AN INTEGRATED GIS-BASED APPROACH TO IMPROVE FISH MIGRATION WITHIN THE GREATER THAMES ESTUARY

WANDA BODNAR[1], AMY PRYOR[1], PETER PHILIPSEN[2]
w.bodnar@ucl.ac.uk

[1]Thames Estuary Partnership, University College London,
Office for the Vice-Provost (Research), Room 117, 26 Bedford Way, London, WC1H 0AP

[2]Nature at Work

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 & 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).

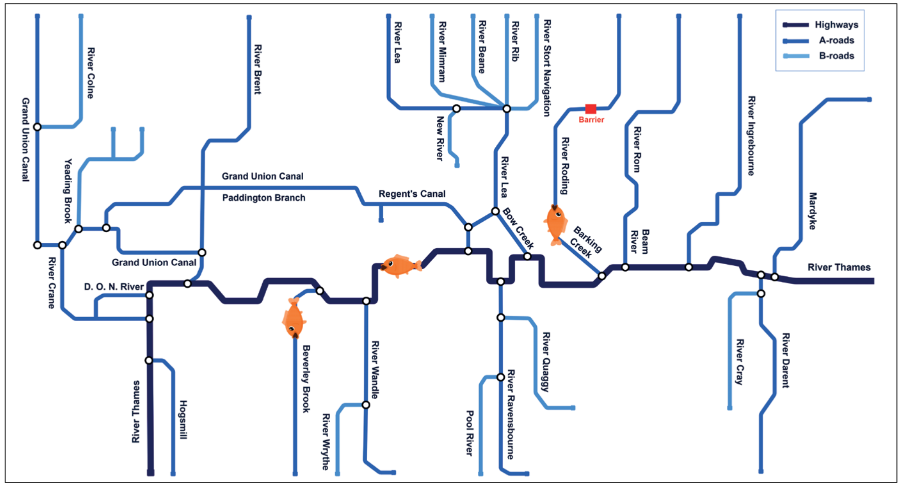


Figure 1: Illustration of rivers as interconnected fish migratory routes in London (Made with diagrams.net)

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).

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

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 Roadmap once complete, 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', and rivers flowing into the A-roads were identified as 'B-roads'. Since elvers (juvenile European Eel) move into freshwater rivers up to a maximum of 30 kilometres from the tidal limit, the boundary of the migratory routes was also established at 30 kilometres from the tidal limit (ZSL, 2018) (Figure 2).

Data collection

The baseline dataset for the Roadmap was created using barrier data, river and

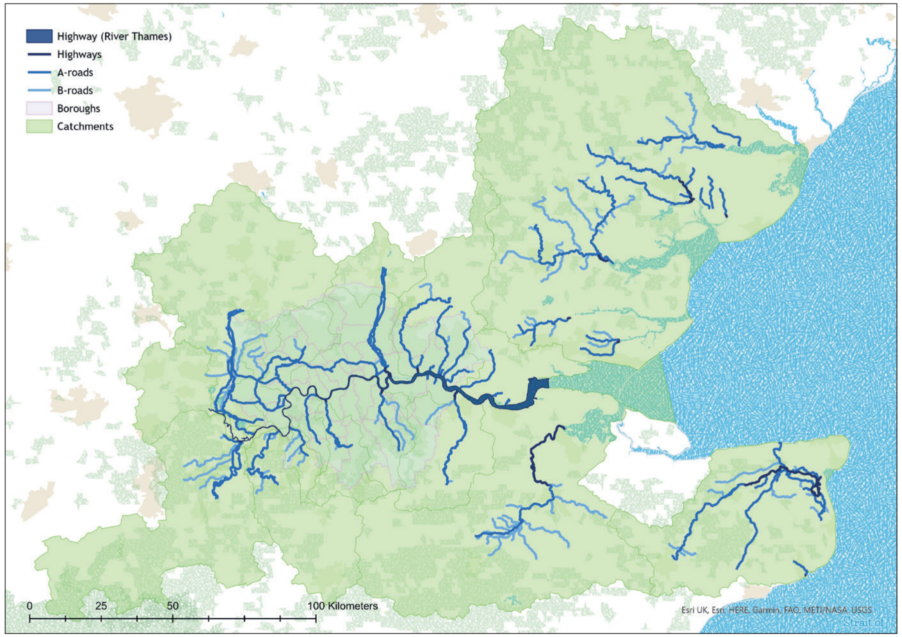


Figure 2: Map showing the study area and the migratory routes (Made with ArcGIS Pro)

catchment shapefiles. Barrier location information was obtained from multiple sources 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 Ordnance Survey website (OS Open Rivers). In addition, further digitisation of river sections was carried out using ArcMap (10.4.1) (ESRI 2018). Catchment data was downloaded from the Catchment Based Approach (CaBA) open data website.

To create the web-based GIS tool, additional datasets were 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.

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 (20 catchments).
2. The separately received 'Fish and eel passes' (135 locations) data and the 'Thames obstruction' (1,333 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 1,368 barrier 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.)

Table 1: Summary data table of the received barrier datasets

	AMBER	CaBa	RiverObs	EA	CRT	Essex	SERT	TEP
Catchments	20	20	20	18	5	1	1	5
Barriers	2118	2096	2143	1368	193	814	9	188
Pass	85 (fish)	105 (fish)	40 (fish)	69 (fish)	0	24 (fish)	0	6 (fish)
		71 (eel)		63 (eel)		44 (eel)		4 (eel)

3. The Adaptive Management of Barriers in European Rivers (AMBER), Catchment Based Approach (CaBA), Environment Agency (EA), Essex and River Obstacles App (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
   - Water Framework Directive (WFD) fish rank (from the CaBA data)
   - Salmonid rank (from the CaBA data)
   - Eel priority (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'.
4. 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.
5. The Canal and River Trust (CRT), South East Rivers Trust (SERT) and TEP barrier datasets (Excel sheets) and the barrier information received in the form of reports (London Wildlife Trust and Zoological Society of London) were manually integrated into the

final 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.

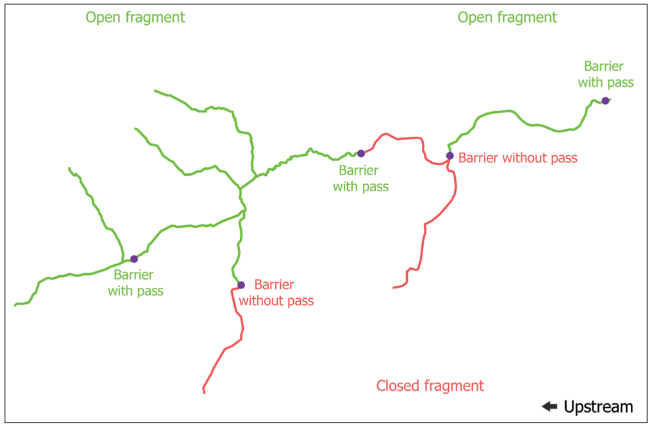
6. The finalised barrier data went through an additional verification process by checking through each barrier location using Google Earth 3D (Google Earth 2020) satellite imagery. (This step allowed the project to account for any barrier that might have been lost during step 5.) During this process:
   - 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 43.

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 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.
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 and B-roads) (Figure 4).

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



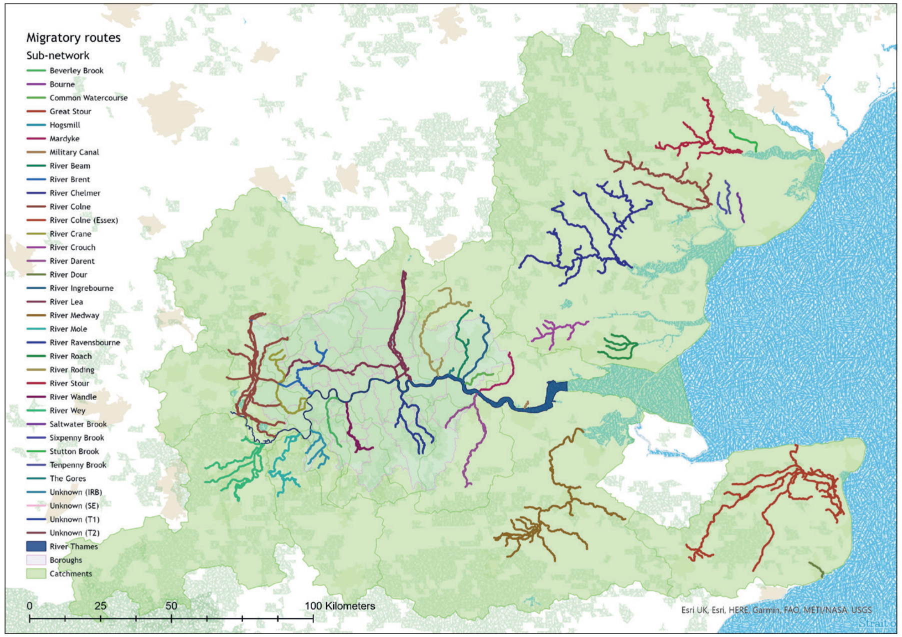


Figure 4: Map of the catchments and their subnetworks (Made with ArcGIS Pro)

Table 2: Summary table of the catchments and their subnetworks

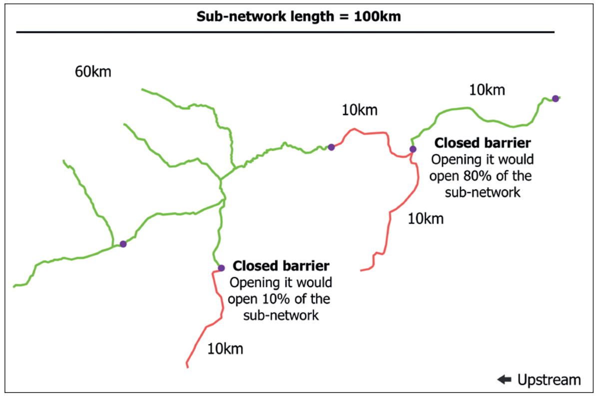
Catchment	Sub-network	Catchment	Sub-network
Beverley Brook	Beverley Brook	Maidenhead to Teddington	River Wey
			River Thames
Brent	River Brent		
Colne	River Colne	Marsh Dyke & Thamesmead	Unknown waterway (T1)
	River Colne		Unknown waterway (T2)
	River Roach	Medway	River Medway
	River Stour	Mole	River Mole
Combined Essex	River Chelmer	Ravensbourne	River Ravensbourne
	Stutton Brook	Roding, Beam & Ingrebourne	River Roding
	Sixpenny Brook		River Beam
	Tenpenny Brook		River Ingrebourne
Crane Valley	River Crane		Unknown (IRB)
Darent & Cray	River Darent	South Essex	Mardyle
	River Dour		Military Canal
East Kent	River Dour		Unknown waterway (SE)
	Great Stour	Wandle	River Wandle
Hogsmill	Hogsmill	Wey	The Bourne
London Lea and Lower Lea	River Lea		River Wey
		Your Tidal Thames	River Thames

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 *et al*. 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 3).

Table 3: Summary data table of the classification categories of the river habitat survey data

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	37 to 37	Significantly modified	2
Poor	1 to 25	Severely modified	1

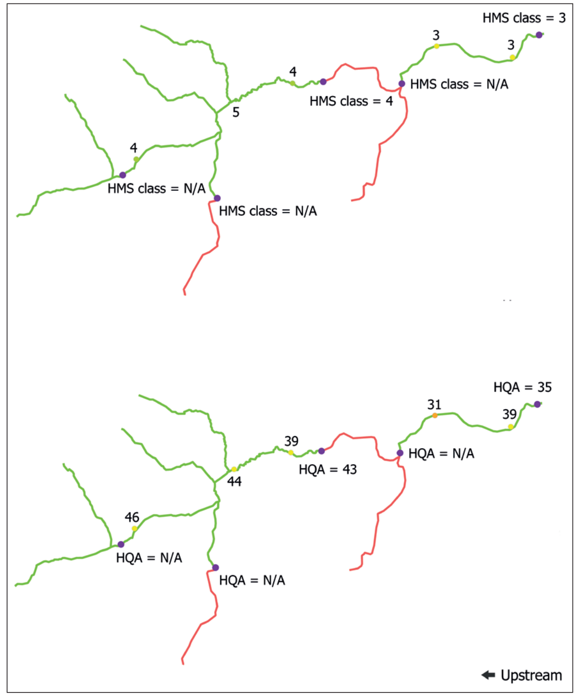


Figure 6: Conceptual illustration of river habitat survey data integration (Made with QGIS and Paint 3D)

   - 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.

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'.
   - Locations where it is known that passes are not present were marked as 'Pass not installed'.
   - Locations where it is known that passes are not needed were marked as 'Pass not needed'.

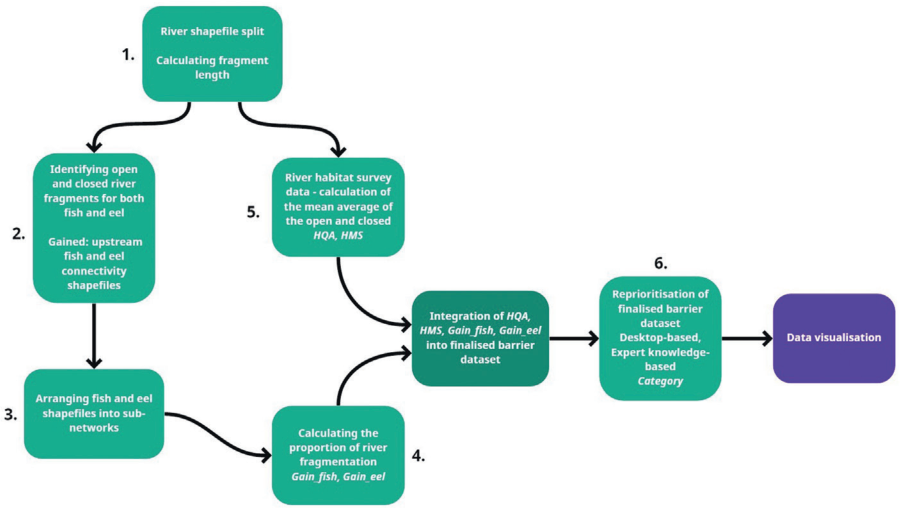


Figure 7: Summary of the steps of the data analysis (Made with Miro)

- 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, additional categories were introduced here 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.

The flowchart in Figure 7 summarises the steps of the data analysis.

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 three scenarios where habitat priority, connectivity gain 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.

The Roadmap has been featured in the Institute of Fisheries Management's FISH magazine and presented at conferences and forums. TEP has also become 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.

Results

The map shows the finalised barrier dataset with the location of barriers on the migratory routes within the project area (Figure 8).

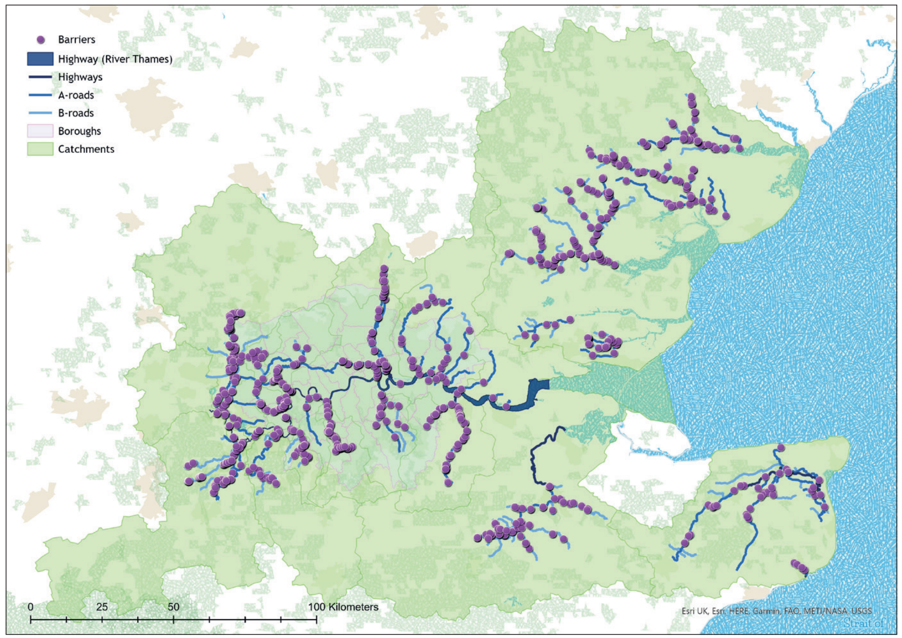
The data table gives a summary of the number of barriers, and number and type of passes within each catchment, along with the total river length (Table 4).

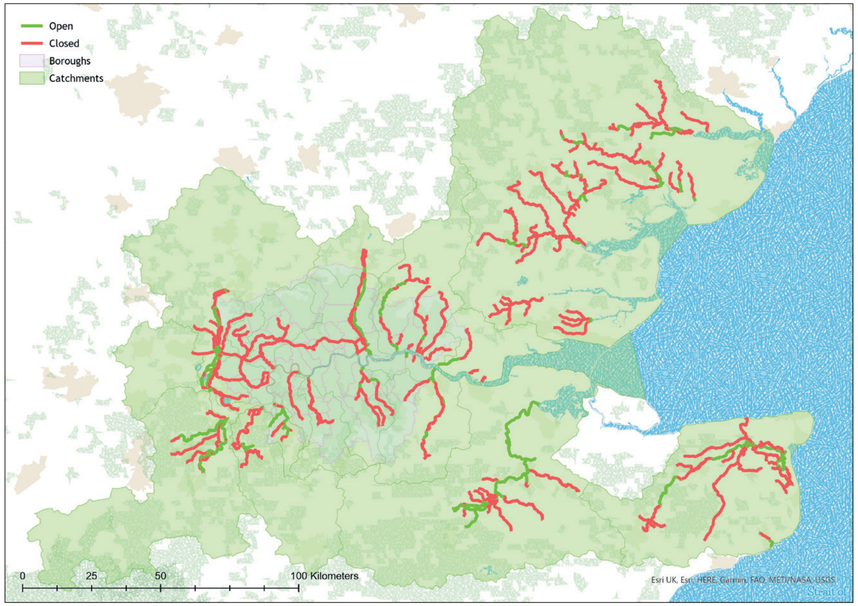
The upstream river connectivity maps for fish (Figure 9a) and for eel (Figure 9b) visualise the extent of connectivity within the project area. (Note that the barriers with multi-species pass were incorporated into both the fish and eel connectivity.)

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:

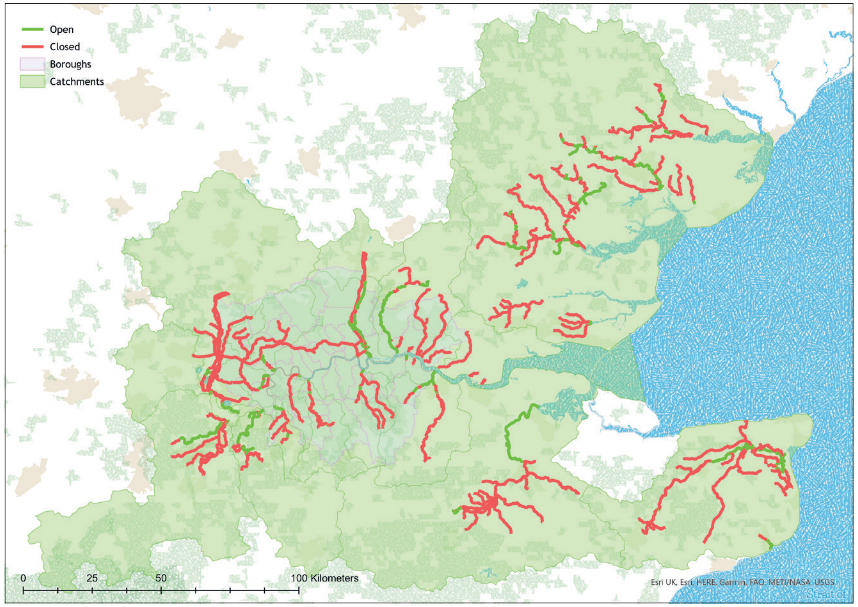
Figure 8: The finalised barrier dataset with the migratory routes (Made with ArcGIS Pro)





Above: Figure 9a: Upstream river connectivity for fish (Made with ArcGIS Pro)

Below: Figure 9b: Upstream river connectivity for eel (Made with ArcGIS Pro)



Catchment	Number of barriers	Number of fish pass	Number of eel pass	Number of multi-species pass	Total river length (km)
Beverley Brook	2	0	0	1	14.34
Brent	52	0	3	0	41.66
Colne	107	14	0	3	151.44
Combined Essex	251	4	25	4	437.81
Crane Valley	54	0	2	0	52.4
Darent & Cray	54	3	5	0	43.58
East Kent	42	3	2	0	209.72
Hogsmill	28	12	2	3	24.73
London Lea	101	0	8	2	84.26
Lower Lea	17	1	0	0	15.74
Maidenhead to Teddington	34	11	6	1	30
Marsh Dyke & Thamesmead	2	0	0	0	3.11
Medway	67	18	3	3	158.7
Mole	18	1	6	2	45.81
Ravensbourne	20	1	0	0	47.71
Roding, Beam & Ingrebourne	26	1	3	0	97.94
South Essex	4	1	0	0	19.97
Wandle	81	0	6	0	27.83
Wey	60	2	0	3	93.82
Your Tidal Thames	8	1	0	0	91.25
Total	**1028**	**73**	**71**	**22**	**1685.82**

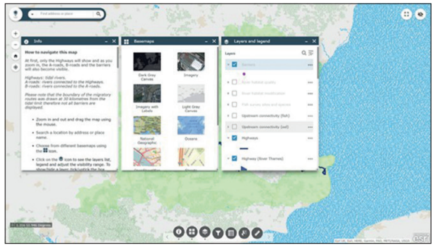
Table 4: Summary table of the number of barriers, fish pass, eel pass, multi-species pass and total river length in each catchment

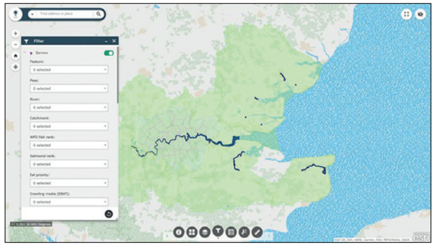
Datasets: finalised barrier dataset, migratory routes (Highways, A-roads, B-roads), upstream fish and eel connectivity shapefiles, river habitat surveys, fish surveys and species, catchments, London boroughs, London plan development opportunity area, risk of flooding from rivers and sea, and potential 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 10a).

Figure 10a: Mapping application with tools and widgets in the centre bottom (Screenshot of the web-based GIS tool)





Above left: Figure 10b: Mapping application Info, Basemaps, and Layers and legend widget windows open (Screenshot of the web-based GIS tool)

Above right: Figure 10c: Mapping application with Filter widget window open (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 10b).
- 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 10c).

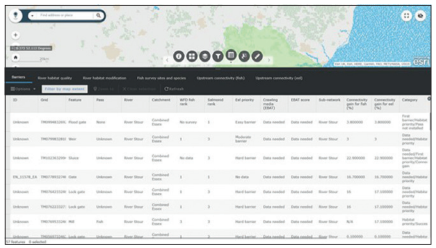
  The Attribute table can be used to inspect the datasets (Figure 10d).
- The Select widget can be used to select and download specific barrier locations. The Measure widget can be used to measure area and length (Figure 10e).

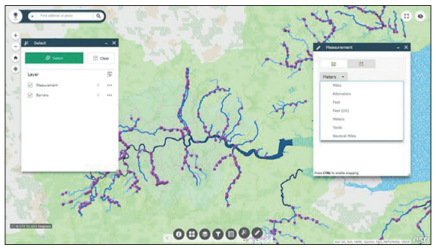
Using the interactive web-based GIS tool

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 areas upstream. This can then be overlayed on top of the upstream eel connectivity layer to visualise connectivity (Figure 11a).

Below left: Figure 10d: Mapping application with Attribute table widget window open (Screenshot of the web-based GIS tool)

Below right: Figure 10e: Mapping application with Select and Measure widget windows open (Screenshot of the web-based GIS tool)





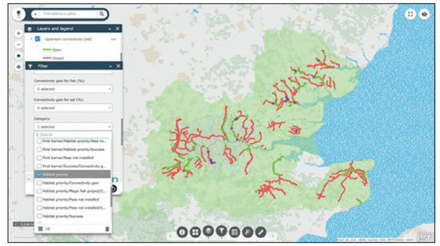


Figure 11a: Scenario 1 (Screenshot of the web-based GIS tool)

In this scenario 22 barrier locations could be identified out of which one barrier had an eel pass installed and three barriers needed no mitigation.

Scenario 2: From scenario 1, further filtering the finalised barrier dataset, two barriers 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 11b).

Scenario 3: 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 11c).

In this case, the area where Barking Riverside is being developed, 13 barriers can be identified out of which in the case of 11 barrier locations no pass is installed/not known if there is a pass installed.

Discussion

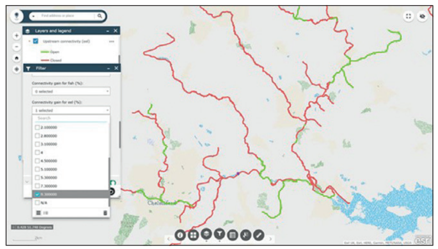
The main objectives of the Roadmap project were:

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 1,028 barriers recorded covering a total length of 1686 kilometres. 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 (20 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

Below left: Figure 11b: Scenario 2 (Screenshot of the web-based GIS tool)

Below right: Figure 11c: Scenario 3 (Screenshot of the web-based GIS tool)



discrepancies and create a robust barrier dataset.

The data merging process highlighted that those stakeholder barrier datasets that had been ground-truthed (e.g. Essex 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 (43) 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 (height and 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 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 1: 18 barrier remediations were identified as having high potential to improve upstream eel migration to reach diverse/high quality and near-natural river habitat areas.
- In scenario 2: Building on scenario 1, two barriers at a location with the highest connectivity gain were identified. Inspecting the data further at this location in the Roadmap, found a lock system which made upstream fish and eel migration completely impossible. Addressing just one of these barriers could open up 9.3% of the River Chelmer sub-network for both fish and eel (Figure 12).

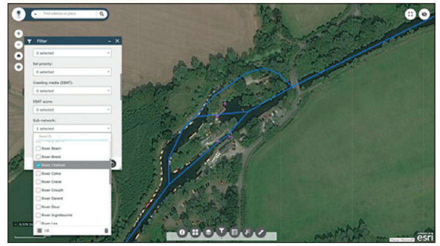


Figure 12: Location with four barriers on the River Chelmer (Screenshot of the web-based GIS tool)

- In scenario 3: 11 impassable barriers were identified, most of them on the confluence of the Highway and A-roads, which 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.

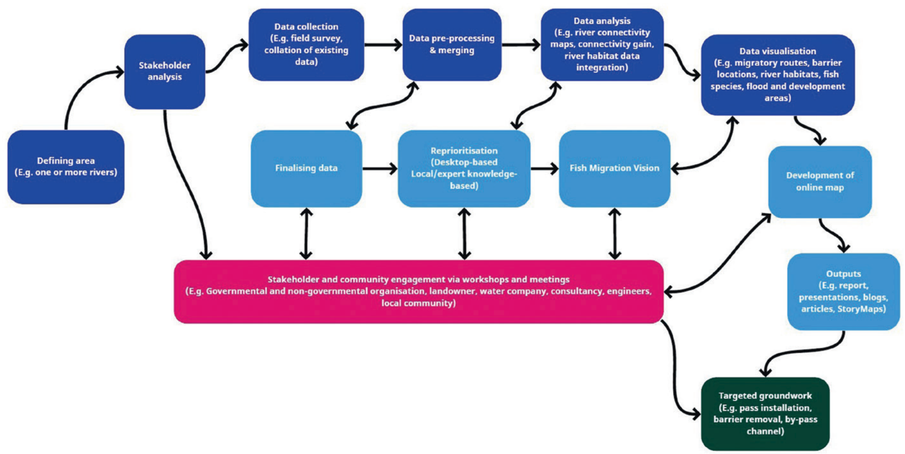
The steps of the creation of the Roadmap were summarised in Figure 13.

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

Figure 13: Flowchart of strategic steps (Made in Miro)



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.

Going forward, the Roadmap database will be maintained by TEP's in-house data personnel. In addition, both the project report and the methodology will be free available on the dedicated project page, and support will be provided for catchment partnerships through the London River Restoration Group (LRRG) and Catchment Partnerships in London (CPiL) group.

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) and will evolve over time (e.g. creation of eel migration specific Roadmap).

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.

APPENDICES

APPENDIX 1

Roadmap for fish migration in the Dutch delta. Prepared by Peter Philipsen (Nature at Work) and Herman Wanningen (Wanningen Water Consult)

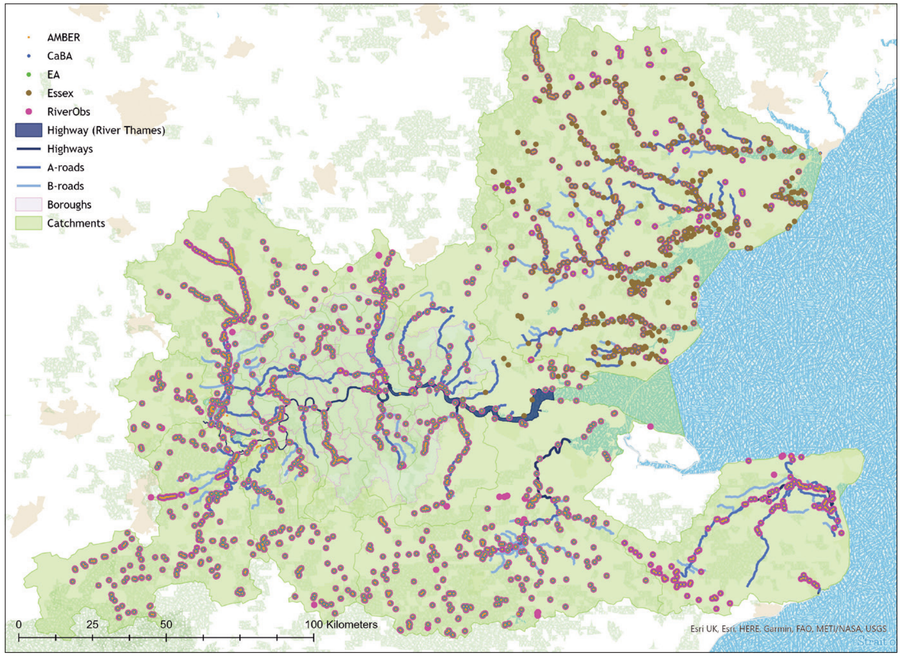
APPENDIX 2

		Barrier information					
Type of data	Project acronym	Name	Area covered	Data collection method	Source	Date	Note
Shapefile	AMBER	AMBER_Barrier_Atlas_GB	20 catchments	Not indicated	Catchment Based Approach Open Data website	11/07/2019	Environment Agency indicated as source in the metadata
Shapefile	CaBa	All_Barriers	20 catchments	Not indicated	Catchment Based Approach Open Data website	12/07/2019	Environment Agency indicated as source in the metadata
Shapefile	RiverObs	rivobsdata-export	20 catchments	Not indicated	River Obstacle app website	13/072019	Environment Agency indicated as source in the metadata
Excel sheets	N/A	Thames obstructions and Fish and eel passes	18 catchments	Not indicated	Environment Agency (Darryl Clifton-Dey)	04/02/2017	Separate datasets
Shapefiles	N/A	Locks_View_Public, Sluices_View_Public, Weirs_View_Public	5 catchments	Not Indicated	Canal & River Trust Open Data website	10/05/2020	None
Excel sheet	N/A	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	N/A	barriers CG	Hogsmill	Not indicated	South East Rivers Trust	25/10/2018	None
Excel sheet	N/A	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	06/01/2018	None
Shapefile	N/A	OS Open Rivers	20 catchments	N/A	Ordinance Survey website	01/05/2020	N/A

		Barrier information					
Type of data	Project acronym	Name	Area covered	Data collection method	Source	Date	Note
Excel sheet	N/A	River Habitat Surveys - Survey Details and Summary Results	20 catchments	Environment Agency standard for collecting data on the physical character and quality of river habitats across the UK	DEFRA file sharing service	16/05/2020	None
Shapefile	N/A	FW_Fish_Counts	20 catchments	Electric fishing and various netting methods	EA Ecology and Fish Data Explorer	22/10/2020	This dataset contains site and survey information, the numbers and species of fish caught, fish lengths, weights and ages (where available), for all the freshwater fish surveys carried out across England from 1975 onwards.
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 potential improvements to public transport accessibility.
Excel sheet	N/A	london-borough-profiles	N/A	N/A	London Datastore	16/05/2020	N/A
Shapefile	N/A	CaBa Catchment Partnerships	20 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	23/03/2019	This dataset shows the chance of flooding from rivers and/or thesea, based on cells of 50m.
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 indentified.

APPENDIX 3

Mapping the AMBER, CaBA, EA, Essex and RiverObs datasets showed that large number of barriers did occur away from the migratory routes.



Map showing all barrier locations from the AMBER, CaBA, EA, Essex and RiverObs datasets

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 only included less than 5% more barriers. Likewise, 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	1221
150m	1194
100m	1173
75m	1155
50m	1127

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

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