WildFish.

River Barriers

Literature Review

March 2026

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What are river barriers?

A river barrier is a structure or obstacle, either natural or man-made, which prevents the movement of aquatic organisms either upstream or downstream. Barriers modify the flow and depth of water in river systems and can influence water chemistry. They can have many purposes including industrial, agricultural, infrastructure, flood defence, land reclamation, environmental management or aesthetic. They can be temporary or permanent.

Natural river barriers have always existed, usually a result of the erosion of underlying geology creating obstacles such as waterfalls or lakes. Natural barriers have allowed for the creation of distinct ecological niches, and shaped the species distribution of aquatic flora and fauna at local, regional, and global scales (Nakazawa, 2013).

Human populations have profoundly altered the behaviour of many rivers through the creation of artificial river barriers. Since the development of agriculture and sedentary human habitation, river barriers have been created to irrigate crops, provide flood defences, and facilitate the transport of goods. In fact, the oldest known dam, at the Bronze Age settlement of Jawa in Jordan was thought to have been constructed as early as 3000 BC (Helms, 1977). However, as agricultural and energy technology has developed, especially since the onset of the Industrial Revolution the number of artificial river barriers has increased exponentially. Today, it is thought globally up to 63% of all rivers over 1000 km in length are no longer free flowing, with the extent of barriers on smaller rivers and tributaries most likely even greater (Grill et al., 2019).

Understanding the environmental impacts of river barriers is not straightforward. Barriers can have both positive and negative effects on the environment at a variety of scales. For example, dams provide us with a renewable source of energy via hydropower generation (reducing carbon emissions, hence helping to address global warming) but can reduce habitat connectivity at local and regional scales (Barbarossa et al., 2020). It is therefore imperative that construction of new barriers and removal of existing barriers considers their environmental impact at a variety of scales.

Types of barriers

When investigating river barriers, it is important to distinguish which type of barrier is being discussed, as barriers can have very different effects on the flow of water. Barriers come in all shapes and sizes, but can be broadly categorised into several different structures:

Dams:

A dam is a barrier which blocks or constrains the flow of water, raising the water level on the upstream side forming a reservoir.

Howden Dam, The Peak District, England (Canva, 2025).

Weirs:

A weir is a low barrier which aims to regulate flow conditions, change the direction of flow, intercept sediment or reduce the channel slope in order to stabilise the channel bed. Weirs are designed in many ways, but most commonly water flows freely over the top of a weir. Weirs typically result in a change in the height of the river level.

Pulteney Weir on the River Avon, Bath, England (Canva, 2025).

Sluice Gates/Locks:

A sluice gate is a movable barrier used to control water levels and flow rates. By opening and closing the sluice water levels and flow can be increased or decreased accordingly. They are typically found in locks in canals, allowing boats to traverse sections of differing levels on the waterway, to control water flow into and out of flood meadows, or to control tidal ingress into drained coastal land.

Camden Lock, London, England (Canva, 2025).

Culverts:

A culvert is a structure which channels a river to flow through or under an obstruction, typically in the form of a circular pipe. They are typically used to allow roads to pass over waterways without the need of a bridge. In the UK, the term is also used to refer to longer artificially buried watercourses, such as the 'lost' rivers of London.

Hackney Brook Culvert, London (Canva, 2025)

Fords:

A ford is a structure within a river which allows for the crossing of vehicles or pedestrians but involves them being physically in the river. These are typically an artificially-created shallow area.

Ford on the River Esk at Grosmont, North Yorkshire, England (Canva, 2025)

Ramps:

A ramp or bed sill is a structure aimed at stabilising the channel bed and reducing erosion. These barriers come in many forms though most are underwater structures (i.e. not blocking the flow of water, only acting on riverbed and channel slope). They typically have a height of less than 1-2 meters.

River Ramp (AMBER Consortium, 2020)

Natural Barriers:

Barriers occur naturally in rivers and streams too. However, there is some debate on how anthropogenic actions may influence these barriers. For example, human impacts such as climate change can increase blockages caused by landslides. Forestry activities can cause log jams. Species introductions (purposely or accidently introduced) such as beavers may increase the prevalence of certain natural barriers. Where to draw the line between what is truly a natural barrier is open to debate. Examples of natural barriers include waterfalls, river rapids, boulders, temporary obstructions from vegetation or geology and beaver dams.
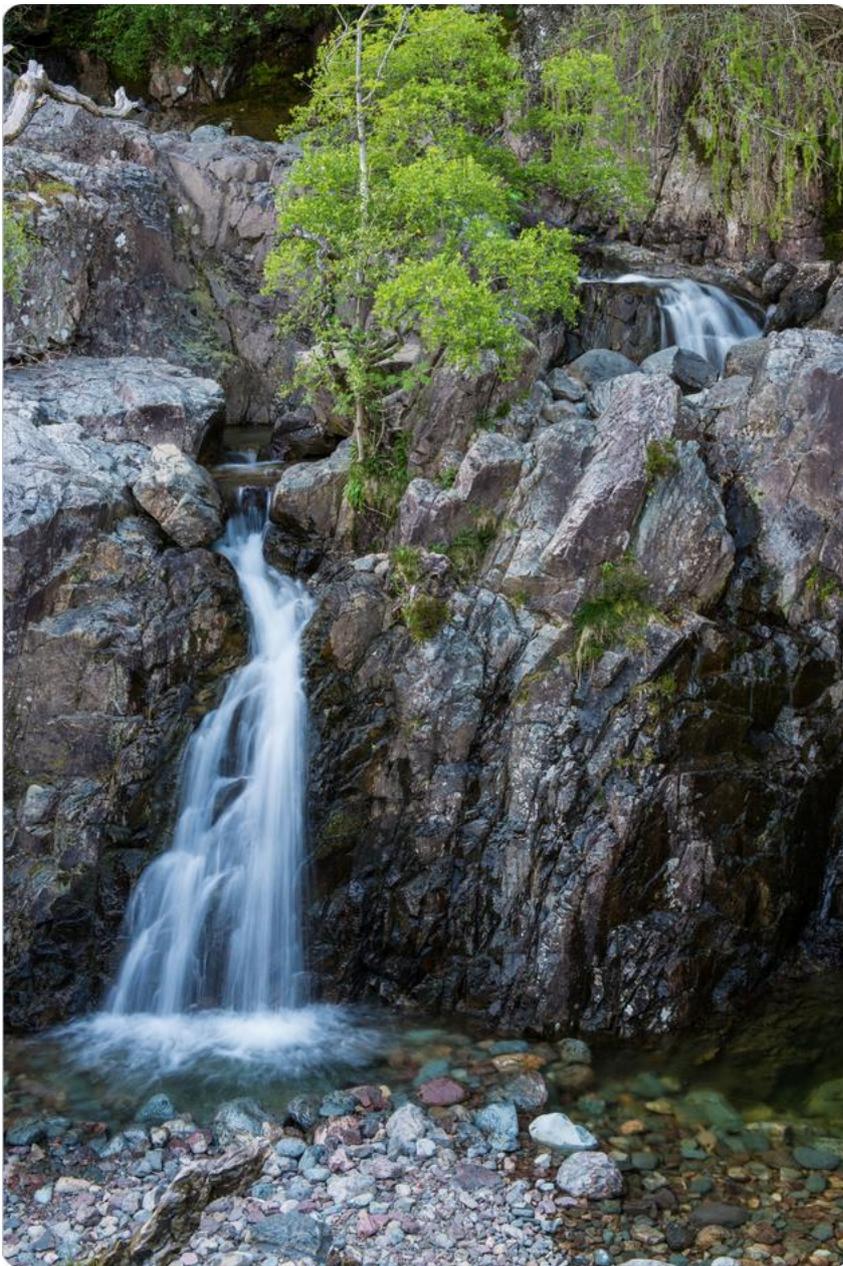
Stickle Ghyll (waterfall), Cumbria, England (Canva, 2025).

Non-Physical Barriers:

By far the most understudied area of river barriers are those which are non-physical. This is where an in-stream barrier in the form of a change in chemical water quality, aquatic biota, water temperature or flow conditions is observed. An example of a natural non-physical barrier would be increasing salinity between river and the sea. Anthropogenic non-physical barriers include water quality or thermal barriers from pollution inputs.

Unlike physical barriers, non-physical barriers can be transient, and appear and disappear depending on the control of pollution releases, abstractions etc. This makes it very hard to study non-physical barriers accurately, and even more difficult to investigate their effects on wildlife, especially migratory species. Pollution events that cause such barriers at key times in fish migrations could be very detrimental to migration and spawning success.

Barriers from point source pollution and fixed water abstraction sites are easier to monitor but, there is still little research here. We know that in species such as eels, changes in velocity are important factors in energy expenditure and thus migration success (Piper et al., 2017). This is also the case in juvenile salmon (smolt) migration (Steel et al., 2013). Therefore seasonal, monthly, and hourly variations in flows and water chemistry as a result of pollution or water resources engineering can influence aquatic wildlife migrations and need to be studied further.

Light pollution caused by artificial light at night (ALAN), can also become a non-physical barrier to aquatic organisms. Light pollution caused by ALAN is becoming an increasing problem globally. As electric lighting has become more widespread and accessible, night time sky brightness began increasing 3-6% annually during the second half of the last century, and in the past decade has been increasing 10% per year (Hölker et al., 2023). Consequently, many areas with high human population density are experiencing loss of night, which can then extend into unlit areas where light is scattered into the atmosphere and returned to earth in a process called skyglow. Direct ALAN can reach up to 1000 times brighter than natural full moon conditions (Jechow & Hölker, 2019). Rivers are under particular pressure from the potential harmful effects of ALAN, as more than half the global population lives within 3km of a freshwater shoreline, and are thus more exposed to light pollution (Kummu et al., 2011).

Illuminated overpasses, bridges, weirs and other barriers can interrupt animal movement (Fig.1). Salmonids and eels have been shown to interrupt their upstream and downstream migrations at such light barriers (Cullen & McCarthy, 2000; Riley et al., 2013). Consequently, migration in these species may take more time and energy, potentially impacting their reproductive success.
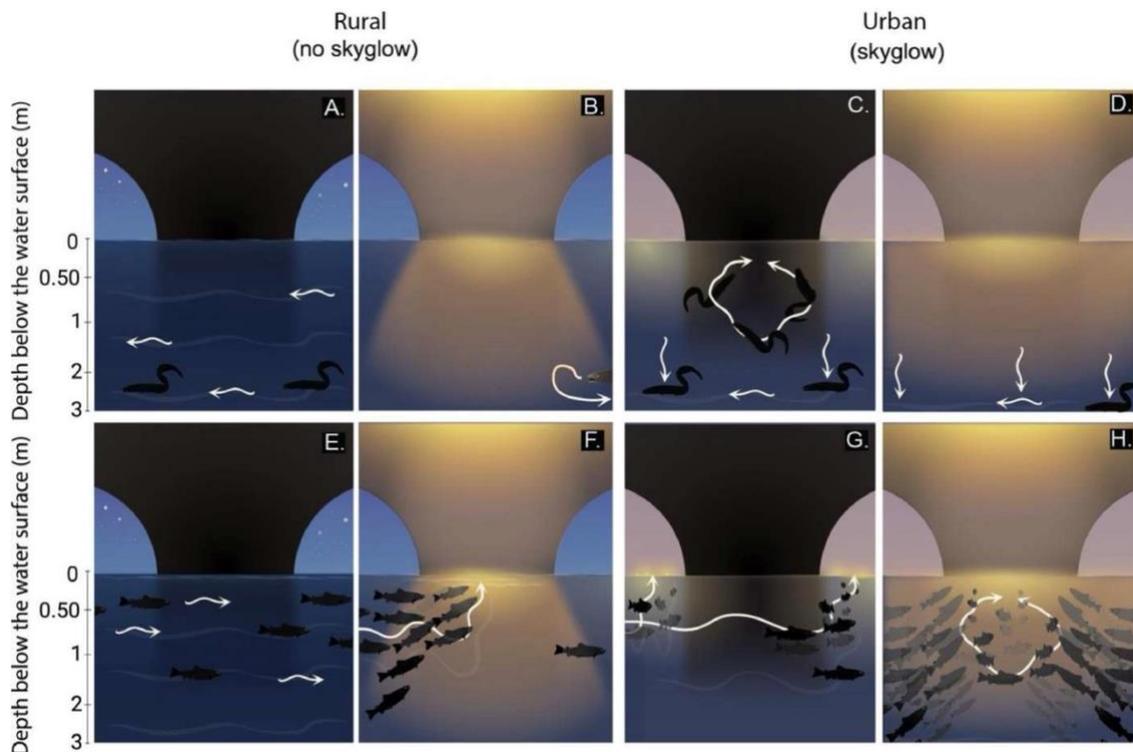
Fig 1: Expected responses of European eel (A,B,C,D) and Atlantic salmon smolt (E,F,G,H) to illuminated bridges in different environments (Pérez Vega et al., 2024).

Effects of barriers:

The effects of a barrier on the environment will be dependent on the type of barrier present, as well as its size, geographical context and location (Fuller et al., 2015). Larger barriers will typically affect the river for greater distances up and downstream than smaller barriers (Fig.2). The predicted longevity of a barrier, as well as its permeability must also be considered when assessing its environmental impact, with short lived and permeable barriers having a far lesser impact compared to long term impenetrable

barriers. It has been hypothesised that barriers permeability seems to decrease with increased longevity (Fig. 3).
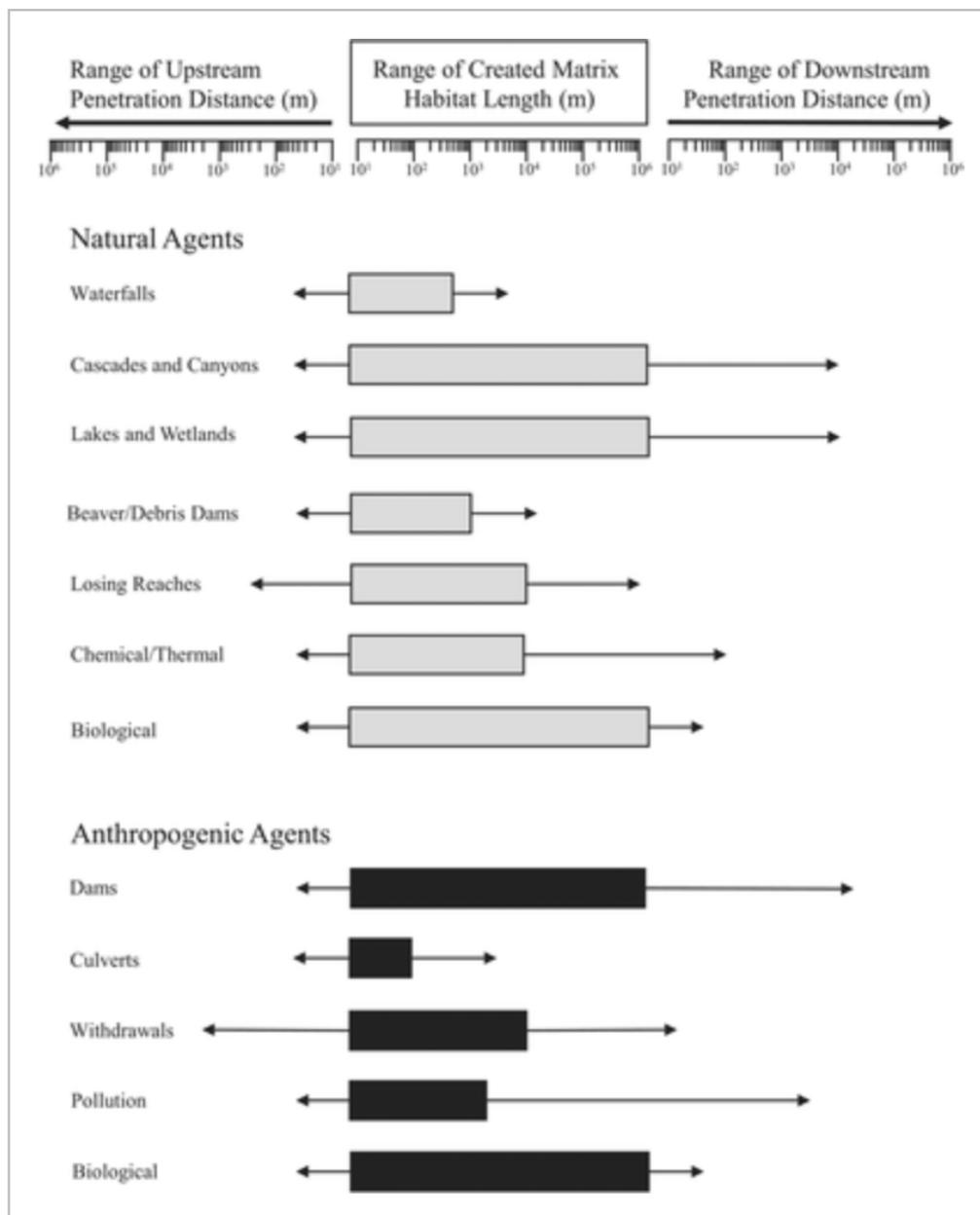
Fig 2: Hypothesised ranges of matrix habitat created by different types of natural and man-made river barriers (box length on log scale). Arrows represent the potential upstream and downstream ranges for potential edge effects caused by each different type of barrier. Simplistically, a measure for which types of barrier have the greatest impact on habitat fragmentation. (Fuller et al., 2015)
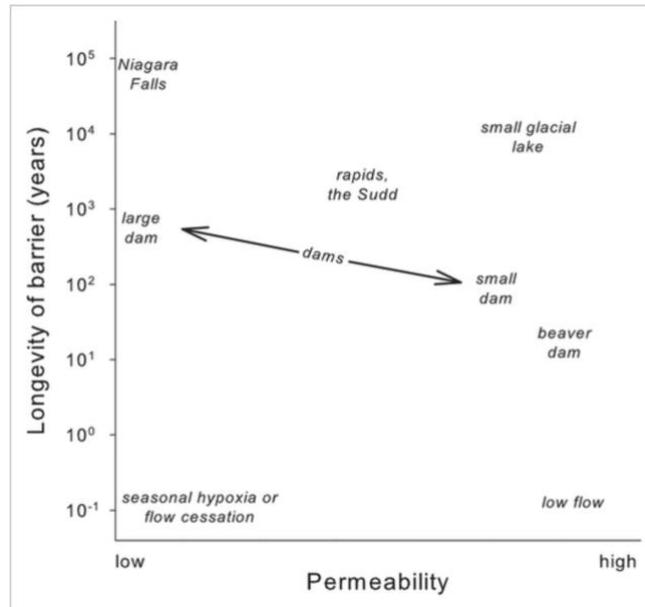
Fig. 3: Hypothesised relationship between barrier longevity and permeability. (Fuller et al., 2015)

Why do we need river barriers?

Despite the growing concern about the detrimental environmental impacts of river barriers, it is important to consider the reasons so many man-made barriers exist, and why they continue to be built (NOAA, 2021):

Irrigating crops

River barriers are important for transporting water for irrigation. They are especially important in water-scarce countries and regions where precipitation and groundwater stores are not sufficient to support local populations. Traditional forms of irrigation which more frequently involve river barrier installation channelling water to agricultural lands in arid climates are still especially important in less developed parts of the world.

Drinking water

River barriers (mainly dams) are essential in creating reservoirs which are needed for a constant supply of drinking water regardless of seasonal variations in water abundance. Other methods of drinking water supply which do not require river barriers such as groundwater and de-salination are geographically dependent on having a suitable aquifer/coastline meaning that surface water storage can be the only option and/or in many cases the cheapest.

Electricity generation

Hydro-electric power is a source of renewable energy and emits far less CO_2 emissions during its lifetime than fossil fuel alternatives. It is also often coupled with drinking water storage systems.

Transportation

Rivers are important for transporting large quantities of goods. Essential materials such as grain, coal and ores are often transported via rivers. Imports from ports distributed via canals (such as in central Europe) are an efficient and cheap method for the movement of goods but require large numbers of river barriers.

Bridges and other river passes are also important for humans crossing rivers. Many of the world's cities are built alongside rivers and isolated and often impoverished communities in rural and mountainous areas are often dependent on the construction and maintenance of river crossings to maintain social mobility.

Whilst river crossings are much smaller in scale than large dams their cumulative environmental impact can actually exceed that of larger river barriers. In urban areas, numerous small river crossings from road networks have been seen to have more significant impact on longitudinal stream connectivity and landscape connectivity than large dams (Diebel et al., 2015).

Recreation and tourism

River barriers to support tourist and recreational activities are important for attracting visitors to waterfront areas and supporting these communities economically. This could mean making rivers navigable or creating reservoirs for leisure activities. Historical river barrier structures, such as mills or dams may have protected status and form an important part of local identities and culture.

Flood protection

Many urban areas are built on or near rivers and floodplains. Therefore, in-river flood protection, which can include barriers are important to ensure these communities are kept safe and minimise economic damage to the area. In England, 5.2 million (one in six) properties are at risk of flooding. More than 5 million people live and work in properties at risk of flooding from rivers or the sea, one million of which are also at further risk of surface

water flooding (Environment Agency, 2009). To remove barriers in these areas alternative flood protection methods would need to be found, or residents moved to houses in more suitable areas, both of which are extremely costly.

River Barriers: The Statistics

Only a third of the world's rivers are still unobstructed by river barriers and free flowing (Grill et al., 2019). The issue is especially prevalent in Europe and the UK, where rivers have been an integral part of the movement of goods for millennia, and the industrial revolution further necessitated the need for barrier construction for a variety of industrial, agricultural and infrastructure needs.

Records on river obstacles and barriers are very hard to quantify. There are a number of databases for river barriers in the UK and Europe. Estimates have been made by many organisations, from governments to NGOs, with a range of different findings.

The most complete dataset for Europe is the AMBER project (Adaptive Management of barriers in European Rivers), which utilises citizen science reporting via an app to monitor and try and build a dataset of river connectivity across Europe (including the UK). AMBER is used by the European Environment Agency (AMBER Consortium, 2020). In the UK, a project called River Obstacles, working with the Rivers Trust, also utilises citizen science reporting via an app to tag and categorise river barriers effecting river connectivity. The Environment Agency (EA) in England utilises a combination of datasets for their Catchment Based Approach (CABA) which includes AMBER, River Obstacles and Prioritised River Obstacles to try and assess the impact of barriers on English rivers (CABA, 2023).

Despite AMBER having the most complete dataset for river barriers in Europe, they estimate that they have only recorded around half of all river barriers. Many barriers are old and forgotten, having fallen out of use but still remain in the river unrecorded.

Knowledge of the location and characteristics of river barriers is an imperative first step in identifying the state of river fragmentation, and subsequently informing mitigation actions aimed at restoring habitat connectivity (Atkinson et al., 2020). Therefore, our currently incomplete and fragmented inventory of obstacles highlights the need for a standardised river barriers database, as currently they have differing results and methods of categorisation and accessibility.

Barrier datasets

The rivers and streams of the UK contain numerous river barriers both historical and contemporary. Historically barriers were used to power mills, raise riverbed levels and redirect water courses. Today many are needed for transportation, drinking water supply and flood protection. AMBER (2020) estimate that there are currently 0.75 barriers per 1 km of river in Great Britain, and only 1% of rivers are free of artificial barriers. This has serious implications for habitat connectivity and the ability of aquatic wildlife to migrate up and downstream, creating isolated populations putting them more at risk of localised extinctions. Due to artificial barriers, only 3.3% of the total river network of Great Britain remains connected and would allow unrestricted movement of aquatic fauna (Jones et al., 2019).

The two most comprehensive datasets for river barrier numbers in the UK are AMBER and River Obstacles, although even between these datasets the number and types of barriers recorded vary considerably. River Obstacles records the total number of barriers in the UK at 55,876, whilst AMBER put this figure at 62,235 barriers. Therefore, WildFish have decided to combine the two datasets to try and establish a clearer picture of the barrier situation in the UK.

WildFish UK River Barrier Analysis

Methodology:

The two main barrier datasets (River Obstacles and AMBER UK) were accessed in September 2025 to get the most up to date information of as many UK river barriers as possible. Due to the size of the dataset, and the disjointed data collection of barrier locations it was assumed that many entries in the over 100,000 recorded were potential duplicates recorded in both the original datasets, and within each dataset (especially with the inclusion of citizen science data). Therefore, the decision was made to merge data points within a certain radius together. Where points were merged, the barrier information (which primarily consisted of the type of barrier) would be either the most common barrier type amongst the merged points or, if there were equal amounts of different barrier types, priority would be given first to point information from the River Obstacles dataset, then the AMBER dataset. This hierarchy was chosen due the River

Obstacles dataset being specific to the UK, rather than the Europe wide AMBER database, and it also being the most active and recently updated database. The decision of within what radius a barrier must be in relation to another barrier in order to be merged was another important point to consider. Barriers are often found in close proximity to each other, such as a series of locks to traverse a gradient, or culverts passing under human infrastructure. Therefore, too large a radius would result in the resolution of barriers being reduced. Inaccuracies in GPS devices, or user error in marking the location of difficult to reach or inaccessible barriers could also mean that too many duplicate barriers would survive the merge. A conservative decision of a 10m radius was used based on the accurate radius of a GPS enabled smartphone, which is between 5-10m, and most likely lowest accuracy GPS enabled device used to mark the location of river barriers (GPS.gov, 2025).

All river barrier datasets accept that they currently underestimate the number of barriers which exist in a river system (Fig. 4). Without in field confirmation of every single river barrier by walking the length of a river to identify hidden, submerged, or inaccessible barriers then it is almost impossible to record fully the true extent of river barriers. Ones et al. (2019) conducted a study of selected rivers in Great Britain, comparing river barrier records from EA records (Environment Agency, 2019), Scottish Obstacles to Fish Migration (SEPA, 2018), the Global Reservoir and Dam database (Grill et al., 2015) and the European 108 Environment Agency catchments and rivers network system (Ecrins) dam database (European Environment Agency, 2012) with on-the-ground, in-field observations from walking the length of the river. The study found that the existing barrier databases underreported compared to the true number of barriers present and thus underestimated stream fragmentation by at least 68%. Similarly AMBER estimates that its Europe wide dataset at best only covers half of existing barriers. Therefore, it is safe to assume that even with our conservative 10m radius for barrier merging, we are still massively underestimating the number of river barriers present in the UK.

Barriers were assigned by their origin into 3 categories: man-made, natural, and unknown. Barriers were also classified by type. Originally due to differences in naming standards between the 2 datasets there were over 20 different categories. To reduce clutter when mapping barrier types, they were sorted into 8 main categories: culverts, weirs, dams, fords, ramps/bed sill, sluice gates, locks, waterfalls, and other. Geological barriers

other than waterfalls, such as large boulders and landslips, were categorised as natural ramp/bed sill.
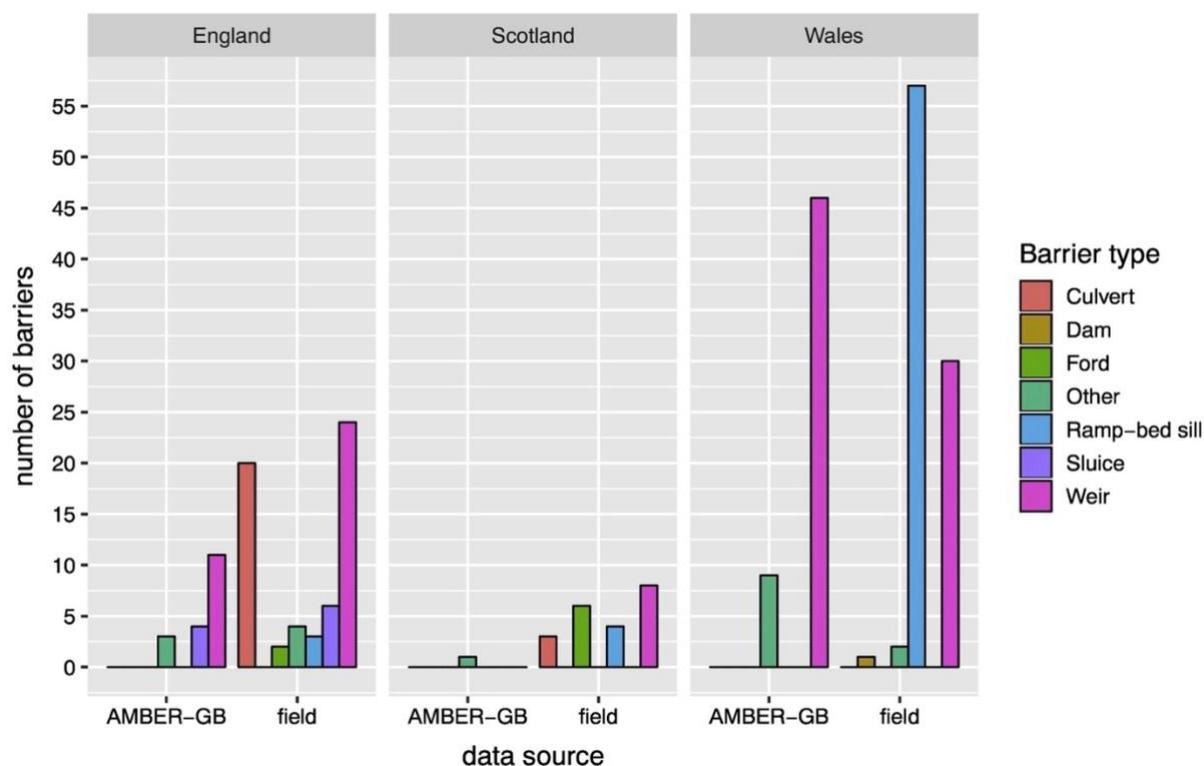
Fig. 4: Comparison between number of barrier types recorded in the AMBER Great Britain database and observed field validation. Total river length surveyed in England was 84 km, 113 km in Scotland and 106 km in Wales (Jones et al., 2019).

Following the merge process we were left with currently the most comprehensive list of river barriers in the UK to date. This allowed for statistical and spatial analysis of barrier locations and characteristics which can help identify problem areas, where habitat connectivity is being reduced, and inform people about the barrier situation in their local area. All work was done in ArcGIS Pro 3.4 (ESRI, 2025).

Results and Analysis:

A total of 70,652 river barriers were recorded in the UK. This total was 26% more than the River Obstacles estimate (55,876) and 14% more than the AMBER figure (62,235) highlighting the potential for underreporting of barriers which has been observed by Jones et al. (2019) previously.

Following the merge, 54,602 (77%) barriers were from the River Obstacles dataset, 14,916 (21%) from the AMBER database and 1,134 (2%) from the AMBER citizen science app. If the academic consensus that more than half barriers remain unrecorded it would be reasonable to assume that the true total number of barriers in the UK could be well over 100,000.
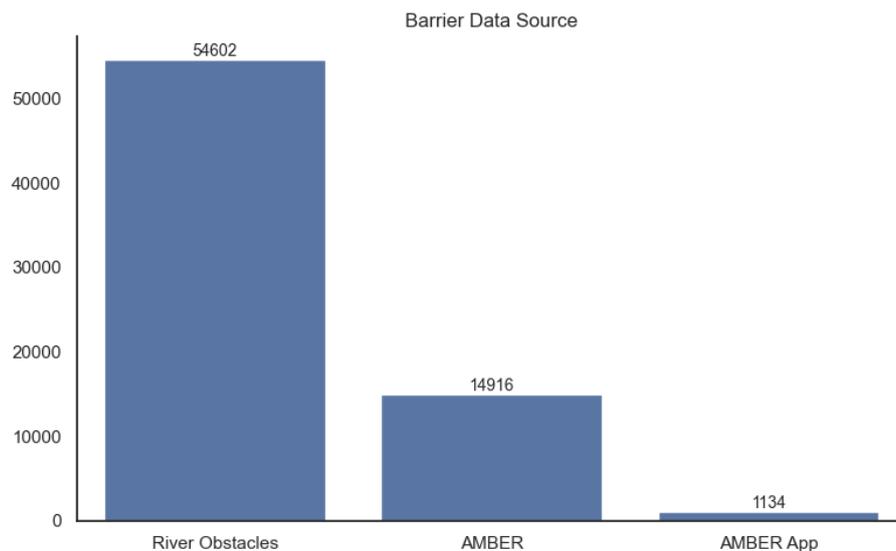
Barrier Origin:

The origin of river barriers in the dataset, whether they be natural, man-made or 'unknown' (where the barrier could not be identified – usually the case in citizen science data but also where this was left blank in the data recording) showed that man-made barriers were by far the most prevalent across the UK. 87.5% of barriers were recorded as being man-made in origin, compared to just 10.8% being natural. It is thus fair to assume that artificial man-man barriers on river are having a far greater impact on aquatic wildlife than natural barriers have ever had. No organisms are capable of adapting to such a large number of artificial barriers in comparison to their natural counterparts.
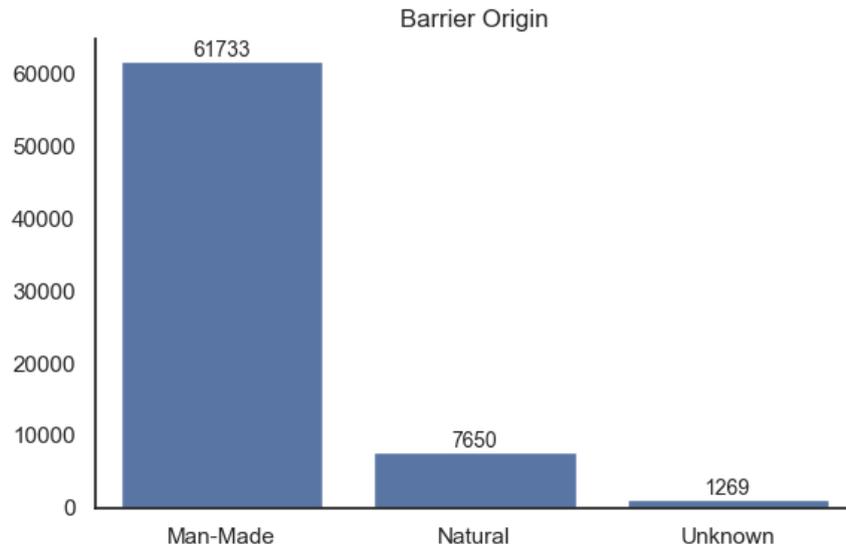
Barrier Density:

The density of man-made and natural barriers was then calculated. There was a distinct geographic separation between where natural and man-made barriers were observed. Natural barriers were most densely located in upland areas such as the Pennines, Lake District and Scotland, and in coastal cliffs in the south and north east. Man-made barriers were most common in urban areas with a history of industry such as Lancashire/Greater Manchester, The Midlands and South Wales. Such a distribution is to be expected, as upland areas are characteristic of rivers with steeper gradients and dramatic changes in topography, from both erosion and historical glacial activity. As a result natural features such as waterfalls and other geological barriers are more likely to be present here, and explains the concentration of most natural barriers in mountainous areas of the UK.

In comparison, man-made barriers were also as to be expected, more densely located in heavily urbanised areas. Cities such as Manchester, Liverpool, Cardiff, Swansea, Birmingham and London were all identified as man-made barrier hotspots. During the early Industrial Revolution, heavy goods were primarily transported by canals and other waterways, before the advent of rail and road transportation. As a result many barriers to control water levels and ensure rivers remained navigable were needed to move goods from industrial areas to the coast. However, as most freight now is transported by road, rail, or air, it highlights that many of these historical barriers may no longer be necessary, and their removal could

improve habitat connectivity without reducing infrastructure capacity. Further, roads are more numerous and denser in urban areas, and culverts were by far the most common type of barrier identified. Culverts are often used to direct waterways under roads and other urban infrastructure, and is likely another reason we see such high densities of barriers clustered around large urban areas.
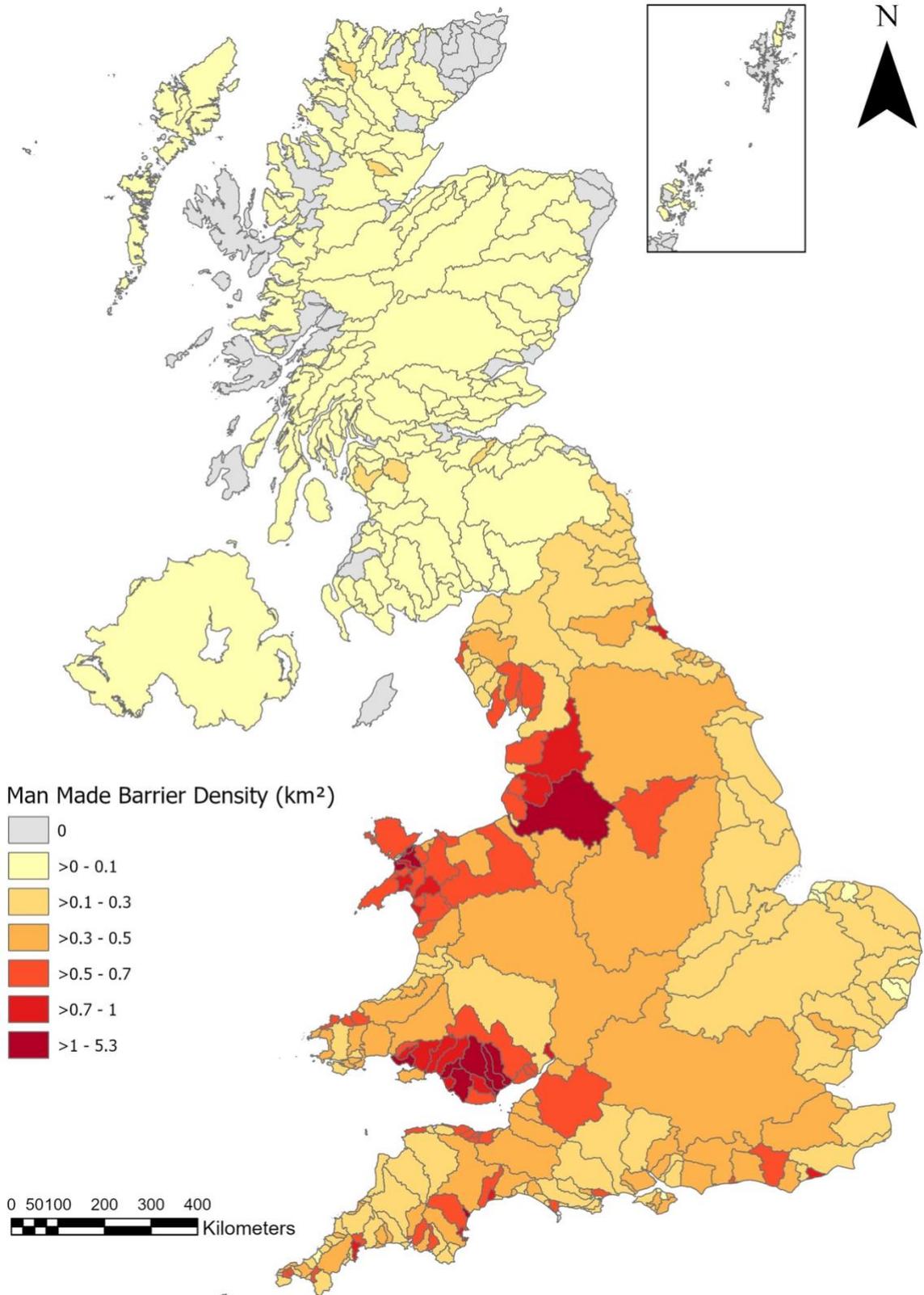
Man-made barrier density of UK river catchments

Man Made Barrier Density (km²)

- 0
- >0 - 0.1
- >0.1 - 0.3
- >0.3 - 0.5
- >0.5 - 0.7
- >0.7 - 1
- >1 - 5.3

0 50 100 200 300 400 Kilometers

Natural barrier density of UK river catchments

Natural Barrier Density (km²)

- 0
- >0 - 0.1
- >0.1 - 0.3
- >0.3 - 0.5
- >0.5 - 0.7
- >0.7 - 1
- >1 - 5.3

N

0 50 100 200 300 400
Kilometers
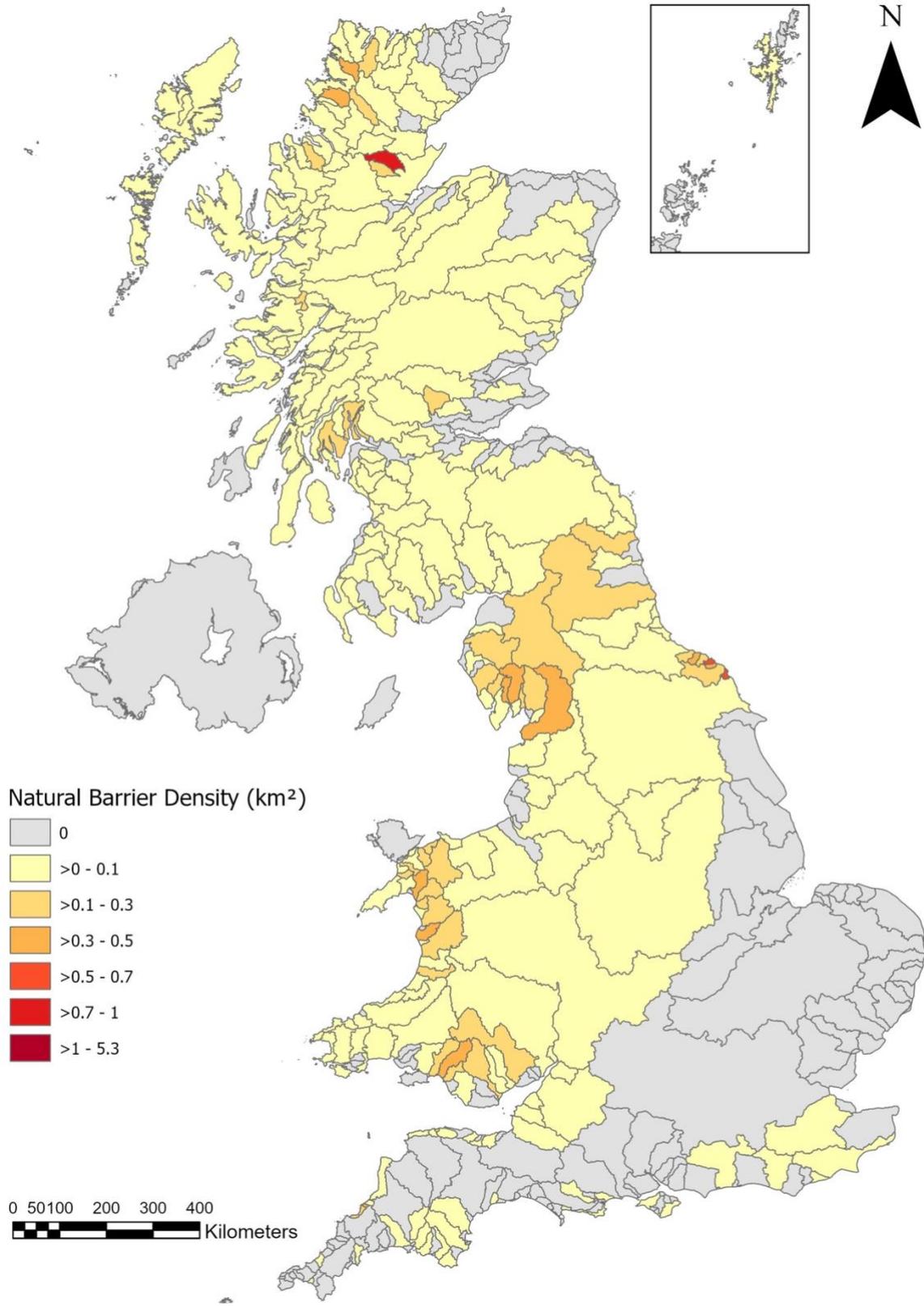
Man-made and natural barrier density per km^2 was then calculated for each river catchment in Great Britian (plus Northern Ireland as one singular catchment, due to the lack of data). Catchments were taken from the *Catchment boundaries for England, Scotland and Wales based on existing Fish Health Inspectorate (FHI) and SEPA catchments (BNG) 2023*, available from the Cfas data portal. Boundaries for river catchments in England, Scotland and Wales were based on the dataset Hydrological sections for England, Scotland and Wales with associated river catchment 2023, Water Framework Directive (WFD) waterbody and regional information British National Grid (BNG). Catchment boundaries were derived from hydrological sections, have boundaries almost identical to existing Fish Health Inspectorate river catchments, and include complete coverage of the waterbodies under the Water Framework Directive. There was a total of 599 river catchments.

This allowed to identify problem areas at a higher resolution, as well as providing a tool which local residents could use to learn more about the state of artificial river barriers in their area. A total of 13 river catchments had a man made barrier density of 1 per km^2 or more. 4 had barrier densities of over 2 per km^2, all located in Wales (Afan, University of Swansea, Groeslon and Menai).

The average artificial barrier density per catchment in the UK was 0.32 barriers per km^2. Density would be affected by the size of the catchment, and future work could calculate catchment density by wetted area of the catchment to provide a more accurate result, as current density estimates will be an underestimate. Catchments above this average were primarily located in Wales, Lancashire, The Midlands, Greater London, the South West.

The catchments with the most man-made barriers were the Thames, Severn, Trent Yorkshire Ouse and Mersey. The catchments with the most natural barriers were the Yorkshire Ouse, Tyne, Lune, Cumbrian Eden and Wye.

The 20 largest catchments and their statistics are shown in the table below. The full man-made and natural barrier counts and statistics for each county can be found in the appendix. The unusually low number for Northern Ireland, and the lack of individual catchments was due to lack of entries into the original datasets, highlighting a weak point in UK data collection.

Table 1: River barrier count and density of the 20 largest river catchments in the UK

Catchment Name	Catchment Area (km²)	Man Made Barriers	Man Made Density (km²)	Natural Barriers	Natural Density (km²)
Thames	13698	5940	0.43	64	0
Northern Ireland	13590	74	0.01	0	0
Severn	11018	4823	0.44	184	0.02
Trent	10646	4620	0.43	59	0.01
Ouse (Yorkshire)	9483	3902	0.41	897	0.09
Great Ouse	8368	1963	0.23	5	0
Tweed	5023	254	0.05	88	0.02
Tummel	4993	97	0.02	104	0.02
Wye	4199	1223	0.29	220	0.05
Witham	3363	715	0.21	3	0
Spey	2949	77	0.03	55	0.02
Tyne	2941	698	0.24	554	0.19
Mersey	2503	2851	1.14	95	0.04
Nene	2404	550	0.23	2	0
Eden (Cumbria)	2374	501	0.21	319	0.13
Avon (Bristol)	2313	1223	0.53	20	0.01
Dee (Wales)	2251	1154	0.51	86	0.04
Dee (Scotland)	2084	70	0.03	101	0.05
Lewis & South Harris	2019	74	0.04	66	0.03
Tees	2008	525	0.26	190	0.09

Barrier Types:

The original data sets used contained a variety of barrier characteristics which could provide more in-depth insights into barriers at a nation-wide scale. Characteristics included information such as the barriers height, width, usefulness (weather still in use or abandoned) and the presence of a fish pass. Unfortunately however, the number of barriers which contained this information in the final dataset was less than 2%, as most often when recording a barrier these options were left blank or marked as NULL meaning that little data of any significance could be gained. The only constant characteristic which was routinely recorded was the barrier type.

Natural Barrier Tyoes
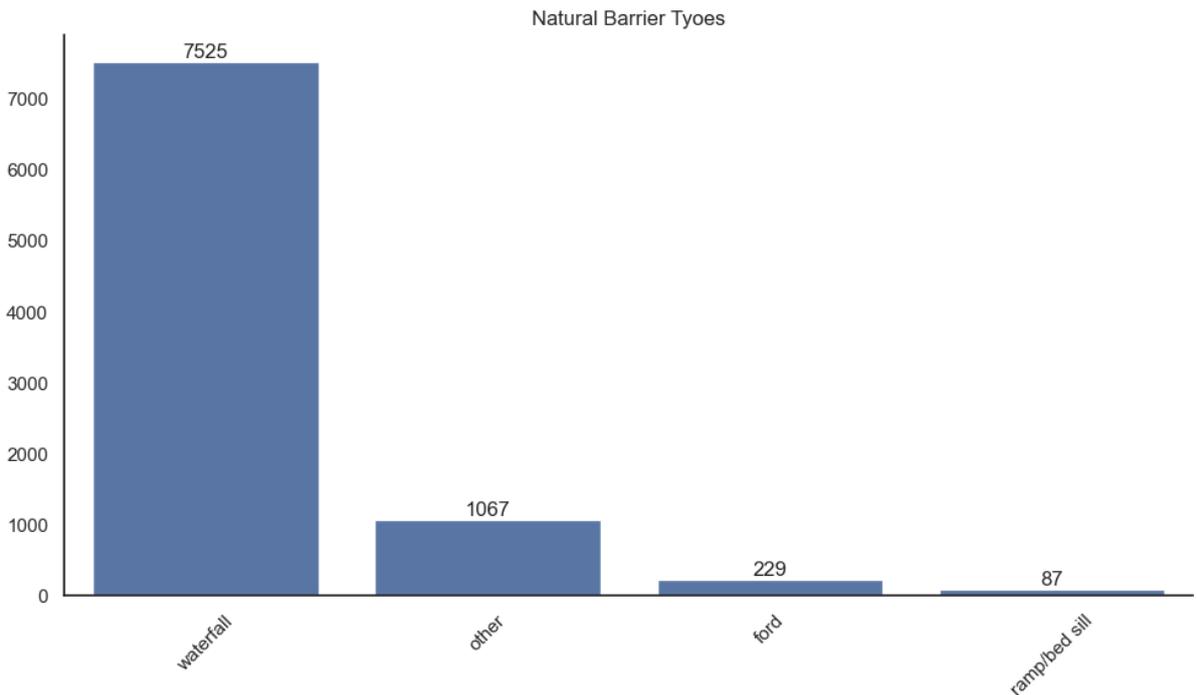
For natural river barriers, waterfalls are by far the most common type of barrier. Waterfalls accounted for 98.4% of all natural barriers. This is to be expected as waterfalls are the most common type of natural barrier globally, and what most aquatic species have adapted to crossing if the need arises, or will set the natural limits of species which cannot.

Man-Made Barrier Types
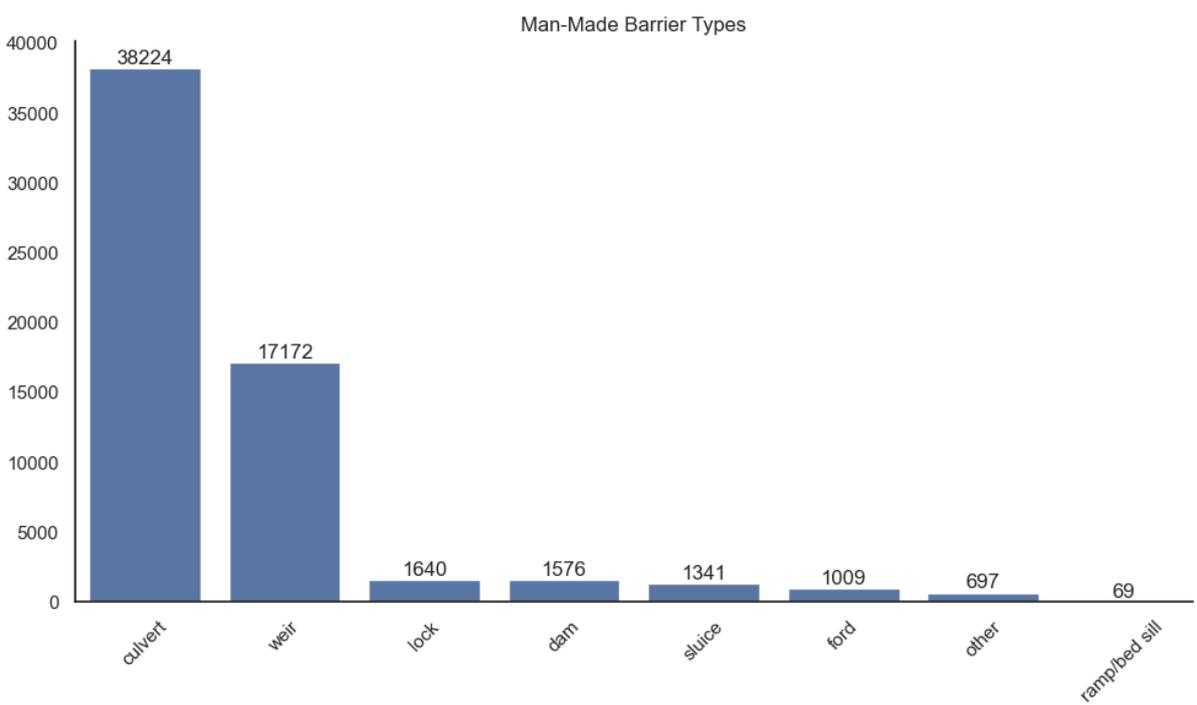
Culverts and weirs were by far the most common types of artificial barriers recorded in the UK, making up 61.9% and 27.8% of man-made barriers respectively. Dams, which many would consider the archetypal man-made river barrier, and what many people would envisage when considering an artificial river barrier made up just 2.6% of barriers. Therefore, when it is suggested that artificial river barriers are removed to improve habitat fragmentation and biodiversity, we are not primarily talking about large infrastructure projects such as dams, which are needed for water supply and green energy, but smaller obstructions such as culverts and weirs, which make up the majority of barriers in the UK. These are often unnecessary and would be far cheaper to remove which would have a greater cumulative effect on areas such as fish passage than focusing on several large dam projects. These numerous small barriers may actually have a far greater impact on habitat fragmentation, as whilst they can be passed successfully by aquatic wildlife, often without the need of fish passage solutions, they take a cumulative toll, meaning organisms have to expend energy at each barrier. Large barriers such as dams, whilst not ideal, can be somewhat mitigated by fish passage, but this is not feasible for smaller barriers such as culverts and weirs due to their large numbers.

Each individual barrier type was then grouped by their corresponding river catchment, allowing us to see the spatial distribution and quantity of different barrier types across the UK:

Culverts in UK river catchments

Culvert Count
- 0
- 1 - 10
- 11 - 25
- 26 - 50
- 51 - 100
- 101 - 250
- 251 - 500
- 501 - 750
- 751 - 1000
- 1001 - 3500

0 50 100 200 300 400
Kilometers

Weirs in UK river catchments

Weir Count
- 0
- 1 - 10
- 11 - 25
- 26 - 50
- 51 - 100
- 101 - 250
- 251 - 500
- 501 - 750
- 751 - 1000
- 1001 - 3500

0 50 100 200 300 400
Kilometers

Dams in UK river catchments

Dam Count
- 0
- 1 - 10
- 11 - 25
- 26 - 50
- 51 - 100
- 101 - 250
- 251 - 500
- 501 - 750
- 751 - 1000
- 1001 - 3500

0 50 100 200 300 400
Kilometers
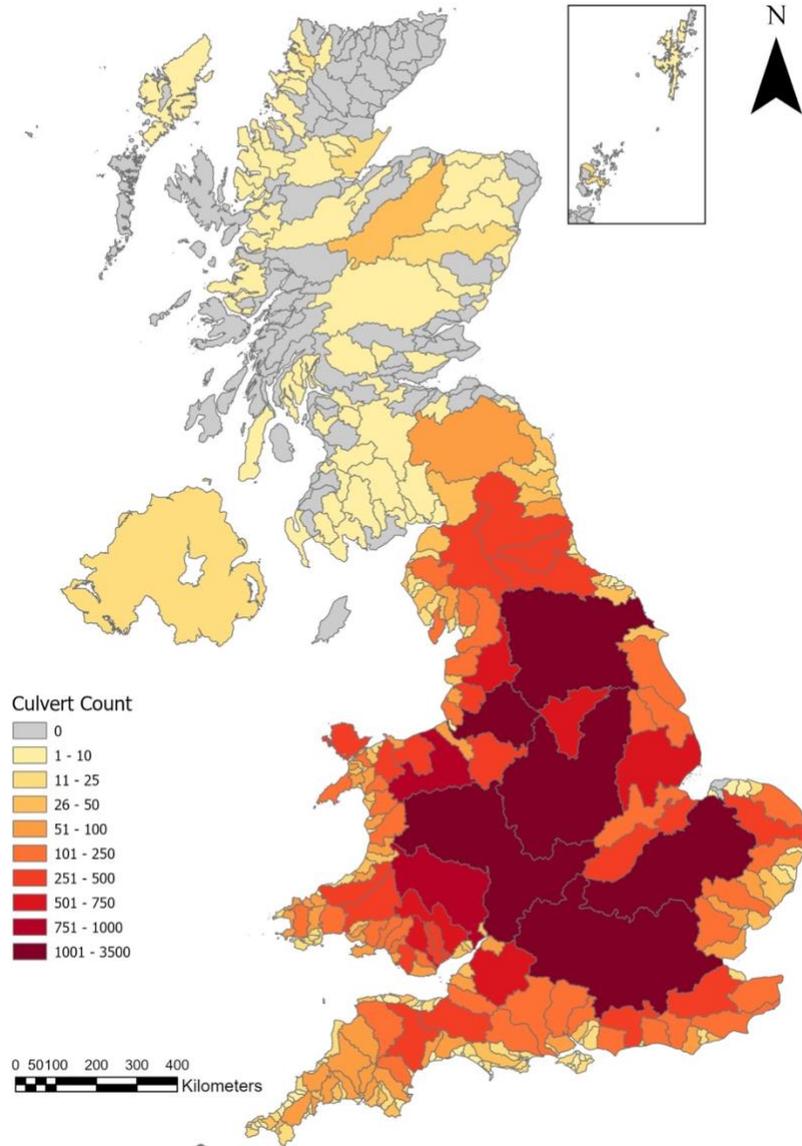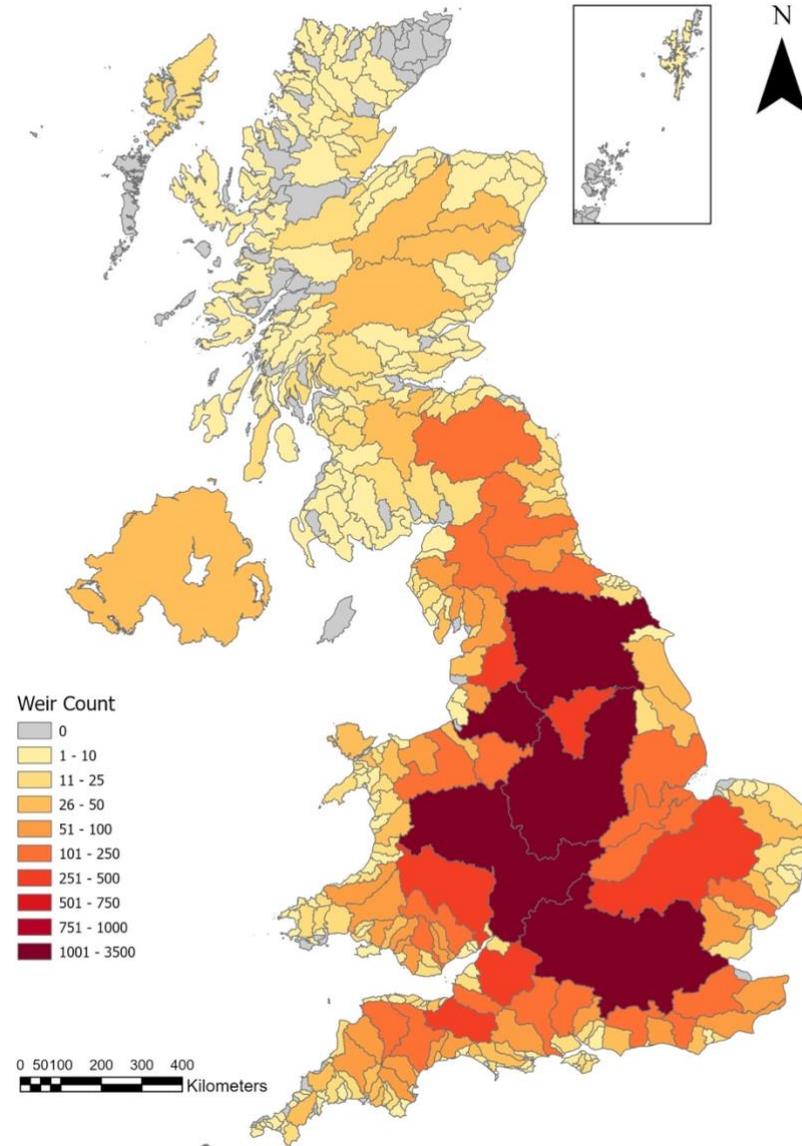
Sluices in UK river catchments

Sluice Count
- 0
- 1 - 10
- 11 - 25
- 26 - 50
- 51 - 100
- 101 - 250
- 251 - 500
- 501 - 750
- 751 - 1000
- 1001 - 3500
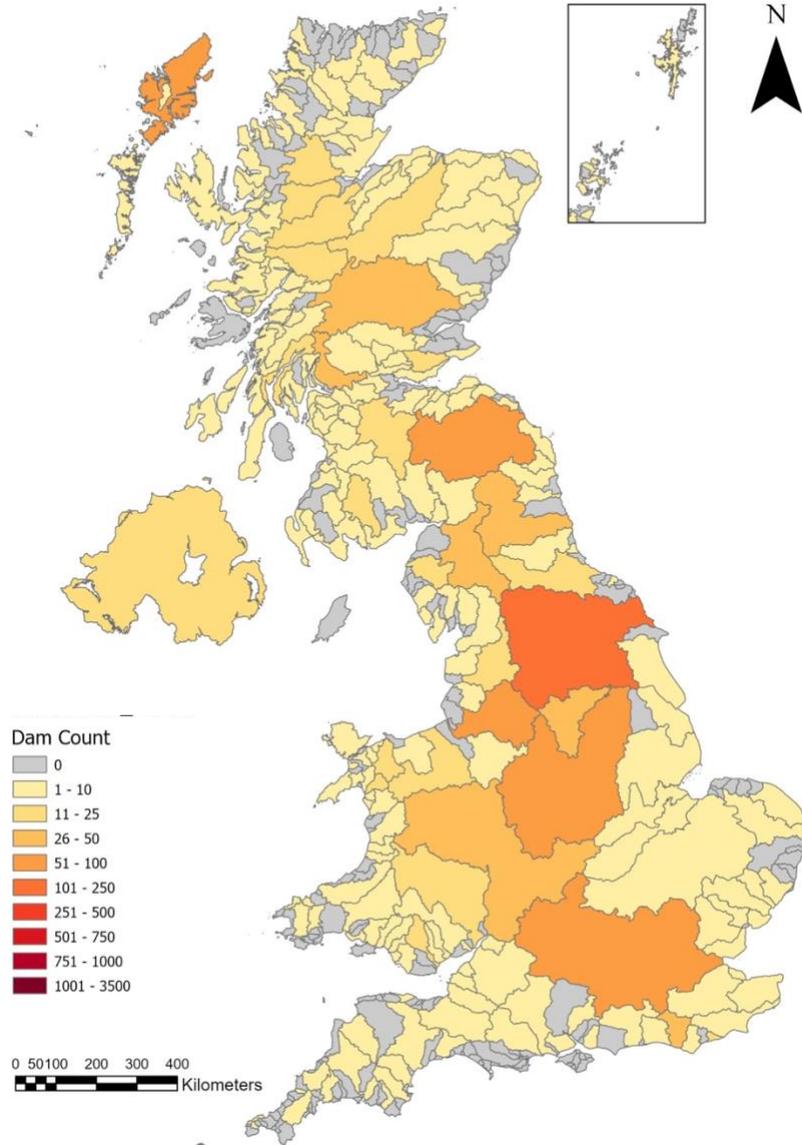
0 50 100 200 300 400
Kilometers
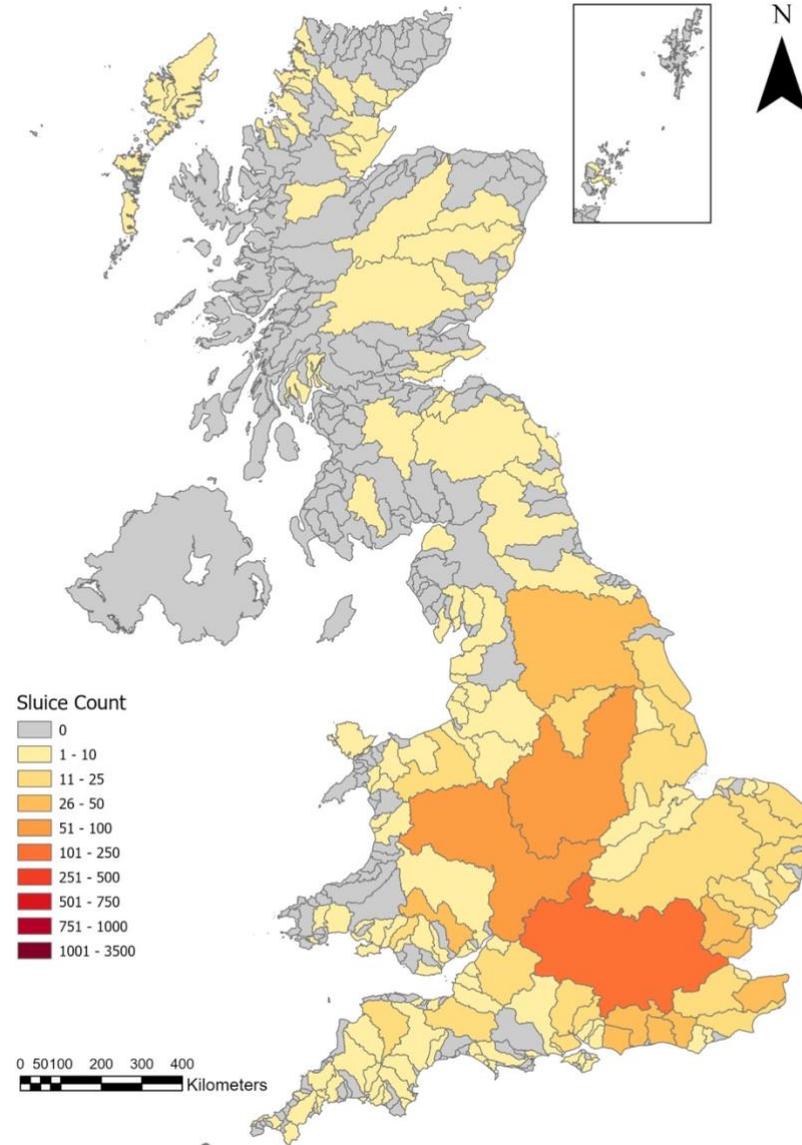
Locks in UK river catchments

Fords in UK river catchments

Lock Count
- 0
- 1 - 10
- 11 - 25
- 26 - 50
- 51 - 100
- 101 - 250
- 251 - 500
- 501 - 750
- 751 - 1000
- 1001 - 3500

Ford Count
- 0
- 1 - 10
- 11 - 25
- 26 - 50
- 51 - 100
- 101 - 250
- 251 - 500
- 501 - 750
- 751 - 1000
- 1001 - 3500

0 50 100 200   300   400
Kilometers

0 50 100 200   300   400
Kilometers
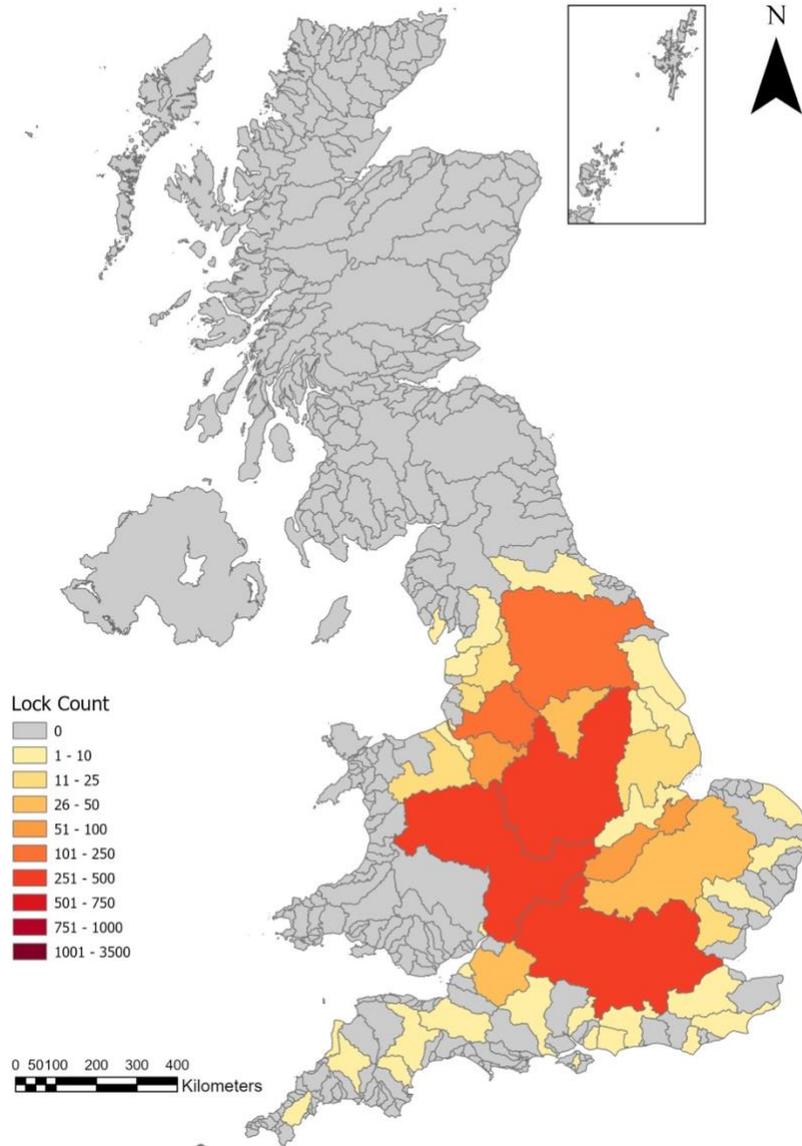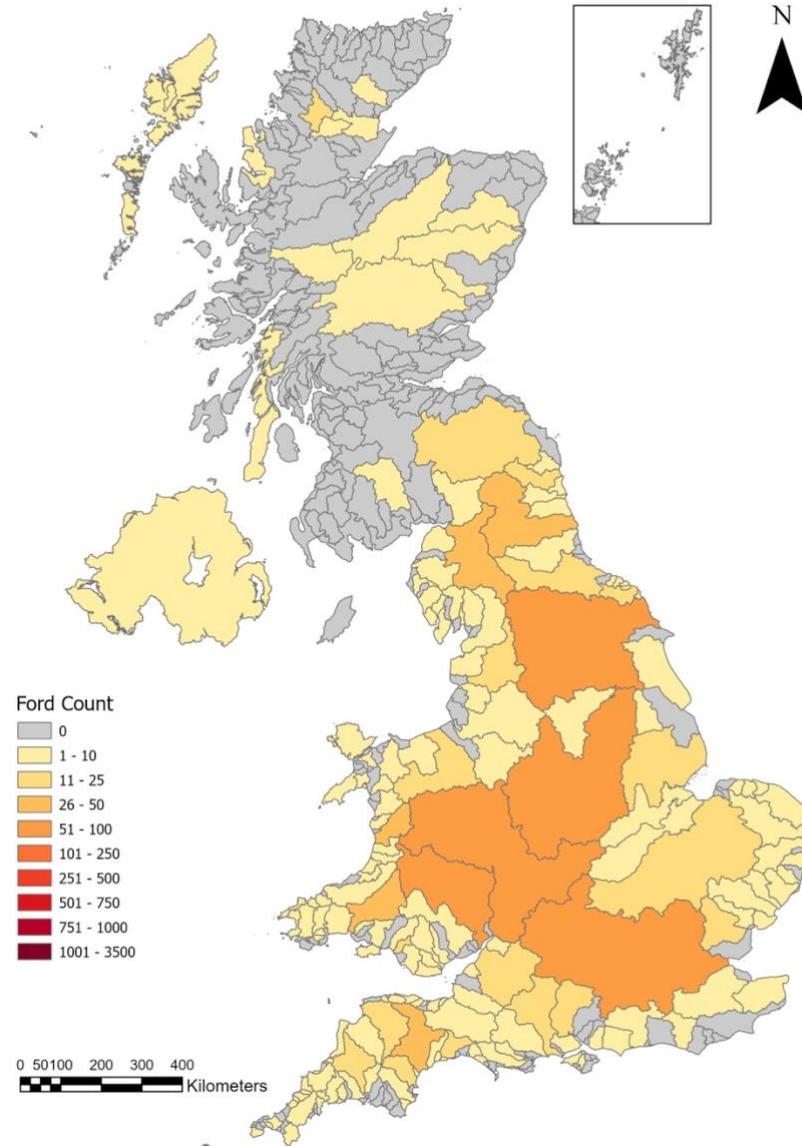
Waterfalls in UK river catchments

Waterfall Count
- 0
- 1 - 10
- 11 - 25
- 26 - 50
- 51 - 100
- 101 - 250
- 251 - 500
- 501 - 750
- 751 - 1000
- 1001 - 3500

0 50 100 200 300 400
Kilometers
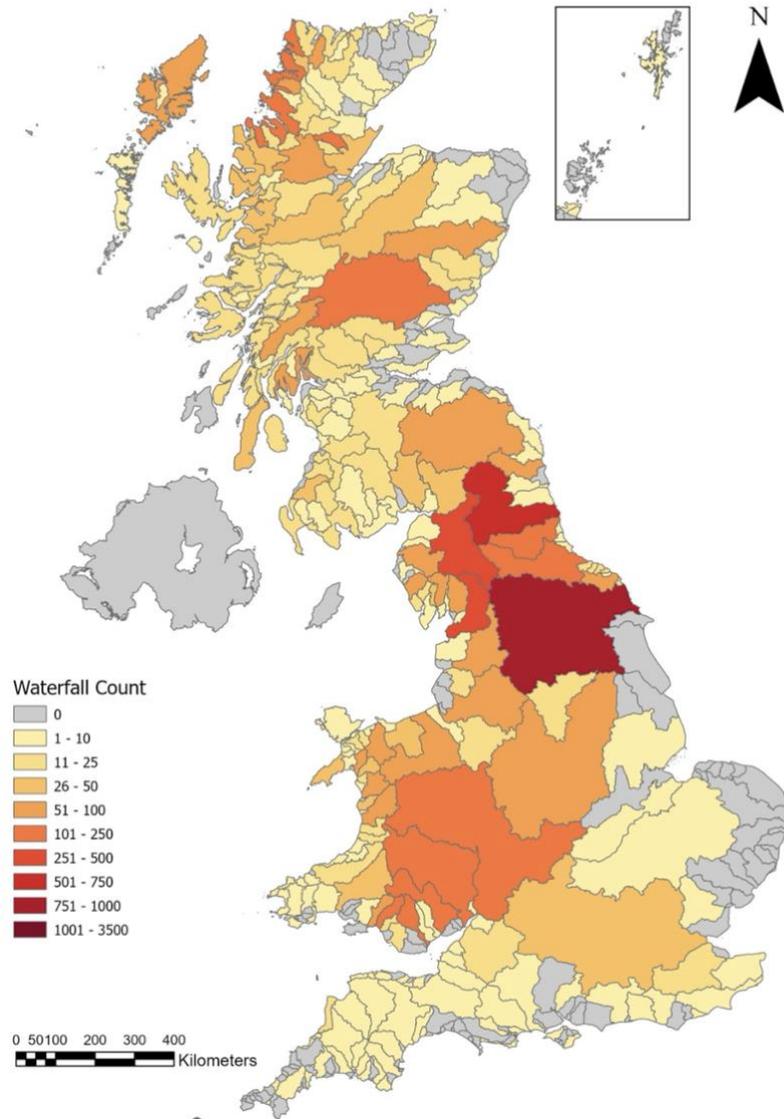
Ramp/Bed Sills in UK river catchments

Ramp/Bed Sill Count
- 0
- 1 - 10
- 11 - 25
- 26 - 50
- 51 - 100
- 101 - 250
- 251 - 500
- 501 - 750
- 751 - 1000
- 1001 - 3500

0 50 100 200 300 400
Kilometers
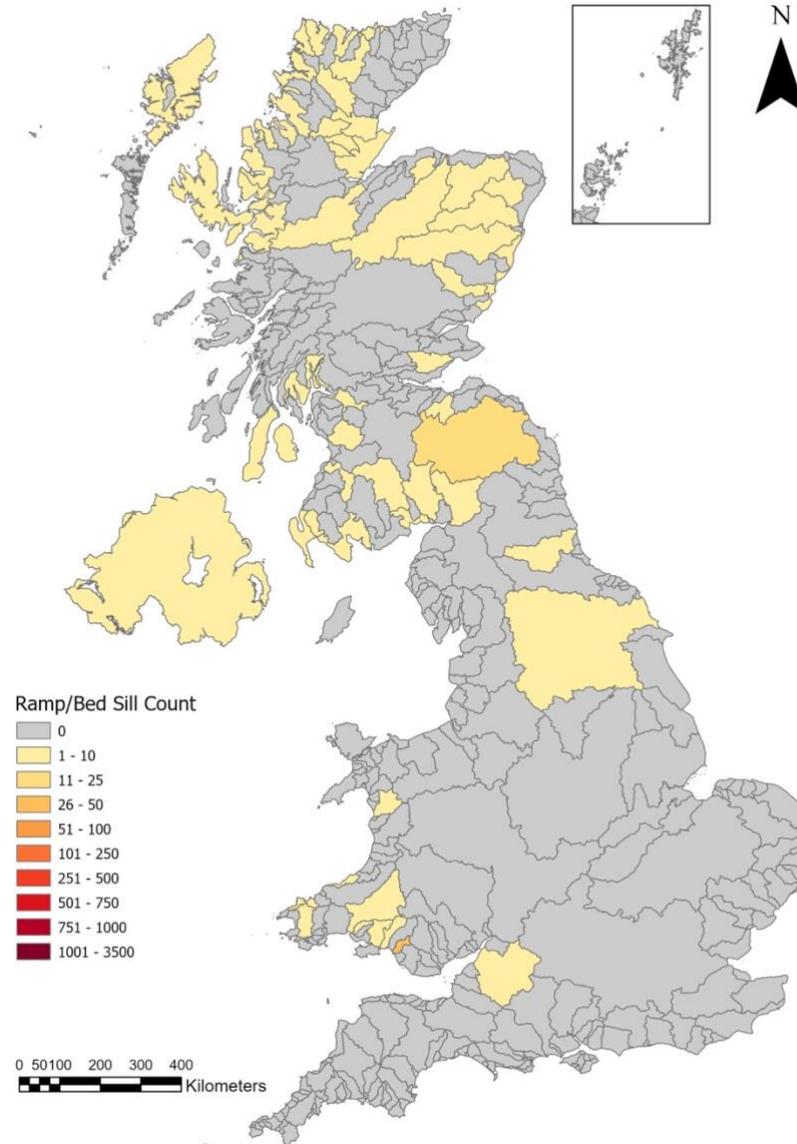
"Other" barrier types in UK river catchments

N

Other Count
- 0
- 1 - 10
- 11 - 25
- 26 - 50
- 51 - 100
- 101 - 250
- 251 - 500
- 501 - 750
- 751 - 1000
- 1001 - 3500

0 50 100   200   300   400
Kilometers
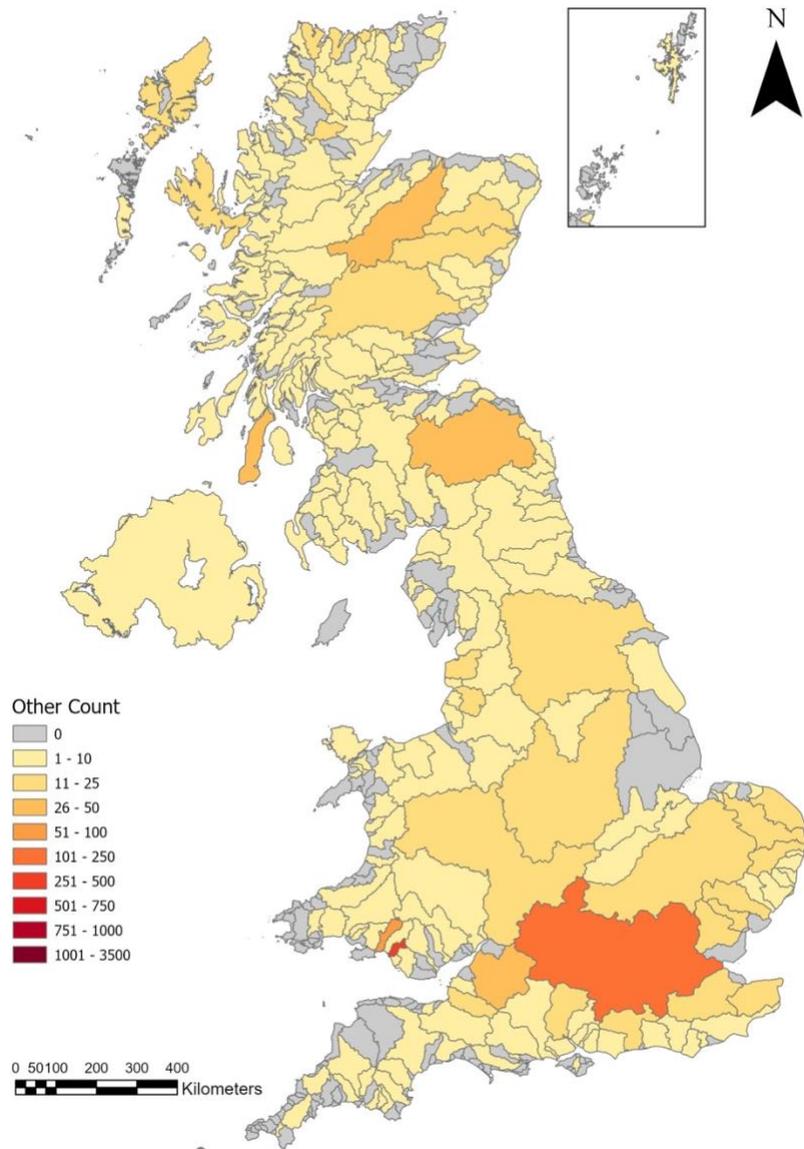
The data shows that the distribution of different types of barriers varies geographically across the UK. Culverts (the most common type of barrier) are predominantly found in England and Wales and are found in large numbers across most of the two countries. Weirs are again mostly located in England and Wales, but have a stronger tendency to be found in historically industrialised areas across Lancashire, Yorkshire, The Midlands, Wales, and Greater London, as well as The South West. Sluices/Locks are less prevalent in Wales than weirs, but follow a similar distribution, although more strongly correlated to the canal network, explaining their lower numbers in Wales. Dams are mostly found in upland terrain such as Northern England and especially Scotland, where they are more suited to power generation and water retention in existing valleys, or necessary due to the steep terrain. Fords are found mostly in Northern England, Wales and the South West, due to their more rural location, but with sufficient population to necessitate road river crossings, in comparison to Scotland which is less densely populated. Waterfalls and ramp/bed sills were found in upland areas, as is to be expected as the barrier types most likely to be natural, and shaped by the more varied topography found in areas of Wales, Northen England and Scotland.

Conclusions:

WildFish have created to date the most complete inventory of river barriers that exist in the UK, detailing the location and type of 70,652 river barriers. 61,733 (87.5%) were artificial barriers, 7,650 (10.8%) were natural and 1269 (1.8%) were of unknown origin. The most prevalent type of barrier was by far culverts totalling 38,224 which accounted for 62% of all artificial barriers and 54.% of all river barriers. The second most common barrier type were weirs, with a total of 17,172 accounting for 27.8% of all man-made barriers. The third most occurring barrier type were waterfalls, with a total of 7,525 and 98.4% of all natural barriers.

The average artificial barrier density per catchment in the UK was 0.32 barriers per km^2. Catchments above this average were primarily located in Wales, Lancashire, The Midlands, Greater London, the South West. The catchments with the most man-made barriers were the Thames, Severn, Trent Yorkshire Ouse and Mersey. The catchments with the most natural barriers were the Yorkshire Ouse, Tyne, Lune, Cumbrian Eden and Wye. A total of 13 river catchments had a man made barrier density of 1 per km^2 or

more. 4 had barrier densities of over 2 per km^2, all located in Wales (Afan, University of Swansea, Groeslon and Menai).

These numbers are alarming, 26% more than the River Obstacles estimate (55,876) and 14% more than the AMBER figure (62,235. What is even more concerning is that most academics believe we are still severely underestimating the number of river barriers globally, so it is likely that this total number is even higher than what we have found. However, this dataset is the first step, and builds on work done by AMBER, the Environment Agency and other NGOs in creating a database which accurately reflects the state of river barriers in the UK. We have found most river barriers are culverts, most often small and easily removed, which could easily begin to improve habitat fragmentation seen in UK rivers. When we talk about barrier removal, this can be low cost and scale, and will still provide real benefits to aquatic wildlife. It is hoped that this data can be paired local knowledge about individual catchments, river and streams to identify barrier hotspots and problem areas, and target barrier removals can take place to improve stream passage in the most efficient way possible.

Barriers in Europe (AMBER)

The AMBER European Atlas of river barriers is to date the most comprehensive database for river obstructions in all of Europe (including the UK). Currently over 600,000 barriers have been identified through a combination of citizen science reporting, existing government and commercial datasets and in field validations. Despite this, AMBER estimate the over 600,000 barriers already recorded represent at most half of the total number of in stream barriers; there could be well over one million artificial barriers across Europe (AMBER, 2020).
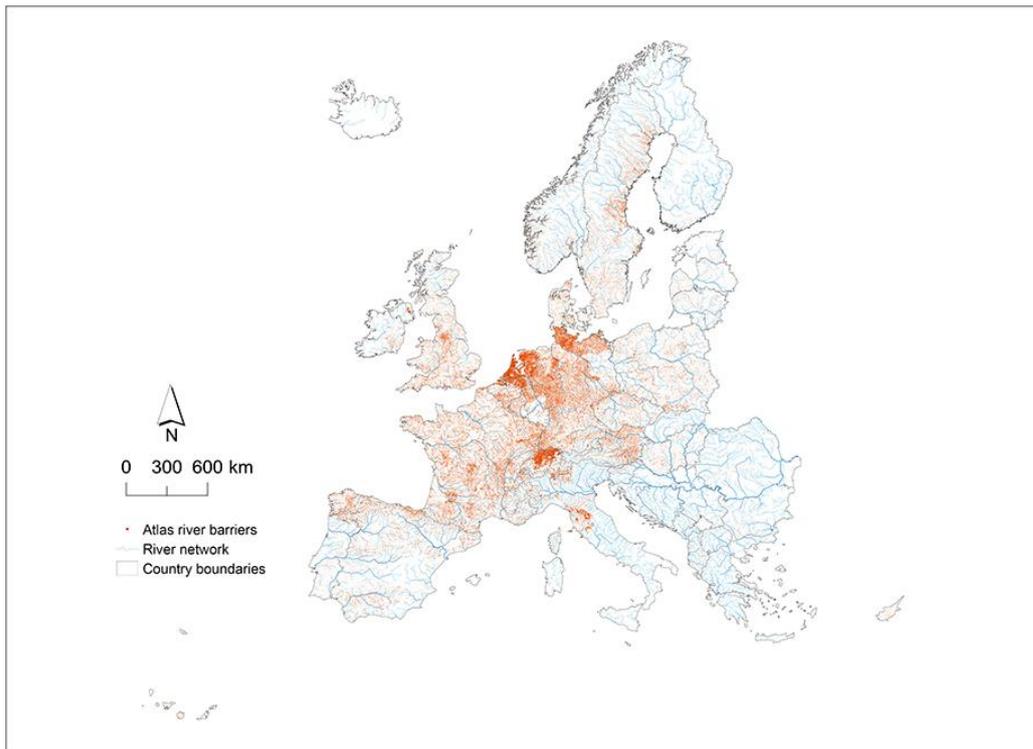
Fig. 5: Compilation of 630,000 unique barrier records from existing datasets in the AMBER database. Another 400,000 additional barrier points locations are being modelled and will be added to the dataset in the future.

Amber Atlas Data Europe - Barrier Types
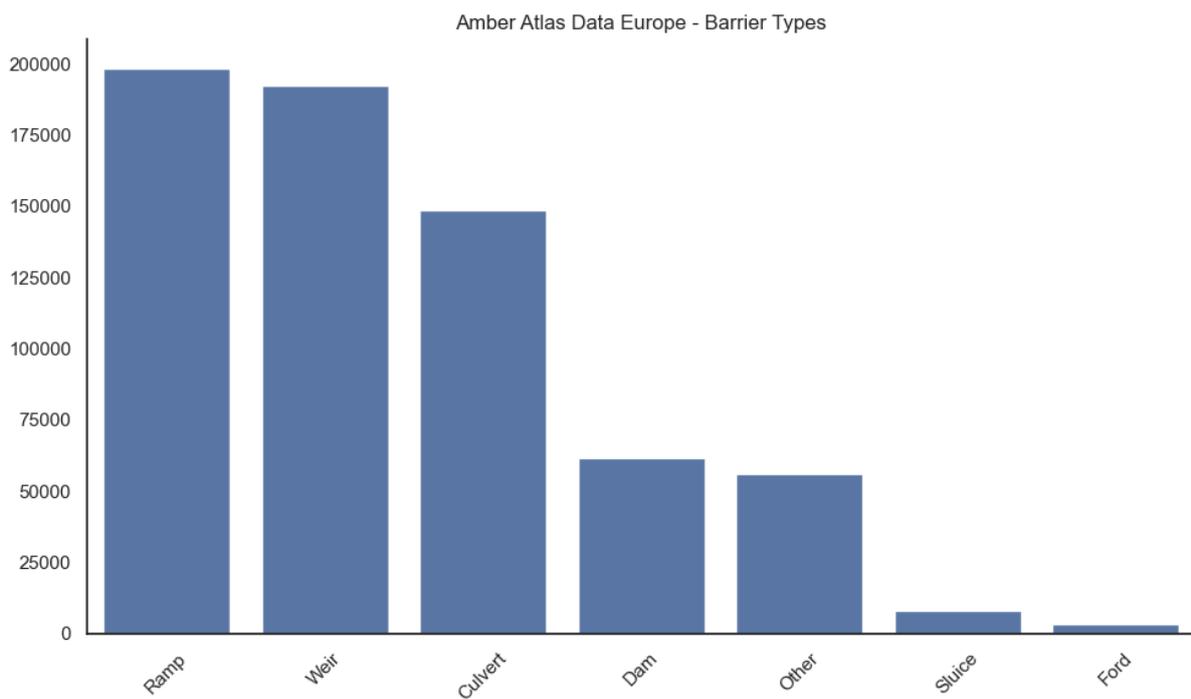
The AMBER Atlas European dataset reported a total of 668,868 river barriers. The wider European perspective is similar to the UK, with culverts and weirs again being 2 of the most common types of barriers however, ramps/bed sills were reported as the most common form of barrier accounting for 29.7% (198,591) of barriers in Europe. One explanation for the discrepancy between the European and UK data could be explained by the higher volumes of good transported via inland waterways in continental Europe compared to the UK. In the UK it was estimated that for 2020 24.7 million tonnes of goods were transported by inland waterways, comparison to the annual average of 400 million tonnes transported on the Rhine alone (Department for Transport, 2020; ICPR, 2021). River ramps/bed sills are often used to control bank erosion in navigable waterways which are more prevalent in Europe, especially the Netherlands which also has the most comprehensive inventory of river barriers. Ramps are often used as flood defence mechanisms in urban rivers and land reclamation, again most common in the Netherlands which may explain some of the large numbers of recorded ramp/sill beds.

The limitations of barrier datasets

Limitations exist within such datasets trying to identify river barriers. While the use of citizen science recording is an acceptable way to collect large volumes of data it is important to note this will not be 'expert' recording and may not accurately identify and record all river barriers and their characteristics. This can be seen in the AMBER app datasets where 'other' is by far the largest category, in contrast to the official datasets which highlight small obstacles such as culverts, weirs and ramps as the most common types of barriers. This would most likely be explained by non-expert users being unable to identify barrier types as they have not received any formal training and/or do not possess the knowledge of different types of barriers. Further, not all barriers are permanent, with many being used temporarily for numerous infrastructure, industrial and agricultural reasons and so may not be properly recorded. Finally, chemical barriers may be invisible, and near impossible to identify without instream monitoring of water chemistry or temperature, which is costly. Monitoring of the whole length of river networks would likely be practically impossible. Therefore, chemical and thermal barriers are an important topic for further study to see how we can better monitor these potential

barriers to aquatic migration in real time and, in the future try to incorporate them into existing barrier databases.

River barriers effects on wildlife

Habitat connectivity

One of the main effects of anthropogenic river barriers is to habitat connectivity, causing fragmentation of river systems for aquatic organisms. Large areas of watersheds/catchments have lost fish species, especially diadromous fish due to anthropogenic barriers disrupting migration routes. Although it's important to remember all fish species need to move within rivers, just to differing degrees. River barriers have also shifted the distribution of accessible aquatic habitat reducing the diversity, accessibility and quantity of high quality habitat locations (Sheer & Steel, 2006).

From a legislative perspective, the presence of barriers is important for determining the hydromorphological status of a river in terms of hydrological regime, continuity and morphological condition when being assessed by the EU Water Framework Directive (EEA, 2000) as now assimilated into UK law.

Habitat fragmentation from natural river barriers has been part of wide scale hydrological and geological change throughout history. For example, fossil records and other environmental proxies have shown that rivers became isolated when the English Channel (which was previously a series of river basins) flooded at the end of the last glacial maximum ca. 7000 B.C. The new salt water channel experienced higher extinction rates than rivers further inland which remained connected (especially for fish which were not tolerant to a range of salinity). This is due to an inverse relationship between extinction probability and population size (Hugueny et al., 2011). As fragmentation isolated populations into smaller units, the chance of extinction increased. Naturally, such largescale fragmentation events are rare. They are important in species diversity as natural fragmentation can create niche environments for specifically-adapted organisms to evolve or persist. However, the massive global expansion of anthropogenic river barriers has led to habitat fragmentation on a scale not seen before with over half of the world rivers now no longer free-flowing (Grill et al., 2019).

Habitat connectivity can be measured using the Dendric Connectivity Index (DCI). It is an index of river connectivity calculated from stream length, which assesses the probability that a fish may move between two

points in a river network (Fig 6). In a river system with no barriers, the DCI would have a maximum value of 100. The introduction of a single barrier would create two stream sections and the DCI would be dependent on the total channel length and the permeability of the new barrier in both upstream and downstream locations (Cote et al., 2009). Further, the DCI of a fragmented river system would change depending to what species of fish were being considered. With diadromous fish the location of the barrier relative to the downstream end is also considered.
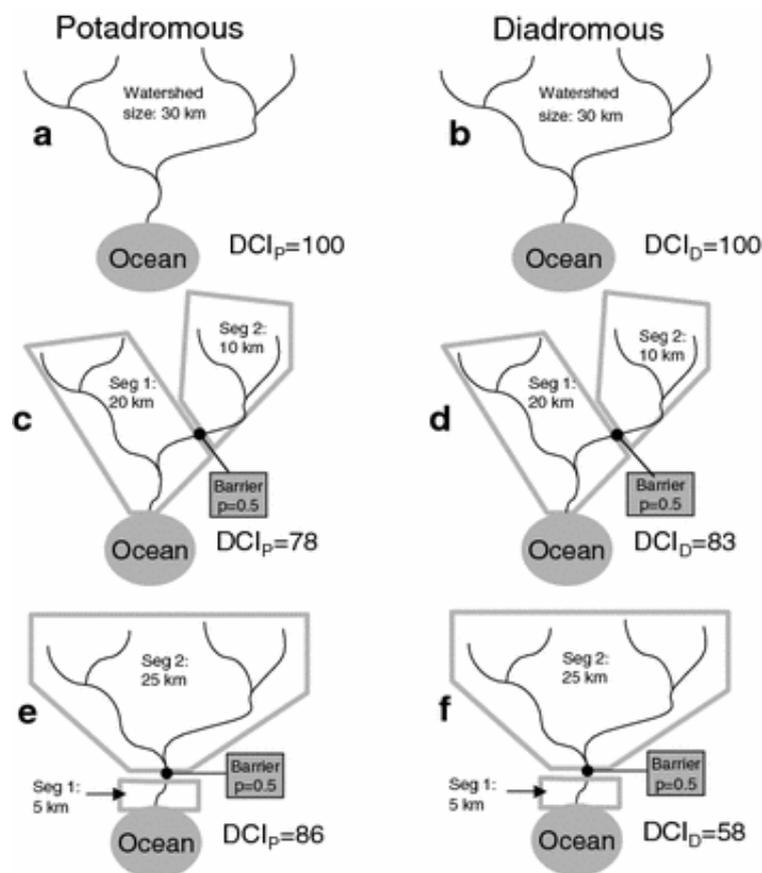
Fig. 6: DCI for a river system with barriers in different locations for potadromous (**a**) and diadromous (**b**) fish. (Cote et al., 2009)

The theory of island biogeography has been the central tenet of conservation biology for several decades. Continental landscapes are viewed islands of suitable habitat patches embedded in a matrix of unsuitable habitat (J. F. Franklin & Lindenmayer, 2009). This can also be applied to river systems affected by barriers. River barriers and impoundments would be seen as matrix habitat as, whilst aquatic life can

live there, it is an unnatural environment and not suitable for local species previously adapted to free-flowing river conditions (much like urban areas or agricultural land). Patch habitat therefore becomes fragmented by less suitable matrix habitat. Fuller et al. (2015), expands on this concept further, suggesting the existence of edge habitat at the boarders between matrix and patch habitats (Fig. 7). Therefore, the effects of river barriers on habitat quality may stretch even further beyond their immediate boundaries as hydrological conditions from a dam and impoundment will alter flow regime upstream and downstream beyond the boundaries of the initial reservoir. Introduction of new predatory species, changes in channel morphology, and changes water chemistry can encroach into patch habitat further reducing connectivity and putting greater stress on the fish populations which survive there.
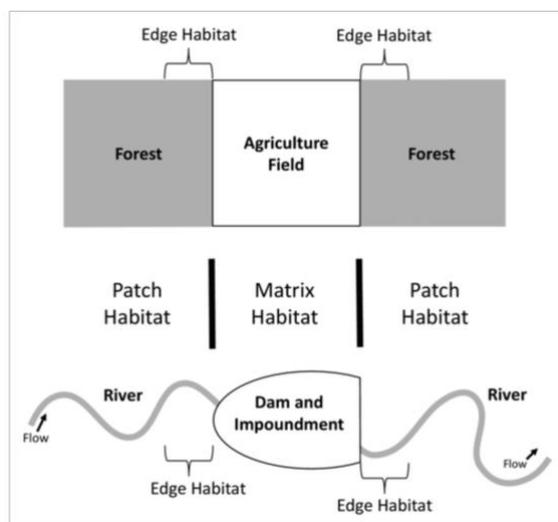
Fig. 7: Analogous parts of a terrestrial forest and a river split by a single fragmentation agent (agriculture field and impoundment, respectively). Patch and matrix habitat are labelled accordingly and locations for potential edge habitat are bracketed. (Fuller et al., 2015)

Salmonids

Diadromous fish populations are perhaps most strongly affected by the presence of barriers within river networks. Barriers cause habitat fragmentation, constrain productivity by reducing the range in which fish can search for prey or maintain territory and prevent completion of their lifecycle mainly via constricting migration pathways (Buddendorf et al., 2019). River barriers have been identified as one of the leading causes of

global declines in many migratory fish species, including lampreys (Baras & Lucas, 2001; Limburg & Waldman, 2009; Renaud, 1997). Negative impacts on diadromous fish populations are most pronounced when watercourses are traditionally dammed. However, the cumulative effect of numerous smaller river barriers, such as those often seen in the UK's rivers can also have significant impacts, albeit over a longer time period dependent on barrier density and seasonal or annual variations in river flow (Lucas et al., 2009; Nunn et al., 2008; Nunn et al., 2010).

Diadromous fish need to migrate from spawning and nursery habitats found far upstream in river tributaries to large downstream lakes and the sea to feed and grow in the latter stages of their lifecycle. Atlantic salmon, in particular, have been affected by habitat fragmentation caused by river barriers which along with a host of other environmental stressors has seen them moved onto the ICUN's 'red list' of threatened species as of December 2023. Numerous scientific studies have documented significant population decline of Atlantic salmon in rivers which have had their flow regulated by in-stream barriers (Jonsson & Jonsson, 2011; MacCrimmon & Gots, 1979; Parrish et al., 1998).

In-stream barriers effect the migration and movement of diadromous fish to and from spawning and rearing habitats in three different ways:

1. Firstly barriers can limit the number of fish being able to move between these habitat types, creating genetic bottlenecks in smaller localised populations (Brown et al., 2013; Holbrook et al., 2011). Even accessibility interventions at barriers such as fish passes will limit the number of fish being able to successfully traverse the obstacle as they do not provide 100% passability.

2. Secondly, fish can be delayed on their migrations by river barriers (Nyqvist et al., 2017; Venditti et al., 2000). This may be because fish must wait for ideal flow conditions to be able to successfully traverse barriers, that they need to adapt a successful route through barriers (such as using a fish pass) or they need to expend more energy than previously needed after the installation of barriers. This can affect the timings of fish spawning and lead to lower chances of egg survival

due to climatic and hydrological conditions (which are already increasing in unpredictability due to climate warming).

3. Finally, barriers can prevent movement and migration of fish altogether (Gephard & McMenemy, 2004). This happens where there is no way for fish to traverse the barrier successfully and can lead to localised extinctions upstream of the barrier (Birnie-Gauvin et al., 2017; Sun et al., 2022). Research has shown with confidence that variation in fish assemblage composition due to obstructions is reflected by the absence in variation or abundance of migratory fish species upstream of barriers.

There are numerous potential interventions to reduce the impact of river barriers on migratory fish species. Fish passages, movable weirs, and fish friendly flap gates are all options which can increase the passability of a barrier (Nunn & Cowx, 2012). The complete removal of barriers however, is associated with the most unambiguous benefits. In many cases this is not economically or practically viable which necessitates the development of novel passage solutions and enhanced management of existing barriers (Buddendorf et al., 2019; Nunn & Cowx, 2012). Where local salmonid populations have been monitored before and after dam removals there has been significant and often rapid recolonisation of previously inaccessible habitats and population increase. The Adour River in south west France saw Atlantic salmon catch numbers crash from 10,000 per year at the start of the 20th century to just 500 in 1976 (Barracou, 2008; Marty & Bousquet, 2001). A large hydroelectric power plant constructed in the 1940s was identified as the leading cause of habitat fragmentation and subsequent salmon decline (Perrier et al., 2014). However, a sustained program of dam removals and installation of fish passes, as well as a supplementary stocking program, saw returning adults increase to 6,500 per year by 2008 (Barracou, 2008). Today the Adour River is the most productive salmon basin in southern Europe, and larger than many northern European salmon runs. Salmon numbers on the Adour have recovered to the extent that it is the only river in France where wild salmon can be commercially fished (Produits de Nouvelle Aquitaine, n.d.).

In Washington State, the Elwah River dams completely disconnected the upper and lower watersheds for over 94 years, reducing potential salmonid

habitat by 90% (Pess et al., 2008). In 2014, two of the largest dams were removed from the river and within 5 years, the maximum upstream ranges of adult Chinook Salmon and Summer Steelhead had increased by 50 km and 60 km respectively (Duda et al., 2021). Similar studies also measured the increase in habitat suitability for salmonids following dam removal. On the Boquet River in New York State, the Willsboro Dam was removed in 2015. Habitat suitability was assessed by measuring river depth, velocity and substrate size at redd sites. Following dam removal, the mean and variance in depth at redds decreased, as did the variance in substrate size, increasing the habitat suitability for salmonid spawning within two years (Hill et al., 2019). Dam removal, whilst extremely costly, shows near instant benefits for migratory fish species and should be prioritised above all other options.

Potamodromous migration

Although the migrations between habitats for potamodromous fish species like resident brown trout (*S. trutta*) are not as striking as diadromous species, they nevertheless serve an important role in the survival and fitness of individuals (Atkinson et al., 2020)
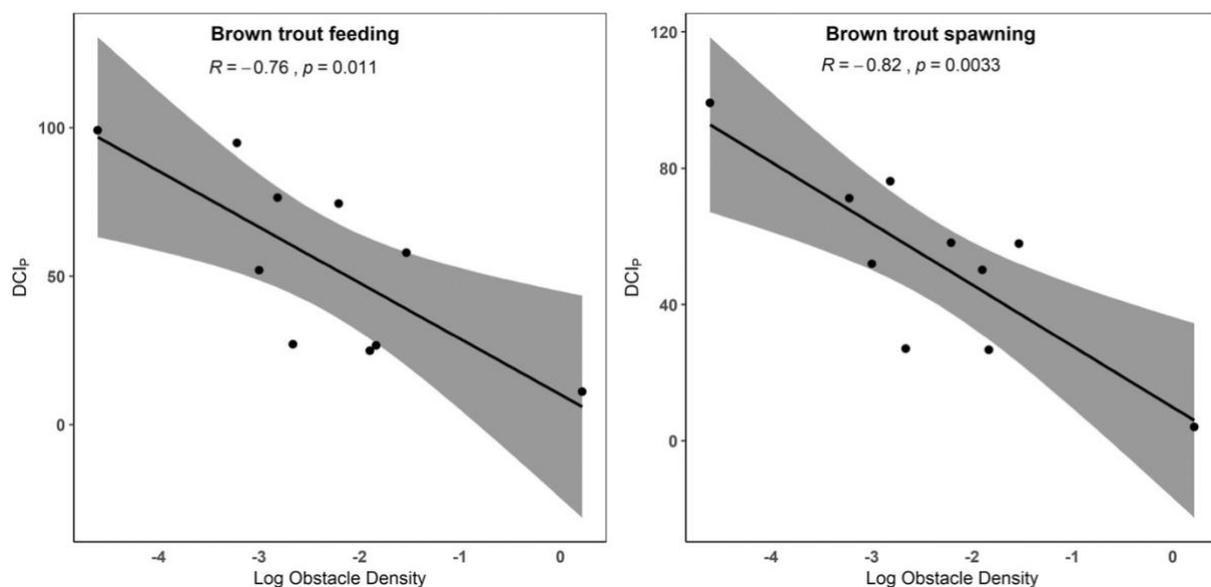
Fig. 8: Atkinson et al., (2020) found significant correlation between obstacle density and connectivity for (potamodromous) brown trout - denser obstacles reduce habitat connectivity.

Therefore, barriers can be just as much a threat to in-stream migrations and movements in -potamodromous fish as they are for diadromous

species. It is important for many species to have access to the full range of the river for both feeding and spawning activity.

Eels

Eels are another migratory fish species which are particularly impacted by river barriers. *Anguilla anguilla* or the European Eel- a catadromous species of fish- have suffered massive population decline since the 1970s across Europe. Estimates range from 90-99% reduction in European Eel populations throughout Europe since 1975 (Bevacqua et al., 2015; Correia et al., 2018). Accordingly they have remained on the IUCN red list of threatened species, listed as 'critically endangered' continuously since 2006 (Pike et al., 2020). There is no single issue to which the dramatic decline in eel numbers can be attributed. There is a compounding effect of various stressors. Changes in oceanic circulation and sea temperatures, along with anthropogenic water pollution have both been documented to have negatively affected eel populations (Castonguay et al., 1994; Geeraerts & Belpaire, 2010).

River barriers impact eel escapement, or the ability for an eel to leave a river system and return to the Sargasso Sea in order to spawn and reproduce (Bilotta et al., 2011). Barriers also limit the extent of eel colonisation upstream as they migrate into freshwater (as glass eels) for the majority of their lifecycle reducing potential habitat and increasing competition for resources (Halvorsen et al., 2020). Where physical barriers will directly prevent or delay migration, non-physical barriers such as pumping, abstraction and hydropower sites have been found to entrain and impinge eels leading to direct mortality in many cases (Carter et al., 2023; Turnpenny & Horsfield, 2014). In heavily impacted rivers, the cumulative effect of multiple barriers quickly reduces successful eel escapement to worryingly low numbers (Piper et al., 2013). The rivers Meuse and Rhine, both heavily obstructed rivers in central Europe used for commercial shipping, have estimated silver eel escapement to be just 15% and 15-32% respectively (Breteler et al., 2007; Breukelaar et al., 2009; Verbiest et al., 2012). Other studies have found that where barriers do not completely prevent eel migration, they also result in significant energy expenditure to overcome and increased predation risk whilst trying to do so (Wright et al., 2015). This can have knock on effects on migration and spawning success rates as eels must use valuable energy reserves

immediately prior to completing a 5000-6000 km migration to the Sargasso Sea.

Harwood et al (2022) identifies three main areas of conservation management to aid eel stock recovery where dam removal is not possible. As is the case with salmonids, complete dam removal is the most effective form of conservation bringing the fastest and most complete recovery but, where this is not possible priority should be given to:

1. Improving connectivity and assisting migration of elvers across 'problem' barriers that cannot be removed or modified.
2. River restoration and rewilding, especially measures that increase instream woody material to provide refuge habitat.
3. Enhancement or creation (where necessary) of suitable lacustrine habitat to benefit large females in particular (Harwood et al., 2022).

Other aquatic organisms

Whilst the effects of river barriers are most pronounced on migratory fish, they have far reaching consequences across all aquatic organisms. Aquatic flora, much like animals on land, need to be able to travel freely along waterways in order to successfully reproduce and colonise in stream and riparian areas. Studies have shown that river barriers can effect plant colonisation directly by entrapment and re-routing, and also indirectly by changing water chemistry (Fink & Scheidegger, 2018).

Beavers have perhaps the most complicated relationship with river barriers, and there is much debate in the scientific literature on whether they enhance or degrade the aquatic environment around them. Beaver dams alter the circulation of nutrients and chemicals in river systems, change flow and sediment regimes and increase water retention by creating beaver ponds (Połeć & Grzywna, 2023). Beaver dams are usually small-scale river barriers but can be at high density in areas with significant beaver populations. Many small river barriers have been shown to reduce watershed scale water quality in studies from South Africa and thus it could be assumed that areas with many beaver dams could produce similar results (Hughes & Mantel, 2010). However, studies in the UK (where beaver populations are low) have shown beaver ponds improve water quality by reducing phosphate and nitrate loading into rivers due to sedimentation behind beaver dams (Puttock et al., 2017). However, in

Germany (where beaver populations are larger) the improvement of water quality as a result of wetland generation from beaver dams was negligible (Smith et al., 2020). It is also important to consider that beaver dams are only temporary structures, usually operative for 2-3 years before failure of sedimentation of the upstream pond. When this occurs the chemicals stored in sediments of the pond may be re-released back into the river system, turning the dam from a pollutant sink to a pollutant source (Kalvīte et al., 2021; Shepherd & Nairn, 2022).

Currently it is unclear what the full environmental impact of 'reintroduced' beaver dams are on the hydrosphere; it is difficult to conclude whether they provide a net positive or negative to overall environmental health. The effects on water quality and fish migration are still unclear and further research is needed before further re-introduction projects are undertaken such as in the UK (Połeć & Grzywna, 2023).

Invasive species

When deciding on building or removing river barriers it is important to weigh up opposing environmental concerns. As discussed already, barriers have widespread negative impacts on habitat connectivity and fish migration. However, barriers can also have positive impacts on biodiversity. In specific circumstances they can provide an effective tool to limit the movements and spread of non-native invasive species (Sharov & Liebhold, 1998). Aquatic invasive species are becoming an increasing problem, especially in areas such as the UK and other temperate/polar countries due to the escalator effect as species migrate towards higher latitudes as ocean temperatures warm due to climate change (Marris, 2007). Therefore, while removing in stream barriers will decrease habitat fragmentation, it is also important to consider whether this will facilitate the spread of invasive species and induce further ecosystem degradation (Procheş et al., 2005).

In Great Britain alone, the cost of controlling freshwater invasive species in 2011 was estimated at £26.5 million per year (Oreska & Aldridge, 2011). By 2023 the total cost of all invasive non-native species (terrestrial, plant, aquatic) was estimated at £1.84 billion per year by the UK government, with some independent estimates putting it as high as £6 billion (Murphy, 2023; NatureScot, 2023).

The relationship between barrier removal and invasive species is complex: on the Medway in Kent the upstream movement of mitten crab (*Eriocheir sinensis*) was restricted by barriers but downstream movement of signal crayfish (*Pacifastacus leniusculus*) was not affected as they dispersed in a downstream direction (Robinson et al., 2019). Therefore, decisions on barrier removal or modification to combat invasive species would be best done on a case-by-case basis dependent on target organism. For example, if invasive crayfish species are a concern then barriers should be vertical wall with an overhanging lip above the water surface; smooth sections to prevent crayfish from walking or climbing over the obstacle, combined with flow velocities of 0.65 m/s act as a barrier within the waterbody (Krieg & Zenker, 2020). Traps have also been designed for Chinese Mitten Crabs which can be incorporated into fish passes, allowing migratory fish to successfully traverse barriers whilst trapping crabs which can be later collected and destroyed (Schoelynck et al., 2021). Innovations such as this may be one solution to increasing the passability of barriers whilst still controlling invasive species spread.

Danger to Humans

Low-head dams can be especially dangerous to people due to the formation of strong subsurface current (submerged hydraulic jump) creating an inescapable trap which can drown people who enter the water near a river barrier. A 2023 study, aiming to raise awareness concerning the safety hazards posed to swimmers, kayakers, and other recreational users compiled documentation of incidents involving drowning by low head river barriers in Europe (Mouchlianitis, 2024).

A total of 82 incidents resulting in 129 fatalities were identified across 16 countries. Multiple incidents were reported on several rivers, indicating recurring dangers associated with certain watercourses. Fatality was highly probable in the majority of incidents, with 80.5% resulting in at least one death. The age distribution of individuals involved ranged from 2 to 59 years, with a notable concentration observed in the mid-20s to mid-30s demographic. Various recreational pursuits, including swimming, canoeing, rafting, fishing, and paddleboarding, were represented among those involved in incidents, illustrating the diverse range of activities susceptible to the hazards posed by low head dams. Despite the presence of warning signage, their efficacy in preventing incidents proved limited, as

evidenced by at least 15 reported cases where warnings were disregarded by individuals involved, emphasizing the need for alternative safety measures and public education initiatives.

River barriers effect on water quality

River barriers not only directly affect wildlife through habitat fragmentation, but also indirectly through changes in water chemistry. River barriers alter the natural flow conditions of the river and provide a pathway for new chemicals into the water. This can have similar effects on aquatic wildlife: reducing habitat quality and accessibility.

Pollutants

Potential pollution starts during construction. As barriers are built in-stream, pollutants can be released from improperly managed and monitored works. Impacts in this stage typically include the release of excessive sediment loads as a result of excavation or potentially harmful chemicals (Skaggs et al., 1994). Further, many environmentally hazardous substances are used in the construction of river barriers such as concrete topping, petrol, solvents and paints (Khir Alla & Liu, 2021). These are used and stored in close proximity to the river increasing the risk of accidental spills and leakage if improperly managed.

Dams can also trap pollutants in the sediments which accumulate in reservoirs (Milenkovic et al., 2005; Palanques et al., 2014; Watkins et al., 2019; Zhao et al., 2017). In the short term, this can be seen as a positive as the reservoirs act as a pollutant sink, preventing their wider distribution into the hydrosphere. However, the pollutants accumulating in sediments can affect benthic macroinvertebrates (Archaimbault et al., 2010; Pettigrove & Hoffmann, 2005b, 2005a). Accumulation can also effect many other organisms at higher trophic levels which feed on macroinvertebrates via biomagnification and bioaccumulation (Krause et al., 2021; Moiseenko & Gashkina, 2020). This also raises concerns about water quality in reservoirs used for human consumption and crop and livestock production (Siziba, 2017).

Pollutants such as PCBs, POPs, heavy metals and microplastics have all been found to both accumulate in dam reservoirs (Ajima et al., 2015; Arunakumara & Zhang, 2008; Watkins et al., 2019). It is also important to consider that while sediments can act as a sink for pollutants, those pollutants can persist in sediments. Some pollutants such as heavy metals are non-biodegradable, and will persist in sediments indefinitely (Briffa et

al., 2020). As many studies have shown, barrier removal is necessary to improve habitat and environmental quality in the long run. However, removal , can mean these pollutants become re-mobilised, threatening water quality after dams are removed (Wildi et al., 2004; Zoumis et al., 2001). Remobilisation can also shift contaminants such as heavy metals from their solid phase trapped in sediments to their dissolved phase allowing for greater distribution within the hydrosphere (Monnin et al., 2018).

Sediments

River barriers can block or reduce sediments, leading to increased sedimentation upstream, and reduced suspended sediment loads downstream. Sediments carry important nutrients. Decreased fertility of arable land downstream can occur when sediments are removed or reduced in a river system. This has famously been the case in the Nile Delta; for millennia the annual flood waters fertilised the densely populated region, allowing large scale agriculture in an otherwise desert region. However, since the construction of the High Aswan Dam, these annual floods stopped due to flow regulation and as a result, salinity dramatically increased due to high rates of evaporation, and increasing amounts of agricultural fertiliser are needed due to the lack of nutrient rich sediments (Abd-El Monsef et al., 2015; Gu et al., 2011).

Similar reductions in sediment supply have been found on heavily controlled river systems across the world. Before 1900, the Mississippi River was estimated to have transported 400 million tons of sediment from the American interior to coastal Louisiana and the Mississippi delta, by 2006 this had fallen to an average of 145 million tons per year (Meade & Moody, 2010). Continuous annual supply of huge sediment loads from large rivers helped in forming many of the Earth's great deltas, an important biodiverse ecological niche, home to many endangered species. However, with the intensification of river barrier construction, many of these deltas are shrinking, primarily due to decreased sediment loads, as well as continuous subsidence, increased coastal erosion and sea level rise (Gupta et al., 2012). Between 2000 and 2010, 85% of 33 important deltas across the world experienced severe flooding, resulting in the temporary submergence of 260,000 km^2 (Syvitski et al., 2009).

95% of current sediment fluxes entering the world oceans are thought to come from rivers (Syvitski, 2003). Riverine sediment transport further accounts for over 90% of total river-borne fluxes of the immobile elements, including P, Ni, Mn, Cr, Pb, Fe and Al (Martin & Meybeck, 1979). 45% of the transport of organic carbon from the land to the oceans in particulate form is also estimated to mobilised in river sediments (Ludwig et al., 1996). This shows that consistent and large suspended sediment loads from the earths rivers to the oceans is an important pathway for nutrients to exchange between the terrestrial and aquatic environment. Changes in annual sediment fluxes to coastal seas, which has been observed in river systems, which have been heavily controlled, may result in reductions in oceanic primary productivity, as many of these elements are used by phytoplankton as micronutrients (Gupta et al., 2012).

The accumulation of fine sediments upstream of river barriers can lead to habitat degradation, increased turbidity, reduced flow, and deoxygenation. This can particularly effect the spawning and egg-to-fry survival of salmonids (Jensen et al., 2009). Salmonids are particularly at risk as they prefer to spawn in the upper reaches of river systems, and thus, even if fish passage interventions are used to facilitate upstream migration, the presence of river barriers may reduce habitat suitability for successful completion of their lifecycle.

Further, river barriers can significantly change the structure and morphology of a river by altering sedimentation and erosion patterns (Yu et al., 2022). Braided river systems for example, are being more tightly managed across the world for water abstractions and flood prevention and are thus contributing to the decline in water quality (Bora & Goswami, 2017). Such rivers typically have extreme high and low flows dependent on seasonality and lots of geomorphological movement and thus constructing river barriers can lead to huge changes in river morphology.

Temperature

Large dams can mitigate the effect of warming atmospheric temperatures downstream. As dams may form large reservoirs, these reservoirs can become thermally stratified. The hypolimnion is the bottom layer of the lake, where the coldest most dense water is found (Kędra & Wiejaczka, 2018). Dams which have reservoirs large enough to experience thermal

stratification and release water from the bottom of the dam will change downstream conditions to be cooler than air temperatures (Fig. 9). This modifies the natural thermal conditions suitable for many native types of biotas, reducing habitat quality, changing aquatic community structures and reducing any correlation between air and water temperatures (Kędra & Wiejaczka, 2018; Poff et al., 2007). In many parts of the world, especially in temperate northern regions such as the UK, warming air temperatures have correlated with warming river temperatures, reducing native biodiversity (Orr, Johnson, et al., 2015). Average air temperature in the UK has increased by 1°C since 1900, and river temperatures increased by 0.03°C between 1990 and 2006, with further increases since then highly probable (Orr, Simpson, et al., 2015). Therefore, any cooling effect of large dams could actually be beneficial to many native aquatic species as a way to regulate the water temperature increases caused by atmospheric warming. However, as seen in the analysis of river barriers in the UK and Europe in this literature review, the vast majority of barriers are less than 1m in height and thus these benefits would be negligible. Further, studies on the Colorado River have shown that declines in native big river fish have been linked to hypolimnial-release dams (Clarkson & Childs, 2000). Cooler temperatures reduce growth rates and the time taken to transform form larval to juvenile life stages, increasing mortality rates in populations. Therefore, research in the UK is needed to analyse the impacts of large dams only on river temperatures to determine the effects on native fish populations.
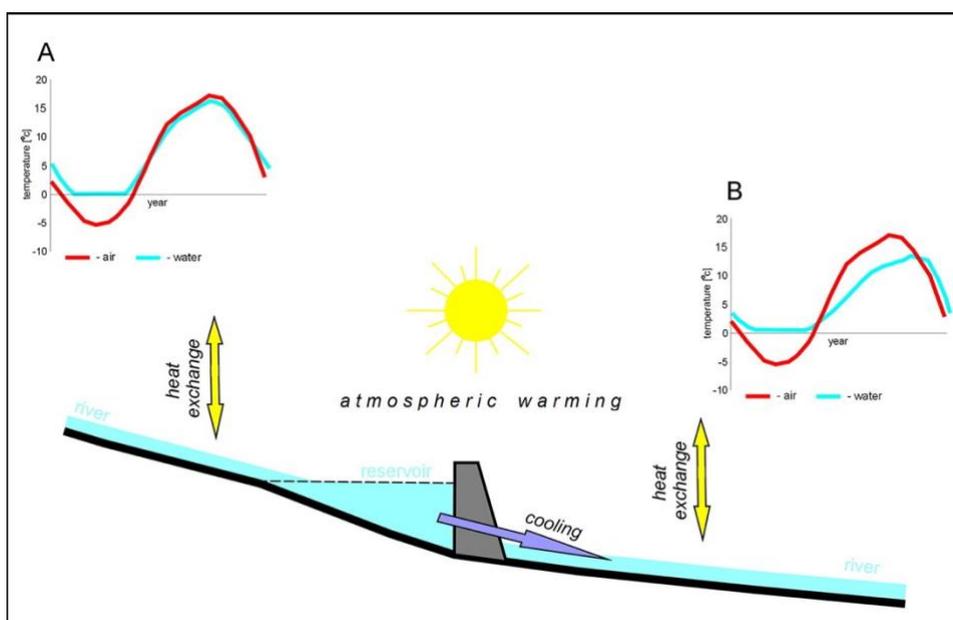
Fig. 9: Relationship between air and water temperature upstream (A) and downstream (B) of a hypolimnial-release dam (Kędra & Wiejaczka, 2018).

Of more concern in a UK perspective is the effect of smaller river barriers, as they are the most prevalent type of barrier as seen with the most common types of barriers in the UK being culverts and weirs less than 1m in height. Many studies have highlighted the cooling effects of large dams which release cold hypolimnetic water, but the effects of smaller dams releasing warmer surface water over their top, such as weirs, has been less thoroughly investigated in the academic literature. Lessard & Hayes (2003) examined species richness of fish and macroinvertebrate communities downstream of small dams in Michigan, USA. Changes in mean summer temperatures varied from cooling of 1ºC to warming of 5ºC, with increasing temperatures coinciding with lower densities of cold-water fish particularly brown trout. Downstream magnitude of temperature increases from surface release dams have been directly correlated with dam height, impoundment volume, impoundment widening, impoundment residence time, impoundment area, watershed area and watershed forest cover (Zaidel et al., 2021). The strongest predictor of warming magnitude downstream of a small dam was impoundment widening, as loss of riparian vegetation and thus shade increased exposure to solar radiation (Dripps & Granger, 2013). 75% of cold-water classed rivers had shifted to a warmer thermal class downstream in a study of small dams in Massachusetts, USA (Zaidel et al., 2021).

Macroinvertebrate assemblages are also correlated to water temperature, and warming downstream of surface-release dams has been suggested as a probable cause of shift to lower quality macroinvertebrate communities in these areas (Bellucci et al., 2011; Lessard & Hayes, 2003; Santucci Jr. et al., 2005). Heavy metal uptake rates have been found to be higher in warmer water temperatures and have been found to be in higher concentrations behind dams, further increasing their potential for bioaccumulation and biomagnification (Dijkstra et al., 2013; Fritioff et al., 2005). Increased water temperatures have also been shown to increase the prevalence of harmful algal blooms and increase decomposition rates in aquatic ecosystems, altering available energy throughout the food chain and putting further stress of aquatic biota where river barriers are present (Martínez et al., 2014; Przytulska et al., 2017).

The number of barriers in a river system can also have a cumulative impact on temperature changes. Monitoring on the Yangtze River following the construction of the Three Georges Dam saw average water temperatures increase by 2.1 °C, with the construction of Xiangjiaba and Xiluodu dams temperatures increased to 2.7 °C, and finally after the Baihetan and Wudongde dams are constructed water temperatures were 3.1 °C higher than before (He et al., 2020). The study suggested that as more dams were built cumulative extremes in temperature were more likely to be observed (including summer cooling of the river). A further study of over 45,000 sites across 9 river basins in continental USA by Dean et al. (2023), found that the cumulative effect of dams was the most important controlling factor on migratory fish abundance when compared to other human influences of agriculture, urbanisation, water abstractions and road crossings. However, other studies which measure the cumulative impact of dams on all fish species found that human land uses and air temperature were more important controlling factors, highlighting that dams and dam accumulation on river systems disproportionately impact migratory fish, which may explain the disproportionate population decline in migratory species as compared to other fish species (Van Looy et al., 2014; Wang et al., 2011).

Future solutions

Barrier Removal

Sometimes barriers can have a beneficial ecological function, as is the case with natural barriers for isolated/niche species, where they form part of a healthy and diverse natural environment.

Problems arise when numerous barriers are constructed in inappropriate locations.

There are many examples of river systems where barriers will have to be removed if we wish to reverse ecological damage and protect migratory fish species from further decline.

From the review of current academic literature and conservation projects, it is clear that the most effective method of mitigating the negative environmental impacts of river barriers is their complete removal (Branco et al., 2014). This is especially important where the barriers no longer serve any practical purpose, as they are needlessly damaging the environment whilst providing no practical benefit and should therefore be prioritised for removal.

Due to the huge number of barriers which exist methodologies using automatic interdisciplinary environmental impact assessments at large scales are needed, and some have been proposed. A study of the Tagus River which flows through Spain and Portugal developed a methodology using habitat suitability modelling (Boosted Regression Trees) to weight nodes. That study highlighted the importance of removing the correct barrier; removing one particular dam, as per the modelling, would have the most significant impact. Removing just 7 of the 29 river barriers would very significantly improve habitat connectivity by as much as 37% (Branco et al., 2014). Fuller et al. (2015) provides a simple decision tree which can be the first point of consultation when deciding how to manage improving habitat fragmentation. It clearly shows that when high habitat connectivity is needed, the only possible solution is some form of barrier removal (Fig. 10).
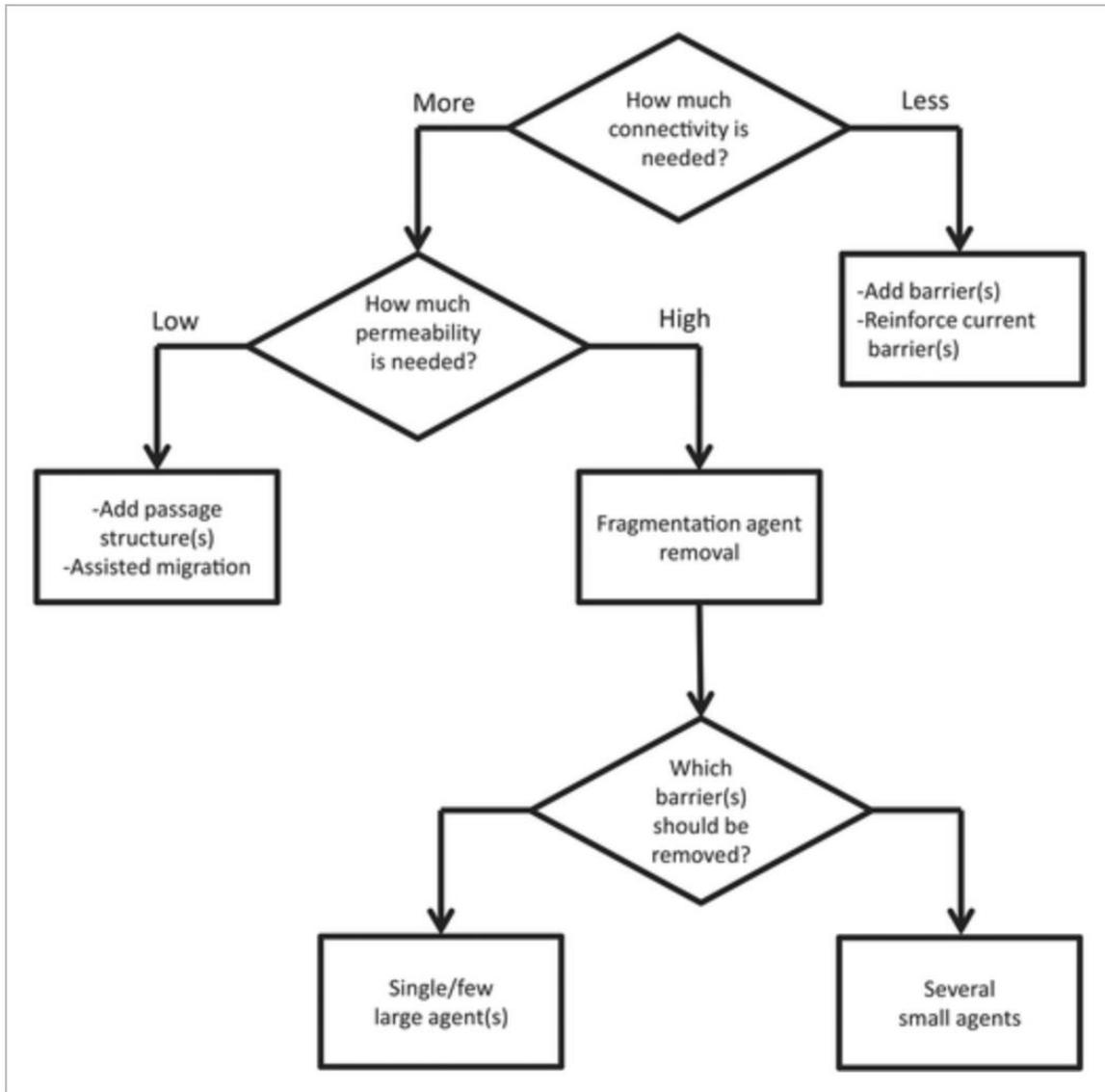
Fig. 10: Decision tree explaining the process by which habitat fragmentation could be managed in river networks (Fuller et al., 2015).

The removal of river barriers has gained recognition as an effective restoration strategy, with increasing efforts across Europe, particularly in regions with high barrier density. The EU has enacted the Nature Restoration Law, mandating the removal of man-made barriers to restore river connectivity, aiming to restore at least 25,000 km of rivers by 2030. (Mouchlianitis, 2024)

Dam Removal Europe (DRE), is one coalition of organisations, promoting barrier removal as a restoration tool and mainstreaming its practice (DRE, 2024). Data on barrier removals in 2023 showed significant progress, with 487 barriers removed in 15 European countries, representing a 49.8% increase from the previous year (Mouchlianitis, 2024). Various types of

barriers were removed, with 46% being weirs, 36% culverts, and 12% dams. Most removed barriers (78%) were lower than 2 m in height, and more than 4300 km of river were reconnected through removals. These types and heights of barriers are highlighted in the AMBER and River Obstacles datasets presented above as the most common types of river barrier found in the UK and Europe (AMBER Consortium, 2020; River Obstacles, 2023)

Case studies from DRE highlight successful projects in countries across Europe demonstrating the ecological and socio-economic benefits of barrier removal. The top 5 countries for number of dams removed in 2023 were 1. France (156), 2. Spain (95), 3. Sweden (91), 4. Denmark (72) and 5. UK (36). Future steps for DRE include continuing to mainstream barrier removal, providing support to practitioners, and monitoring trends in removal efforts.

UK barrier removals

Morton Quarry Wier (Mouchlianitis, 2024)

In the autumn of 2023, the Morton Quarry Weir, an obsolete barrier dating back to the 1800s oil shale industry, situated on Linhouse Water, a tributary of the Almond River in West Lothian, was meticulously removed by the staff of the Forth Rivers Trust. This 2-meter-high structure presented unique challenges due to its location within a steep gorge, rendering it inaccessible to heavy machinery. Acknowledging the prohibitive costs associated with creating access, a decision was made to undertake the dismantling process manually.

The removal procedure involved the systematic stripping away of both the weir's top concrete layer and the underlying natural cobblestone weir. Employing this approach was cost-effective and minimized ecological disturbance. The redistribution of cobblestones downstream of the removal site was strategically implemented to bolster the aquatic habitat within Linhouse Water and to provide resting places for the fish traversing the gradient section.

8.5 kilometres of fish spawning habitat was made accessible upstream of the weir. Trout and salmon were observed attempting upstream migration

even as the removal operations were taking place. Poaching incidents downstream, previously attributed to obstructed fish passage at the weir, have also decreased.
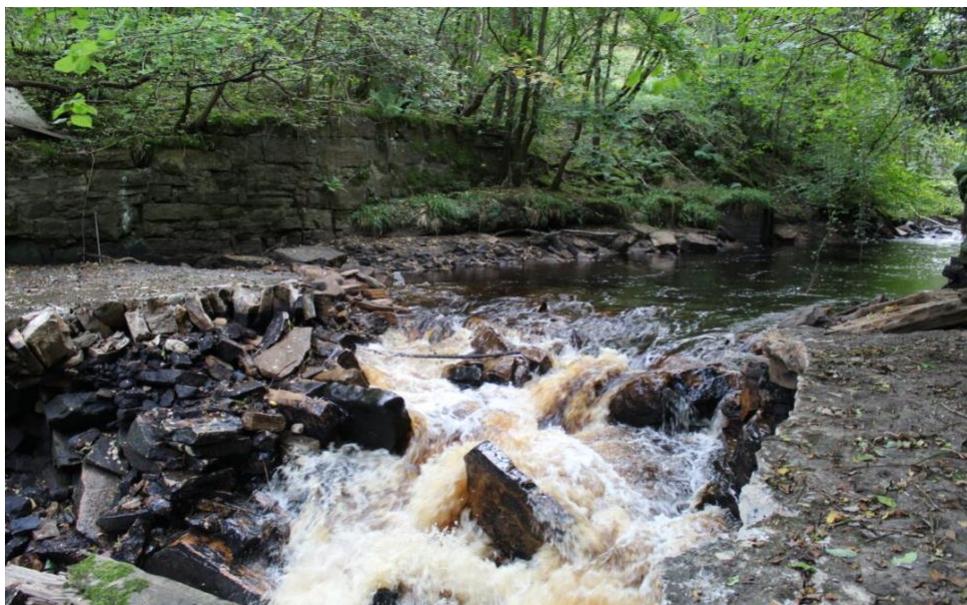
Morton Quarry post weir removal ([Forth Rivers Trust)](#)

Cribynau weir (NRW, 2023)

The 1950s Cribynau weir obstructed fish migration, disrupted sediment flow, and degraded habitat quality, particularly impacting trout populations on the River Clywedog in Wales. The barrier had become obsoleted and was no longer needed for the operation of the Llyn Clywedog reservoir. As part of Natural Resources Wales Salmon for Tomorrow 2 Programme, removing the weir aimed to restore fish passage and habitat conditions. Despite challenges posed by fluctuating water levels and logistical complexities, the project succeeded using a spider excavator to access the weir during the winter when flows were lowest in 2023.

The removal has brought notable ecological benefits. Fish now have unrestricted access to approximately 4 kilometres of suitable spawning and juvenile salmonid habitat upstream of the weir. Eliminating the impounded river section has created more natural habitat conditions, increasing aquatic biodiversity, specifically restoring sediment movement has facilitated crucial gravel transport for salmon and trout spawning.

In progress removal Cribynau weir, River Clywedog, Wales. (NRW, 2023).

Barriers can however serve many important functions to the human population, from electricity generation and drinking water supply, to transportation and flood protection. Where barriers cannot feasibly be removed, other restoration strategies must be considered. Some possible solutions include in-stream habitat modifications, pollution abatement, rehabilitation of riparian zones and land use restrictions (O'Hanley et al., 2013).

Fish passes

One of the most popular methods to mitigate habitat fragmentation caused by river barriers are fish passes, fish ladders or fishways, to provide a detour route for migrating fish to pass a particular obstruction. The specific design of a fish pass depends on the type of barrier, river flow and target species which needs to pass the barrier. Generally, fish passes all follow the same basic design principle: a series of ascending pools reached by swimming against a stream of water; fish rest in each pool before moving on to the pool above (NOAA, 2023).

The main types of fish passes (Ravichandran & Student, 2016; The Constructor, 2019; Thorncraft & Harris, 2000):

1. **Pool and Weir fish ladder:**

This is the most well-known type of fish passage. It consists of a series of overflow pools and weirs configured in a series of ascending steps where fish jump from pool to pool in order to move upstream. These passages are suitable for all types of barriers but do require a lot of space to construct, especially if the barrier is high.
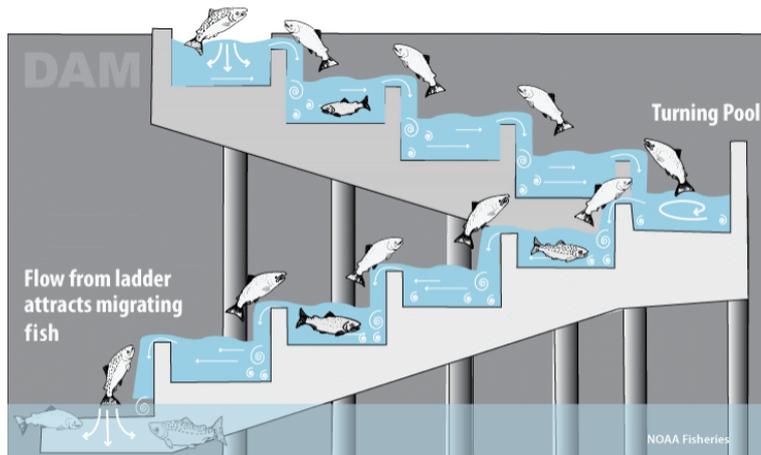
Fish ladder example (NOAA)

2. **Pool and Orifice fish ladder:**

Is similar to the pool and weir ladder, but instead of fish having to jump over a weir crest, they can swim through a submerged orifice within the weir. This potentially reduces the energy expenditure of fish on their upstream migration.

3. **Vertical Slot Fish Ladder**

Another variation of the pool and weir ladder, in this case the weirs are replaced by walls with vertical slots in them. This allows the fish to migrate upstream of a barrier whilst continuing to swim at their preferred depth, and is recommended where there is a very large volume of fish migration on a river.

Conceptual layout of a vertical-slot fishway

flow — flow

slots are full depth of channel

protective gridmesh covers

resting pool

trashrack over fishway exit

auxiliary water for high tailwater levels

diffusing screen

notch in weir crest to attract fish to fishway entrance

flow

fishway entrance close to weir

fishway channel slope varies depending on location (1:18-1:30)

Not to scale

Drawing by Parragraphics

(Thorncraft & Harris, 2000)

4. Baffle fishway

These passes allow fish to migrate upstream via a series of baffles perpendicular to the direction of water flow. Unlike previous fish passes described, water flows continuously down these passages and does not provide places for the fish to rest between ascending levels of the passage, although pools are sometimes installed if fish struggle to successfully pass the barrier. The 4 types of baffle fishways are:

- Denil Fishway
- Larinier Fishway
- Alaskan Fish pass
- Chevron Fishway
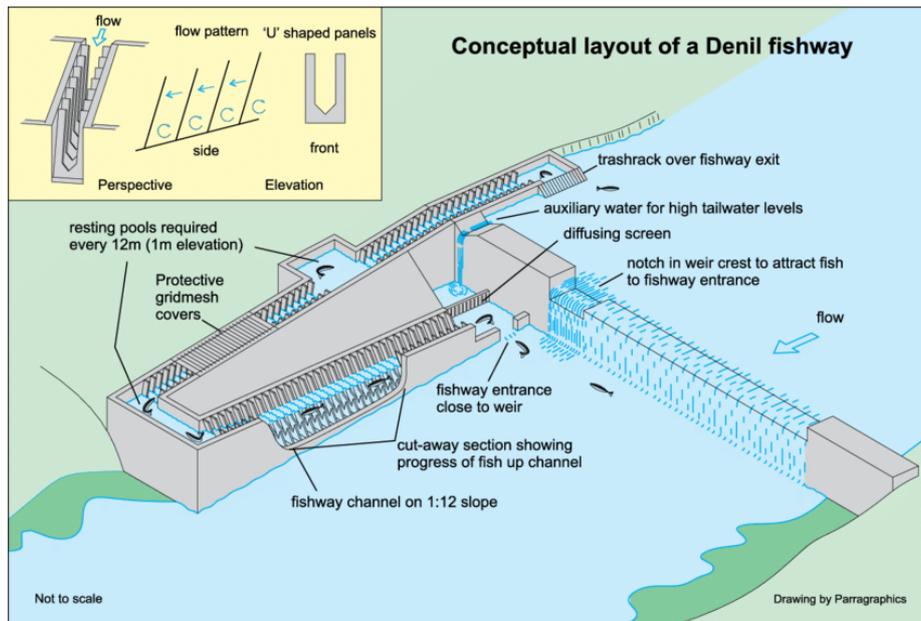
(Thorncraft & Harris, 2000)

5. Rock Ramps

Rock ramps are constructed using large rocks or pieces of timber directly onto the obstruction across part of, or its entire length. Pools and falls are created by the stepped construction of rows or rocks or logs creating pools the fish can easily move up. These are best suited to low height obstructions, as they are placed directly over the barrier, and best suited to areas where upstream water level control is not essential. They are also a low-cost fish passage and can even be constructed temporarily during migration seasons if need be.
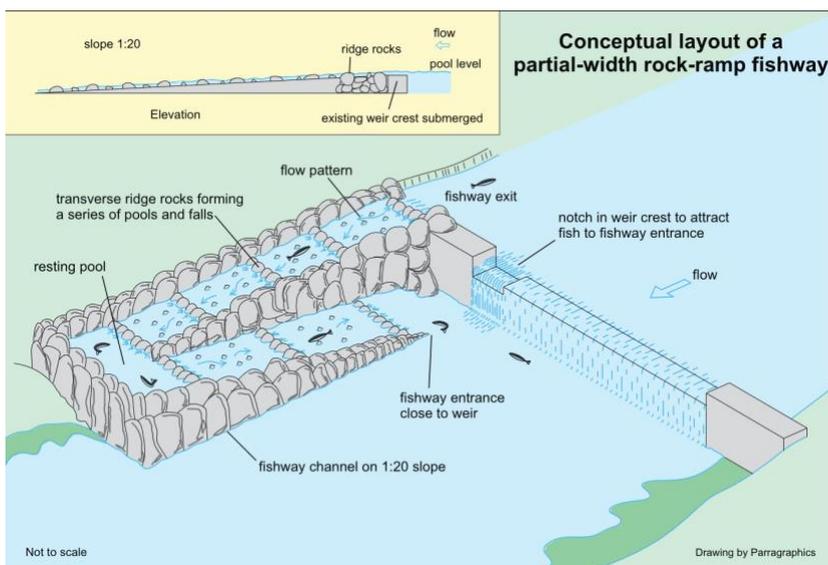
(Ravichandran & Student, 2016)
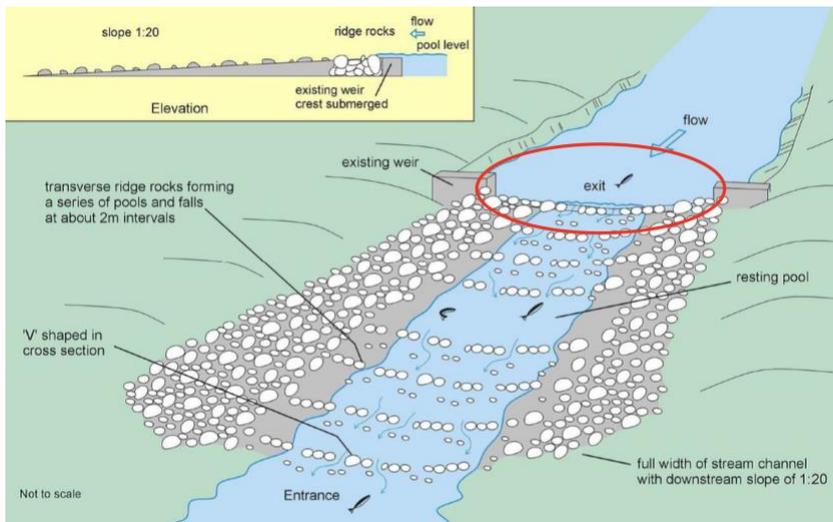
(Yantsch et al., 2018)
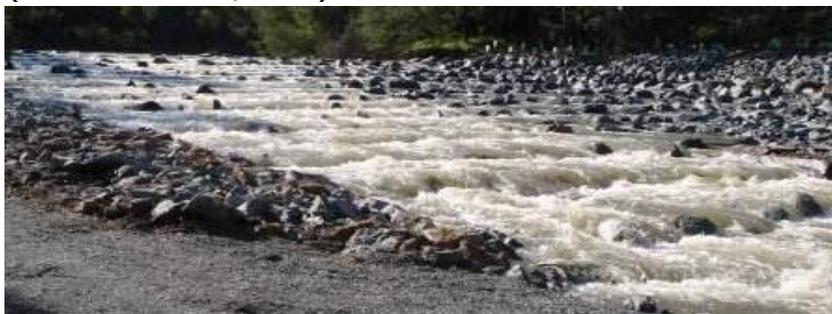
(Moore et al., 2014) Rockramp fishway on the Goulburn River, Victoria, Australia.

6. Fish elevator/Lock fishway

Fish elevators or lifts allow fish to pass very large river obstacles such as tall dams and weirs. They operate by moving large number of fish at one time through a water filled chamber from downstream to upstream. These lifts are effective for larger fish which struggle to navigate other fish passages due to their size compared to passage openings, or poor swimming abilities. They can consist of either a physical hopper which traps fish before being mechanically elevated to the top of the river barrier, or as a lock type chamber which fills with water allowing the fish to float upwards to the top of the barrier. The Deelder fish lock is a variation of the lock fishway for use on low barriers.
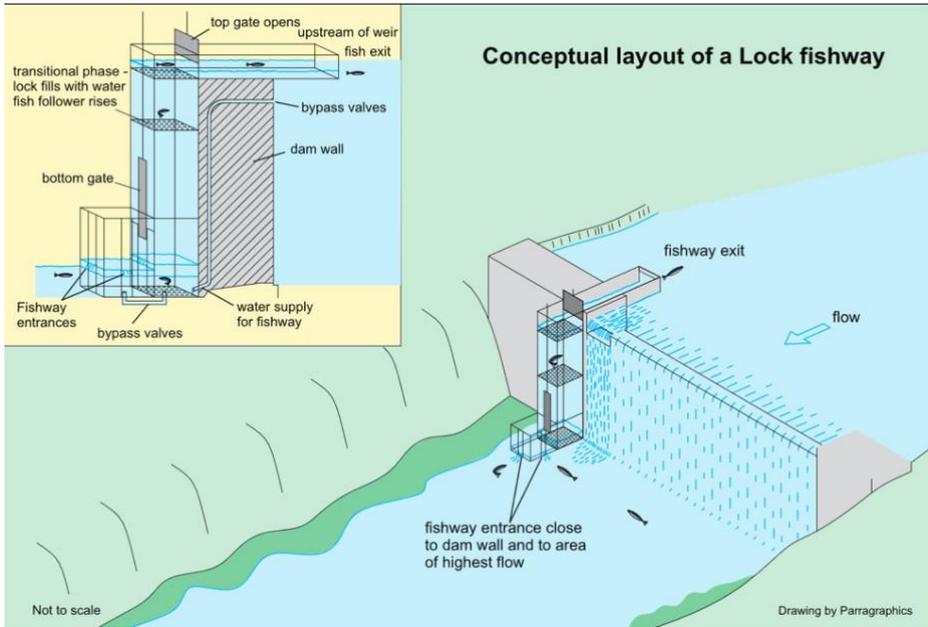
(Ravichandran & Student, 2016)
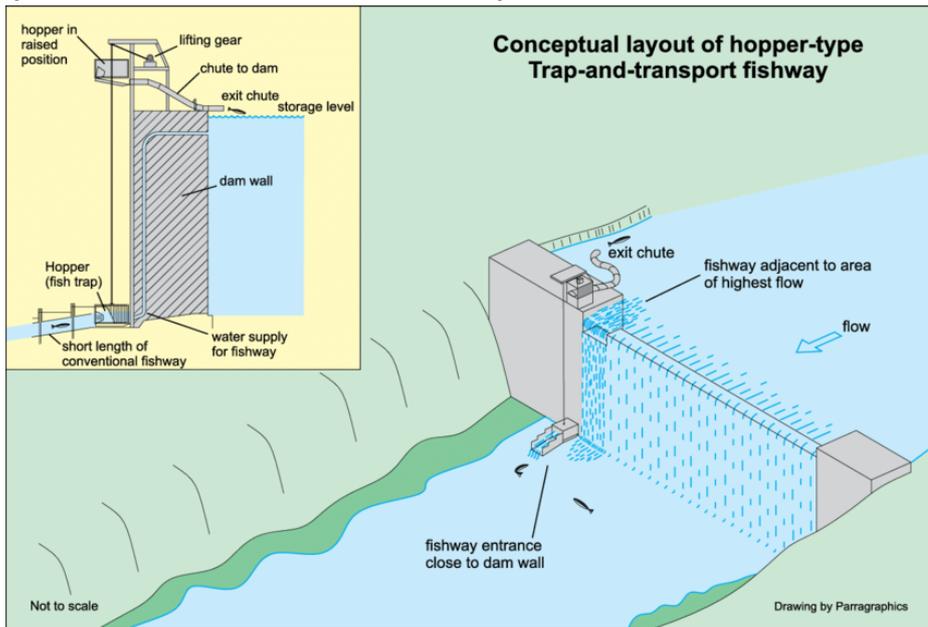
(Thorncraft & Harris, 2000)
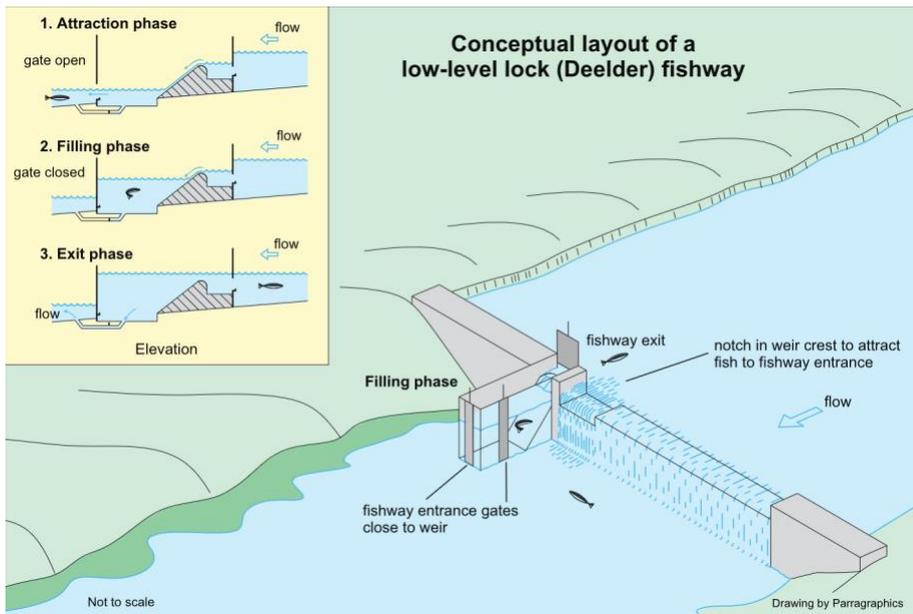
(Thorncraft & Harris, 2000)

7. Siphon fishway

Siphon fishways are a type of closed passage allowing fish to pass between two watercourses. They consist of an enclosed tube which is partially filled with water and the flow rate is then controlled by the siphon effect. These passages are particularly effective in allowing fish to migrate during flood periods. Another advantage is that they allow fish of all sizes and athleticism to pass through. The siphon can be slowed down during off seasons to allow smaller organisms frogs and glass eels to use the passage.
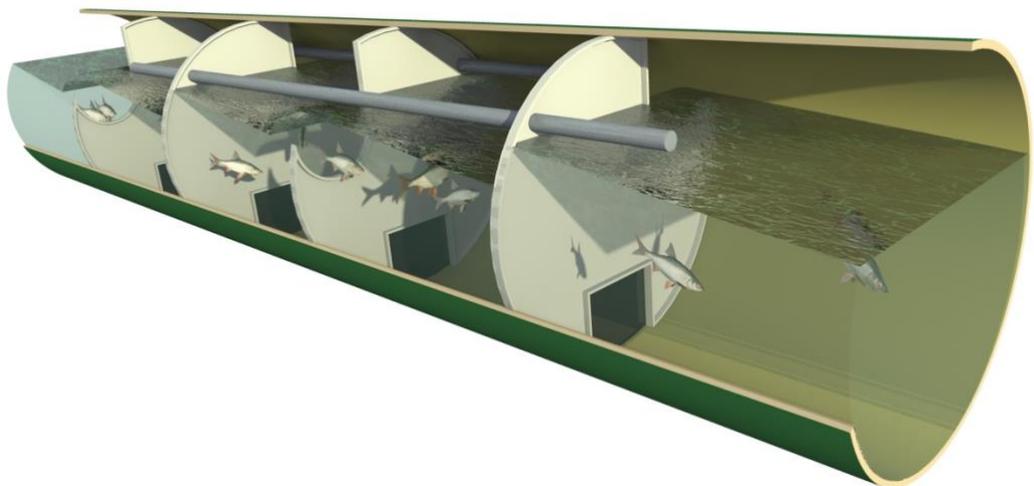
(Siphon fishway design by FishFlow Innovations, 2024)

8. Bypass fishways

These structures typically comprise low-gradient earthen or rocky channels designed to emulate natural stream morphology, often characterized as 'nature-like' fishways. While certain flood bypass channels exist either naturally or through construction efforts, their implementation remains limited.

Conceptual layout of a bypass fishway

'nature-like' meanders: earth, rock, plants

Fishway exit

intake structure to control fishway flow

Flow-control structures

notch in weir crest to attract fish to fishway entrance

flow

fishway entrance close to weir

Not to scale

slope of bypass channel less than 1:30

Drawing by Parragraphics
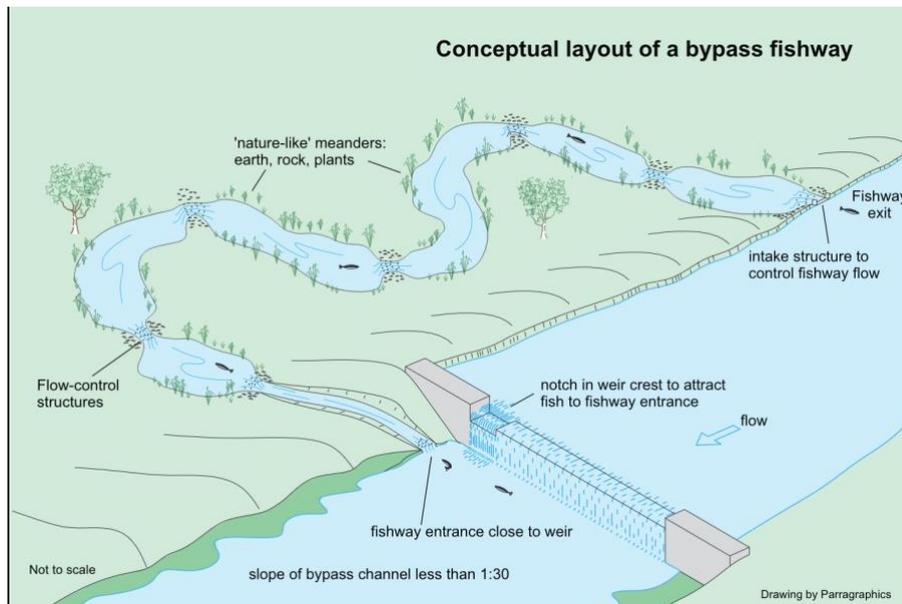
(Thorncraft & Harris, 2000)

9. Eel and elver fishways

An eel or elver pass typically consists of a narrow conduit, commonly constructed from materials such as coarse brushes, designed to offer juvenile eels a moist and intricate surface conducive to their wriggling motion to climb as they migrate.

tailwater level

inclined crawling medium

elver pass

headwater level
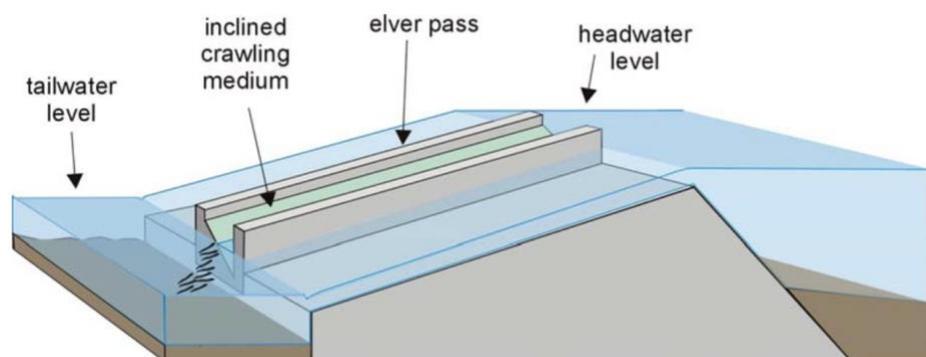
(Eel fishway design, Solomon & Beach, 2004)

Fish ladders are assumed to be an effective way of re-establishing habitat connectivity, especially for migratory fish which need to travel up and downstream to successfully complete their lifecycle (Agostinho et al., 2007). Installation of fish ramps and baffles in tributary streams in New Zealand have been shown to increase species richness and total fish density upstream of culverts used as road crossings (P. A. Franklin & Bartels, 2012).

However, fish passes are not 100% effective, and in some cases cause new problems for fish attempting to migrate upstream. As reservoirs which form behind barriers have very different hydrodynamics compared to the riverine habitat they have replaced, this can provide an additional barrier to fish movement once they have traversed the pass, or when they are migrating downstream (Agostinho et al., 2007). Fish barriers have also been found to increase predation of juvenile fish (especially salmonids) downstream of barriers, as fish are concentrated into a single area trying to pass the barrier (Agostinho et al., 2012). The Tees barrage has become a hotspot for seal predation on migrating salmonids despite the installation of two fish passes and instalment of acoustic deterrent devices (Canal River Trust, 2017). Another proposed solution on the Tees has been to clamp barrage gates open at a width which is large enough for fish to pass through but not for seals to follow them. Natural barriers are already predation hotspots, famously bears and other large predators congregating in great numbers at shallow streams with less pool volume during salmonid migration periods (Andersson & Reynolds, 2018).

The passability (percentage of fish which can successfully navigate past an obstacle) of 'passable' manmade barriers must also be considered when looking at fish and eel passages. No barrier will be 100% passable and reducing the passability only slightly can have serious knock on consequences (Buddendorf et al., 2019). This can have escalating knock-on consequences for habitat connectivity upstream and has been shown to reduce DCI even when fish pass efficiency is as high as 95% (Fig 11). Fish barrier efficiency must also account for the downstream movement of fish. While most passages are focused on the upstream movement of fish, diadromous fish must also migrate downstream either as smolts in the case of salmonids or, silver eels in the case of eels. This means that some fish ladders may actually only serve as one-way route for migrating fish, only partially mitigating the environmental impacts they were intended to reduce (Agostinho et al., 2007). A comprehensive literature review of 65

articles from 1960 to 2011 looking at fish passage efficiency found that downstream passage efficiency was 68.5%, and upstream passage efficiency was 41.7% (Noonan et al., 2012). Salmonids were more successful than non-salmonids in passing upstream (61.7 vs. 21.1%) and downstream (74.6 vs. 39.6%) through fish passage facilities. The type of fish passage present also significantly affected barrier passability, with pool/weir ladders and vertical slot passages having the highest efficiency and baffle and fish elevators having the lowest (Noonan et al., 2012).
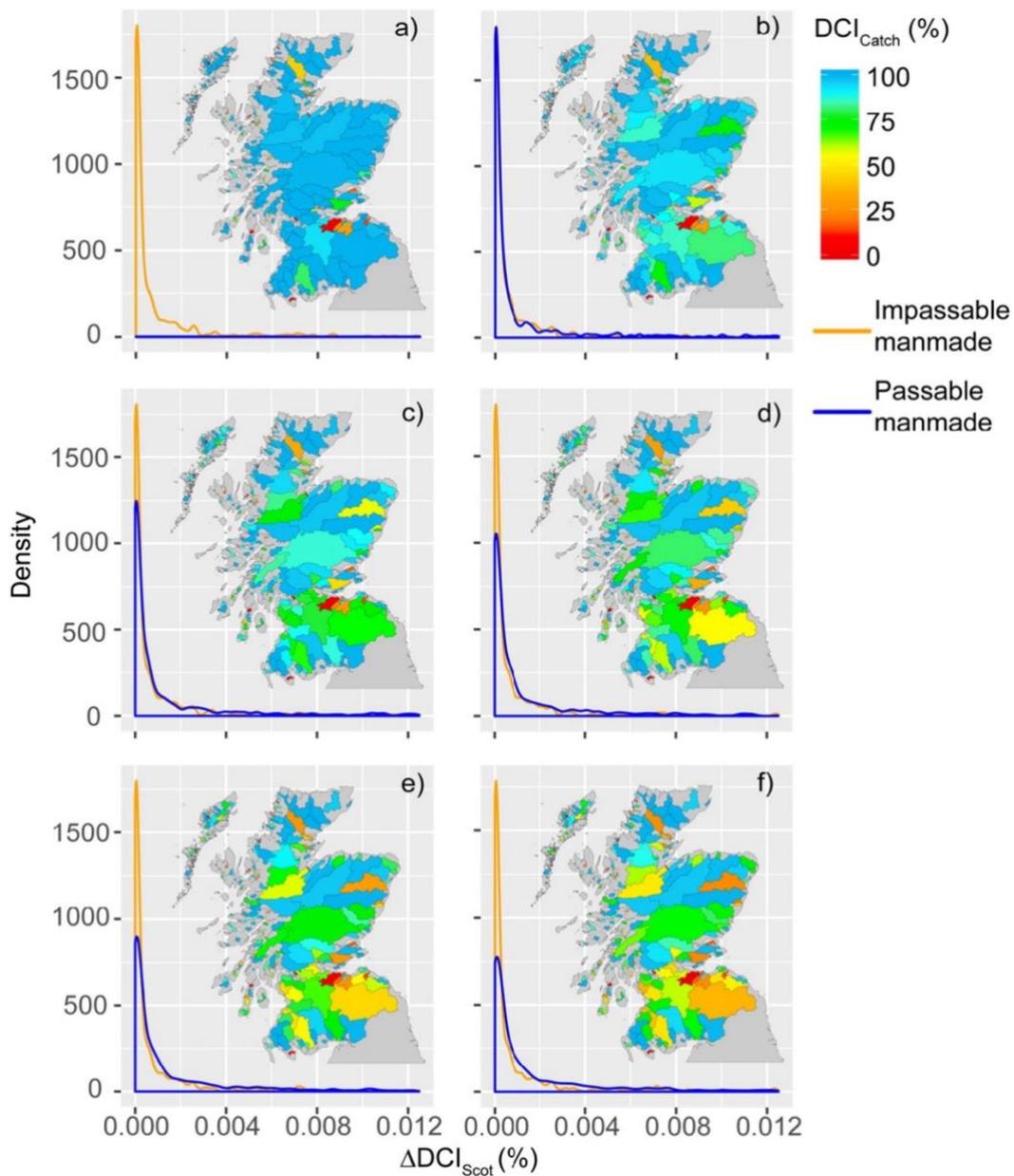
Fig. 11: Density plots of DCI for impassable manmade barriers (yellow) and passable manmade barriers (blue) where the passability of Passable

Manmade Barriers is 100%, 95%, 90%, 85%, 80%, and 75% in subplots a–f, respectively (Buddendorf et al., 2019).

Conclusions

River barriers, both natural and man-made, have significant impacts on the environment, wildlife, and water quality. They are structures or obstacles that obstruct the movement of aquatic organisms upstream or downstream. While natural barriers have always existed and shaped the distribution of aquatic flora and fauna, human populations have increasingly created artificial river barriers for various purposes such as agriculture, flood defence, and energy generation. Studies have consistently shown that barriers, both natural and man-made, often have detrimental impacts on the environment, damaging habitat connectivity and reducing water quality.

One of the key concerns regarding river barriers is their disproportionate impact on migratory fish. These species rely on unobstructed river systems to complete their life cycles, and barriers can disrupt their natural migration patterns, leading to population decline and loss of genetic diversity. Protecting and restoring fish passage is crucial for the conservation of migratory fish species.

Different types of barriers, such as dams, weirs, sluice gates, culverts, fords, ramps, and natural barriers, have varying effects on water flow and habitat fragmentation. It is important to consider the type, size, and permeability of a barrier when assessing its environmental impact. Larger barriers tend to affect rivers for greater distances, while the longevity and permeability of a barrier also contribute to its overall impact.

Furthermore, non-physical barriers, such as changes in water quality, temperature, and flow conditions, pose additional challenges. These barriers, which are often influenced by pollution and water resource engineering, can have transient effects on wildlife, making them difficult to study and mitigate. Understanding the effects of non-physical barriers, especially on migratory species, is crucial for protecting aquatic ecosystems.

Many barriers are no longer in use, making their removal a viable option. While these structures may have served their intended purposes in the

past, their continued presence poses ongoing environmental risks. Removing outdated and unused dams can restore river connectivity, improve water quality, and enhance the overall health of aquatic ecosystems.

When addressing the challenge of fish passage, novel solutions have been developed to enable fish to navigate past barriers. However, it is important to recognize that these solutions are often not as effective as complete barrier removal. Where feasible, the removal of dams and barriers should be prioritised over fish passage solutions. This approach not only benefits migratory fish but also restores riverine habitats and supports the recovery of entire ecosystems. In cases where removal is not feasible, alternative solutions, such as fish passage systems, should be considered. However, it is important to recognise that these solutions may not fully mitigate the environmental impacts associated with barriers.

Despite the environmental concerns associated with river barriers, their construction and maintenance continue due to various societal needs. River barriers play important roles in irrigating crops, supplying drinking water, generating electricity, facilitating transportation, supporting recreation and tourism, and providing flood protection. These functions are particularly vital in water-scarce regions, for ensuring a constant supply of drinking water, and for supporting economic activities.

However, it is essential to strike a balance between the benefits derived from river barriers and their associated environmental impacts. Effective management strategies should be implemented to minimise negative effects on wildlife, water quality, and habitat fragmentation. This may involve considering alternative methods of water supply, implementing sustainable hydropower practices, improving fish passage systems, and mitigating the impacts of pollution and water abstraction.

Further research is needed to enhance our understanding of the environmental impacts of river barriers and to develop more effective management strategies. Studies should focus on the ecological effects of different types of barriers, the cumulative impacts of numerous small river crossings, the effects of non-physical barriers on migratory species, and the mitigation of pollution and water abstraction impacts. This research will contribute to informed decision-making and promote the sustainable development and management of river systems.

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Appendix

Man-made and natural barrier counts and density (km²) for the UK and
Northern Ireland (listed as one catchment):

Catchment Name	Catchment Area (km²)	Man Made Barriers	Man Made Density (km²)	Natural Barriers	Natural Density (km²)
Thames	13698	5940	0.43	64	0
Northern Ireland	13590	74	0.01	0	0
Severn	11018	4823	0.44	184	0.02
Trent	10646	4620	0.43	59	0.01
Ouse (Yorkshire)	9483	3902	0.41	897	0.09
Great Ouse	8368	1963	0.23	5	0
Tweed	5023	254	0.05	88	0.02
Tummel	4993	97	0.02	104	0.02
Wye	4199	1223	0.29	220	0.05
Witham	3363	715	0.21	3	0
Spey	2949	77	0.03	55	0.02
Tyne	2941	698	0.24	554	0.19
Mersey	2503	2851	1.14	95	0.04
Nene	2404	550	0.23	2	0
Eden (Cumbria)	2374	501	0.21	319	0.13
Avon (Bristol)	2313	1223	0.53	20	0.01
Dee (Wales)	2251	1154	0.51	86	0.04
Dee (Scotland)	2084	70	0.03	101	0.05
Lewis & South Harris	2019	74	0.04	66	0.03
Tees	2008	525	0.26	190	0.09
Medway	1969	681	0.35	19	0.01

Duneaton Water	1944	57	0.03	21	0.01
Garry	1852	35	0.02	36	0.02
Avon (Hampshire)	1802	351	0.19	2	0
Don (Yorkshire)	1766	1076	0.61	17	0.01
Hull	1696	277	0.16	0	0
Welland	1685	263	0.16	0	0
Parrett	1654	710	0.43	5	0
Skye	1621	5	0	13	0.01
Exe	1520	695	0.46	2	0
Yare	1514	348	0.23	0	0
Weaver	1484	618	0.42	12	0.01
Ullapool & Highlands West Coast	1477	20	0.01	117	0.08
Tywi	1379	427	0.31	41	0.03
Ribble	1378	1036	0.75	89	0.06
Mucomir Cut	1331	27	0.02	27	0.02
Usk	1323	926	0.7	161	0.12
Don (Scotland)	1319	41	0.03	7	0.01
Test	1264	256	0.2	0	0
Stour (Dorset)	1245	279	0.22	2	0
Taw	1240	280	0.23	1	0
Deveron	1233	19	0.02	6	0
Elchaig	1203	8	0.01	46	0.04
Chelmer	1193	330	0.28	1	0
Orrin	1177	33	0.03	84	0.07
Esk (Border)	1162	61	0.05	36	0.03
Dowalton Burn	1145	7	0.01	13	0.01
Stour (Kent)	1136	306	0.27	2	0
Lune	1134	328	0.29	409	0.36
Wear	1126	365	0.32	104	0.09
Great Eau	1119	178	0.16	0	0
Arun	1116	508	0.46	8	0.01
Pennyland Burn	1115	31	0.03	26	0.02

Rother	1088	230	0.21	7	0.01
Stour (Suffolk)	1086	295	0.27	0	0
Forth	1029	25	0.02	24	0.02
Teifi	1021	348	0.34	18	0.02
Tamar	1001	200	0.2	4	0
Loch Mullardoch & Monar & River Affric	987	17	0.02	13	0.01
Loch Shiel	982	7	0.01	17	0.02
Bure	957	161	0.17	0	0
Water of Milk	950	23	0.02	33	0.03
Shetland	935	3	0	5	0.01
Loch Ken or Dee	900	19	0.02	6	0.01
Lussa	875	2	0	16	0.02
Earn	868	12	0.01	15	0.02
Torridge	855	141	0.16	2	0
Awe	828	18	0.02	55	0.07
Clwyd	818	386	0.47	35	0.04
Waveney	809	237	0.29	0	0
Endrick Water	796	42	0.05	25	0.03
Findhorn	787	4	0.01	16	0.02
Cromarty Firth	775	31	0.04	24	0.03
North Esk	766	5	0.01	13	0.02
Conie Water	758	20	0.03	44	0.06
Loch Fyne Coastal	709	15	0.02	18	0.03
Anglesey	708	388	0.55	3	0
Brue	702	316	0.45	11	0.02
Dionard	694	4	0.01	17	0.02
Dyri (Dovey)	682	252	0.37	76	0.11
Derwent	681	254	0.37	99	0.15
Argyll & Bute	677	7	0.01	26	0.04
Loch Torridon	621	5	0.01	33	0.05
Coquet	613	75	0.12	77	0.13
Islay	613	3	0	0	0

Ruel	608	36	0.06	66	0.11
Ouse (Sussex)	595	337	0.57	6	0.01
Water of Coyle	584	12	0.02	15	0.03
Shin	583	14	0.02	7	0.01
Ancholme	583	131	0.22	0	0
Allt na h-Aireimh	573	3	0.01	7	0.01
Conwy	568	324	0.57	81	0.14
Isle of Man	568	0	0	0	0
Adur	565	234	0.41	1	0
South Esk	564	11	0.02	14	0.02
Wyre	564	296	0.52	9	0.02
Water of Cruden	548	2	0	0	0
Crouch	545	144	0.26	0	0
Ythan	539	14	0.03	4	0.01
Taf	537	190	0.35	3	0.01
Chichester Harbour	534	218	0.41	0	0
Teign	533	287	0.54	7	0.01
Deben	528	79	0.15	0	0
Taff	527	852	1.62	131	0.25
Naver	513	4	0.01	12	0.02
Dornoch Firth	513	21	0.04	9	0.02
Dart	491	156	0.32	3	0.01
Thurso	487	2	0	0	0
Kennal	486	157	0.32	1	0
Itchen	485	205	0.42	2	0
Frome	482	105	0.22	0	0
Loch Linne (South)	481	1	0	14	0.03
Scaddle	481	1	0	12	0.02
Irvine	481	15	0.03	8	0.02
Kent	476	287	0.6	59	0.12
Douglas	470	440	0.94	22	0.05
Bluther Burn	461	8	0.02	1	0
Urr water	457	3	0.01	1	0

Colne	455	139	0.31	0	0
Orwell	453	106	0.23	0	0
Wampool River	449	53	0.12	1	0
Ewe	441	1	0	34	0.08
Blyth	434	84	0.19	1	0
Cowie Water	431	16	0.04	4	0.01
Isle of Arran	426	4	0.01	23	0.05
Brora	425	4	0.01	6	0.01
Kinross	423	32	0.08	0	0
Bamburgh	422	59	0.14	4	0.01
Camel	414	100	0.24	0	0
Axe (Devon)	407	160	0.39	0	0
Kinglass	397	4	0.01	15	0.04
Western Cleddau	389	114	0.29	2	0.01
Gogar Burn	388	39	0.1	3	0.01
Mawddach	387	236	0.61	76	0.2
Oykel	382	2	0.01	22	0.06
Orkney Main Island Coast	375	17	0.05	0	0
Lleyn Peninsula	369	236	0.64	26	0.07
Penkiln Burn	368	4	0.01	12	0.03
Ellesmere Port	365	134	0.37	1	0
Esk (Yorkshire)	364	86	0.24	69	0.19
Corran	361	4	0.01	11	0.03
Kelvin	353	21	0.06	4	0.01
Peffer Burn	351	5	0.01	0	0
Burn of Lyth	345	1	0	1	0
Stinchar	343	1	0	29	0.08
Wansbeck	341	61	0.18	6	0.02
Loughor	339	300	0.88	9	0.03
Nairn	336	4	0.01	2	0.01
Tarf Water	335	3	0.01	1	0
South Ugie Water	333	1	0	0	0
Neath	326	321	0.98	113	0.35
Burn of Boyne	326	7	0.02	0	0

Esk	324	32	0.1	2	0.01
Ogmore	322	339	1.05	19	0.06
Doon	322	12	0.04	18	0.06
Gypsey Race	319	35	0.11	0	0
Cuckmere	316	115	0.36	0	0
Kinloss	315	5	0.02	2	0.01
Dundee & Coast	315	1	0	1	0
Eden (Scotland)	314	3	0.01	2	0.01
Lymington	314	109	0.35	1	0
Leven	313	159	0.51	99	0.32
Tyne	313	16	0.05	1	0
South Uist	303	6	0.02	9	0.03
Carron	301	15	0.05	21	0.07
Motray Water	296	4	0.01	0	0
North Uist	295	5	0.02	2	0.01
Fowey	284	85	0.3	1	0
Alt	283	182	0.64	0	0
Thurso Coast	280	0	0	1	0
Tawe	277	207	0.75	61	0.22
Irt	271	56	0.21	69	0.25
Lossie	271	17	0.06	6	0.02
Lynher	267	80	0.3	2	0.01
Wick	264	0	0	0	0
Trantlebeg Burn	262	0	0	0	0
Axe (Somerset)	261	89	0.34	4	0.02
Aln	260	37	0.14	9	0.03
Ebbw	257	446	1.74	6	0.02
Water of Girvan	253	2	0.01	15	0.06
Tavy	252	95	0.38	2	0.01
Bude	247	39	0.16	20	0.08
Blyth (Suffolk)	247	46	0.19	0	0
Otter	246	167	0.68	1	0
Rheidol	245	69	0.28	20	0.08

Holland Brook	245	57	0.23	0	0
Bogrie Lane	244	3	0.01	2	0.01
Rhymney	243	355	1.46	8	0.03
Furness	241	150	0.62	3	0.01
Levern Water	241	31	0.13	3	0.01
Eastern Cleddau	240	76	0.32	2	0.01
Garnock Water	235	25	0.11	11	0.05
Molendinar Burn	230	4	0.02	1	0
Pow Burn	228	4	0.02	4	0.02
Avon (Little)	228	87	0.38	2	0.01
Wallington	226	29	0.13	0	0
Helford	222	46	0.21	0	0
Alde	219	21	0.1	0	0
Allan Water	217	18	0.08	24	0.11
Loch Hope	214	9	0.04	64	0.3
Barry	208	118	0.57	0	0
Piddle	207	55	0.27	2	0.01
Yell	207	3	0.01	0	0
Averon	203	13	0.06	152	0.75
Dwyryd	203	176	0.87	49	0.24
Cross Water of Luce	201	3	0.01	9	0.04
Kirtle Water	199	3	0.02	1	0.01
Devon	198	10	0.05	4	0.02
Ystwyth	197	45	0.23	24	0.12
Urr Water	197	2	0.01	6	0.03
Firth of Forth (South)	196	0	0	0	0
Avon	195	4	0.02	0	0
Bonny water	192	17	0.09	4	0.02
Blackwater Reservoir	192	1	0.01	1	0.01
Cassley	190	13	0.07	20	0.11

Abhainn an t-Sratha Charnaig	186	0	0	0	0
Gower	178	65	0.37	0	0
St. Brides Bay	176	56	0.32	3	0.02
Bannock Burn	174	7	0.04	0	0
Brora Coast	172	2	0.01	3	0.02
Glaslyn	171	109	0.64	53	0.31
Plym	171	101	0.59	4	0.02
Ely	171	141	0.82	0	0
Aeron	170	65	0.38	4	0.02
Langwell Water	170	0	0	0	0
Morar	169	2	0.01	12	0.07
Inver	165	7	0.04	57	0.35
Loch Dughaill (River Carron)	163	0	0	9	0.06
Turnberry & Girvan Coastal	163	0	0	0	0
Hamble	160	74	0.46	0	0
Stiffkey	160	16	0.1	0	0
Etive	159	1	0.01	3	0.02
Avon (Devon)	156	37	0.24	2	0.01
Gruinard	154	0	0	19	0.12
Three Pools Waterway	152	81	0.53	0	0
Dysynni	151	79	0.52	49	0.32
Ehen	151	39	0.26	6	0.04
Loch Loyal	149	0	0	1	0.01
Cur	145	1	0.01	5	0.03
Ellen	144	24	0.17	1	0.01
Abhainn Cuileig	143	0	0	12	0.08
Ledmore	141	0	0	1	0.01
Forss Water	140	0	0	0	0
Loch of Harray & Loch of Stennes	138	0	0	0	0

Moray Firth (South)	137	1	0.01	0	0
Calder (Cumbria)	136	9	0.07	4	0.03
Congresbury Yeo	135	47	0.35	1	0.01
Fishguard	134	87	0.65	4	0.03
Lunan Water Source	134	3	0.02	0	0
Ling	133	0	0	12	0.09
Hoy	132	1	0.01	0	0
Bervie Water	132	0	0	0	0
Kingsbridge	131	38	0.29	2	0.02
Lyne	130	32	0.25	0	0
Fithie Burn	129	1	0.01	0	0
Llanrhystud	128	34	0.27	6	0.05
Gryffe	127	7	0.06	6	0.05
Glaven	127	29	0.23	0	0
Park Burn	126	1	0.01	0	0
Yealm	125	53	0.42	2	0.02
Burn	125	14	0.11	0	0
Afan	124	662	5.34	17	0.14
Nyfer	124	65	0.52	1	0.01
Loch Glass	122	15	0.12	25	0.2
Add	121	2	0.02	5	0.04
Strathy	121	0	0	0	0
Bute	120	2	0.02	6	0.05
Eye Water	120	5	0.04	1	0.01
Laxford	118	14	0.12	47	0.4
Seiont	118	149	1.26	12	0.1
Dwyfor	118	100	0.85	10	0.08
Brit	117	47	0.4	0	0
Water of Leith	117	27	0.23	0	0
Unst	117	0	0	0	0
Duddon	116	22	0.19	16	0.14
Whitbeck	116	21	0.18	11	0.09
Meon	116	26	0.22	0	0

Ffynnonddewi	115	26	0.23	8	0.07
Minsmere River	115	11	0.1	0	0
Sheerness	114	23	0.2	0	0
Muckle Burn	114	2	0.02	0	0
Burn of Houstry	113	0	0	0	0
Loch Langavat	111	3	0.03	1	0.01
Lytham	111	30	0.27	0	0
Colwyn Bay	109	61	0.56	2	0.02
Yar	108	44	0.41	3	0.03
Western Isle of Wight	108	30	0.28	3	0.03
Doniford	107	65	0.61	1	0.01
Kinloch	106	0	0	1	0.01
Erme	106	60	0.57	0	0
East Looe	106	49	0.46	0	0
North Norfolk	106	1	0.01	0	0
Allt Beitheach	105	0	0	6	0.06
Hayle	105	40	0.38	0	0
Wallers Haven	105	29	0.28	0	0
Lyn	104	13	0.12	2	0.02
Bandirran Burn	104	2	0.02	0	0
Farg	103	1	0.01	0	0
Caldicott Level	102	55	0.54	0	0
Kip Water	102	4	0.04	0	0
Burry Port	100	105	1.05	0	0
Ogwen	99	65	0.66	13	0.13
Menalhyl	99	21	0.21	0	0
Milford Haven South	96	16	0.17	2	0.02
Crake	95	40	0.42	32	0.34
Braid Burn	95	4	0.04	0	0
Gwendraeth Fach	93	62	0.67	0	0
South Dorset Coast	91	12	0.13	3	0.03
Moniack Burn	91	0	0	0	0
Porlock	89	59	0.66	0	0

Gwendraeth Fawr	79	61	0.77	0	0
Lamorna	79	21	0.27	0	0
Allerdeanmill Burn	79	0	0	0	0
Skelton Beck	78	38	0.49	12	0.15
Whitehaven and Distington	78	42	0.54	0	0
Crowhurst	77	66	0.86	6	0.08
St. Austell	76	65	0.86	1	0.01
Abhainn a' Bheidhe	76	0	0	0	0
Benbecula	74	1	0.01	1	0.01
Kessingland Hundred	73	7	0.1	0	0
Isle of Coll	73	0	0	0	0
River Gannet	72	11	0.15	0	0
Par	71	46	0.65	0	0
Medina	71	35	0.49	0	0
Crimdon Beck	70	64	0.91	2	0.03
Keer	70	37	0.53	2	0.03
Afon Cynffig & Eglwys Nunydd Reservoir	69	65	0.94	0	0
Poole Harbour	68	37	0.54	5	0.07
Grange	68	26	0.38	2	0.03
Glenfinnan	67	2	0.03	9	0.13
Artro	66	42	0.64	16	0.24
Ilfracombe	66	42	0.64	2	0.03
Red River (North Cornwall)	66	20	0.3	0	0
Slapton Ley & Gara	65	14	0.22	0	0
Ritec	64	22	0.34	3	0.05
Char	63	11	0.17	0	0
Calder (Scotland)	63	9	0.14	0	0

Penmaenmawr	62	27	0.44	10	0.16
Wey	62	34	0.55	0	0
Corfe	62	14	0.23	0	0
Seaton	61	21	0.34	0	0
Heacham Harbour	61	1	0.02	0	0
Raasay	60	0	0	0	0
Avill	59	33	0.56	2	0.03
Bride	59	11	0.19	0	0
Gwyfrai	58	52	0.9	8	0.14
Lyd	58	57	0.98	4	0.07
South Ronaldsay	58	0	0	0	0
Barra	57	2	0.04	0	0
Castle Eden Burn	56	15	0.27	3	0.05
Cober	56	34	0.61	0	0
Winster	54	31	0.57	7	0.13
Ysgethin	53	45	0.85	2	0.04
Kilton Beck	52	23	0.44	18	0.35
Castroggy Brook	52	36	0.69	0	0
Roxby Beck	51	13	0.25	15	0.29
Llyfni	51	31	0.61	7	0.14
Portreath	51	4	0.08	1	0.02
Cresswell	51	15	0.29	0	0
Sanday (Orkney)	47	0	0	0	0
Groeslon	46	101	2.2	3	0.07
Perranporth Stream	46	12	0.26	0	0
Rousay	46	2	0.04	0	0
Washford	45	30	0.67	4	0.09
Sid	45	36	0.8	3	0.07
St. Ives	45	21	0.47	0	0
Avon Water	45	16	0.36	0	0
Westray	45	0	0	0	0

Alun	43	19	0.44	4	0.09
Carew	43	15	0.35	0	0
The Ingol	43	3	0.07	0	0
Seaham	42	29	0.69	1	0.02
Pembroke	42	17	0.4	0	0
Sherford	41	16	0.39	0	0
Treligga	40	13	0.33	5	0.12
Mounton Brook	40	22	0.55	0	0
Liverpool	39	9	0.23	0	0
Houbie	39	0	0	0	0
Spey Coast and Valley Ridges	38	1	0.03	0	0
Falkirk	38	0	0	0	0
Porth Stream and Reservoir	37	12	0.32	0	0
Geilston Burn	37	0	0	0	0
Red River (South Cornwall)	36	6	0.17	0	0
Heddon	33	9	0.27	1	0.03
Newlyn & Heamoor	33	22	0.67	0	0
Stogursey Brook	33	12	0.36	0	0
Stronsay	33	0	0	0	0
Blackbridge Brook	32	2	0.06	0	0
Tor Bay	31	27	0.87	0	0
Morecambe	31	1	0.03	0	0
Den Burn	31	0	0	0	0
Caerhayes Stream	30	6	0.2	0	0
Menai	29	60	2.07	1	0.03
Allt a' Cham Loin	29	0	0	0	0
Eday	29	0	0	0	0

Robin Hoods Bay	28	9	0.32	15	0.54
Dawlish	28	50	1.79	0	0
Mickleby Beck	27	8	0.3	16	0.59
Torpoint	27	5	0.19	0	0
Bressay	27	0	0	0	0
Shapinsay	27	0	0	0	0
East Row Beck	26	13	0.5	9	0.35
Valency	26	4	0.15	1	0.04
Pol	26	12	0.46	0	0
Allt Liath	25	0	0	2	0.08
Trevaylor Stream	25	16	0.64	0	0
Portloe	25	7	0.28	0	0
Abbotsbury and Fleet	25	4	0.16	0	0
Holywell	25	4	0.16	0	0
Ferring Area	23	12	0.52	0	0
Ryde	23	9	0.39	0	0
Ulva	23	0	0	0	0
Dyffryn Gwyn	22	9	0.41	1	0.05
Poole Harbour Water	21	1	0.05	0	0
Lismore	21	0	0	0	0
Lim	20	10	0.5	0	0
Branscombe	20	5	0.25	0	0
Ceibwr	20	3	0.15	0	0
Great Bernera	19	0	0	0	0
Walsay	19	0	0	0	0
Pill	18	11	0.61	0	0
Broad Fleet	18	1	0.06	0	0
Breage	17	4	0.24	1	0.06
Southern Isle of Wight	17	3	0.18	0	0
Isles of Scilly	17	0	0	0	0
Muckle Row	17	0	0	0	0

River Annan (Coastal)	16	0	0	0	0
Grange Chine	15	7	0.47	0	0
Pentrefelin	14	14	1	0	0
Gwril	14	4	0.29	0	0
Luing	14	0	0	0	0
Scarba	14	0	0	0	0
Cowes	13	1	0.08	0	0
Balvicar	13	0	0	0	0
Da Burn o Ham	13	0	0	0	0
Isle of Gighe	13	0	0	0	0
Taransay	13	0	0	0	0
Portland	12	0	0	0	0
Rocky Valley	11	4	0.36	5	0.45
Flimby	11	2	0.18	0	0
Great Cumbrae	11	0	0	0	0
Isle of Canna	11	0	0	0	0
Isle of Kerrera	11	0	0	0	0
Longhope & Switha	11	0	0	0	0
Scarp	10	0	0	1	0.1
Loch Bhrusda (Berneray)	10	1	0.1	0	0
Hether Burn	10	0	0	0	0
Mayflower International Marina	10	0	0	0	0
Soay	10	0	0	0	0
St. Just	10	0	0	0	0
Winniford	9	2	0.22	0	0
Flotta	9	0	0	0	0
Rona (Portree)	9	0	0	0	0
Vatersay	9	0	0	0	0
Lee	8	0	0	2	0.25

Zeneca - ICI Brixham Laboratory	8	7	0.88	0	0
Baleshare	8	0	0	0	0
Iona	8	0	0	0	0
Pabbay	8	0	0	0	0
Papa Westray	8	0	0	0	0
St. Kilda	8	0	0	0	0
Eriskay	7	1	0.14	0	0
Taicochion Area	7	1	0.14	0	0
Loch Carabhat	7	0	0	0	0
North Ronaldsay	7	0	0	0	0
Papa Stour	7	0	0	0	0
River Don Coastal	7	0	0	0	0
River Lochy	7	0	0	0	0
Scalpay	7	0	0	0	0
Vaadal	7	0	0	0	0
Eglisay	6	0	0	0	0
Eilean Shona	6	0	0	0	0
Mingulay	6	0	0	0	0
West Burra	6	0	0	0	0
University of Swansea	5	13	2.6	0	0
Axemouth Coast	5	0	0	0	0
Isle of Muck	5	0	0	0	0
Kingston	5	0	0	0	0
Lunga and Slate Islands	5	0	0	0	0
Oronsay	5	0	0	0	0
Ronay	5	0	0	0	0
Castle Stream	4	2	0.5	0	0
East Burra	4	0	0	0	0
Graemsay	4	0	0	0	0

Isle of Shuna	4	0	0	0	0
Lundy	4	0	0	0	0
Sandray	4	0	0	0	0
Summer Isles	4	0	0	0	0
Fara	3	0	0	0	0
Gairsay	3	0	0	0	0
Hascosay	3	0	0	0	0
Isle of Ewe	3	0	0	0	0
Isle of Noss	3	0	0	0	0
Little Cumbrae	3	0	0	0	0
Pabaigh	3	0	0	0	0
Stroma Island	3	0	0	0	0
Vaila	3	0	0	0	0
Vementry	3	0	0	0	0
Wiay (Outer Hebrides)	3	0	0	0	0
Wyre (Orkney)	3	0	0	0	0
Berneray	2	0	0	0	0
Boreray	2	0	0	0	0
Brownsea Island	2	0	0	0	0
Bruray	2	0	0	0	0
Burlington	2	0	0	0	0
Caldey Island	2	0	0	0	0
Crowlin Islands	2	0	0	0	0
Eilean Shiophoirt	2	0	0	0	0
Ensay	2	0	0	0	0
Fuday	2	0	0	0	0
Holy Isle	2	0	0	0	0
Kirkbost	2	0	0	0	0
Midpark	2	0	0	0	0
Monach Islands (East)	2	0	0	0	0
Papa Little	2	0	0	0	0
Priest Island	2	0	0	0	0
Sanday	2	0	0	0	0

Tinkers Hole	2	0	0	0	0
Trondra	2	0	0	0	0
Uyea	2	0	0	0	0
Wiay	2	0	0	0	0
Auskerry	1	0	0	0	0
Balta	1	0	0	0	0
Beinn a Charnain	1	0	0	0	0
Calve Island	1	0	0	0	0
Cara Island	1	0	0	0	0
Davaar Island	1	0	0	0	0
Eilean Chaluim Chille	1	0	0	0	0
Eilean Fladday	1	0	0	0	0
Eilean Liubhaird	1	0	0	0	0
Eilean Mhealasta	1	0	0	0	0
Eriska	1	0	0	0	0
Faray	1	0	0	0	0
Flodaigh	1	0	0	0	0
Fuaigh Mor	1	0	0	0	0
Hermetray	1	0	0	0	0
Hildasay	1	0	0	0	0
Killegray	1	0	0	0	0
Little Bernera	1	0	0	0	0
Little Colonsay	1	0	0	0	0
Monach Islands (West)	1	0	0	0	0
Mousa	1	0	0	0	0
Mullach a Charnain	1	0	0	0	0
Oxna	1	0	0	0	0
Pabaigh Mor	1	0	0	0	0
Pabay	1	0	0	0	0
Rona & Sule Skerry	1	0	0	0	0

Sanda Island	1	0	0	0	0
Shuna Island	1	0	0	0	0
Swona	1	0	0	0	0
Torsa Island	1	0	0	0	0
West Linga	1	0	0	0	0
Ardantrive Bay Island	0	0	0	0	0
Bass Rock	0	0	0	0	0
Bay of Firth Islands	0	0	0	0	0
Bhacasaigh	0	0	0	0	0
Castleton Island	0	0	0	0	0
Ceallasaigh	0	0	0	0	0
Cherarabhaigh	0	0	0	0	0
Cliatasaigh	0	0	0	0	0
Colsay	0	0	0	0	0
Coolas Bad a Chrotha Beach	0	0	0	0	0
Cramond Island	0	0	0	0	0
Easdale Island	0	0	0	0	0
Eilean Balnagowan	0	0	0	0	0
Eilean Casach	0	0	0	0	0
Eilean da Mheinn	0	0	0	0	0
Eilean Leathann	0	0	0	0	0
Eilean na Beithe	0	0	0	0	0
Eilean nam Feannag	0	0	0	0	0
Eileanan Iasgaich	0	0	0	0	0
Fiaraidh	0	0	0	0	0
Flodaigh Beag	0	0	0	0	0
Flodaigh Lewis	0	0	0	0	0

Flodaigh Mor	0	0	0	0	0
Flodday	0	0	0	0	0
Gasaigh	0	0	0	0	0
Glimps Holm	0	0	0	0	0
Haskeir	0	0	0	0	0
Huney	0	0	0	0	0
Inchcolm	0	0	0	0	0
Inchkeith	0	0	0	0	0
Isle of Horrisdale	0	0	0	0	0
Isle of May	0	0	0	0	0
Lamb Holm	0	0	0	0	0
Lamba	0	0	0	0	0
Linngeam	0	0	0	0	0
Lismore North Islands	0	0	0	0	0
Little Roe	0	0	0	0	0
Loch an t-Saile	0	0	0	0	0
Loch Barraglom Small Island	0	0	0	0	0
Loch Eil Beach	0	0	0	0	0
Loch Nighe	0	0	0	0	0
Loch Rog Small Island	0	0	0	0	0
Muckle Skerry	0	0	0	0	0
Ornsay	0	0	0	0	0
Sgeotasaigh	0	0	0	0	0
Skerryvore	0	0	0	0	0
Staffa	0	0	0	0	0