Greater Thames Estuary Fish Migration Roadmap

Project Report

Thames Estuary Partnership

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Version 2

Contents

Executive summary

Rivers in the North Sea region are some of the most fragmented by human development in the world. In the United Kingdom, river restoration and intertidal habitat enhancement works are completed in an opportunistic way: when specific damages from developments need to be mitigated or when flood asset management must be addressed. Similarly, fish migratory barriers such as weirs are only dealt with as and when opportunities arise and usually only one barrier at a time. As a result, many flood asset or land development projects can miss opportunities to deliver environmental enhancement and other social benefits because relevant information is not easily accessible.

To address this issue within the Greater Thames Estuary area, the Greater Thames Estuary Fish Migration Roadmap was developed. This is based on the conceptual framework of the 'Roadmap for Fish Migration' (created by Peter Philipsen, Director at Nature at Work) used nationally in the Netherlands.

The Roadmap focuses on a 'wholescape' approach and looks at rivers as interconnected migratory roads. Rivers within the project area were classified as 'Highways', 'A-roads', 'B-roads', 'C-roads' and 'D-roads' and, after gathering information on existing migratory barriers, the extent of river fragmentation was visualised and the proportion of fragmentation was calculated. Then, the collated barrier data and river connectivity layers were integrated into an interactive mapping application along with data on the ecological status of rivers, fish species, flood risk areas, development opportunity areas, and riverine and marine habitat areas.

The resulted GIS application enables the visualisation of barrier locations and river network connectivity in entire catchments. The application also allows the different datasets to be overlayed, and with the use of an in-built filter widget, the barrier, habitat, and the fish species data can be filtered. This, along with the other data layers, can help pinpoint those barrier locations where, for example, the upstream river sections have high quality habitats, but fish passes are not installed, or where riverside developments are planned, and mitigation works could be carried out to help improve connectivity.

The Roadmap is both a method and a GIS tool that helps riverside communities and stakeholders to understand the extent of river fragmentation, and it can be used to make data-driven decisions and develop an integrated approach when sustainable restoration works are carried out. The Roadmap also contributes to the data needed for both statutory monitoring and provides a pathway for building relationships across the freshwater and marine boundary.

Introduction

Rivers play an important role in our environment - regulating floods, transporting sediments, and supporting biodiversity. Many of these functions performed by rivers are also linked to factors that indicate river health, such as river flow and connectivity; influencing species migration, diversity, and habitat occupancy (Shao et al. 2019).

The rivers of the North Sea region are some of the most fragmented by human development in the world. Artificial structures installed for water management purposes (i.e. weirs, sluices, and locks), can be found on almost every kilometre of river (Belletti et al. 2018). These structures also act as barriers for migratory fish species, preventing or causing a significant delay to their migration with negative consequences on their diversity and abundance (Jones et al. 2019). Diadromous fish species such as the European eel (*Anguilla anguilla*), sea bass (*Dicentrarchus labrax*), sea lamprey (*Petromyzon marinus*) and flounder (*Platichthys flesus*) move large distances between marine and freshwater environments to fulfil their lifecycle. Thus, maintaining river connectivity is important to sustain their healthy and diverse population (Nunn and Cowx 2012).

In the United Kingdom, river restoration works are carried out under the Water Framework Directive (WFD) to resolve water environment issues, under the Fisheries Improvement Programme (FIP) to address barriers that have a negative effect on fisheries and habitat, or as environmental enhancement projects delivered by NGO's through catchment partnership projects. However, some of these works are often completed in an opportunistic way – when specific damages from developments need to be mitigated or when flood asset management must be addressed (Amy Pryor, pers. comm.). Similarly, barriers such as weirs are only dealt with as and when opportunities arise and usually only one barrier at a time. Consequently, many flood assets or land development projects can miss opportunities to deliver environmental enhancement and other social benefits, because relevant information is not easily accessible and other benefits are hidden.

To address this issue within the Greater Thames Estuary, the Thames Estuary Partnership (TEP) and Nature at Work (NAW) launched the Greater Thames Estuary Fish Migration Roadmap project (here on referred to as Roadmap). The Roadmap is both a method and a web-based GIS tool, based on the conceptual framework of the 'Roadmap for Fish Migration', developed by Peter Philipsen (Director, NAW).

The Roadmap considers rivers as interconnected fish migratory routes – by mapping fish migratory barrier location data on top, river network connectivity can be visualised (Figure 1).

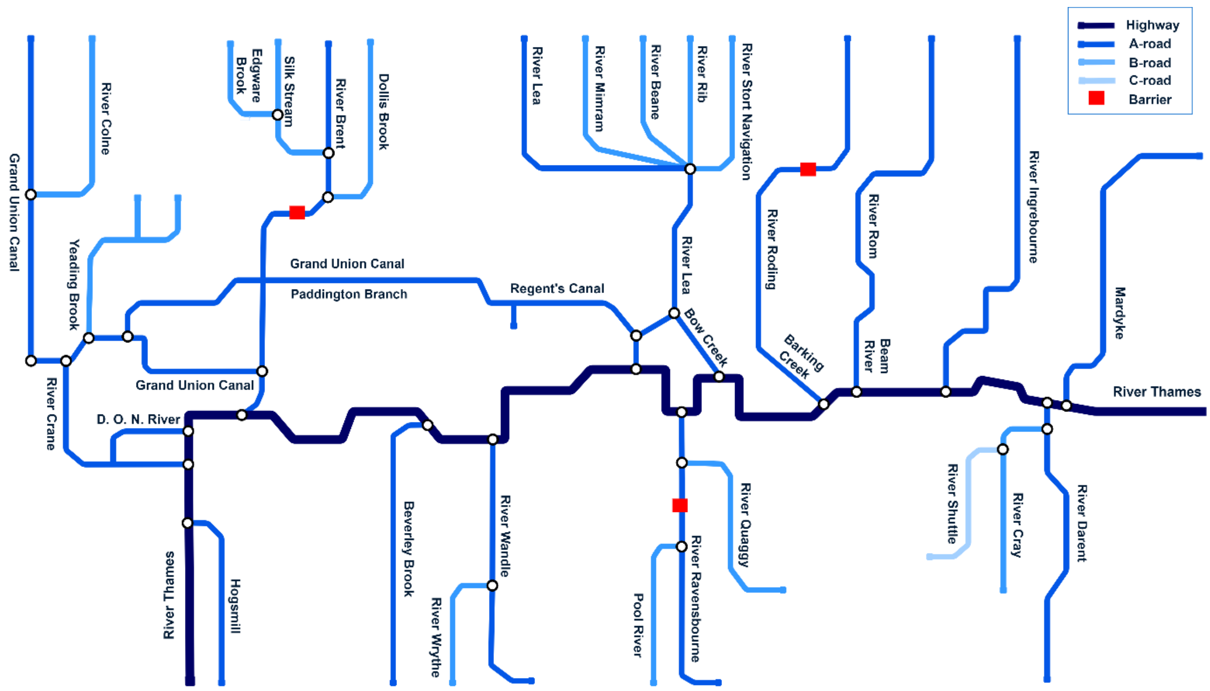

Figure 1: Conceptual illustration of rivers as interconnected fish migratory routes in London (Made with diagrams.net)

This highlights river fragmentation, and subsequently helps develop a strategic approach to identify locations where barrier works may need prioritisation. In addition, locations carrying the greatest environmental and social benefits can be targeted by integrating data on river habitats, fish species, flood risk, development opportunity and potential habitat creation areas.

Thus, utilising Geographic Information Systems (GIS), the Roadmap helps create an integrated, 'wholescape' approach, across land and water within a catchment, and helps make data-driven decisions when it comes to river restoration, riverside development, and flood mitigation schemes. The Roadmap also contributes to data needed for both statutory monitoring and community-based environmental action, providing a pathway for building relationships among stakeholders and communities locally, across the whole river continuum and across the freshwater and marine boundary.

Roadmap for Fish Migration in the Dutch Delta

The conceptual framework of the 'Roadmap for Fish Migration' was developed and first rolled out in the Netherlands. The *Roadmap for Fish Migration in the Dutch Delta* project identified waterways as 'Highways', 'Regional waterways' and 'Local waterways'. Next, information on barriers, fish passes, and habitat quality was gathered in a web-based GIS (GeoWeb) tool and were plotted on the migratory routes. Then connectivity maps were produced to indicate which barriers need to be lifted first (Appendix 1). Working with regional waterboards and with the national water authority (Rijkswaterstaat), this approach is now being used nationally in the Netherlands (Kroes et al. 2017).

Methodology

The Roadmap project had three objectives:

1. To gather information on fish migratory barriers and river connectivity within the Thames River Basin and adjacent catchments.

2. To develop an online, easy-to-access and easy-to-use web-based GIS tool to visualise all relevant data.

3. To develop a replicable, strategic method that can be used in other catchments in the UK.

These objectives were executed via the following processes:

- Data science
    - Designation of project area
    - Data collection
    - Data pre-processing and merging
    - Data analysis
    - Data visualisation
- Stakeholder and community engagement via the local Catchment Partnerships and Rivers Trust

Both processes began in parallel, with the aim of collating baseline knowledge for the project and identifying data holders and those who would benefit from using the completed Roadmap, such as environmental charities and government organisations. Involving these key stakeholders from the start ensured that the development of the Roadmap would be end-user led and could link into statutory and local plans, such as River Basin Management Plans and Catchment Plans.

Data science

Designation of project area

The project area was defined within the Thames River Basin plus the Combined Essex and East Kent catchments. This area was chosen to reflect the 'whole system' of the river basin with rivers draining into the estuary and ultimately the ocean, and the opportunistic nature and need of migratory fish species for full connectivity across that system. An aim was to embody the message that rivers and estuaries within the project area are linked to the ocean, and thus are migratory corridors for many species. Migratory fish species coming into the Thames Estuary are opportunistic in choosing where they go. They follow freshwater and other environmental signals to find suitable habitat as part of their life cycle, and this is particularly so for the European eel, one of the target species for this project.

Rivers within the study area were categorised as follows: tidal rivers (rivers directly connected with the North Sea) were identified as 'Highways', rivers flowing into the highways were identified as 'A-roads', rivers flowing into the A-roads were identified as 'B-roads', rivers flowing into the B-roads were identified as 'C-roads' and rivers flowing into the C-roads were identified as 'D-roads' (Figure 2).

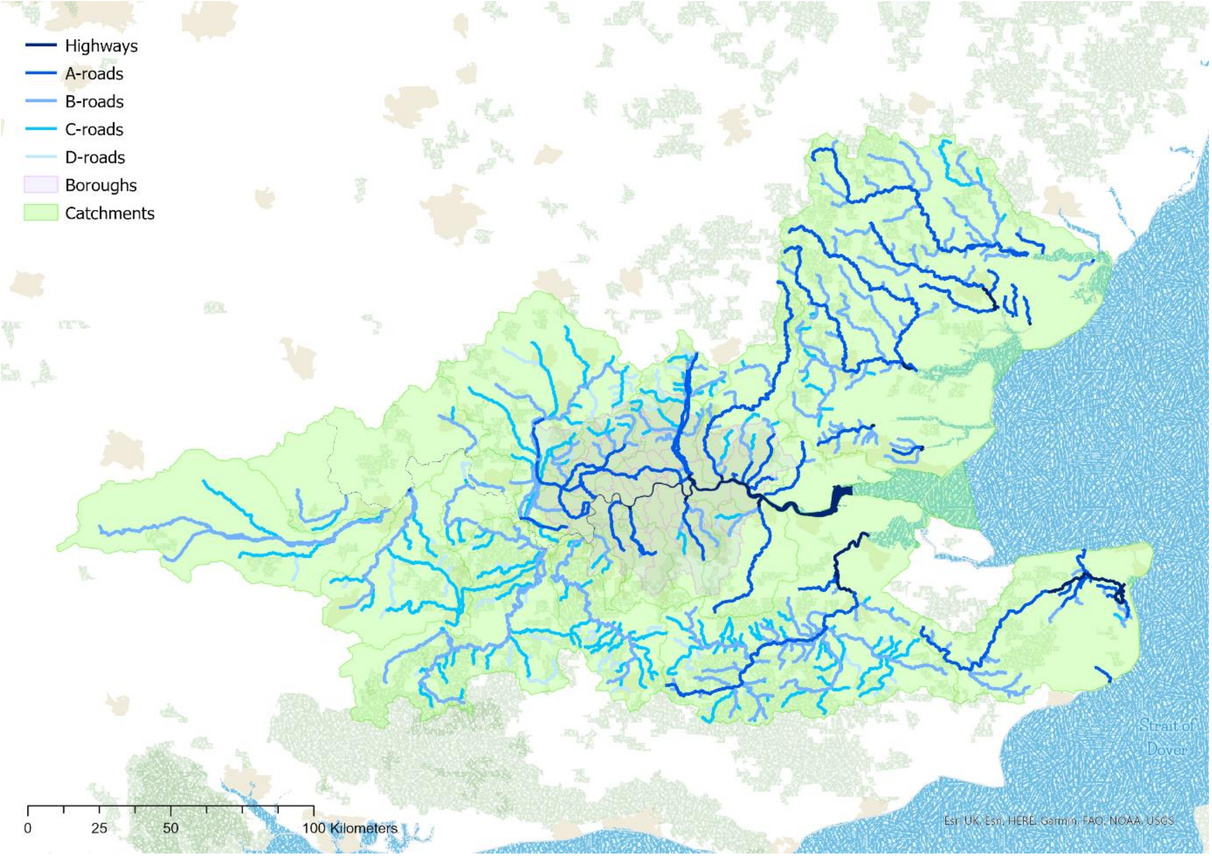

Figure 2: Map showing the study area and the migratory routes (Made with ArcGIS Pro)

Data collection

The baseline dataset for the Roadmap was created using barrier data, river and catchment shapefiles. Barrier location information was obtained from multiple sources, including the data collected as part of the Thames Catchment Community Eels project (TCCEP, from now on referred to as Thames Eels), in the form of datasets (Excel sheet or shapefile) and reports. The river shapefile data used to visualise the fish migratory routes was obtained from the Ordinance Survey website (OS Open Rivers). In addition, further digitisation of river sections was carried out using ArcMap (10.8.2) (ESRI 2018). Data on the ecological status of rivers and catchments were downloaded from the Catchment Based Approach (CaBA) open data website.

To create the web-based GIS tool, additional datasets were also gathered. River habitat survey data was obtained from the Department for Environment, Food and Rural Affairs (Defra) website. The London Plan opportunity areas and London borough data were downloaded from the London Datastore. Data such as risk of flooding from rivers and sea (CaBA) and potential habitat creation sites for oyster, seagrass, and saltmarsh areas (CaBA) were added as a map service via ArcGIS Online. Fish survey and species data was gathered from the Environment Agency (EA).

See Appendix 2 for the detailed table for all dataset and their sources.

Data pre-processing and merging

Due to the different barrier data types and sources, a process was created to combine them into one robust and standardised barrier dataset. The methodology devised for the data merging was carried out over seven steps. This was essential to provide an accurate baseline barrier data for the Roadmap.

In the outline of this procedure, pre-processed results were also presented.

1. All barrier datasets (Excel sheet and shapefile) were clipped in ArcMap (Clip tool) to focus on the project area only (23 catchments).
2. The separately received 'Fish and eel passes' (135 locations) data and the 'Thames obstruction' (1333 locations) data from the Environment Agency (EA) were spatially joined in ArcMap (Spatial join tool).

   Result:

   - The joining process resulted in 35 extra locations with pass data only. At these locations, the type of the barrier was recorded as 'unknown'.
   - The joined dataset (from now on referred to as EA) yielded all together 1368 barrier locations.
3. The data fields same across the barrier datasets were barrier types and locations, and pass type and locations. The total number of barriers and passes from these datasets were summarised in Table 1. (The table excludes the barrier information that were received in a report format.)

	AMBER	CaBA	RiverObs	EA	TCCEP	CRT	Essex	SERT	TEP
Catchments	*23*	*23*	*23*	*21*	*5*	*5*	*1*	*1*	*5*
Barriers	2452	2430	2491	1601	457	193	813	9	188
Pass	119 (fish)	150 (fish) 77 (eel)	61 (fish)	145 (fish) 70 (eel) 19 (multi-spcies)	28 (fish) 16 (eel)	0	24 (fish) 44 (eel)	0	6 (fish) 4 (eel)

Table 1: Summary data table of the received barrier datasets

4. The AMBER, CaBA, EA, Essex and RiverObs barrier datasets were spatially joined in ArcMap (Spatial join tool) and standardised.

   Process and result:

   The following fields were kept from the datasets:

   - ID
   - Barrier location (both grid and latitude and longitude)
   - Barrier type
   - Pass type
   - WFD fish rank (from the CaBA data)
   - Salmonid rank (from the CaBA data)

- Eel priority (from the CaBA data)
- Height (from the CaBA data)
- A 'Source' field was also created to feature the original data source for each barrier location.

Barrier type and pass type were kept where they were the same across at least two datasets. In all other instances, the barrier type and pass type were recorded as 'unknown'. The resulted dataset is called 'finalised barrier dataset'.

5. The finalised barrier dataset was cut down in ArcMap (Buffer tool) using a 100-metre buffer zone to concentrate on those barriers that occurred on the migratory routes only. See Appendix 3 for detailed explanation.
6. The Thames Eels, CRT, SERT and TEP barrier datasets (Excel sheets and shapefiles) and the barrier information received in the form of reports (LWT and ZSL) were manually integrated into the final barrier dataset. The 'EBAT score' and 'Crawling media' fields were added to the finalised barrier dataset from the Thames Eels barrier dataset. The barrier locations in these datasets were ground-truthed and so their integration helped verify some of the 'unknown' entries generated in step 4. A 'Comment' field was also created in this process to add relevant information from the Excel sheets and reports.
7. The finalised barrier data went through an additional verification process by checking through each barrier location using Google Earth 3D (Google Earth 2020) satellite imagery. (This step allowed the project to account for any barrier that might have been lost during step 5.) During this process:
    - Duplicate barrier location was merged following the same rule as in step 4.
    - Any new/additional barrier found was added as 'Satellite imagery' under the Source field. The number of barriers found through satellite imagery was 35.

Data analysis

To facilitate the strategic approach of targeting impassable barriers to improve fish migration and habitat connectivity, the finalised barrier dataset was used through the following steps:

1. The finalised barrier dataset was overlayed on top of the river shapefile in ArcMap. This allowed the river shapefile to be split into fragments using the Split tool. Then the length of each river fragment (km) was calculated (Calculate geometry tool).
2. To visualise upstream river network connectivity for fish and eel, those river fragments where the nearest barrier downstream had fish, eel or multi-species pass installed, were removed, or did not need mitigation (for example high EBAT score) were classified as 'open'. The rest were classified as 'closed' (Figure 3). In this step a separate fish and a separate eel upstream connectivity shapefile was gained.

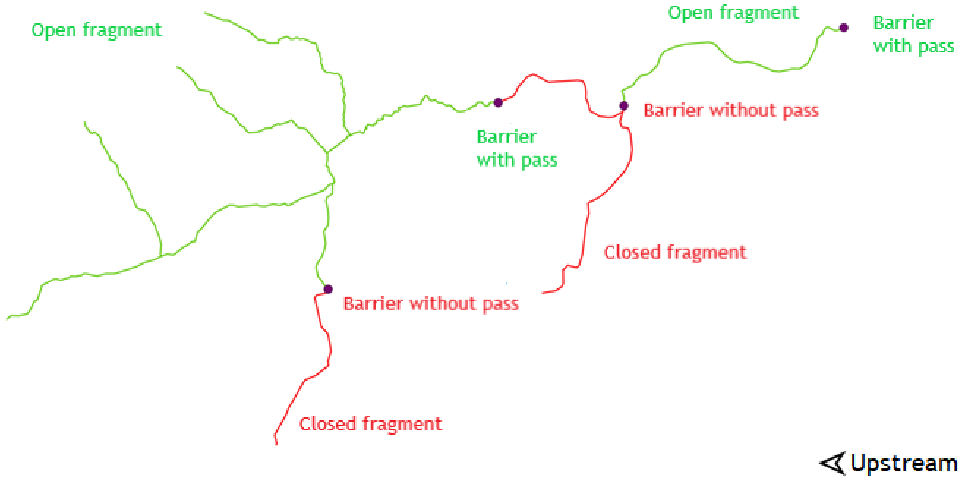

Figure 3: Conceptual illustration of the open and closed migratory routes (Made with QGIS and Paint 3D)

3. Within each catchment, the upstream fish and eel connectivity shapefiles gained in step 2 were further arranged into sub-networks. Each sub-network was made up of interconnected migratory routes (Highways, A-roads, B-roads, C-roads and D-roads) (Figure 4).

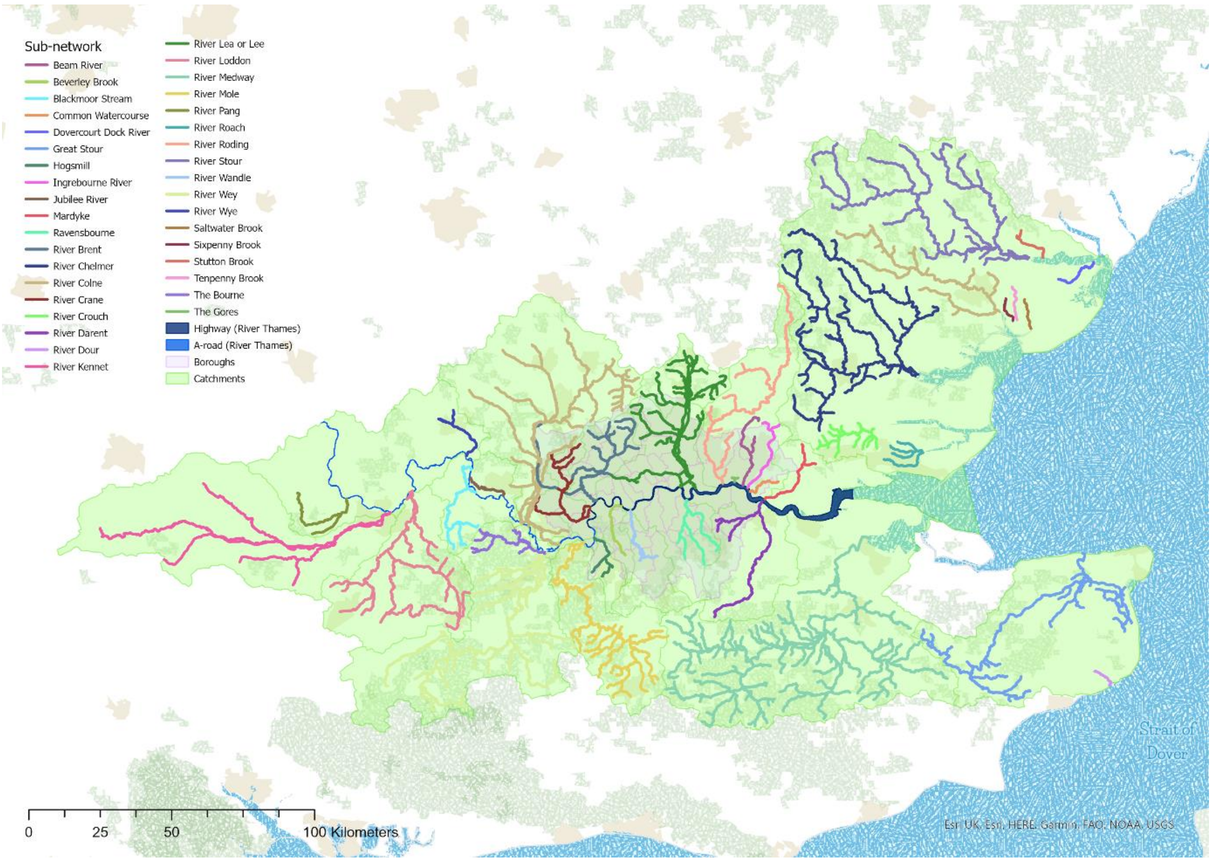

Figure 4: Map of the catchments and their sub-networks (Made with ArcGIS Pro)

4. Using the upstream fish and eel connectivity shapefiles gained in step 3, within each sub-network, the proportion of river fragmentation was calculated.

$$\frac{l}{L} * 100$$

l is the length of a river fragment and *L* is the length of the whole sub-network. This calculation was based on the dendritic connectivity index (DCI) (Cote, Kehler, Bourne, & Wiersma, 2009). The percentage value of a river fragment was then assigned to the nearest barrier downstream and was integrated into the finalised barrier dataset under the 'Gain_fish' and 'Gain_eel' fields (Figure 5).

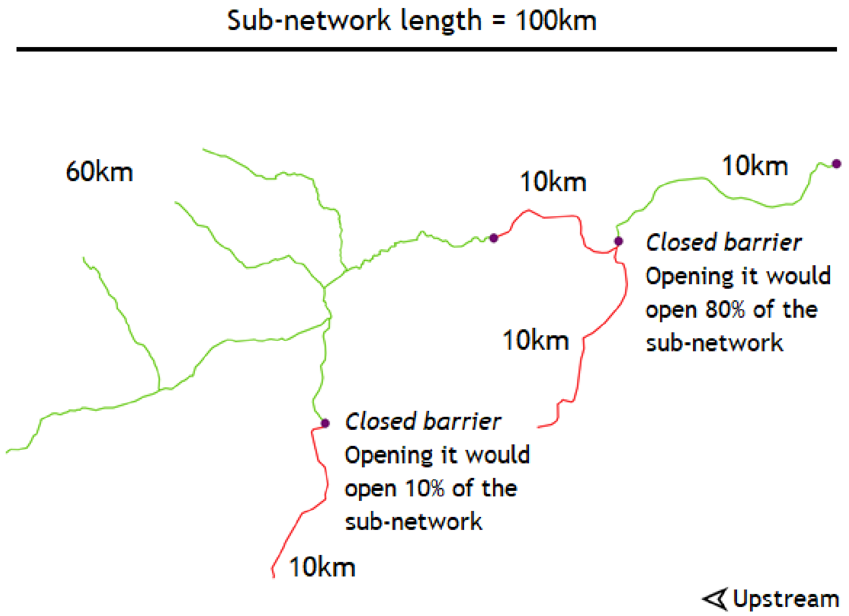

Figure 5: Conceptual illustration of the percentage of upstream connectivity gain when closed barriers are addressed (Made with QGIS and Paint 3D)

5. The river habitat survey data was analysed and integrated into the final barrier dataset through the following steps:

   - The river habitat survey data was cut down using the 100-metre buffer zone (see step 5 in Data pre-processing and merging). The data fields extracted from the river habitat survey data were habitat quality assessment (HQA) and habitat modification score class (HMS class) (Raven et al. 1998) (Table 2).

River Habitat Survey			
Habitat quality assessment		Habitat modification score (class)	
Diverse	61 to 100	Near-natural	5
High	49 to 60	Predominantly unmodified	4
Moderate	38 to 48	Obviously modified	3
Low	26 to 37	Significantly modied	2
Poor	1 to 25	Severely modified	1

Table 2: Summary data table of the classification categories of the river habitat survey data

- Using the single river shapefile gained in step 1, within each river fragment, the mean average was calculated for all HQA and HMS class habitats (Figure 6). The value of the mean average was then assigned to nearest barrier downstream and was integrated into the finalised barrier dataset under the 'HMS' and 'HQA' fields.

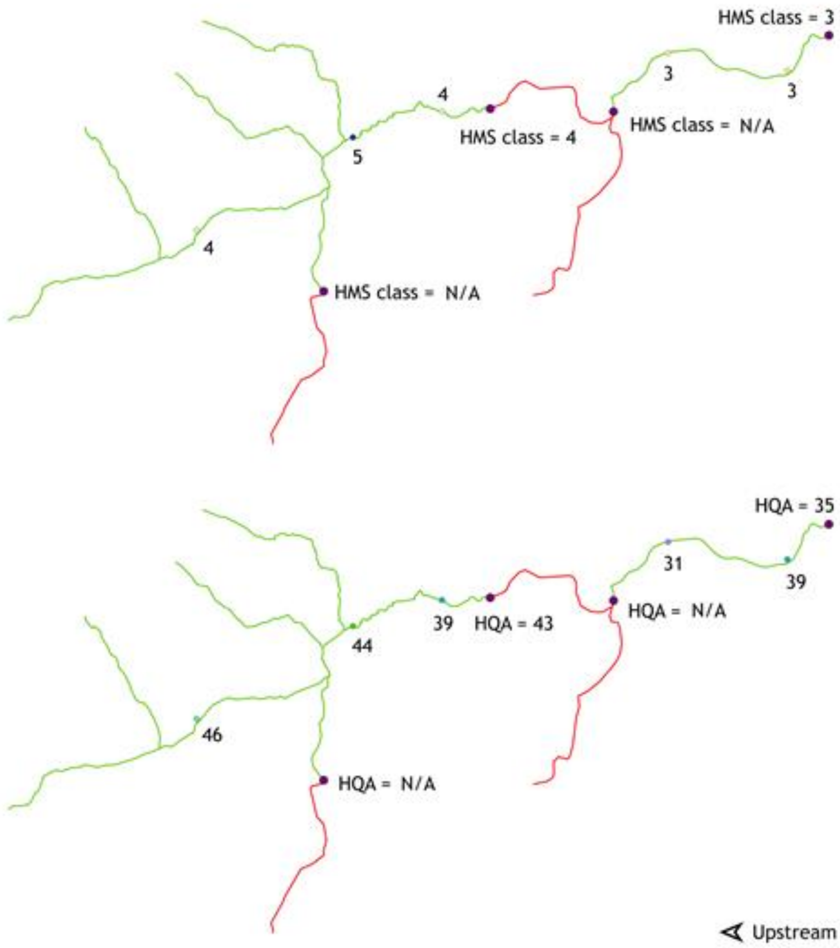

Figure 6: Conceptual illustration of river habitat survey data integration (Made with QGIS and Paint 3D)

6. Lastly, under the 'Category' field, the barriers were reprioritised:

   Desktop-based approach:

   - Barriers with the highest % connectivity gain within the given sub-network were marked as 'Connectivity gain'.
   - Those barriers that had information missing were marked as 'Data needed'.
   - Impassable barriers (barriers without fish/eel pass) on the Highways and at the confluence of the Highways and A-roads were marked as 'First barrier'.
   - Barriers without fish, eel or multi-species pass from where the upstream river sections had habitat scores HQA ≥ 49 and/or HMS class ≥ 4 were marked as 'Habitat priority'.
   - Barriers where it is known that passes are not present were marked as 'Pass not installed'.

- Barriers where it is known that passes are not needed (for example due to high EBAT score) were marked as ‘Pass not needed’.
- Barriers that had fish/eel pass installed or were removed were marked as ‘Success’.
- Barriers that need to be addressed urgently for eel passage were marked as ‘Super critical’.

Following a series of stakeholder engagements in the Combined Essex Catchment and as part of the Thames Eels project, additional categories were introduced as part of the reprioritisation process:

Expert knowledge-based approach:

- ‘Easy barrier’: barrier locations with a quick ‘win’.
- Major fish/eel project: barrier locations where major fish or eel project is needed.
- Missing pass: barrier locations where the fish/eel pass is now missing.
- No connectivity possible: barrier locations where connectivity is not possible.
- Barriers that received an EBAT score between 10-15 were marked as ‘High EBAT’.
- Barriers that received an EBAT score between 5-9 were marked as ‘Medium EBAT’.
- Barriers that received an EBAT score below 5 were marked as ‘Low EBAT’.

The flowchart below summarises the steps of the data analysis (Figure 7).

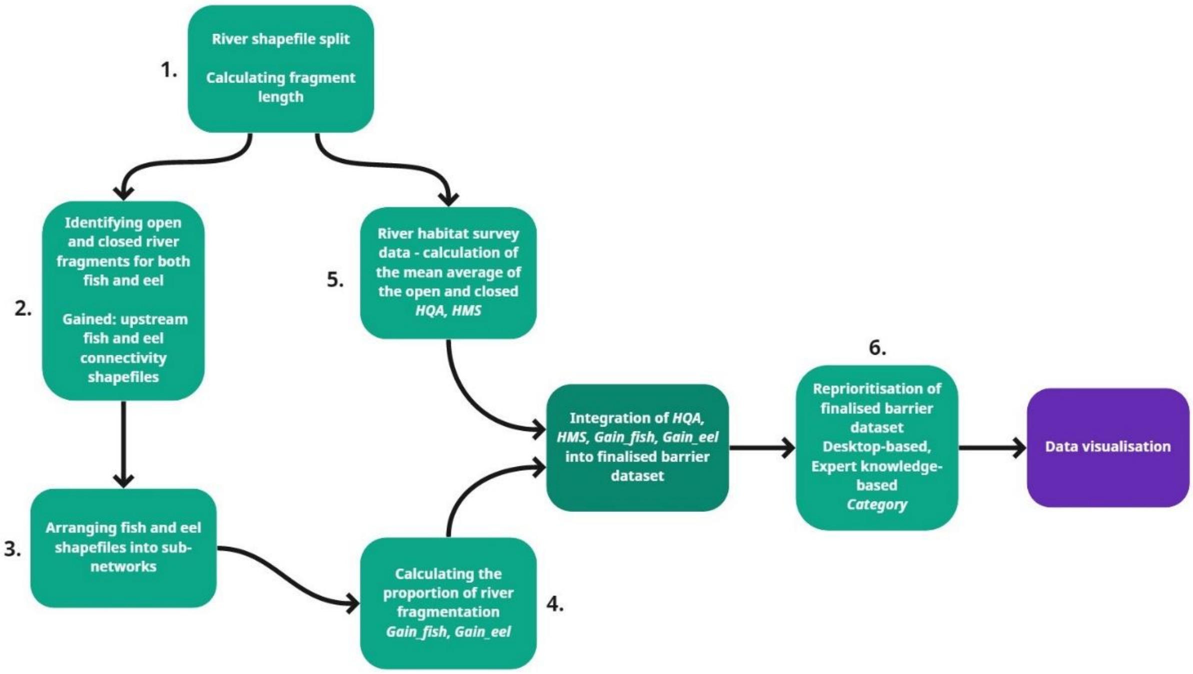

Figure 7: Summary of the steps of the data analysis (Made with Miro)

Data analysis was carried out using ArcMap (10.8.2). Figure 1 illustration of the migratory routes was made using diagrams.net. The flowcharts were made using the online software called Miro. Figures and tables were created using QGIS (3.16.15), ArcGIS Pro (2.9), MS Excel (2016) and Microsoft’s Paint 3D.

Data visualisation

For the creation of the web-based GIS platform, ArcGIS's Web Mapping Application was used as this allows user to fully interact with all datasets.

For the creation of the website, ESRI's ArcGIS Hub website building application was used.

The functionality of the interactive web-based GIS was also demonstrated within the Results section using four scenarios where habitat priority, connectivity gain, EBAT score and development opportunity areas were considered.

Stakeholder and community engagement

To ensure the resulting Roadmap was end user-led, several meetings and workshops were held with various technical and practitioner stakeholders, specifically with the Catchment Partnership in Essex led by the Essex Wildlife Trust and the Thames Rivers Trust.

The Roadmap has been featured in the Institute of Fisheries Management's FISH magazine and presented at conferences and forums. There have also been several meetings and workshops with stakeholders. TEP were also one of the partners in working on reviving the River Obstacles mobile app (developed by Natural Apptitude with the EA and originally published in 2015) to enable a citizen science approach to future barrier assessment and mitigation work. The River Obstacles mobile app was used to collect barrier data as part of the Thames Eels project.

Essex Fish Migration Roadmap

In meetings with the EA's Combined Essex Catchment Management team, the importance of linking the Roadmap with other conversations about flood protection, water abstraction and river navigation was highlighted. The data for this catchment had been fully ground-truthed by the EA and the Combined Essex Catchment Partnership (CECP) and there was enthusiasm to use this data to trial the Roadmap approach locally. Between September 2018 and March 2021, TEP and NAW worked together with the Essex team on the Essex Fish Migration Roadmap. Upon receiving and integrating the detailed barrier data into the Roadmap, a separate interactive and harcopy maps were developed and used to engage with local stakeholders.

Thames Catchment Community Eels project

From December 2020 until March 2022 TEP was a collaborator on the Thames Eels project, which was led by the Thames Rivers Trust with Action for the River Kennet, South East Rivers Trust and Thames21 in collaboration with the Zoological Society of London (ZSL).

As part of this project, TEP had an opportunity to integrate the barrier data collected by citizen scientists across five catchments (South Chiltrens, Kennet, Mole, Brent and Ravensbourne) using the updated River Obstacles app, which included Eel Barrier Assessment Tool (EBAT) scoring method developed by ZSL.

The EBAT score can be derived from four main criteria relating to the barrier slope, length and velocity and incorporates crawling media. The higher the score, the greater the passability likelihood for eel (Figure 8). See Appendix 4 for the steps of the scoring method.

Score Range	
10-15	Unlikely to represent a major barrier to upstream migration
05-09	Partial impact, obstacle may impede passage
<05	Likely to be a complete obstacle to eels migrating upstream

Figure 8: EBAT scoring range

Results

The map shows the finalised barrier dataset with the location of barriers on the migratory routes within the project area (Figure 9).

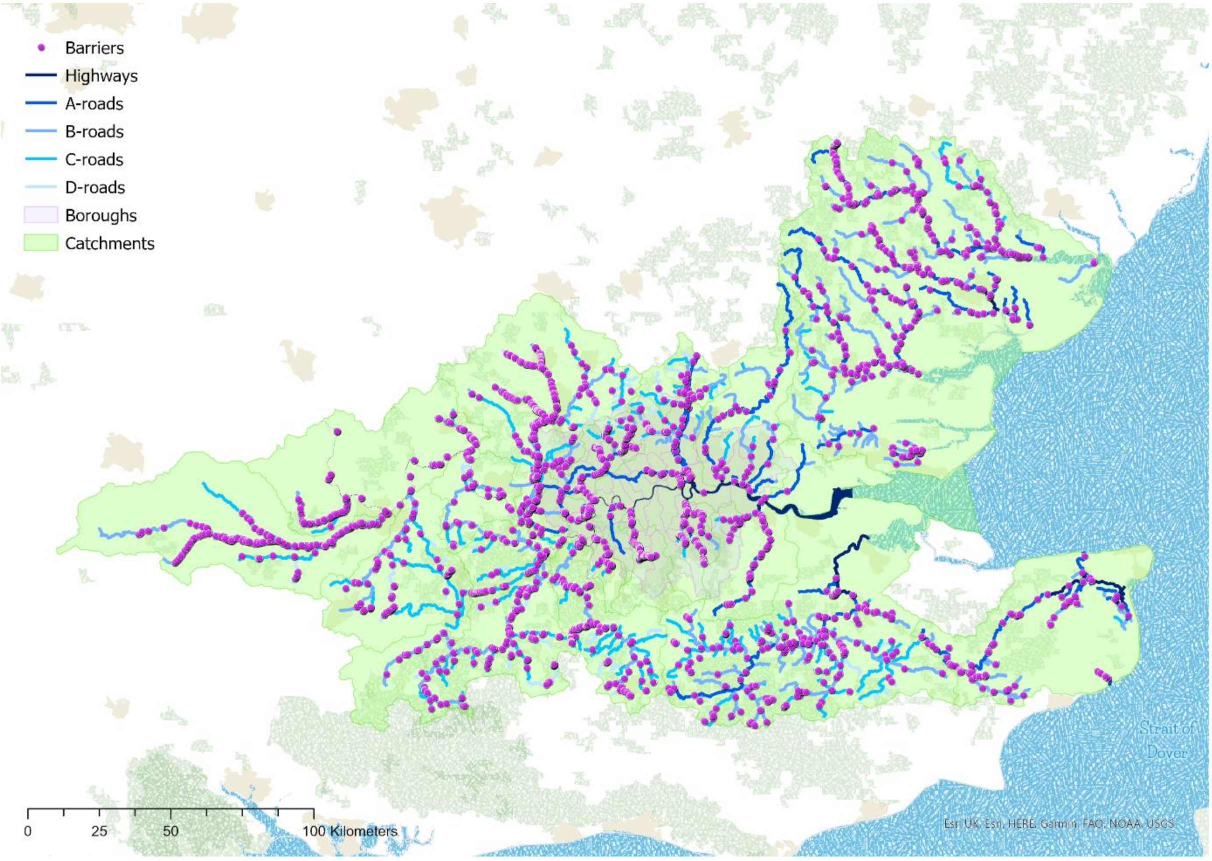

Figure 9: The finalised barrier dataset with the migratory routes (Made with ArcGIS Pro)

The data table gives a summary of the number of barriers, and number and type of passes within each catchment, along with the total river length (Table 4).

Catchment	Number of barriers	Number of removed barriers	Number of fish pass	Number of eel pass	Number of both fish and eel pass	Number of multi-species pass
Beverely Brook	2	3	0	0	0	1
Brent	99	9	3	5	0	0
Colne	250	0	26	1	0	4
Combined Essex	431	5	8	28	1	4
Crane Valley	65	0	2	3	0	0
Darent & Cray	60	0	3	7	0	0
East Kent	80	0	4	2	0	0
Hogsmill	28	2	13	2	0	3
Kennet	180	8	24	2	2	1
Loddon	77	0	8	0	0	0
London Lea	105	0	0	8	0	2
Lower Lea	37	0	1	0	0	0
Maidenhead to Teddington	57	0	19	4	2	1
Medway	220	0	10	0	2	0
Mole	126	3	3	4	5	0
Ravensbourne	100	1	4	5	0	0
Roding, Beam & Ingrebourne	37	1	2	3	0	0
South Chilterns	116	10	12	0	6	0
South Essex	2	0	1	0	0	0
Wandle	81	1	2	7	0	0
Wey	188	0	5	0	0	2
Your Tidal Thames	5	0	1	0	0	0
Total	**2346**	**43**	**151**	**81**	**18**	**18**

Table 3: Summary table of the number of barriers, removed barriers, fish pass, eel pass and multi-species pass in each catchment

The upstream river connectivity maps for fish (Figure 10a) and for eel (Figure 10b) visualise the extent of connectivity within the project area. (Note that the barriers with multi-species pass were incorporated into both the fish and eel connectivity.)

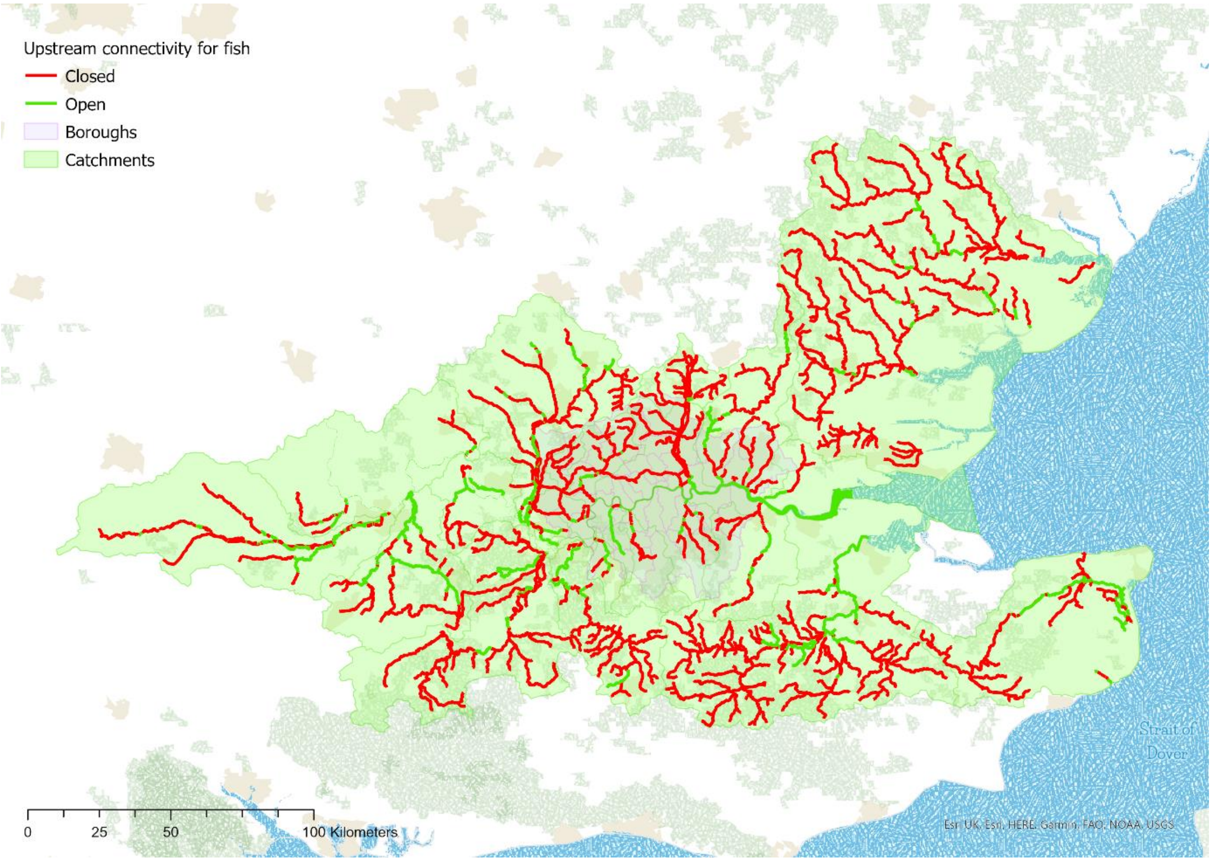

Figure 10a: Upstream connectivity for fish (Made with ArcGIS Pro)

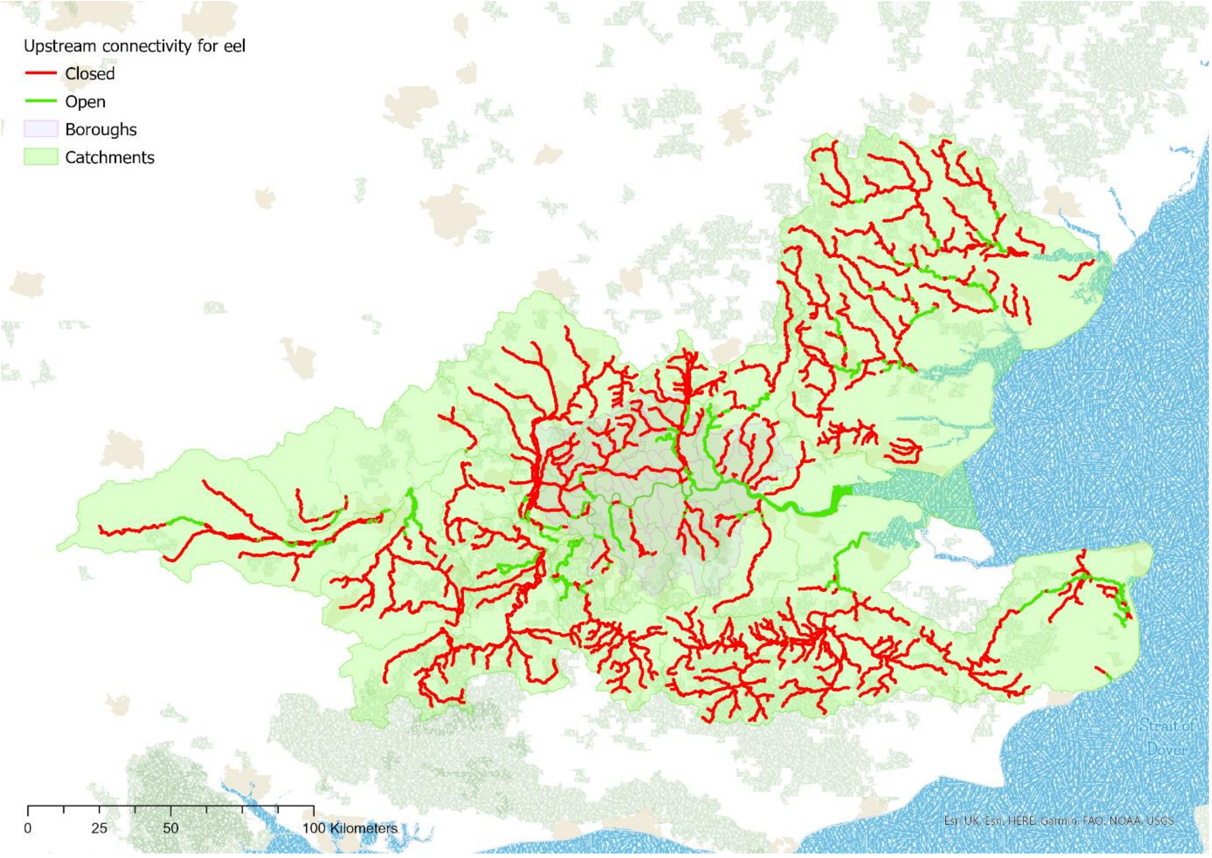

Figure 10b: Upstream connectivity for eel (Made with ArcGIS Pro)

Interactive web-based GIS tool

Using the finalised barrier dataset gained during the data pre-processing, merging and analysis processes, an ArcGIS Hub website (fishroadmap.london) was set up with an ArcGIS Web Mapping Application. The mapping application has the following datasets and functionalities.

Datasets: finalised barrier dataset, migratory routes (Highways, A-road, B-roads, C-roads and D-roads), upstream fish and eel connectivity shapefiles, river habitat survey, fish survey and species, catchments, London boroughs, London plan development opportunity area, risk of flooding from rivers and sea, and potential habitat areas.

Functionalities:

- The map has the usual *Zoom in* and *Zoom out*, *Home* and *Location* buttons to navigate it. The map also has in-built widgets that can be used to interact with the data. These widgets are: *Info*, *Basemaps*, *Layers and legend*, *Filter*, *Attribute table* and *Measure* (Figure 11a).

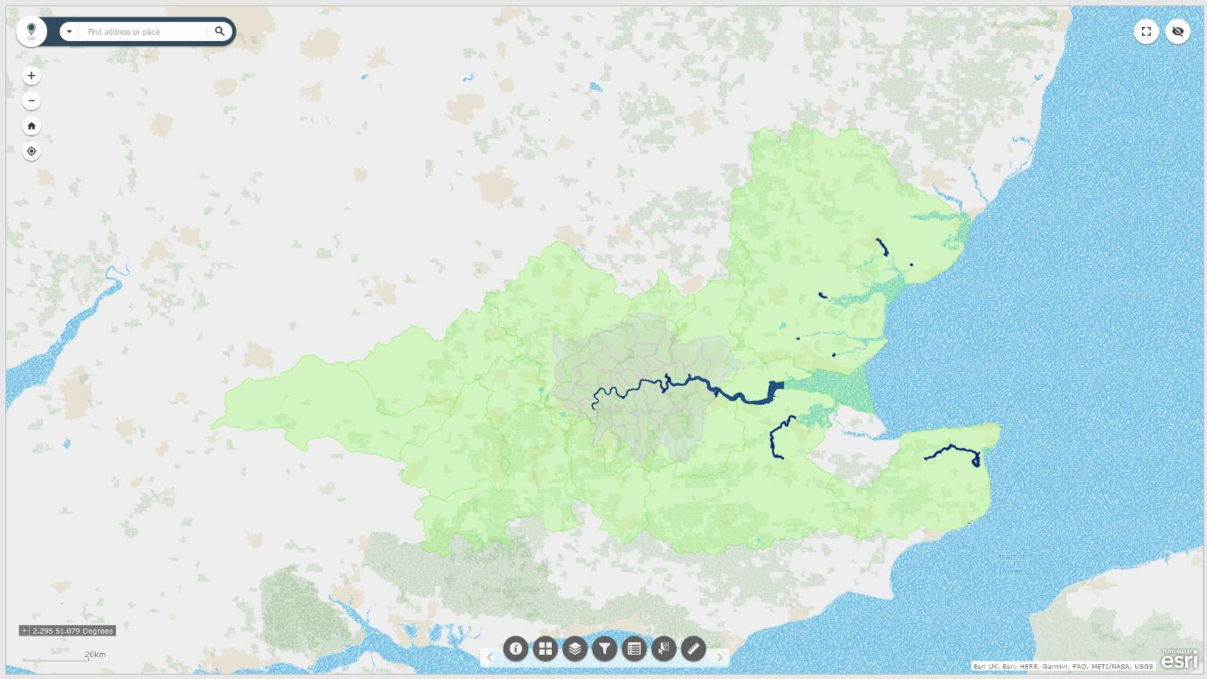

Figure 11a: Mapping application with tools and widgets in the centre bottom (Screenshot of the web-based GIS tool)

- The *Info* widget gives a detailed explanation on how to use the map, the *Basemaps* widget allows the map type to be changed and the *Layers and legend* widget allows to see the data layers (Figure 11b).

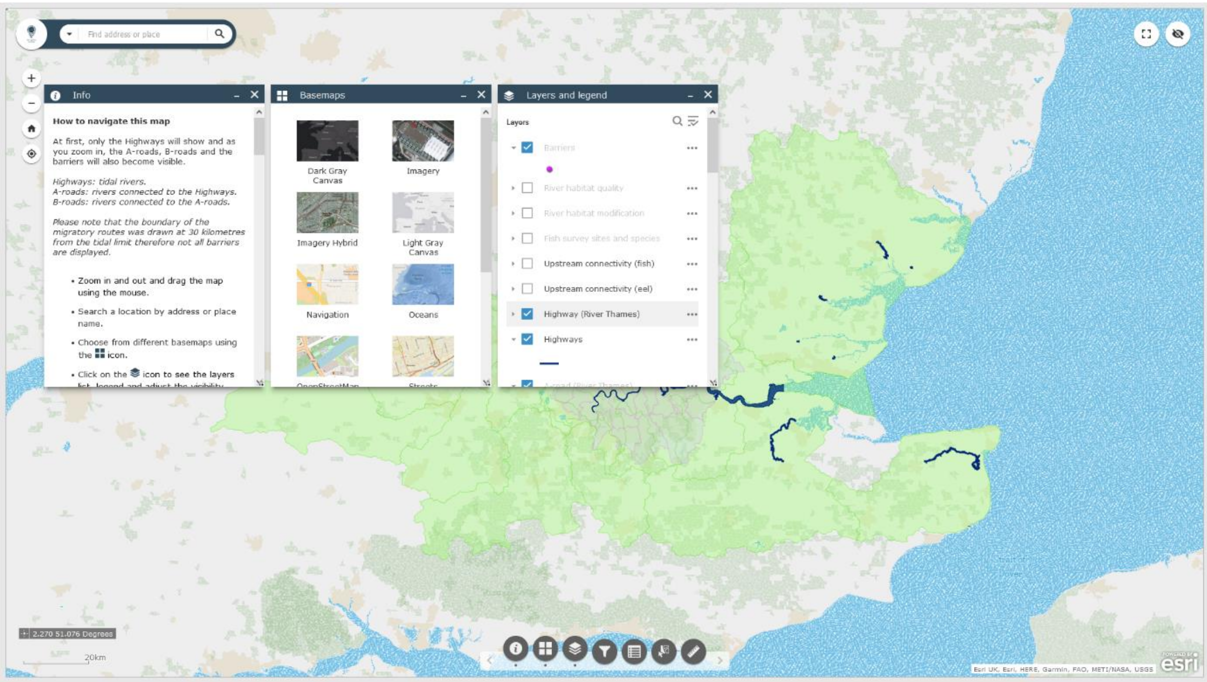

Figure 11b: Mapping application Info, Basemaps, and Layers and legend widget windows open (Screenshot of the web-based GIS tool)

- The *Filter* widget allows the barrier, river habitat, and fish survey and species data to be filtered based several attributes, for example, barrier or pass type, habitat quality or fish species (Figure 11c).

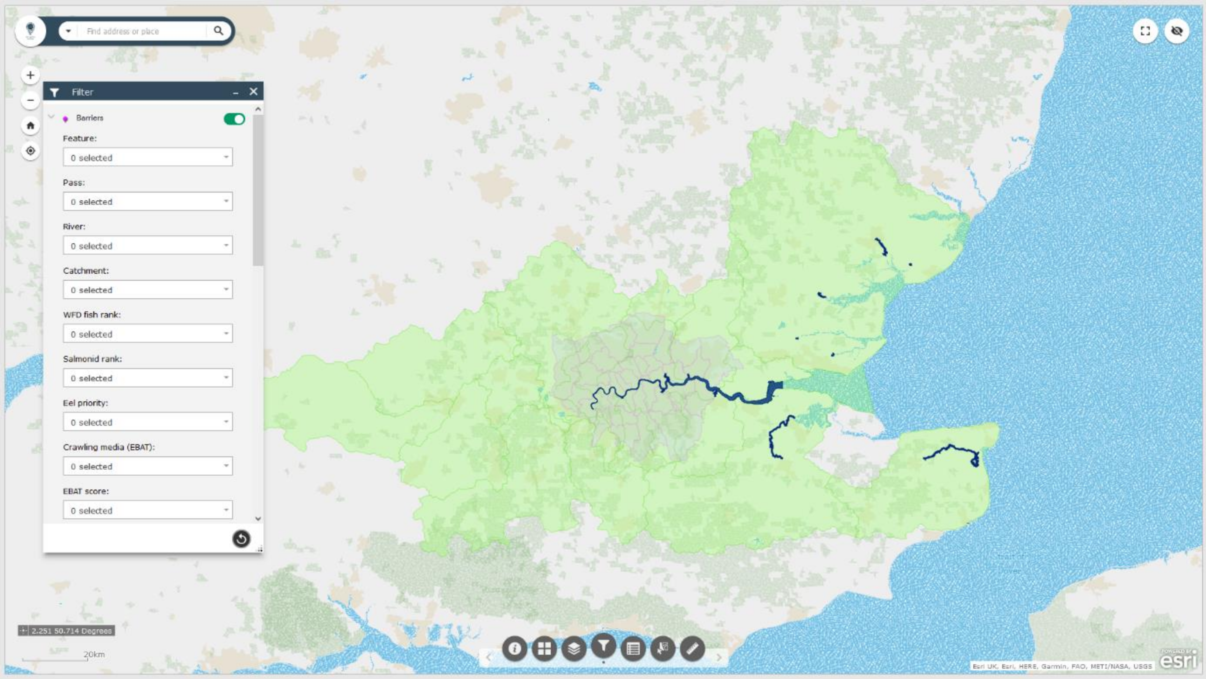

Figure 11c: Mapping application with Filter widget window open (Screenshot of the web-based GIS tool)

The Attribute table can be used to inspect the datasets (Figure 11d).

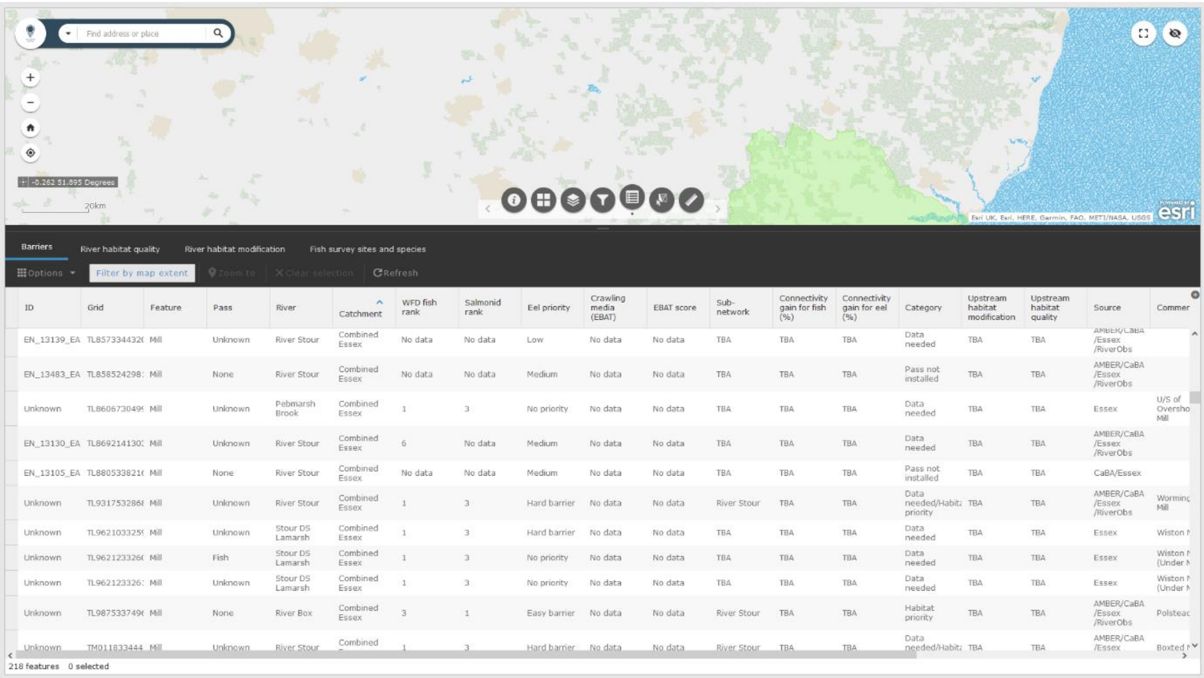

Figure 11d: Mapping application with Attribute table widget window open (Screenshot of the web-based GIS tool)

- The *Select* widget can be used to select and download specific barrier locations. The *Measure* widget can be used to measure area and length (Figure 11e).

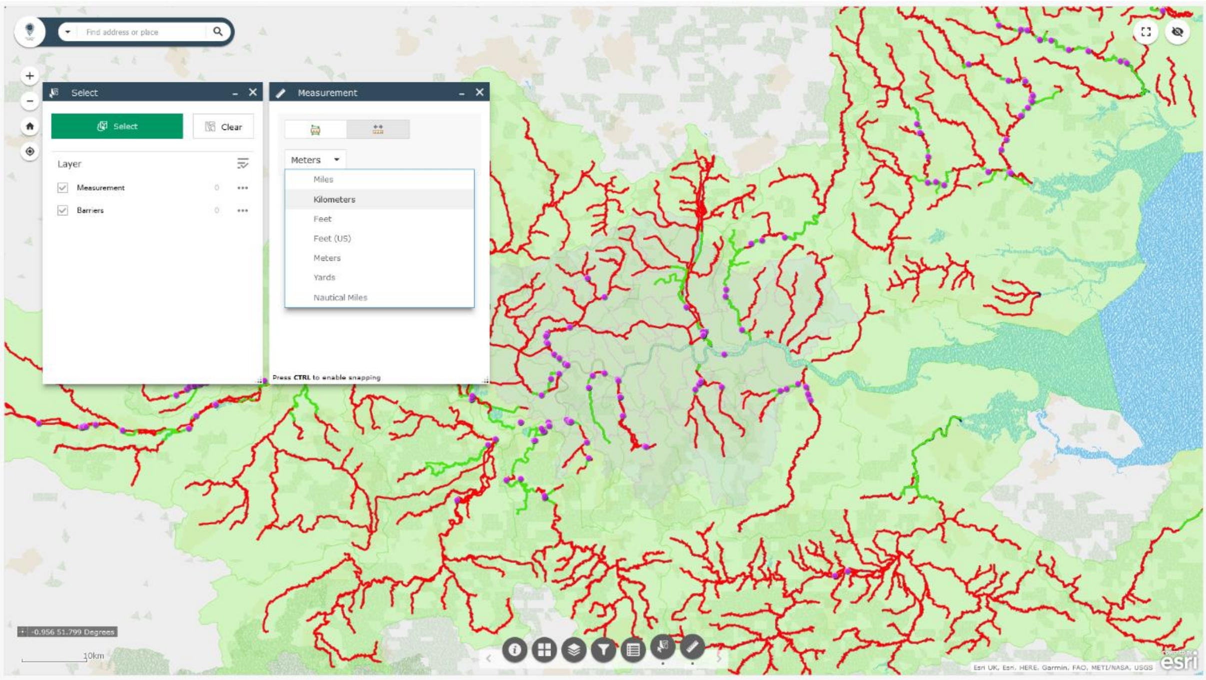

Figure 11e: Mapping application with Select and Measure widget windows open (Screenshot of the web-based GIS tool)

Using the interactive web-based GIS tool

Scenario 1:

Using the Filter widget, the finalised barrier dataset can be filtered based on Category to see, for example, which barrier locations have habitat priority (based on habitat quality) areas upstream. This can then be overlayed on top of the upstream eel connectivity layer to visualise connectivity (Figure 12a).

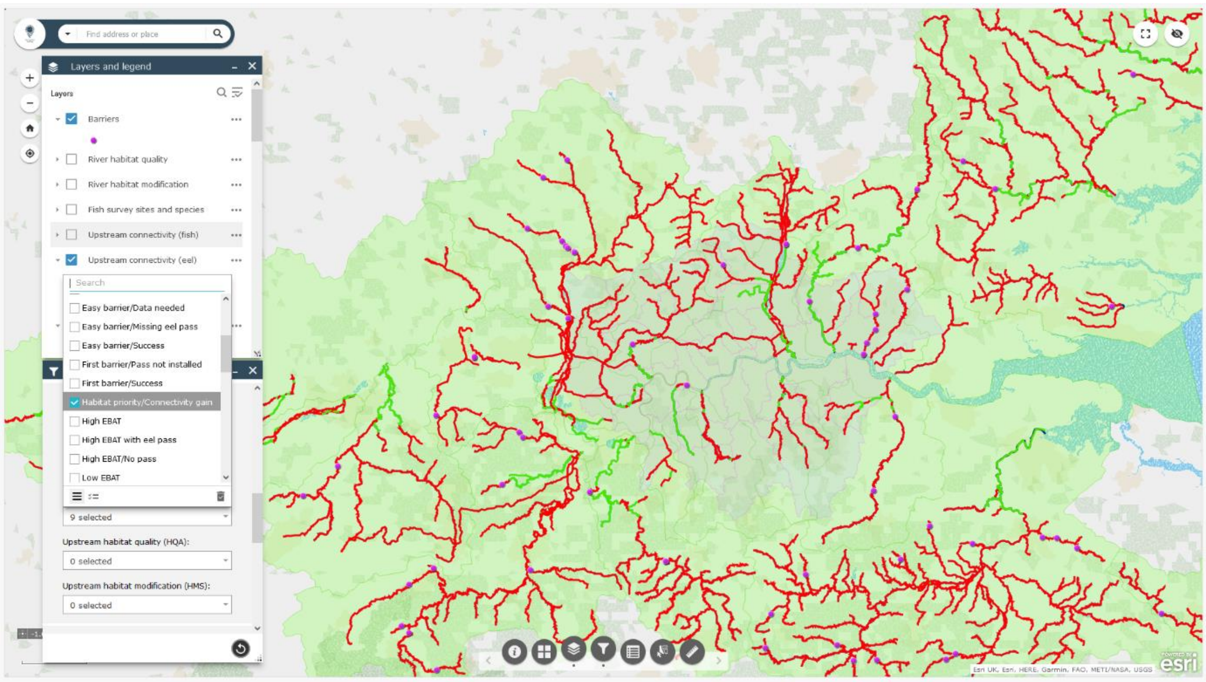

Figure 12a: Scenario 1 (Screenshot of the web-based GIS tool)

In this scenario 78 barrier locations could be identified out of which one barrier had an eel pass installed.

Scenario 2:

From scenario 1, further filtering the finalised barrier dataset, one barrier with the highest upstream connectivity gain for eel could be identified at a location in one of the sub-networks of the Combined Essex catchment (Figure 12b).

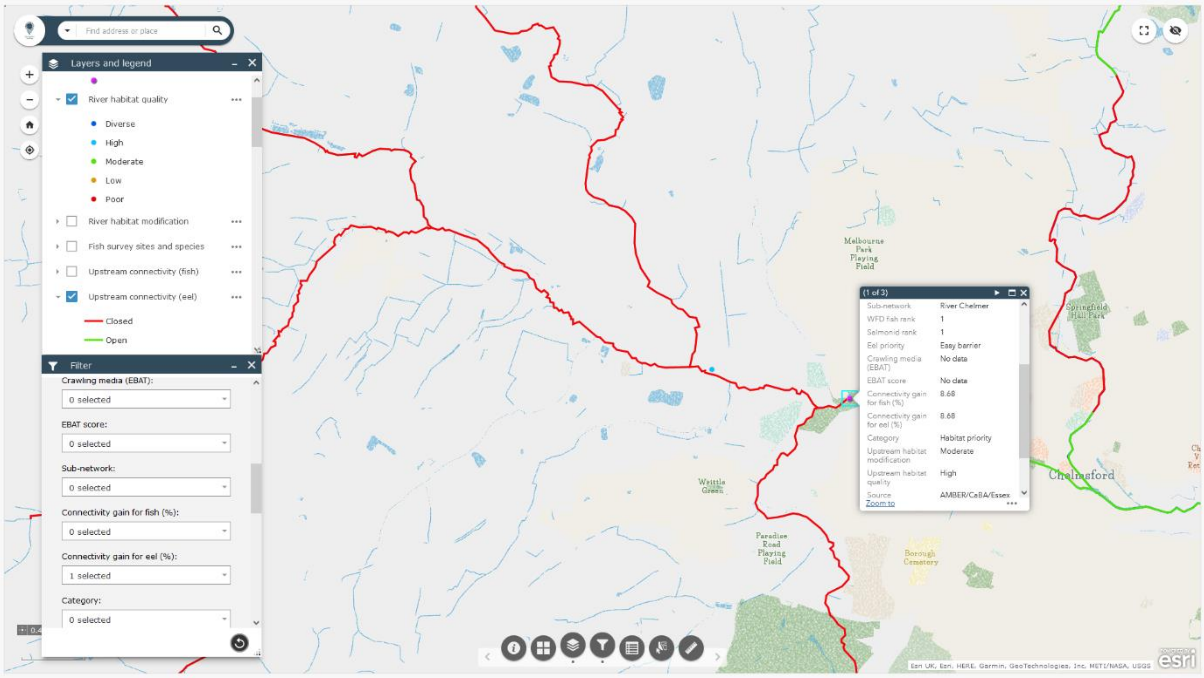

Figure 12b: Scenario 2 (Screenshot of the web-based GIS tool)

Scenario 3:

Using the Filter widget, the finalised barrier dataset can be filtered based on Category to see, for example, which barrier locations without an eel pass have Low EBAT score. This can also be overlayed on top of the upstream eel connectivity layer to visualise connectivity (Figure 12c).

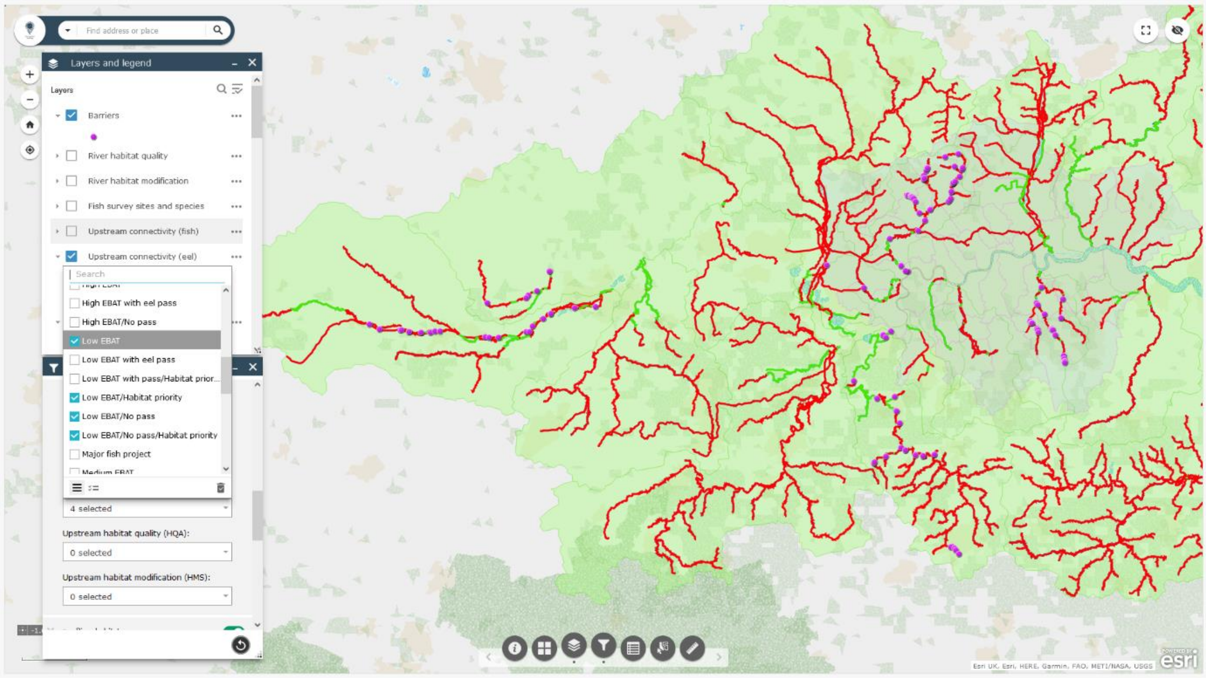

Figure 12c: Scenario 3 (Screenshot of the web-based GIS tool)

In this scenario 135 barriers could be identified out of which two barriers also had habitat priority.

Scenario 4:

Displaying the London plan development opportunity areas and the eel connectivity layers, barriers that fall within the development opportunity area can be selected and saved (as .csv or .geojson file formats) for further inspection and use (Figure 12d).

Figure 12d: Scenario 3 (Screenshot of the web-based GIS tool)

In this case, the area where Barking Riverside is being developed, 11 barriers can be identified out of which 10 barrier locations have no pass installed/not known if there is a pass installed.

Discussion

The main objectives of the Roadmap project were:

1. To gather information on fish migratory barriers and river connectivity within the Thames River Basin and adjacent catchments.

Barrier data collection was successful with 2346 barriers recorded covering over length 6000 kilometres of rivers. However, there was more than one dataset available per barrier, and the information that these datasets held also differed from each other. For example, the AMBER, CaBA and RiverObs barrier datasets covered the entire project area (23 catchments) but the number of barriers and number and type of passes were different across the datasets. These differences may indicate both a lack of consistent data management, and the absence of a joined-up approach when it comes to barrier data collection and surveys across catchments. Thus, a data pre-processing and merging process had to be developed and carried out over a series of steps to overcome these discrepancies and create robust barrier dataset.

The data merging process highlighted that those stakeholder barrier datasets that had been ground-truthed (e.g. Essex, Thames Eels or SERT) helped verify some the information held in the AMBER, CaBA, RiverObs and EA barrier datasets. To mitigate for the lack of capacity to carry out ground-truthing work covering the entire study area, Google Earth 3D (Google Earth 2020) satellite imagery was used to confirm the location and type of barriers on the migratory routes. However, this method was not 100% reliable, as not all locations were visible due to tree cover. Therefore, the location of some barriers could not be confirmed. In this process extra barriers (35) that were not present in any of the datasets were also found.

It is important to highlight that the finalised barrier dataset does not hold information on date of last assessment, barrier dimensions such as width, river width, river flow at a barrier, and the condition of passes. These parameters may be considered for inclusion in future works, especially with the use of the revived River Obstacles mobile app.

The use of the River Obstacles mobile app was a valuable tool in the Thames Eels project. In fact, the barrier data collected by volunteer citizen scientist highlighted the need and necessity of ground-truthing, as out of the 457 barriers surveyed 278 were not present in any other barrier dataset (Table 1 and Appendix 2). This shows a 60% underestimate of number of barriers present on rivers (Figure 13). Similar estimation was also highlighted by other studies in the United Kingdom and in Europe (Belletti et al. 2018, Jones et al. 2019).

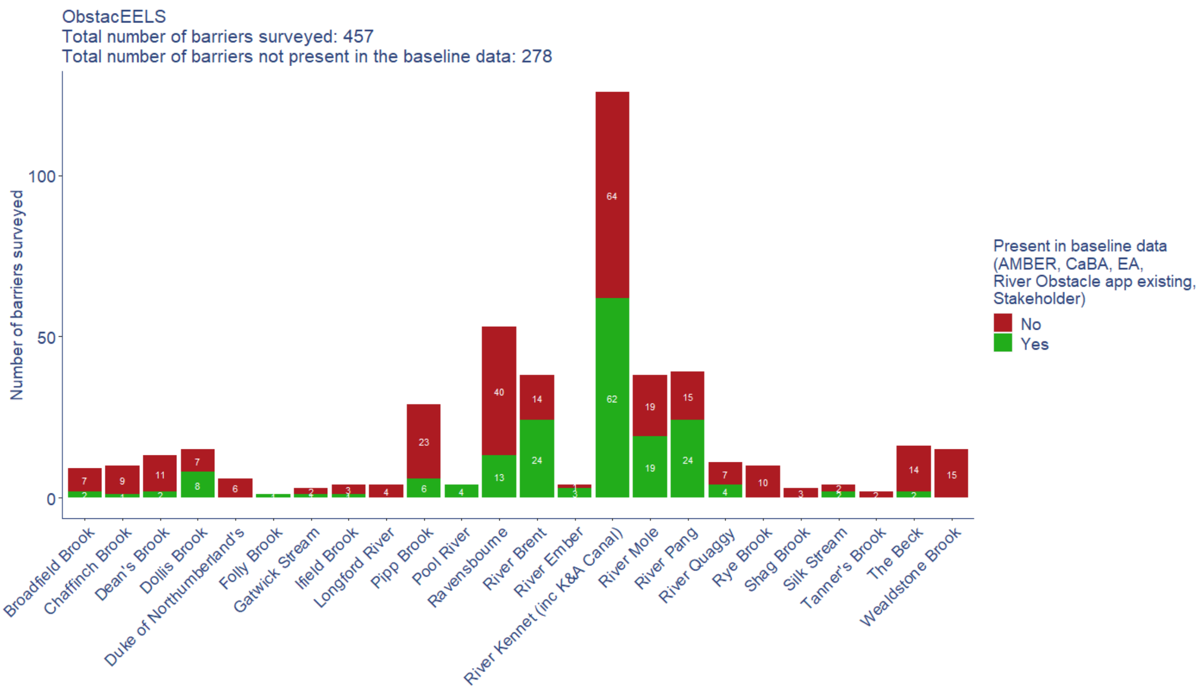

Figure 14: Number of barriers surveyed during the Thames Eels project

The River Obstacles mobile app may also be used to aid a more joined-up approach so that barrier data collection and management is consistent across catchments.

Also, the river habitat data used for this project only provides generic information on river habitat modification and quality. Information specifically about river habitats for fish and eel were not available, however, this would be more appropriate in the context of the project.

2. To develop an online, easy-to-access and easy-to-use web-based GIS tool visualising all relevant data.

This objective was achieved by the creation of the finalised barrier dataset which was then used to create the upstream river connectivity shapefile layers for both fish and eel. Then, by grouping the migratory routes into sub-networks and calculating the proportion of river fragmentation, the upstream connectivity gain for both fish and eel was calculated and integrated into the finalised barrier dataset. Similarly, the river habitat data was integrated into the finalised barrier dataset by calculating mean averages for each river fragment.

When creating the web-based GIS tool, user interactivity and the ability to filter and select the data was extremely important. These functionalities were employed using up-to-date GIS technology, resulting in the finalised website and the web-based GIS tool being user friendly and fully accessible by everyone regardless of technical expertise.

Using the web-based GIS tool, its functionality was also demonstrated by identifying barrier locations to improve upstream river connectivity whilst targeting habitat priority, connectivity gain and development opportunity areas. The example scenarios showed that:

- In scenario one, 77 barriers could be found and addressing these could improve upstream eel migration to reach diverse/high quality river habitat areas.

- In scenario two, a gauging station with high connectivity gain could be identified. Addressing this barrier could open up 8.6% of the River Chelmer sub-network for both fish and eel.
- In scenario three, the use of the EBAT score was demonstrated, identifying 135 barriers out of which two barriers also had habitat priority.
- In scenario four, 10 barrier locations were found with no pass installed/not known if there is a pass installed, most of them on the confluence of the Highway and A-roads. These barriers could potentially be addressed as part of the riverside development works.

3. To develop a replicable, strategic method which also includes the Fish Migration Vision.

The steps of the creation of the Roadmap were summarised in Figure 14.

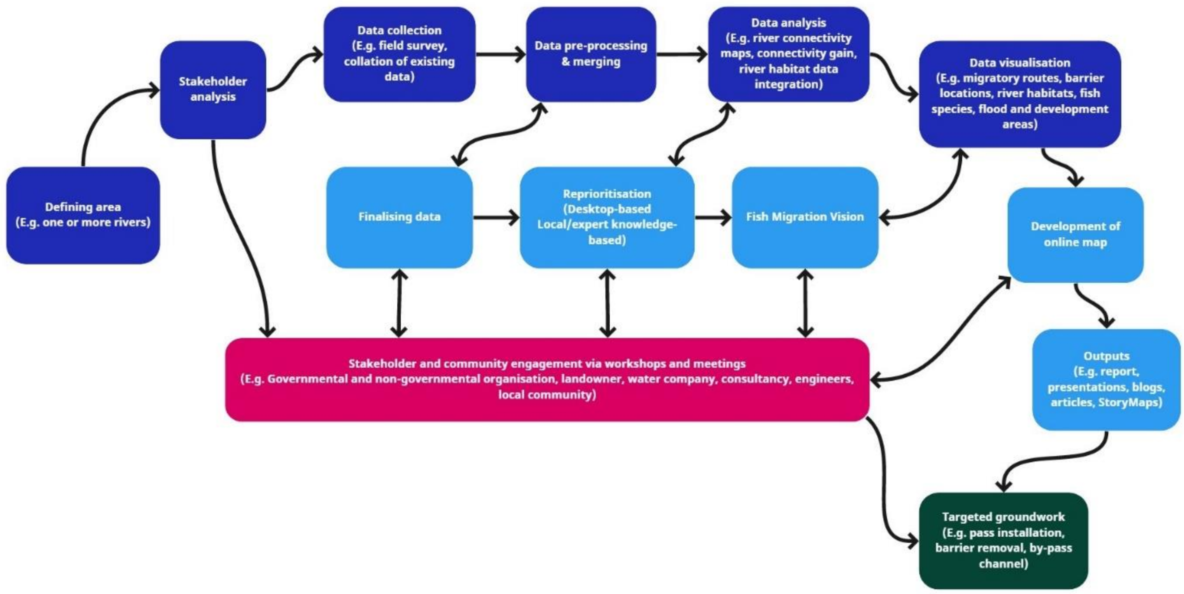

Figure 14: Flowchart of strategic steps (Made in Miro)

This figure indicates those steps that are desktop-based (dark blue) as well as the stages where stakeholder inputs (pink and light blue) are crucial, specifically in finalising the data, in the reprioritisation process and the development of the Fish Migration Vision.

Fish Migration Vision

The Fish Migration Vision is a shared, ambitious long-term goal that envisions what a healthy and connected river corridor could be with collective action across sector initiatives e.g. catchment management, flood asset management and land development. It relies on the web-based GIS tool to deepen understanding of the need to improve river corridors, restore habitats, reprioritise migration barriers, and develop multiple benefit projects. The Vision can also help bring to life the story of a fish's journey from sea to source and within a river system to enthuse other less engaged sectors and the public for whom underwater life is hidden.

As part of the visioning exercise, expert knowledge-based reprioritisation of the barriers can be carried out locally within a catchment or on a single river. This can help develop 'fish-ready' proposals to target barriers greatest environmental and social benefit. For example, a proposal may be developed to remove an impassable barrier with diverse habitat upstream, with the involvement of the local council and the local community. Activities could include educational program about fish migration, and surveying fish passage (citizen science) before and after the barrier removal to measure impact.

Essex Fish Migration Roadmap

As part of the Essex Fish Migration Roadmap delivery phase in 2021, Essex Wildlife Trust visited three fish passage barriers on the River Blackwater and two on the River Colne with another four options appraisals. Mills are a key issue with site visits or options appraisals already undertaken at Abbey Mill (Coggeshall) and Straits Mill (Braintree) on the Blackwater and Cooks Mill (West Bergholt) and Ford Street Mill on the Colne.

At Ford Street the options appraisal found a single bypass could in fact remove three obstructions, two at the Mill and one weir upstream. Straits Mill contains two obstructions which again could be mitigated by the use of a single bypass or the removal of just one structure so there can be multiple benefits from single interventions.

Thames Catchment Community Eels project

Towards the end of the Thames Eels project, the individual catchment hosts applied the Roadmap method and identified a number of barriers for mitigation.

Brent (Thames21)

Two sloping weirs, Abbey Estate Open Space weir (NGR: TQ1879383299) and Abbeydale Road Bridge weir (NGR: TQ1911083509), have been targeted for mitigation on the River Brent because they are the furthest downstream impassable barriers (EBAT scores below 10 and no eel passes) (Figure 15a and b).

Figure 15a and b: Abbey Estate Open Space weir and Abbeydale Road Bridge weir

These weirs have also been chosen because they are less than 400m away from each other, therefore, simultaneously carrying out mitigation work on both weirs will open up at least 975m of river habitat to eels.

Mitigation works at the Abbey Estate Open Space weir are still being finalised: the possibility of removing this weir is being investigated, however if this is not possible due to the weir being situated in a concreted section of the river, eel tiles will be fixed onto the face of the weir. Mitigation works at the Abbeydale Road Bridge weir will comprise the installation of eel tiles because removing Abbeydale Road Bridge weir would bring about stability issues to a road since the obstacle forms part of the footing structure of a bridge.

Ravensbourne (Thames21)

A sloping weir, Smead Way Bridge weir (NGR: TQ3797275501), and a vertical weir, the Silver Road vertical weir (NGR: TQ3800775465), just 50m upstream of the former have been targeted for mitigation on the River Ravensbourne because they are the furthest downstream impassable barriers (EBAT scores below 10 and no eel passes) to eels migrating upstream. These weirs have also been chosen because mitigation works on both weirs would open up a total of 2.8 km to eel passage (Figure 16a and b).

Figure 16a and b: Silver Road vertical weir and Smead Way Bridge weir

Mitigation works will not encompass removal of the barriers due to them both being situated within a concreted section of the Ravensbourne and thus their removal would very likely destabilise the channel's flood walls. Consequently, instead, eel tiles will be fixed to the face of the sloping Smead Way Bridge weir, and a more complex fish pass with integrated eel passage easement will be constructed at the vertical Silver Road weir.

Mole (South East Rivers Trust)

This barrier at Norbury Park on the main River Mole currently has an EBAT score of 4 meaning it is likely to be impassable to eels. If made passable, it would open up over 7 km of the River Mole. After getting a preliminary utility search it looks as if full removal of this barrier should be possible, bringing multiple benefits to the river. The location means there is relatively easy access to the site and the landowner is Surrey County Council.

Figure 17: Norbury Park weir

Mitigation solutions

Passage works can be simple solutions, such as the installation of technical fish passes or an eel pass over a barrier such as weir.

Technical pass types include Larinier, Denil and pool-weir traverse passes that often use a series of metal, plastic, or wooden baffles attached to the bottom/sides of a constructed channel to create very specific flow conditions to allow their target species to pass.

They also include more complex river restoration solutions that reconnect the natural river course by reinstating back channels or creating bypass channels or even reconnecting the historic floodplain. These nature-like passes come in the form of constructed stream channels or rock ramps that are designed to mimic a natural stream channel, often creating a stream bed of boulders, cobbles, and gravels.

Conclusion

The Roadmap is both a method and a web-based GIS tool. It was created to help target fish migratory barriers to improve river connectivity and migration whilst achieving other benefits.

This is the first time that this kind of integrated, 'wholescape' approach was developed in the UK, and because of its ground-breaking nature, the Roadmap may require improvements (e.g. using fish specific river habitat data).

As a method, the Roadmap provides a strategic approach that has multiple benefits, such as flood risk assessment, river restoration and environmental enhancement, helping identify mitigation or enhancement opportunities with land development projects and enabling riverside communities to reconnect with their local waterways, complementing and adding value to existing community-based initiatives such as Catchment Partnership Plans

As a tool, the Roadmap can be used to link into River Basin Management Plans and Catchment Plans, assist with delivery of the Government's targets within the 25 Year Environment Plan, help identify areas where Biodiversity Net Gain can be achieved and help with contributions towards Net Zero targets. Crucially, it can be developed ensure that solutions are implemented where they can achieve the maximum environmental and social benefits. It is a first successful step towards more joined-up environmental river management works across the land and water, sea to source.

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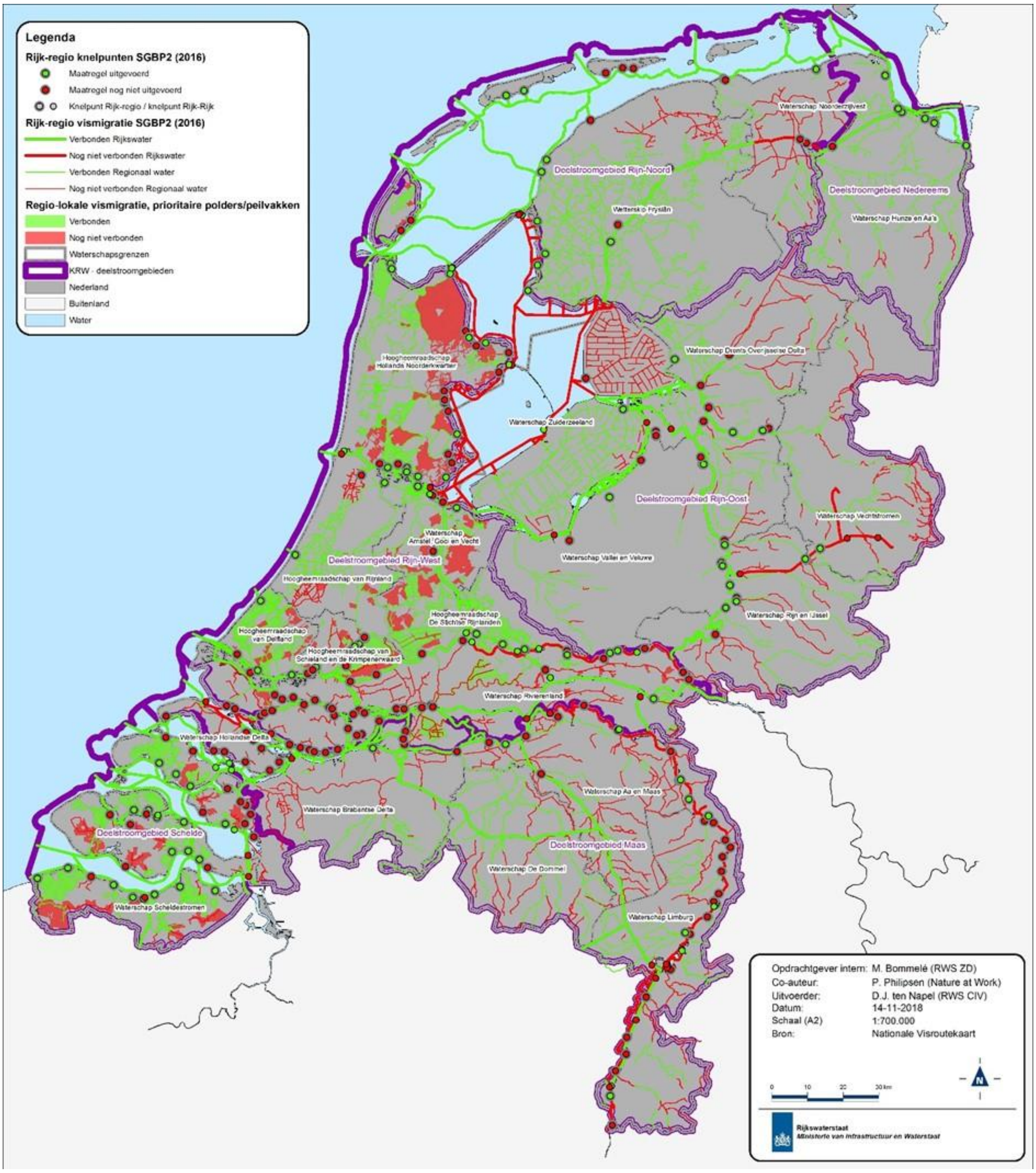
Appendices

Appendix 1



Appendix 2

BARRIER INFORMATION							
Type of data	**Acronym**	**Name**	**Area covered**	**Data collection method**	**Source**	**Date**	**Note**
Shapefile	AMBER	AMBER_Barrier_Atlas_GB	23 catchments	Not indicated	Catchment Based Approach Open Data website	11/07/2019	Environment Agency indicated as source in the metadata
Shapefile	CaBA	All_Barriers	23 catchments	Not indicated	Catchment Based Approach Open Data website	12/07/2019	Environment Agency indicated as source in the metadata
Shapefile	RiverObs	rivobsdata-export	23 catchments	Not indicated	River Obstacle app website	13/07/2019	Environment Agency indicated as source in the metadata
Excel sheets	EA	Thames obstructions and Fish and eel passes	21 catchments	Not indicated	Environment Agency (Darryl Clifton-Dey)	04/02/2017	Separate datasets
Shapefiles	CRT	Locks_View_Public, Sluices_View_Public, Weirs_View_Public	5 catchments	Not indicated	Canal & River Trust Open Data website	10/05/2020	None
Shapefile	TCCEP	N/A	5 catchments	River Obstacles app	Thames Catchment Communtity Eels Project	01/02/2022	None
Excel sheet	Essex	Eastern Area - Barriers to migration (Final)	1 catchment	Ground-truthed barrier dataset according to WFD and Eel Regs 2009	EA's Essex Catchment Management Team	22/03/2018	None
Reports	N/A	An Assessment of Barriers to Fish Passage in the Crane River Catchment, An assessment of barriers to fish migration in the Lower Colne Catchment	Lower Colne and River Crane	SNIFFER Coarse Resolution Rapid-assessment Methodology (Scotland & Northern Ireland Forum for Environmental Research, 2010)	London Wildlife Trust (Tom White)	04/12/2018, 15/10/2018	None
Excel sheet	SERT	barriers CG	Hogsmill	Not indicated	South East Rivers Trust	25/10/2018	None
Excel sheet	TEP	TEP_walked_barriers	River Ravensbourne, Pool River, River Wandle, River Wrythe, Beverley Brook, Regent's Canal, Grand Union Canal (Paddington Arm) and River Brent	Barrier location assessment	Thames Estuary Partnership	June-Oct 2020	None
Reports	N/A	River Roding Barrier Assessment Survey Report, Fish passage in the Lower River Mole, Passage of elvers and small eels in lower Thames tributaries, Fish passage on the River Wandle, Structures that impact the upstream migration of the European eel (Anguilla anguilla) on the River Darent, ZSL' European eel monitoring programme report 2012-2018	Mardyke, Ingrebourne, River Roding, River Mole, Hogsmill, Beverley Brook, River Wandle, River Wrythe, River Ravensbourne, River Pool, River Quaggy	Various	Zoological Society of London	16/01/2018	None

OTHER							
Type of data	**Project acronym**	**Name**	**Area covered**	**Data collection method**	**Source**	**Date**	**Note**
Shapefile	N/A	OS Open Rivers	23 catchments	N/A	Ordiance Survey website	01/05/2020	N/A
Excel sheet	N/A	River Habitat Surveys - Survey Details and Summary Results	23 catchments	Environment Agency standard for collecting data on the physical character and quality of river habitats across the UK	DEFRA file sharing service	22/03/2022	None
Geopackage (gpkg)	N/A	Opportunity areas	7 catchments	N/A	London Datastore	16/05/2020	Opportunity Areas are London's major source of brownfield land with significant capacity for new housing, commercial and other development linked to existing or potential improvements to public transport accessibility.
Excel sheet	N/A	london-borough-profiles	N/A	N/A	London Datastore	16/05/2020	N/A
Map service	N/A	OS Open Greenspace	N/A	N/A	Ordiance Survey	12/03/2021	OS Open Greenspace depicts the location and extent of spaces such as parks and sports facilities that are likely to be accessible to the public. Where appropriate, it also includes access points to show how people get into these sites.
Shapefile	N/A	CaBA Catchment Partnerships	23 catchments	N/A	Catchment Based Approach Open Data website	16/05/2020	N/A
Map service	N/A	Risk of Flooding from Rivers and Sea	N/A	N/A	The Rivers Trust	22/03/2019	The dataset shows the chance of flooding from rivers and/or the sea, based on cells of 50 m.
Map service	N/A	Native Oyster Bed Potential (EA)	N/A	N/A	The Rivers Trust	07/12/2020	The Native Oyster Bed Potential Area layer provides a national 'high level' indication of where native oyster reefs could potentially be restored based on some key environmental variables.
Map service	N/A	Seagrass Potential (EA)	N/A	N/A	The Rivers Trust	07/12/2020	Seagrass potential areas were primarily derived from the EMODnet 2016 wave and current energy models.
Map service	N/A	Saltmarsh Potential (MMO) - Potential habitat creation sites within floodplain	N/A	N/A	The Rivers Trust	07/12/2020	Currently defended floodplain areas in England which could be suitable for managed realignment and / or Regulated Tidal Exchange (RTE) (to create mudflats and saltmarshes) are identified.

Appendix 3

Due to the lack of available data on river and barrier width, and to be able to account for those barriers that occurred on the migratory routes only, different buffer zones were created around the migratory routes. The number of barriers that fell inside each buffer zone were calculated.

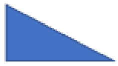
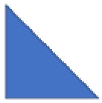
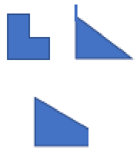
While arguments can be made for all these buffer zones, even if the buffer zone would have been extended to 200 metres, it would have yielded the same number of barriers as the 150m and 75m buffer zone. Also, using the 50-metre buffer zone would have meant less than 5% fewer barriers included. Thus the 100-metre buffer zone seemed the best fit as an estimate of getting all barriers that occurred on the migratory routes included.

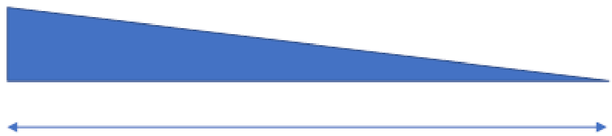
Buffer	Number of barriers
200m	2311
150m	2311
100m	2311
75m	2311
50m	2233

This calculation excluded the River Thames as this migratory route came readily available in a polygon shapefile format.

Appendix 4

Is there a continuous path of crawling media over the structure?		
Yes	No	Sub Total
3	0	

What is the approximate slope of the structure?				
<1 in 4	1 in 4 – 1 in 1	>1 in 1	Variable e.g., stepped, lip at crest or step at toe	
				Sub Total
4	2	1	1	

What is the approximate length of the slope? This applies to the slope across the whole structure, downstream to upstream. If stepped, count the number of steps and record as a note here:					
0-2m	>2-6m	>6-9m	≥10m	Vertical Weir	
					Sub Total
4	3	2	1	0	

What is the approximate velocity over the slope?				
If using the float method:				
Very low (<0.5m/sec)	Low (0.5m-1m/sec)	Medium (>1m-2m/sec)	High (>2m/sec)	
If using the pacing method:				
Slow walk	Walking	Jogging	Running	Sub Total
4	2	1	0	
Where is velocity recorded from?				