering techniques	Large wood structures are installed on identified bends to manage areas of significant erosion that are threatening infrastructure	Protect critical infrastructure such as roads and also provides instream habitat
4	Invasive alien species (IAS) removal/management	Removal and/or management of Knotweed spp. in the upper catchment	Invasive species competition with native vegetation, riverbank erosion
5	Landscape management	Adopting a landscape management approach to improve riverbank and peatland condition, including; stock exclusion on vulnerable banks and slopes, blocking drains, and restoration of wetlands at some locations in the floodplain	Fine sediment delivery, recharge of groundwater to contribute to baseflow during the summer, water quality
6	Forestry maintenance and management	Longer term plan to change the existing coniferous forestry to broadleaf, limiting clear-felling of the current forestry, and blocking of drainage channels.	Fine sediment delivery, water quality

6.2.1 Benefits of the proposed restoration measures

1. **Creation of a riparian broadleaf buffer zone**: Bankside and marginal vegetation provides cover/refuge for juvenile fish in the form of overhanging branches and tree roots, as well as moderations of high summer water temperature from canopy shading (Figure 8). An extensive buffer will help capture fine sediment and nutrients before they enter the river channel. Such landscape features intercept overland flow pathways disrupting fine sediment transport. Wooded buffer zones contribute energy to aquatic food webs directly via the introduction of organic matter such as leaf and woody material and also through falling insects that are an important food source for fish. Additionally, development of a wooded buffer zone and associated root network improve bank cohesiveness and help normalise erosion rates.

Desktop and site investigations show the flowing channel to be largely unmodified, meaning that natural processes such as sediment erosion, transport and deposition are largely unconstrained and shaping river form. The same investigations document the absence of a functioning riparian zone which is associated with excess bank erosion, over-widening of the channel, high water temperatures and lack of overhanging cover for the fish community and other stream biota. The condition of the riparian zone is also linked to option 2,3,4 (Table 5) and is therefore critical to the overall restoration strategy.

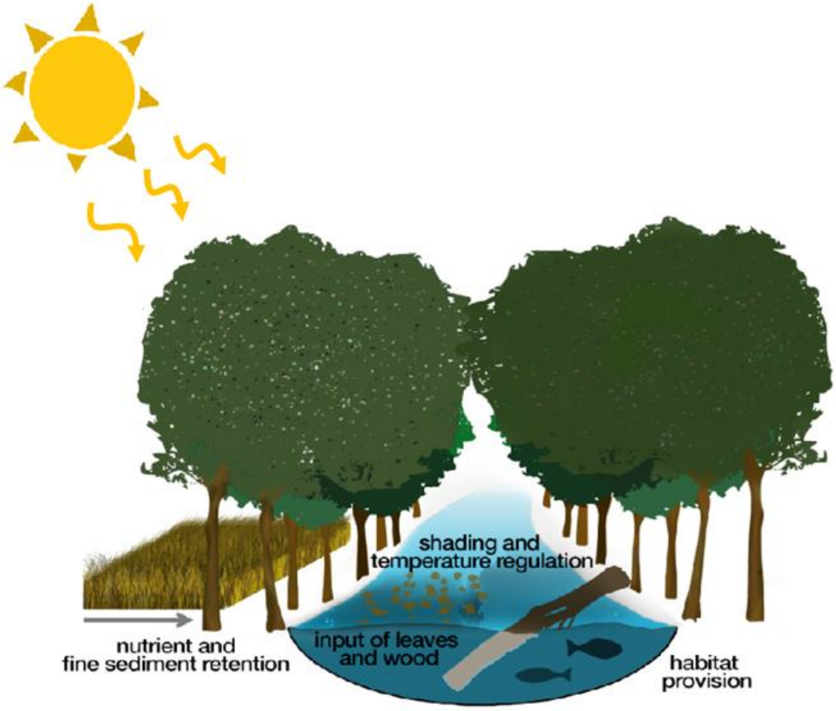


Figure 8. Functioning riparian zones intercept nutrients/fine sediment, regulate water temperature and improve instream physical habitat.

2. Wetland creation: Wetland features in the floodplains are important to consider in river restoration since they increase the structural diversity and provide habitats for a wide range of flora and fauna. Online wetlands are important for providing refugia for many fish species, feeding areas for other wildlife and replenishing local aquifers that can be important in moderating water temperatures through surface-sub surface flow exchange (Poole and Berman, 2001). They can also be used to manage erosion and flooding by slowing and storing water temporarily.

For example, as part of a restoration scheme on the River Nairn, Scotland, online wetland features were constructed to manage flooding and improve salmonid habitat (Plate 7). The project improved overall water quality by taking advantage of the reconnected wetlands' ability to regulate fine sediment transport. Together with reestablishment of native woodland and large wood addition, instream habitat improved and has resulted in significant improvements in salmonid recruitment.

Plate 7. Example of an engineered flood plain on the, as part of river restoration measures to enhance Atlantic salmon and trout populations on the Nairn River Scotland (Image: 2017, Scottish EPA).

3a. Large wood addition to create habitat: Large wood is a naturally occurring component of healthy river ecosystems and provides a range of ecological and geomorphic functions. Trees that grow along rivers and streams can often fall into a watercourse due to natural mortality, floods and high winds. These materials, often referred to as Large Woody Debris (LWD) or large woody habitat may include whole trees or broken limbs (Plate 8). Natural rivers have varying amounts of LWD, covering as much as 25% of the riverbed in undisturbed rivers in the North America. In Europe, the EU water framework directive suggests coverage of approximately 10% for lowland rivers with gravel or sand beds to reach a good - high hydromorphological status.

Plate 8: Example of a step jam in the Owengarrif River (Top), Kerry, and lateral jam in the River Dargle (bottom), Wicklow. These large wood features ‘force’ the creation of habitat feature such as pools and riffles and store sediment to promote bed stability.

However, most rivers have less than natural coverages or even lack LWD completely and this can negatively impact river habitat and their biological communities. Conversely, its re-introduction can significantly enhance river ecology and, in particular, Atlantic salmon populations with increased abundance reported to be ~200% in applied studies (Figure 9). LWD that falls completely across a channel causes water to impound resulting in the formation of upstream pool and a downstream plunge pool as water flows over, under or around the wood (Plate 8, top). These pools are deeper water habitats that provide critical hiding and resting areas for fish and are especially important fish habitats during periods of low flow or high flow. Habitats that provide refugia to fish are important for reducing energy expenditure and predator avoidance. Over time, LWD can trap and stabilise sediment upstream of where it falls and promote development of gravel bars that provide spawning locations for salmonids and lamprey species.

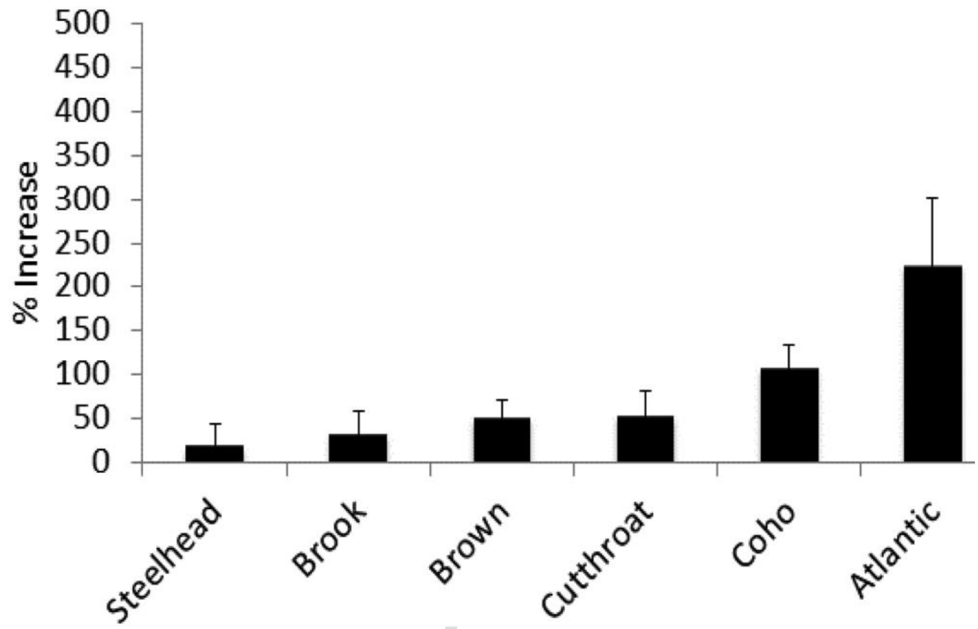


Figure 9. Response of various salmonid species to habitat improvement projects (n=211) that emphasised wood placement (Whiteway et al. 2010). Response is in percent increase, and error bars represent 95% confidence intervals

Both erosion and deposition caused by LWD is highly context dependent and thus may be viewed negatively or positively depending on the context of river restoration goals. LWD can contribute to local bed and bank scour. Bank erosion occurs where flows are deflected into banks and the flowing channel adjusts to pass the structure. Conversely, LWD that has deposited in rivers can often absorb or reduce shear stress by reducing flow velocities and where it has accumulated along riverbanks, it can protect banks from erosion during high flow events. Instream wood also traps sediment which helps armour the riverbed and can be very effective at breaking up high erosional flows. In many cases, where LWD was removed from river sections, this has caused major erosion of the channel, banks and ultimately degradation of instream habitats.

3b. Undertake erosion management using soft engineering techniques: Erosion is an important natural process in upland catchments and is responsible for generating sediments which support the immediate and downstream habitats. However, in Bealnbrack target section, the river meanders close to the (only) road into the valley. This has resulted in significant erosion, bank slumping and cliff collapse at some locations and will eventually result in loss of the road if not managed.

The most sustainable way to manage riverbank erosion is by using living wood (e.g. wiilow weaving) or LWD logs and/or rootwods to cushion the bank from the force of the river. This measure should be undertaken alongside fencing the riverbank to keep livestock away and encourage natural regeneration. One of the main benefits of using wood is that, unlike hard material such as rock, it does not increase the risk of erosion to banks downstream, as wood absorbs much of the stream energy rather than redirecting it. The 'rough' structure of interlaced wood also provides habitat by increasing physical diversity.

Plate 9. example of LWD use in erosion management.

4. Invasive species removal/management: Knotweed (*Fallopia* spp.) has been identified in the Glenosh valley including locations that are close to the target river section. Riparian zones and floodplains are dynamic and naturally disturbed habitat. Consequently, they are very susceptible to invasive species colonisation as they present establishment opportunities on bare soil or substrate. IAS will need to be controlled and managed to prevent it establishing in the proposed riparian buffer zone and floodplain and to prevent further spread downstream. This will require a dedicated IAS management plan that is an ongoing and iterative.

5. Landscape management: Potential fine sediment delivery from forestry clearance (Plate x), forestry and peatland drainage and cutting can impact habitat suitability for salmonids by increasing fine sediment delivery. Management and restoration of surrounding peatlands, including blocking of drainage channels, can reduce instances of fine sediment delivery.

Agricultural land use in the target river section is largely limited to rough grazing, but also include some areas where land the valley floor has been improved (Plate X). Grazing by sheep (and deer) has been identified as a pressure impacting riparian and instream habitat by exacerbating bank erosion. In addition to development of a riparian woodland (Option 1), constructing barriers to livestock and deer at suitable locations between the land and watercourses can befit river habitat by improving riverbank and bed condition.

6. Forestry harvesting and management: High levels of coniferous forestry land cover is associated with acidification of aquatic environments and can be detrimental to biological communities. Fine sediment delivery from forestry can smother of spawning habitat and reduce quality of foraging habitat for salmonids. Should the existing forestry be clear felled, the consequent increase in fine sediment delivery could exacerbate the impact. Selective felling of the existing forestry rather than clear felling would lessen the impact of fine sediment delivery on substrate. Shifting to broadleaf forestry as part of an incremental strategy would reduce the risk of acidification and provide better quality habit for terrestrial species.

7 Outline Plan Proposal

7.1 Goals and objectives

The restoration strategy outlined below offers a long-term vision for Glenosh valley and the Bealnabrack catchment in general, if implemented elsewhere. The strategy adopt elements of approaches that have proven successful elsewhere (e.g. Plate 10). Importantly, this is a provisional plan and is naturally subject to the usual stakeholder agreement and collaboration before it or any of its elements can be implemented on the ground.

Plate 10. Glenosh valley (left) and in a similar landscape setting, the Alledale river valley, Scotland. The Alledale river valley has been subject to extensive landscape restoration including native woodland establishment, wetland creation and peatland rehabilitation.

The high-level goals are to:

- ***Improve habitat quality for salmonids and other stream biota in the short-medium term (5-10 years) by implementing a nature based approach***
- ***Meet the WFD environmental objective of Good Ecological status***
- ***Create a self-sustaining river ecosystem in the longer term (+10 years) by re-establishing the ecological and hydromorphological processes that underpin healthy rivers***

The primary objectives are:

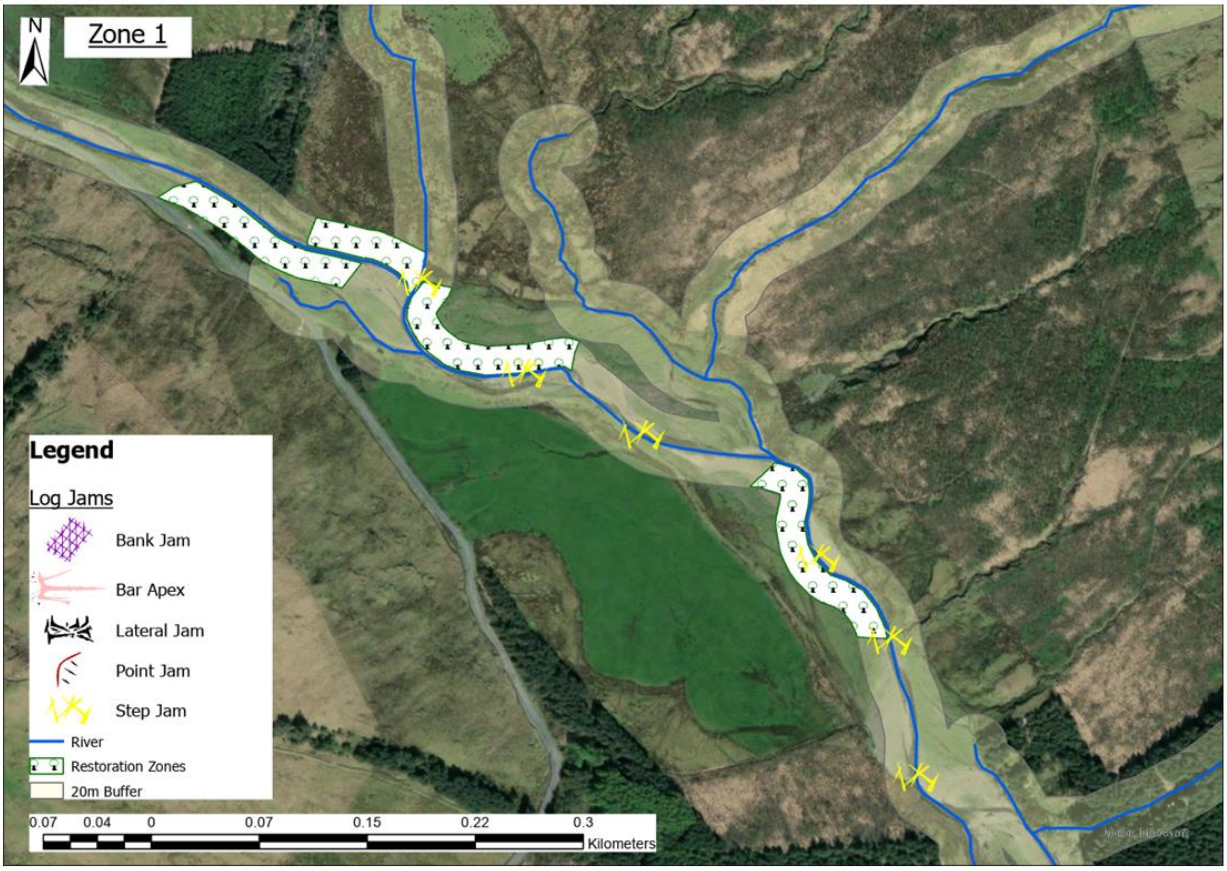
1. Develop a functioning riparian zone and related land management strategy: this is critical considering climate change impacts both in terms of increasing magnitude of flood events and its impact on channel stability and increasing heat/drought events and its impact on thermal habitat. The target river has a degraded riparian zone and high levels of associated bank erosion that reflect this. Development of a functioning riparian zone, including establishment of woody vegetation and wetland features will ease bank erosion without limiting long-term geomorphic evolution, and provide canopy shading that moderates the high temperatures documented in the baseline assessment
2. Elimination/reduction of direct stressors: the impacts caused by human activities or land uses that directly degrade riparian vegetation and/or accelerate bank erosion processes, is a relatively simple way to enhance bank stability. For example, in the target river, over grazing is the pressure leading to riparian vegetation denudation and accelerated bank erosion. However, the impact may be eliminated

through targeted exclusionary fencing, or protection of tree saplings until they establish and improve bank cohesion.

3. Use of nature-based approaches: approaches that do not contain hard elements such as large rocks or concrete as construction materials and that attempt to fix the channel in time. Examples include tree planting to bolster bank strength, log jams that protect banks, create habitat features such as pools and riffles or wetland features depending on their placement. Such an approach will not completely arrest bank erosion but is beneficial when the management aim is short-medium term moderation of erosion processes and habitat creation. It will not inhibit the potential for future restoration or geomorphic processes that are integral to ecological function (e.g. normalised erosion promotes habitat turn over and rejuvenation).

7.2 Specific Measures

The specific measure proposed below are linked and overlapping to provide an integrated approach that focuses on nature-based approaches. These measures (e.g. riparian restoration, rewetting, natural water retention measures, soft engineering to manage erosion) aim to increase ecological resilience to landscapes pressures and broader impacts such as climate change. Relative to hard engineering approaches that incorporate artificial, man-made and high-maintenance instream strategies, that also require repeat external inputs of energy and finance, nature-based approaches should be cost-effective, while providing ecological and social benefits. The measures include a mix of both active (direct interventions to modify the river ecosystem e.g. riparian restoration establishment tree planting) and passive (e.g. exclusion of sheep and deer grazing) restoration means. Some of these are illustrated in Plates 11 and 12, below. In Plates 11 and 12, the main channel has been divided into three zones from upper (1) to downstream (3) segments. The individual measures illustrated in Plate 11 and 12 are described further in the specific measures.



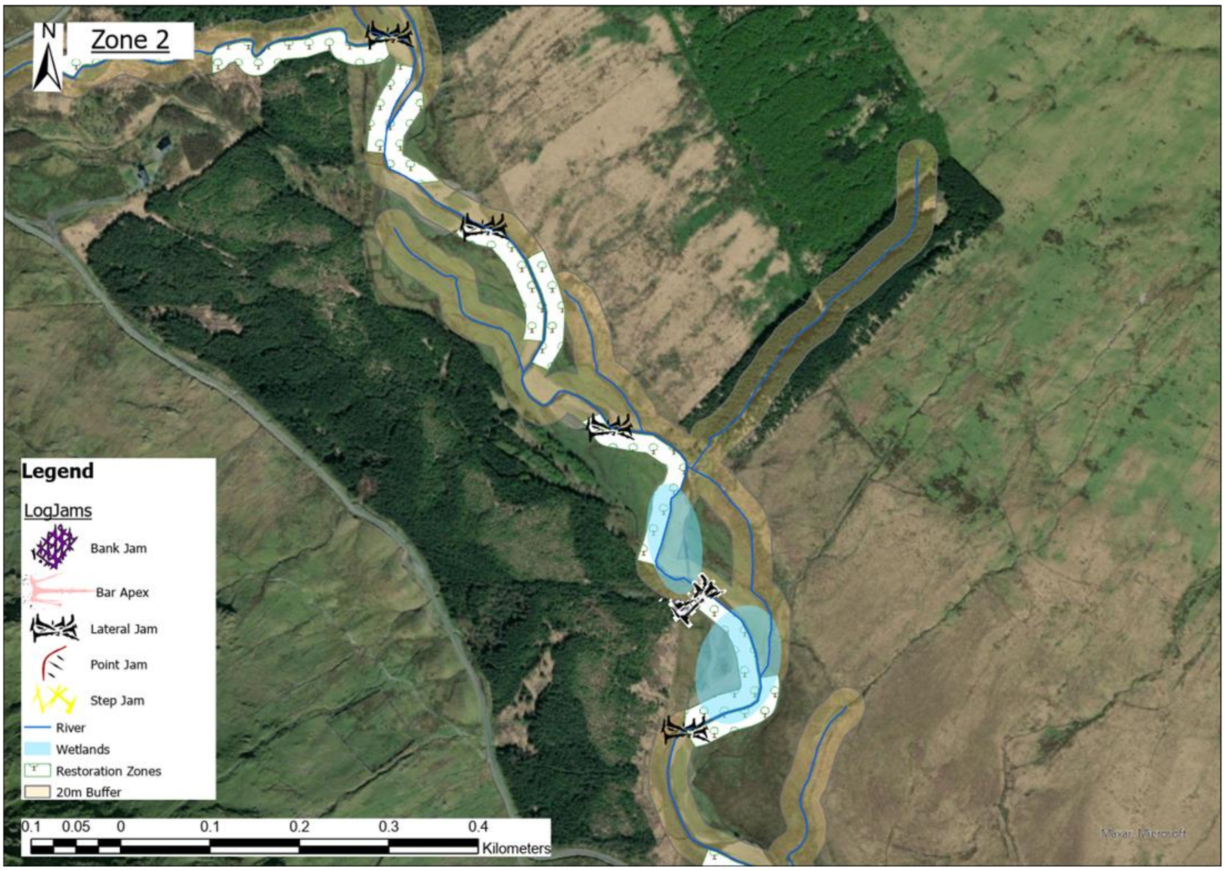


Plate x: Zone 1, upper main channel and Zone 2, the middle reaches of the target river section showing locations of some proposed measures.

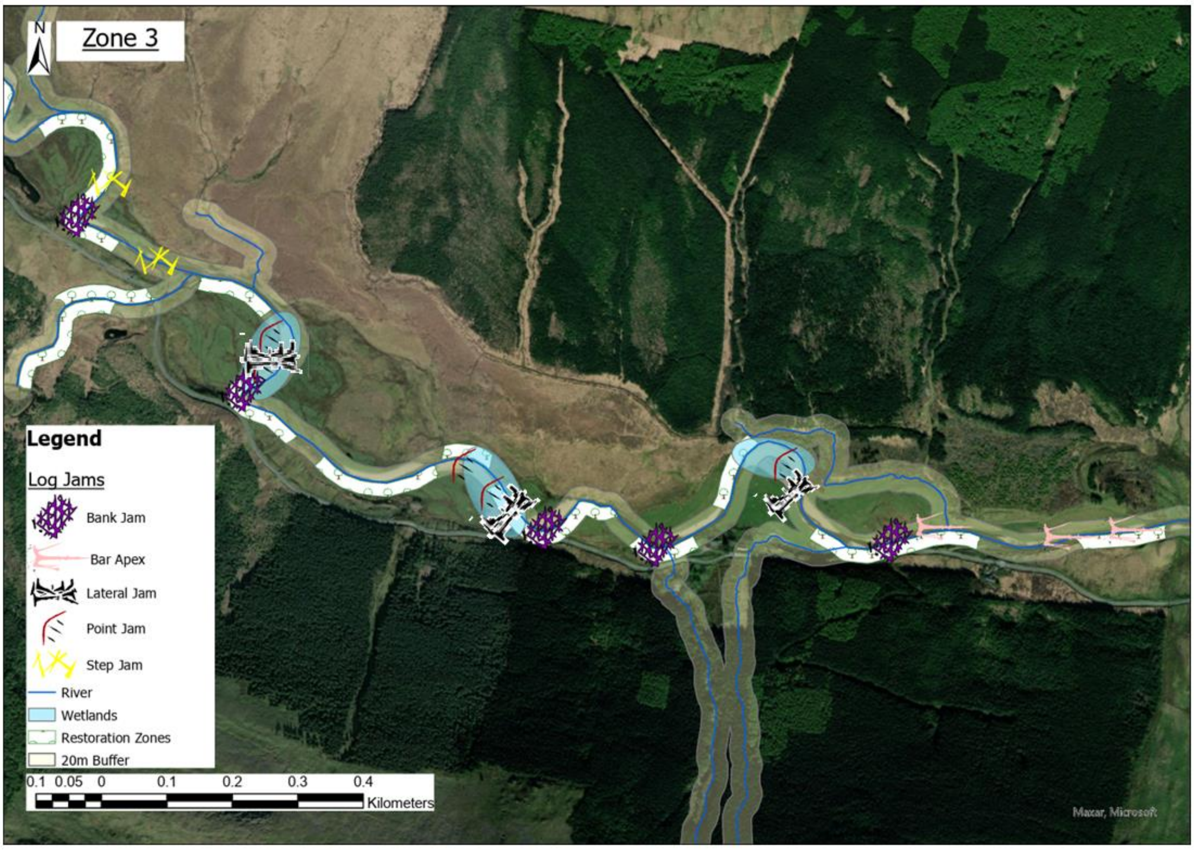


Plate x: Zone 3, the lower reaches of the target river section showing locations of some proposed measures.

Measure 1: Creation of a riparian buffer zone

Description: establish a buffer zone of riparian woodland adjacent to the river containing a diverse assemblage of native riparian broadleaf tree species and associated understorey.

Links. Measures 2, 3 and 4.

Native broadleaved trees are an essential component of river and stream ecosystems; shaping and providing the complex habitat mosaics characteristic of naturally functioning systems. Restoring the natural role of native trees in river systems and increasing appropriate riparian tree cover is critical to achieving favourable habitat condition for salmonids and other river biota. A broad, functional definition of the riparian zone is used in the context of riparian woodland, i.e. 'Any land which adjoins, directly influences, or is influenced by a river'. Using this definition as the basis, the riparian zone includes:

- the land immediately alongside small streams and rivers, including the riverbank itself
- gullies and depressions that sometimes run with surface water or are filled
- wetlands on river floodplains that interact with the river in times of flood

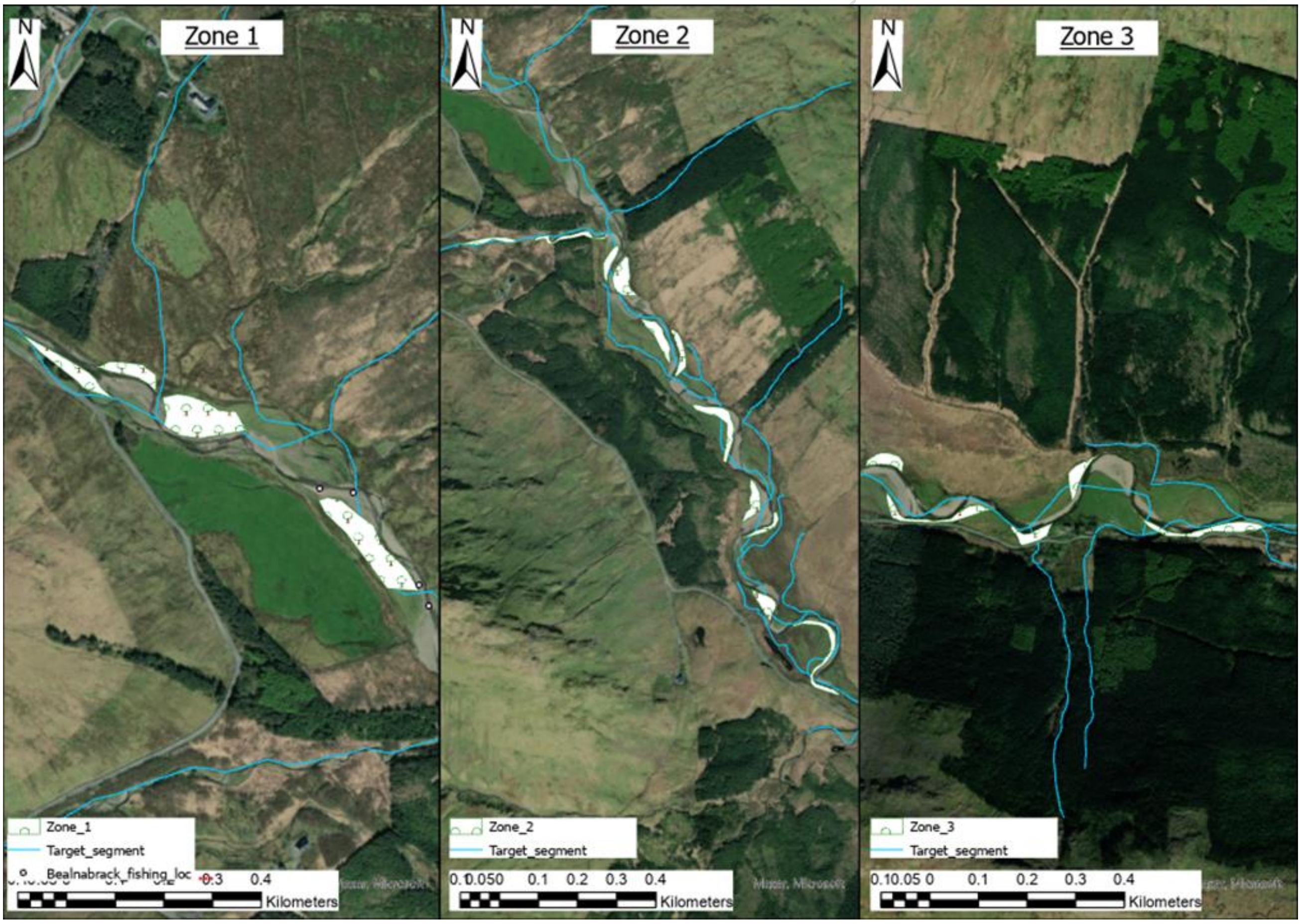


Plate 13. example of potential riparian buffer creation in the upper (zone 1), middle (zone 2) and lower (zone 3) reaches of the target river main channel.

Plate 13 illustrates an example of riparian buffer establishment in the target river section. Establishing riparian buffers that are 20-50m wide is proposed, depending on location and following the planform of the channel with some alternation between the south/southwest bank and the North/northwest bank. Riparian establishment should be heavier on south/southwest bank because this provides the greatest shading effect and at key locations to arrest erosion where the river runs close to the road. Planting ~20% of the valley floor adjacent to the main river is recommended. This equates to approximately 7.7 hectares (25,600 trees at a stocking density of $3m^2$) in the target river section. Additionally, the lower kilometre of the main tributaries should be planted on their south facing bank, with trees two to three rows deep where feasible and one row where space is limited (estimate of 8,000 trees).

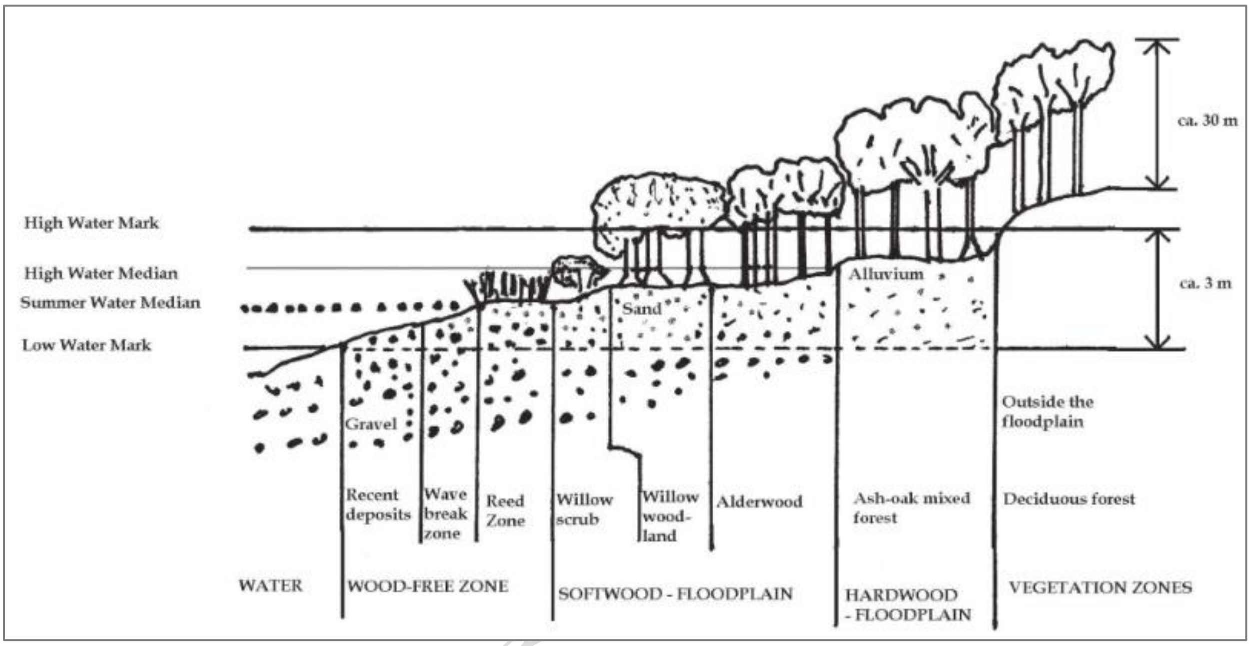


Figure 10: Schematic cross-section through the entire floodplain vegetation sequence adjoining a river. The alderwood can equally occur in the same location as the willow woodland (reprinted from Little et al., 2008).

Creation of riparian zones should follow the succession patterns that are found in natural riparian zones along undisturbed rivers in Ireland. Development of montane type alluvial woodland would be suitable for the Glenosh valley, as the substrate is likely to typically acidic (pH < 6) with limited fertility and characteristic spate flooding. Figure 10 illustrates this pattern with willow (*Salix* sp.) nearest the water as these species are adapted to saturated soils and high levels of flood disturbance. Moving up the bank slope, Alder (*Alnus glutinosa*) is another species that likes to grow alongside water and will readily establish in sand and gravel soils typical of alluvial environments. On higher ground away from the river channels, pedunculate oak-ash woodland with willows is the next band of vegetation. They are characteristically located adjacent to higher order streams and rivers. Here, soils are mostly well-drained but subject to relatively frequent flooding which may persist for several days or even weeks in winter or spring. Sessile oak (*Quercus petraea*) is more suited to the poor soils present in the Glenosh valley if planted back from the river on drier soils. Pedunculate oak (*Quercus robur*) can tolerate some waterlogging and may be suitable at some locations depending on ground conditions. Typically, oak woodlands will contain a scattering of hazel (*Corylus avellana*) and rowan (Sorbus aucuparia) at higher elevations, with both species able to grow on poor soils. Given the widespread impact of ash die-back disease, other species such Downey birch (*Betula pubescens*) may be more appropriate as part of the mixed woodland.

Riparian woodland established near the proposed online wetlands (Measure 2) and any other areas where land adjacent to river is subject to periods of saturation caused by winter flooding can be classed as alluvial woodland. This term is applied to the wetter woodland and is defined by hydrology as it is linked primarily to the occurrence of periodic flooding, mostly by flowing water that leaves a mineral deposit (or alluvium) behind when the waters recede. Alluvial woodlands occur beside rivers and lakes on soils that vary from fine alluvium and silt to sands and gravels, which are common along the Bealnabrack river in the target section.

Presence of trees in the in riparian zone/floodplain will help maintain a higher water table near the river by encouraging infiltration through their root network and slowing subsurface flows towards the channel. This action helps to reduce winter flooding and promote higher baseflows in summer as water enters the channel more gradually through lateral seepage along the valley floor. This process is particularly important for maintaining wet habitat for river biota in spate rivers such as the Bealnabrack that can be subject to very low summer flows (Plate x).

Plate 14: Low flows on the Bealnabrack main channel during the summer of 2022. Spate rivers such as the Bealnabrack are prone to low summer flows which limits habitat availability for river biota

Measure 2: Create online wetlands features

Description: Strategically placement of large wood structures to promote upstream storage of water during high winter floods and create online wetland features.

Link: this measure links to measure 1 (riparian woodland buffer creation) by providing location where wet riparian woodland can be stablished consisting of willow and alder species. It links to measure 3 because large wood is used to create the wetlands by acting as leaky dams and large wood fixed in the riparian zone can also protect tree saplings from floods as they establish.

Desk study and field visits identified six locations suitable for online wetland creation (Plate 15). The locations are generally located on bends and take advantage of existing active channel features such as unvegetated point bars and bare areas adjacent to the channel.

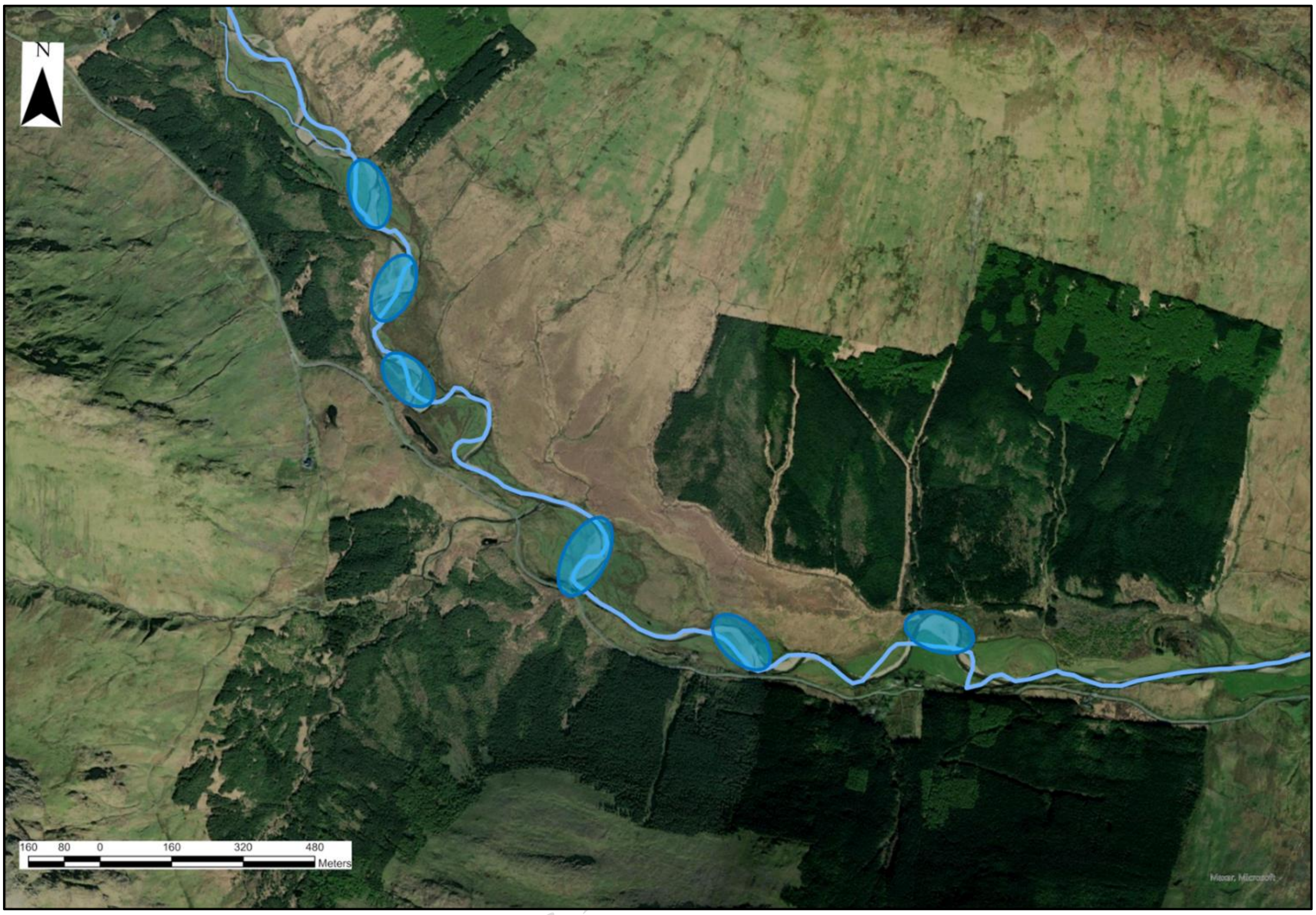


Plate 15. proposed locations for online wetland features in the target river section.

Plates 16 and 17 shows how a series of online wetland features could create a mosaic of river and channel features. The proposed wetland features can improve the hydrological diversity of the river, create a drawdown zone that will help maintain water depths and provide refugia for fish during in low summer and high winter flows.

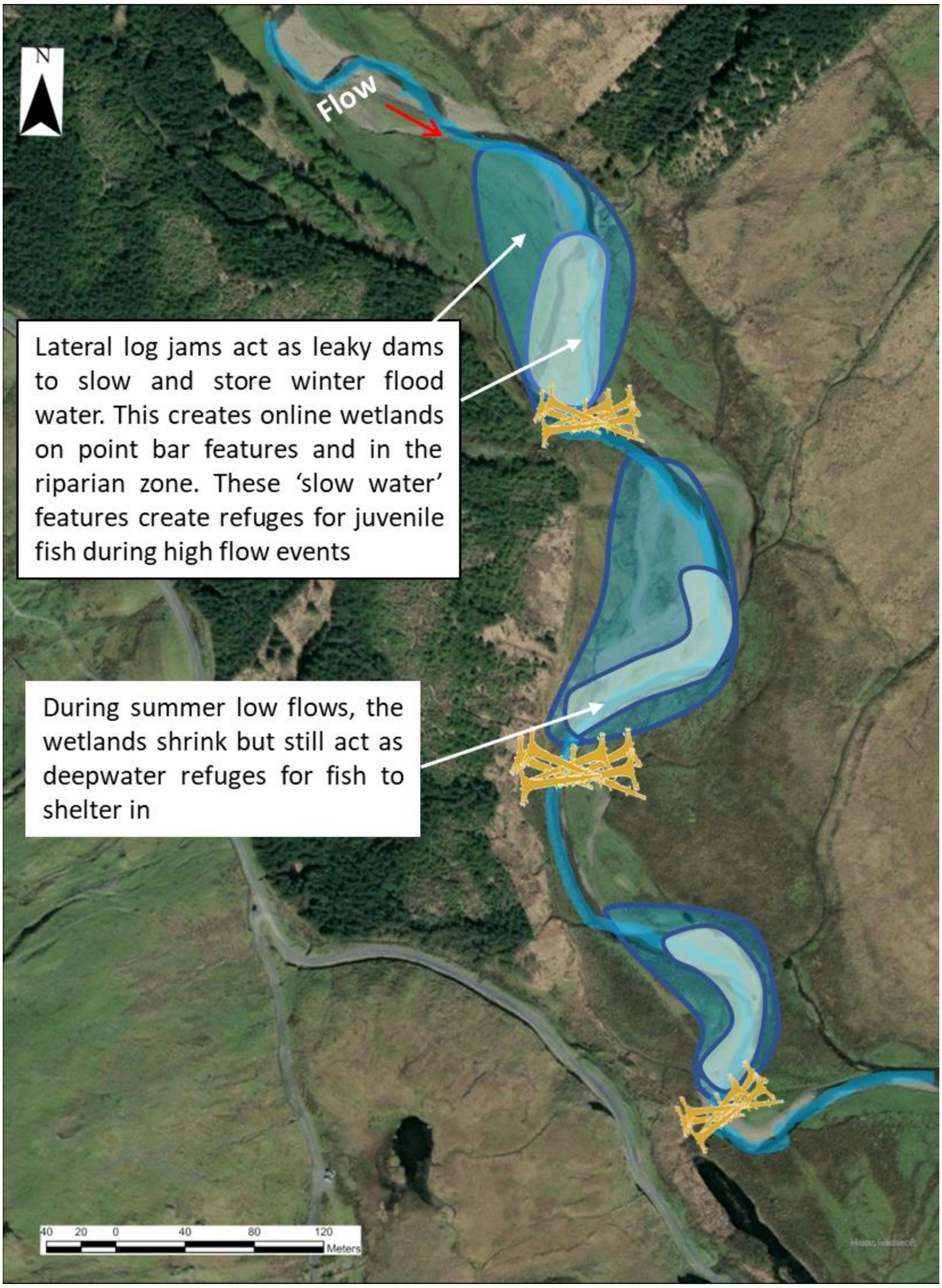


Plate 16. illustrates how online wetland features could look and function in the upper to middle reaches of the target river section.

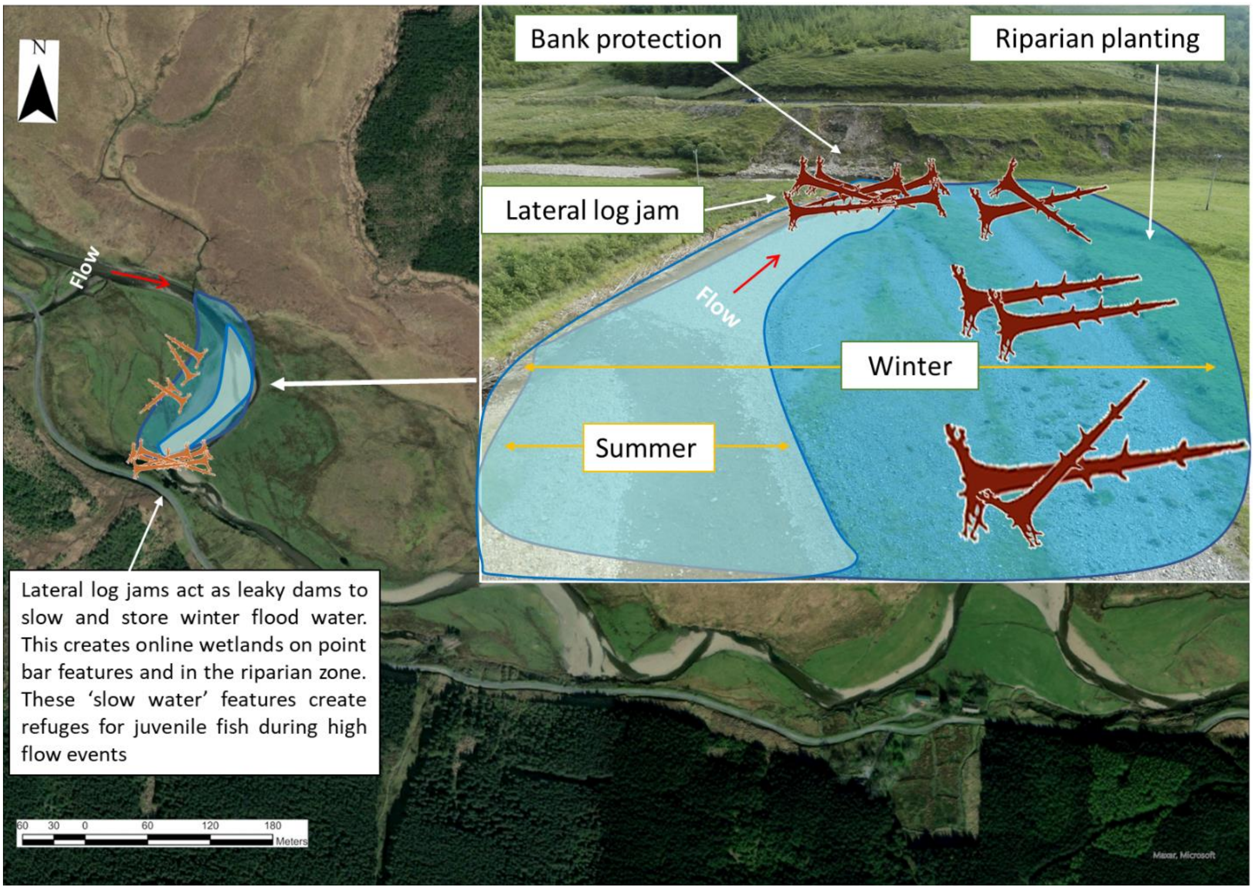


Plate 17: example of a proposed online wetland feature showing summer and winter extent and how this measure can link with other measures such as riparian buffer establishment (measure 1) and large wood installation (yellow) to (measures 3 and 4) to protect riparian vegetation and protect banks from erosion.

Measure 3a: Large wood addition to create habitat

Description: Adding large wood to create habitat features such as pool and riffles and refuge cover for fish.

Link: measures 2 and 3b

As noted in section 6.2.1, large wood is a naturally occurring component of healthy river ecosystems and provides a range of ecological and geomorphic functions. Logs are typically placed either individually or in groups commonly referred to as log jams. Placement of a single log can provide benefits in certain situations but a logjam typically provides more habitat value. A functional log jam is an assemblage of different logs and branches in a state of slow decay together with trapped sediment deposits. This diverse bio-structure provides the base for different aquatic life to find food, shelter, and space to thrive. A log jam also changes water velocity and direction to sort gravels and create pool and riffle habitat (Figure 11). Engineered log jams (ELJs) can replicate the same effect as they obstruct flow and control channel planform, thus serving as one of the principal mechanisms of creating instream habitat features (e.g. pools and riffles), provide grade control and re-connecting channels with their floodplain to create wetland habitat.

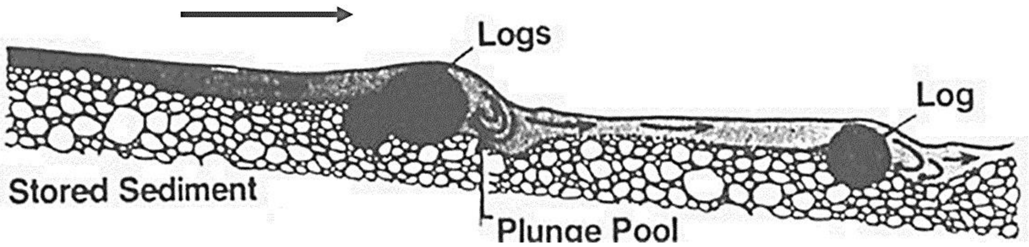


Figure 11. showing the process of riffle and pool formation 'forced' by the presence of step log jam structures.

Five jam types (Figure 12) provide naturally occurring templates for ELJs intended for habit creation, grade control, flow manipulation and erosion management (Figures 13-17). Jam types primarily applicable to creating instream habitat features include step and bar apex jams. Those types more applicable to flow manipulation include lateral jams and those for erosion control/sediment storage include bank and point bar jams.

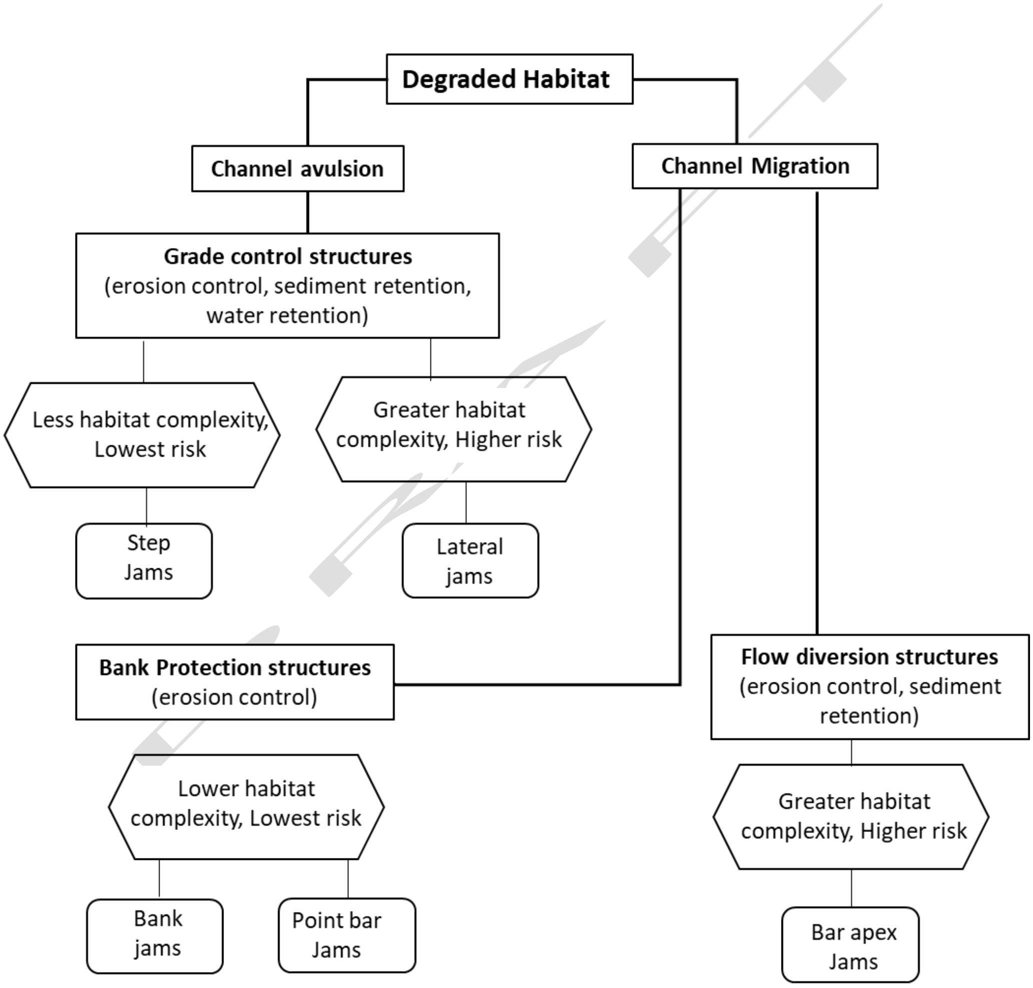


Figure 11. Classification of engineered log jam structures appropriate for treating different problems associated with habitat degradation. The two basic categories of habitat degradation involve channel avulsion (unravelling or collapse of channel structure) and excessive lateral migration.

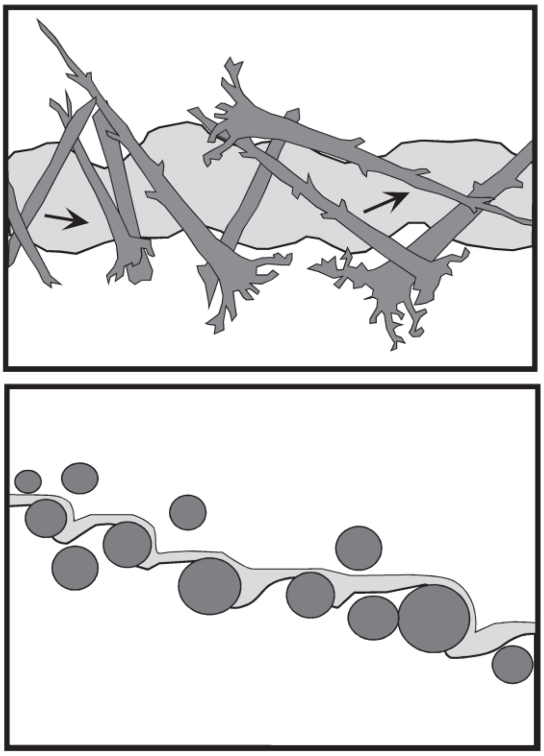


Figure 12. diagram of step jam planform (top) and cross section (bottom).

Step jams (Figure 12) are found in small to medium channels with a range of gradients. In small channel where they span the channel, dense step jam structures can account for more than 80% of the hydraulic head loss and most of the hydraulic habitat diversity where they occur (Abbe 2003). Step jams can enhance salmonid habit through their effect on pool and riffle creation (Fig x). Log lying perpendicular to the flow trap sediment upstream resulting in riffle formation and create a hydraulic drop downstream which generates pool formation through bed erosion.

Where bank jams occur, they divert flows and prevent erosion of the bank (Figure 13). These structures have been successfully replicated as ELJs to limit channel migration, protect banks, and restore aquatic habitat in North America and increasingly in Europe. Point bar jams are another type of jam but these occur on the depositing bend and contribute to sediment storage and protect pioneer vegetation that colonises exposed bars from scour during high flows.

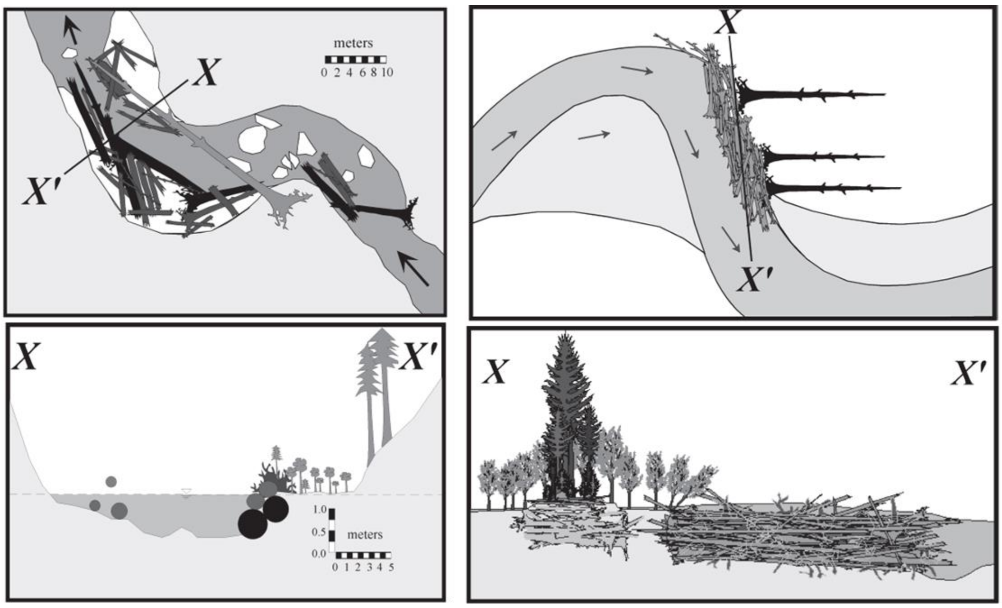


Figure 13. Bank (meander) jams are found where large logs become wedged on the bends of a channel and create local revetments (left). These structures provide a model that has been successfully emulated to limit channel migration, protect banks as part of EJM design (right). *X* is the bank full width.

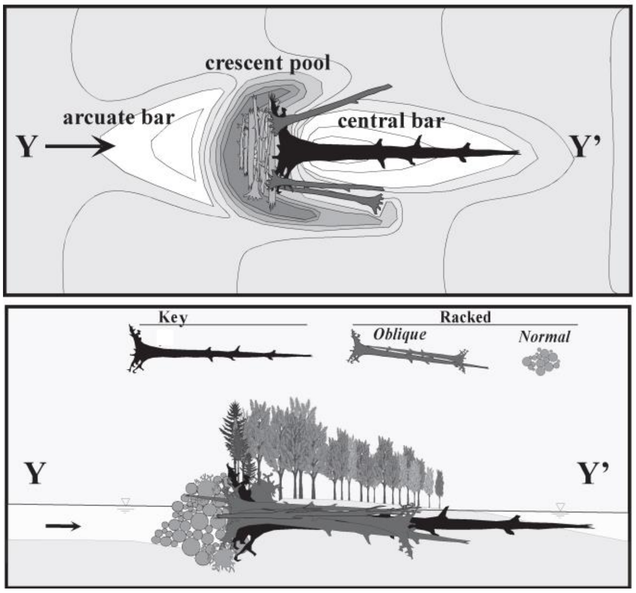


Figure 14. Bar apex jams are bi-directional flow diversion structures found in main stem channels with low to moderate gradients. 'Y' is the longitudinal area of affected by the structure presence.

Single bar apex jams (one tree) create habitat features such as pools at their upstream point and channel bars at the downstream point (Figure 14). Multi-tree structure can contribute to the formation of anastomosing (branching) channel plan form.

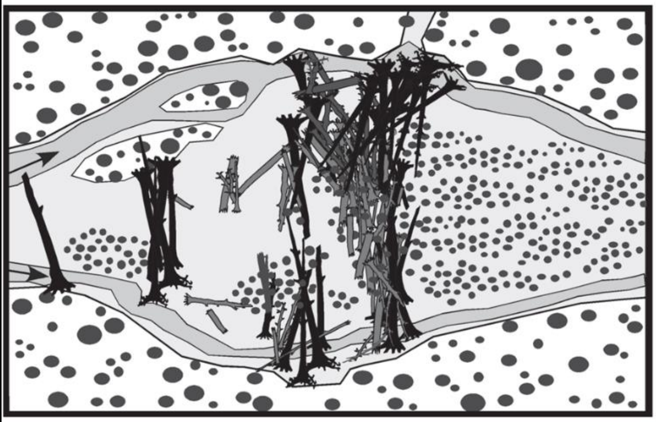
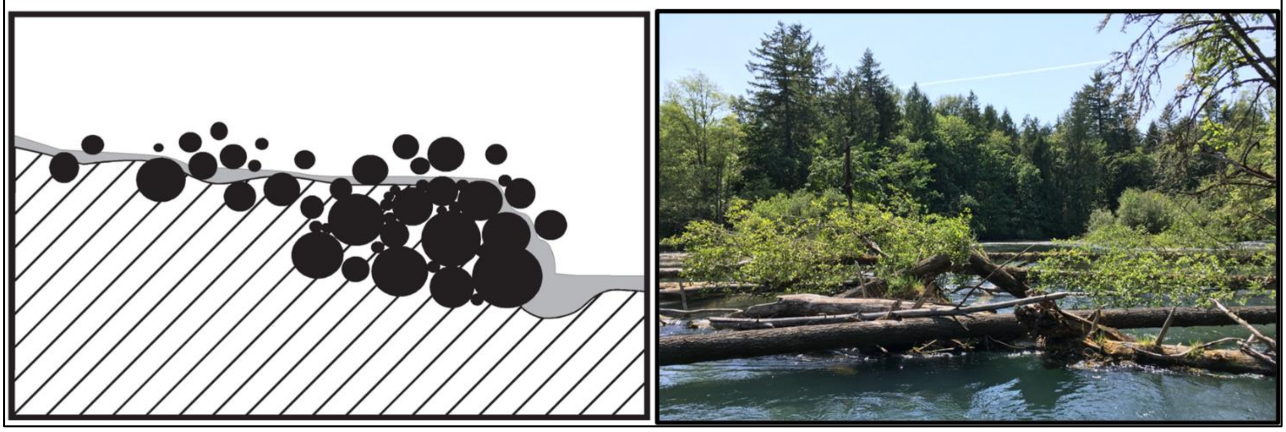


Figure 15: Lateral (valley) jams are large, complex grade control structures found in medium to large channels (planform, top left, and cross section, bottom left). Lateral log jam, bottom right, installed as part of salmonid habitat restoration in the Middle Fork Willamette catchment, Oregon, USA (https://businessforwater.org/projects/elijah-bristow-floodplain-restoration)



Naturally occurring flow obstructions caused by LWD in unmanaged river systems can result in significant changes in water surface topography, locally raising water elevations enough to inundate secondary channels and portions of the floodplain during. These structures are referred to as lateral or valley jams and can be typically composed of tens to hundreds of trees. These structures are also responsible for creating a complex channel network across the valley bottoms in which they occur and have a role in wetland creation where they occur at natural pinch points.

In addition to planting native species as part of the Middle Fork Willamette catchment restoration (Figure 14, photograph) measures focused on restoring floodplain processes by building large wood jams to create seasonal wetland features. The restoration objectives are to spread and slow water flow, increase water storage and groundwater recharge, and provide improve habitat in the aquatic and riparian environment.

Measure 3b: Undertake erosion management using soft engineering techniques

Description: Install engineered log jams (ELJs) on bends to manage of areas of significant erosion that are threatening road infrastructure.

Link: measure 3a

Four locations on the main channel have been identified as requiring this measure (Plate 18). At these locations, the river is migrating close to the road and associated bank erosion is threatening to take the road away.

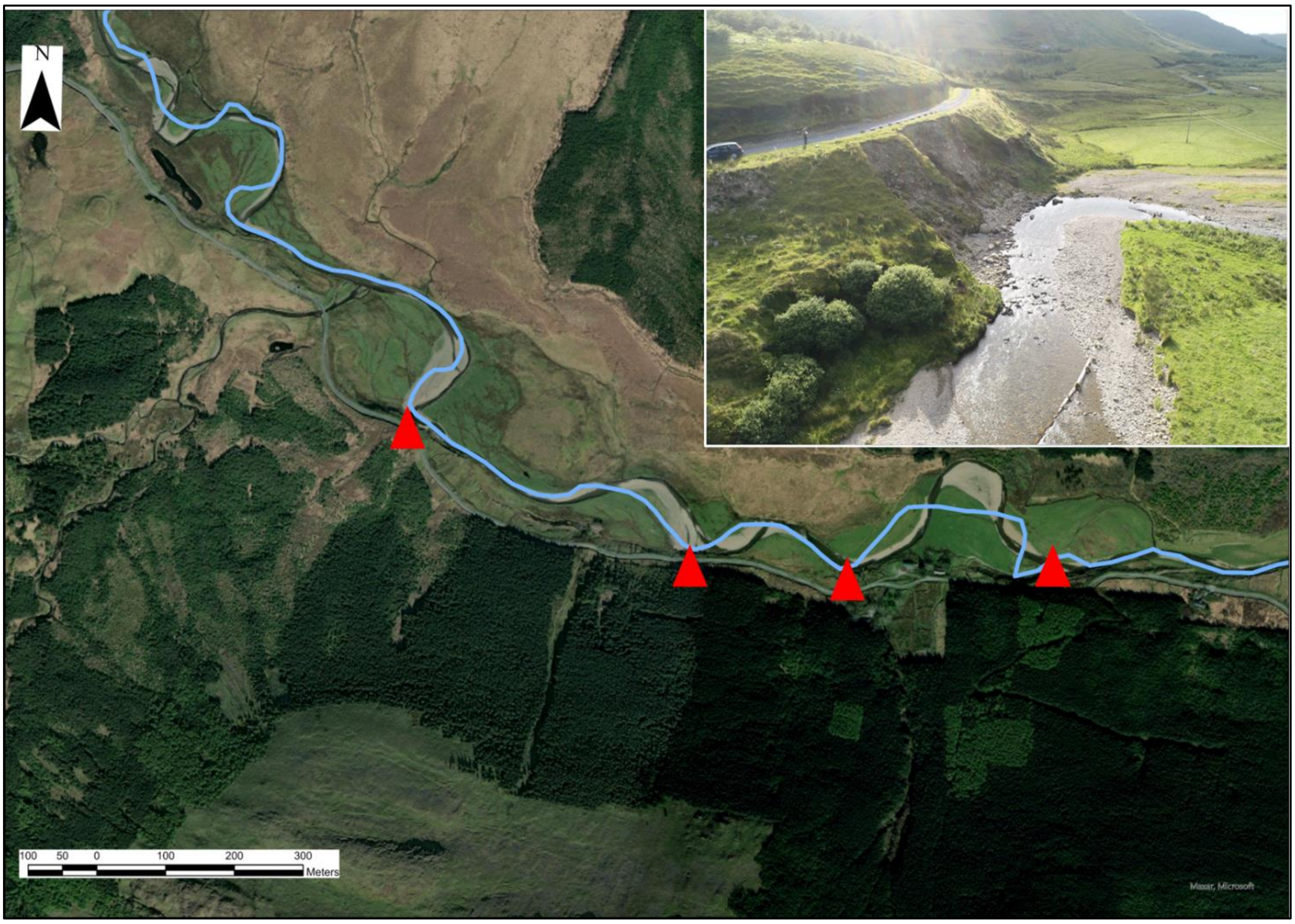


Plate 18. Locations requiring bank erosion management in the Glenosh valley and an example of erosion that is threatening the road infrastructure (top right).

No artificial materials are necessary to construct an ELJ. Trees/logs and alluvium at the site are all that is needed if the trees meet the design specifications for size and shape. If tree are abundant onsite and meet the design specification, they can be used, or more typically, trees can be imported. Trees large enough to act as anchor/key members may need to be bound or bolted together at the site. The stability of ELJs is founded on snagging trees on other tree and backfilling with alluvium to help them bed in. Long-term contributions to bank stability come from trees growing on top of ELJs, due to both root cohesion in alluvium under which the structure is buried and from the weight of the trees themselves.

Measure 4: Invasive alien species (IAS) management

Description: Develop and implement an IAS managment plan for Knotweed spp. removal and control in the upper catchment.

Link: Measure 1 will include fencing to exclude sheep and deer at some planting locations while the trees establish. These sites will be vulnerable to colonisation by knotweed without grazing pressure, making knotweed control and eventual eradication a key objective within the overall restoration strategy.

Invasive species management is an ongoing, iterative process. Any management should follow the five basic steps in Figure 16 with dealing with IAS (DEC, 2017).

Figure 16. Steps to managing IAS.

Depending on the site conditions, the species present, the strategy will target one or more of these outcomes:

- Eradication – eliminate all invasive plants and the seed bank from an area
- Containment – prevent infestations of invasive species from spreading to uninfested areas
- Suppression – reduce the size, abundance, and/or reproductive output of an invasive plant population below the threshold needed to maintain native species or ecosystem functions

Severe IAS infestations will typically require significant resources to eradicate and/or control. However, knotweed seems to be limited to relatively small number of locations in the Glenosh valley and absent from the floodplain in the target river section. As such, the strategy should aim for eradication while the infestation is confined to a few locations. It may be that grazing in the floodplain and riparian zone is preventing knotweed from establishing there, but there will be more opportunities once sheep and deer are excluded from some areas as part of measure 1.

Measure 5: Landscape management

Description: Adopt a landscape management approach to improve riverbank, floodplain and peatland condition.

Links: Measure 1, 2 and 4. A landscape approach that incorporates terrestrial habitat management alongside the other aquatic and riparian focused measures will buffer the river environment against negative impacts such as excess fine sediment and nutrients, invasive species establishment, and once established, become self-sustaining as part of landscape approach.

The restoration of surrounding terrestrial habitats is a key component in buffering and supporting aquatic ecosystems. However, previous river restoration projects have focused on artificial, man-made and high-maintenance instream strategies, which are costly. These are usually, not successful over a longer period of time, as they depend on repeat external inputs of energy and finance, in addition to human management and control. Restoration strategies that manage terrestrial habitats sympathetically around rivers will buffer the aquatic environment against negative inputs such excess fine sediment and nutrients. Examples include stock exclusion from riparian areas and vulnerable banks and slopes, blocking drains to reduce fine sediment delivery, and restoration of wetlands at specific locations in the floodplain to create refuges for wildlife.

As the catchment forms part of the Maumturk Mountains SAC (site code: IE0002008), one of the notified/qualifying features of high nature conservation interest is blanket peat bog. Healthy peatlands deliver a range of benefits to the wider environment and society, such as climate regulation and adaptation (through the accumulation and long-term storage of carbon as peat soil), maintaining water quality and regulating flow, supporting unique, and often internationally declining biodiversity, and preserving historic environment features. However, these benefits are reduced or potentially lost as the habitat becomes damaged and degraded. Damaged, bare peat and drainage channels (both human created and natural gullies) reduce the capacity of the peatland to stay wet and regulate the water flow. Restoring blanket bog by increasing surface flow (rather than drainage channel flow) can reduce the magnitude and frequency of flash floods. Bog habitat in good condition releases water more slowly with the potential to increase ecological resilience during periods of drier weather. Rates of fine sediment production and release are also lower in healthy bogs compared with degraded systems.

A review of aerial imagery for the Glenosh valley revealed evidence of activities that are likely to result in blanket bog damage and degradation. These include historical planting of non-native conifers, that usually occurs in association with land drainage. Areas of bare, eroding peat and gullies are also apparent in the aerial imagery. Several habitat enhancement techniques exist (subject to landowner agreement) that could potentially be implemented to improve the bog condition. These include limits on livestock grazing, blocking of drainage channels, re-establishing vegetation on bare peat soils, and not restocking conifer plantations.

Establishing tree in the riparian zone also offers a seed source for natural regeneration. As part of a medium-longer term approach, establishing enclosures that prevent sheep/deer access in the riparian zone in areas **not** subject to planting will provide establishment opportunities for trees via seed dispersal and replicate the natural succession process.

Measure 6: Forestry maintenance and management

Description: Longer term plan to change the existing coniferous forestry to broadleaf, limiting clear-felling of the current forestry, and blocking of related drainage channels.

Links: this links to measure 5 as component of the landscape management strategy.

The process of replacing coniferous forestry with broadleaf trees is already underway by the landowner and is evident from aerial images the current forestry interspersed with broadleaf stands. Plate x offers a visual example of broadleaf planting beside one of the tributaries that drain flow into main channel with the target river section.

Plate 19. broadleaf riparian zone established by the landowner on a tributary of the Bealnabrack main channel

8 Estimated costs and timelines

Below, costs (Table 6) and approximate timelines (Table 7) are estimated for project delivery. Costs are only estimated for phase 1 and 2 as phases 3 and 4 are from 2025 onwards and estimates may not be reliable.

Table 6: Estimated costs associated with Phase 1 and 2 of the proposed restoration plan.

Item	Description	Note	Estimate (excluding VAT)
Screening assessments	Natura Impact Statement/Appropriate assessment	Site is within an SAC	5000
	Archaeology	6 minor structures in the vicinity of the river	3500
Design	Technical drawings for soft engineering erosion management	5 structures	2000
	Technical drawings for instream structures - engineered log jams	23 structures	2000
	Hydrological analysis -computational river modelling to inform the final design of the restoration project -flood, aquatic habitat and sediment transport response to soft engineering bank protection and engineered log jams		3000
Project supervision and design	To ensure effectiveness in addressing and co-ordinating safety and health matters from the very early stages of a project		3000
Planning and consultancy	Engineer support in the works phase		3500
Invasive species managment	Knotweed control and eradication		6000
Bank and instream works	Supply and installation of soft engineering bank protection and instream habitat structures		
	Build	Machine hire x 6 weeks	28000
	Materials	One acre of mature conifer trees – 10k per acre	10000
Contingency			7000
		Total	€73000

Table 7. proposed timelines for project delivery

Item	Completion date
Phase 1	
Screening assessments	December 2023
Design (technical)	December 2023
Project supervision and design	April 2024
Phase 2	
Planning and consultancy	September 2024
Bank and instream works	September 2024
Phase 3	
Riparian woodland and fencing design	March 2025
Riparian planting and sheep/deer proofing - ongoing over five years (2025-2030)	Spring 2025 - Spring 2029
Landscape and forestry management	Ongoing as the transition from conifers to broadleaf trees takes place

Phase 4	
Riparian enclosures to promote natural tree regeneration	September 2030

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