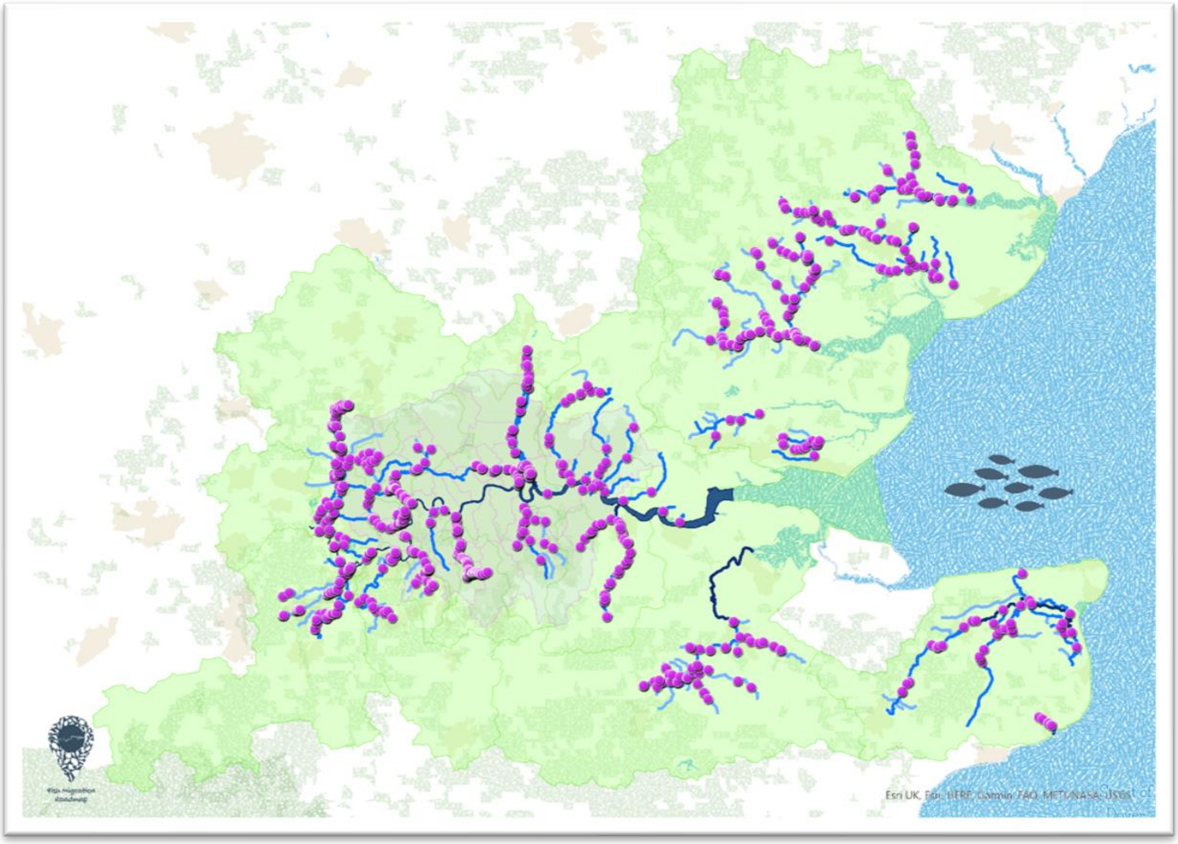
Greater Thames Estuary Fish Migration Roadmap

Project Report



Project officer: Wanda Bodnar

Contact: w.bodnar@ucl.ac.uk

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Executive summary

Rivers in countries of the North Sea region are some of the most fragmented by human development in the world. River restoration and intertidal habitat enhancement is completed in an opportunistic way when either a development needs to mitigate for other damage or flood asset management needs addressing. Similarly, migration barriers such as weirs are only addressed in an ad hoc manner and usually only single barriers 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 and other benefits are hidden.

The Roadmap applies a strategic approach that, like a transport system for a road network, looks at rivers as interconnected migratory routes identified as 'Highways', 'A-roads' and 'B-roads'. This was achieved by gathering information on all existing fish migratory barriers within the Thames River Basin and adjacent catchments and using this data connectivity maps were created to calculate and visualise the extent of river fragmentation. Following the integration of river habitat data, the collated barrier data was then reprioritised to highlight, for example, barriers with fish/eel pass installed and river sections with habitat priority areas. Then, utilising GIS technology, the collated barrier data and connectivity maps were integrated into a publicly accessible interactive map along with flood risk, development opportunity and habitat creation areas.

This sea-to-source approach used by the Roadmap enables the visualisation of river network connectivity in entire catchments, highlighting fragmentation and where barrier works are needed whilst achieving multiple benefits, such as flood risk assessment, habitat restoration and environmental enhancement and it also enables riverside communities to reconnect with their local waterways.

1. 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, which in turn, influence 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, like weirs, sluices and locks, installed for water management purposes, can be found at almost every kilometre (Belletti, et al., 2018). These barriers can significantly delay and hinder the movement of migratory fish species, subsequently reducing 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. Thus, maintaining connectivity is important to sustain their healthy and diverse population (Nunn & Cowx, 2012).

In the UK, 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 (Amy Pryor, personal communication). Similarly, 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 and other benefits are hidden.

To address this issue, Thames Estuary Partnership (TEP) and Nature at Work (NAW) launched the Greater Thames Estuary Fish Migration Roadmap project in January 2018. The project sought to pull together all barrier, pass, priority and river habitat location data in one place and develop a strategic approach that looks at rivers as migratory routes that fish would use. This sea-to-source approach enables the visualisation of river network connectivity in entire catchments, highlighting fragmentation and where barrier works are needed. In addition, the integration of data on flood risk, development opportunity and potential habitat creation areas (native oyster, seagrass, saltmarsh) into the Roadmap help create a 'whole system' approach in decision making for river restoration, riverside development and flood mitigation schemes.

As well as creating a GIS tool, the Roadmap also facilitates the development of a community-led Fish Migration Vision at the catchment and single river levels, thereby helping to identify opportunities for habitat creation and public realm enhancement that could be achieved at the same time as large-scale barrier works.

The Roadmap also contributes to data needed for both statutory monitoring and community-based environmental action and provides a pathway for building relationships among various stakeholders and communities, locally and across the freshwater and marine boundary.

1.1. Roadmap for Fish Migration in the Dutch Delta

TEP was first approached with the Roadmap method by NAW, an organisation which had successfully used this strategic approach to engage with Dutch water authorities. In particular, NAW worked with regional waterboards and the national water authority Rijkswaterstaat to address fish passage and open up entire migratory routes in the Rhine West Delta in the Netherlands.

The Roadmap method looks at rivers as a network of interconnected roads, with fish migratory routes identified as 'Highways', 'A-roads' and 'B-roads'. Diadromous fish need to be able to swim up these migratory routes all the way to their required habitat to fulfil their life cycle. Information on barriers, fish passes and habitat quality was gathered in a web-based GIS tool and plotted on the migratory routes. Connectivity maps were then produced to indicate which barriers need to be lifted first to open entire migratory routes (Appendix 1.). This method has recently been adopted nationally in the Netherlands, and a National Fish Roadmap has been produced.

NAW saw the opportunity to replicate this method in the Thames and asked TEP whether this type of strategic approach was needed. TEP confirmed the need for a similar strategic approach across the Thames River Basin with the Environment Agency. Once funding had been secured, TEP and NAW brought together key stakeholders in the River Thames to adapt the Fish Roadmap method to the Thames Estuary. A Project Advisory Board was established consisting of the Environment Agency (EA), the Institute of Fisheries Management (IFM) and the Zoological Society of London (ZSL).

2. Methodology

The Fish Migration 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 GIS platform visualising all relevant data.

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

These objectives were executed via the following processes:

1) Data science
    a. Designation of project area
    b. Data collection
    c. Data pre-processing and merging
    d. Data analysis
    e. Data visualisation (online and hardcopy maps)
2) Stakeholder and community engagement

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 could ensure 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.

2.1. Data science

2.1.1. Designation of project area

The project area was defined as 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, and this is particularly so for the European eel, one of the target species for this project. The choice of this large area also ensured that a landscape-scale, whole-system approach could be embarked upon from the start and that enthusiasm for the project and progress could be identified quickly whilst providing a framework that is replicable across all rivers.

The fish migratory routes were selected as follows: tidal rivers (rivers directly connected with the North Sea) were identified as 'Highways', rivers flowing into the highways were called 'A-roads', and rivers flowing into the A-roads were called '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 Roadmap migratory routes was established at 30 kilometres from the tidal limit (ZSL, 2018) (Figure 1).

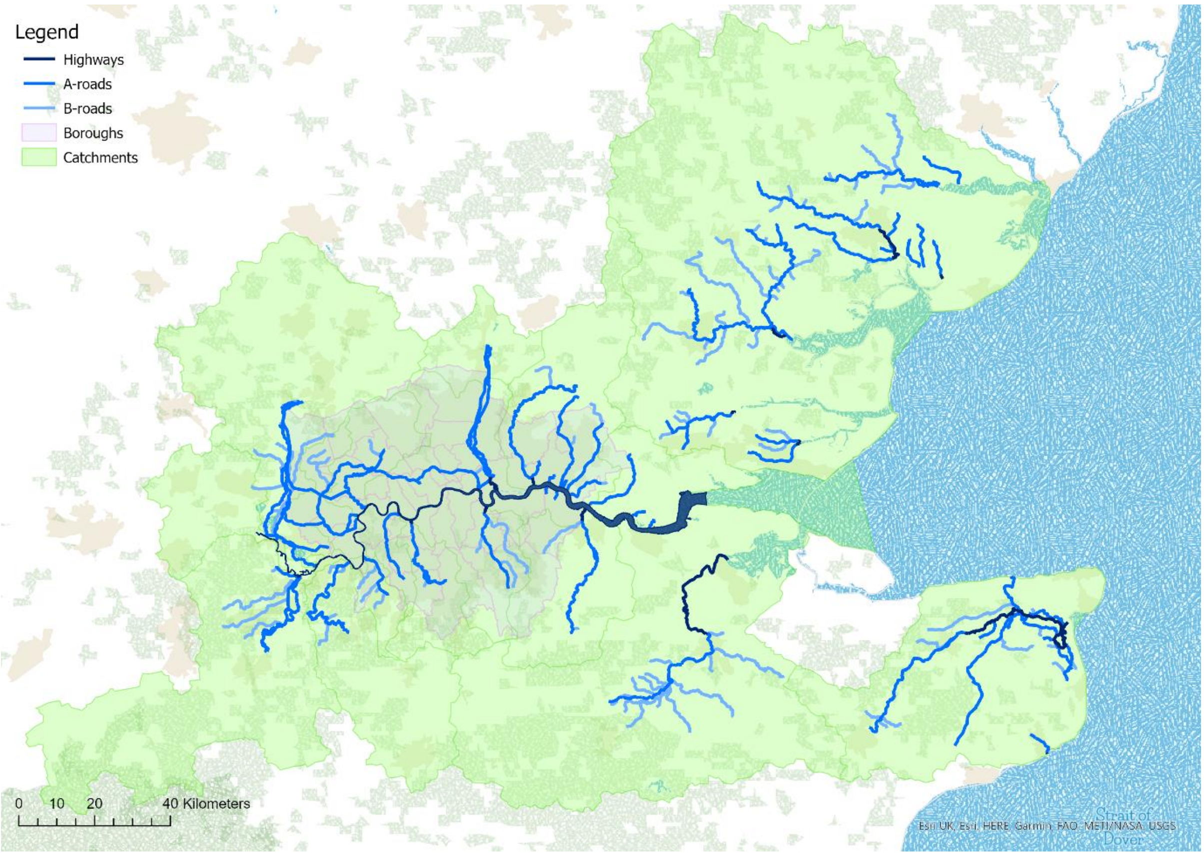


Figure 1: Greater Thames Fish Migration Roadmap project area with the migratory routes (map made in ArcGIS Pro 2.6.3)

The hydrography data used for the migratory routes was obtained from the Ordinance Survey website (OS Open Rivers). In addition, further digitisation of river sections was carried out using ArcMap (10.6.1) (ESRI 2018). The total length of rivers covered by project was 1686 kilometres.

2.1.2. Data collection

Barrier information was obtained from multiple sources both in the form of datasets (Excel sheet or shapefile) and in the form of reports.

River habitat data was obtained from the Department for Environment, Food and Rural Affairs (Defra) website, and the catchments shapefile was downloaded from the Catchment Based Approach (CaBA) Open Data website. The London Plan opportunity areas and London Boroughs shapefiles were downloaded from the London Datastore. Additional data such as risk of flooding from rivers and sea and potential habitat creation sites for oyster, seagrass and saltmarsh areas were added as a map service via ArcGIS Online (The Rivers Trust). See Appendix 2. for the detailed table for all data sources.

2.1.3. 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 dataset. The methodology devised for the data merging was carried out over seven steps. This was essential to provide an accurate baseline 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 to focus on the project area only (20 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.
   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 resulted joined dataset (from now on referred to as EA) yielded all together 1368 barrier locations.
3) For the analysis of river network connectivity, the data fields extracted from the different barrier datasets were the location and number of barriers, and the number and type of passes. The total number of these fields across the barrier datasets were summarised in Table 1. (The table excludes the barrier information that were received in a report format.)

	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) 71 (eel)	40 (fish)	69 (fish) 63 (eel)	0	24 (fish) 44 (eel)	0	6 (fish) 4 (eel)

Table 1: Summary table of number of barriers, and number and type of passes in the different barrier datasets. The number of catchments is shown for reference.

4) The AMBER, CaBA, EA, Essex and RiverObs barrier datasets were cleaned, standardised and spatially joined.
   Process and result:
   - The following fields were kept across all four datasets:
     - ID (asset ID from the EA data)
     - Barrier location (both grid and latitude and longitude)
     - Barrier type
     - Barrier priority
     - Pass type
     - Height (m) (this data was only available in the AMBER dataset)
     - A 'Source' field was also created to feature the original data source for each barrier location

- ID, barrier type and priority, and type of pass were kept where they were the same across at least two datasets. In all other instances, the barrier type, pass type and priority were recorded as ‘unknown’. The resulted dataset is called ‘finalised barrier dataset’.

5) The finalised barrier dataset was cut down 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 CRT, SERT and TEP barrier datasets (Excel sheets) and the barrier information received in the form of reports (LWT and ZSL) were manually integrated into the final barrier dataset. The integration of these datasets, which were ground-truthed, helped verify the ‘unknown’ entries generated in step 4. A ‘Comment’ field was also created in this process to add any relevant information from the Excel sheets and reports.
7) The finalised barrier data went through an additional verification 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.

2.1.4. Data analysis

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

1) First a river connectivity index (RCI) was calculated for each catchment. (The RCI formula was first used by (Grill, et al., 2014) and was based on the ‘Dendritic Connectivity Index’ (DCI) (Cote, et al., 2009). The RCI calculation was carried out through the following steps:
    - Using the finalised barrier dataset, the river shapefile data was split into fragments.
    - The RCI formula is:

$$RCI = \sum_{i=1}^{n} \frac{l_i^2}{L^2} * 100$$

where n is the number of fragments, l_i is the total length of the continuous river fragment i that is disconnected by one or more barriers, and L is the total length of river (Figure 2).

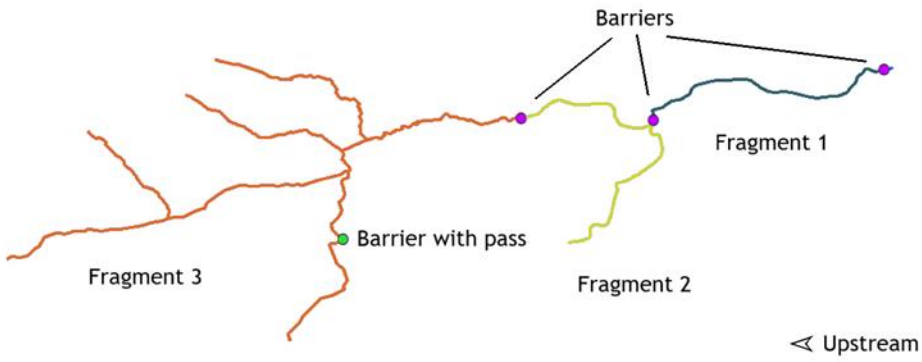


Figure 2: Conceptual illustration of river network fragmentation due to barriers

The calculation of the RCI excluded those barriers that had fish, eel or multi-species pass installed. The RCI value ranges from 0% to 100%. The closer the RCI value is to 0%, the less fragmented the river network is. The results of the RCI were presented as maps and in a data table with each catchment ranked.

2) The river fragmentation shapefile gained in the previous step was used to visualise upstream river connectivity considering the existing passes. Open river sections were identified as those where the closest barrier downstream had a pass (fish, eel, or multi-species) installed (Figure 3).

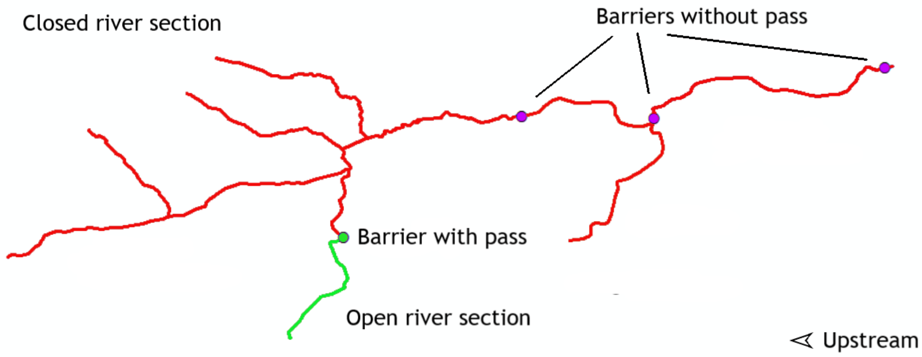


Figure 3: Conceptual illustration of river connectivity with open (green) and closed (red) sections

3) To prioritise barriers based on the number and type of habitats upstream, the river habitat survey data was analysed and integrated through the following steps:

- The river habitat survey data was cut down using the 100-metre buffer zone (see step 5 in 2.1.3. 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) (Table 2.) (Raven, et al., 1998).

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 modied	2
Poor	1 to 25	Severely modified	1

Table 2: Summary table of the HQA and HMS class

- Within each river fragment, the mode average was calculated for all HQA and HMS class habitats (Figure 4). The figure of the mode average was then assigned to nearest barrier downstream and was integrated into the finalised barrier dataset under the 'Upstream HQA' and 'Upstream HMS class' fields.

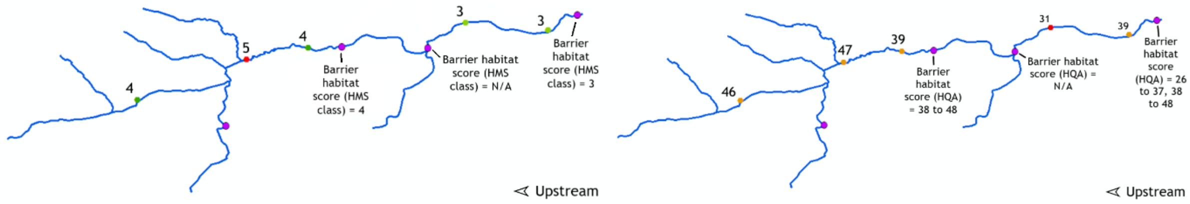


Figure 4: Conceptual illustration of calculating the mode average within fragments

Lastly, in the finalised barrier dataset, under the 'Category' field, barriers were reprioritised through the following steps:

- After inspection of the final barrier data:
    - Those barriers that had no information on barrier type, pass type and priority 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 from where the upstream river sections had high habitat scores (HQA ≥ 49 and HMS class ≥ 4) were marked as 'Habitat priority'.
    - Locations where it is known that passes are not present were marked as 'Pass not installed'.
    - Barriers that had fish/eel pass installed or were removed were marked as 'Success'.

Following a series of stakeholder engagements in the Combined Essex Catchment (from now on referred to as Essex) area (see 2.2.1. Essex Fish Migration Roadmap for more detail), additional categories were introduced as part of the reprioritisation process:

- '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.

Based on these categories, the RCI index was recalculated for both fish and eel in Essex only, and the results were presented in a data table.

Data analysis was carried out using RStudio (1.2.5033) (RStudio 2019) and ArcGIS Desktop (10.6.1) (ESRI 2018). Figures and tables were created using ArcGIS Pro 2.6.3 (ESRI 2020) and MS Excel (2016).

2.1.5. Data visualisation

An interactive online platform was developed for both stakeholder and public engagement. For the online map, the following datasets were used: river shapefile (migratory routes), CaBA catchments, London boroughs, finalised barrier dataset (gained during data merging and analysis), river connectivity (gained during data analysis), river habitat data (gained during data analysis), risk of flooding from rivers and sea and potential habitat areas map service layers, and London plan opportunity areas. For the creation of the interactive online platform, ESRI's ArcGIS Hub website building application was used. For the creation of the interactive map ArcGIS' web mapping application was used as this allows the user to fully interact with all datasets via the filter widget.

To demonstrate the functionality of the interactive Roadmap, considering habitat priority, suggestions were made for possible barrier works to improve river connectivity. These were presented in a data table with the recalculated RCI value.

The hardcopy map is currently in development.

2.2. Stakeholder and community engagement

Since January 2018, the project 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, and TEP has become one of the partners in working on reviving the River Obstacles app (Table 3).

Date	Event
15/02/2018	Project Advisory Group meeting
15/03/2018	Roadmap workshop
23-24/05/2018	8th Annual IFM Specialist Conference
26/09/2018	Roadmap workshop
13/12/2018	Essex Roadmap meeting
13/05/2019	Essex Roadmap Workshop
29-30/05/2019	20th RRC Annual Network Conference
18/06/2019	River Obstacles app Project Board meeting
24/07/2019	Essex Roadmap meeting
24/07/2019	River Obstacles app Project Board meeting
18/10/2019	Essex Rivers Hub meeting
09/01/2020	Essex Roadmap Workshop
30/01/2020	River Obstacles app Project Board meeting
04/03/2020	Essex Roadmap meeting
09/03/2020	Essex Coastal Forum
22/04/2020	Roadmap project summary meeting

Table 3: Timeline of stakeholder engagements

2.2.1. 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. Thus, since September 2018, TEP and NAW have been working together with the Essex team on the Essex Fish Migration Roadmap. Upon receiving and integrating the detailed barrier data into the Roadmap (see 2. Methodology), a separate interactive map was developed and used to engage with local stakeholders (Table 3).

During a series of workshops with the CECP, four rivers (the Chelmer, the Blackwater, the Colne, and the Roman river) were noted as rivers of interest. This was followed by a barrier reprioritisation process (see 2.1.4. Data analysis for more detail).

3. Results

The map shows the finalised barrier dataset with the location of barriers on the migratory routes in the project area (Figure 5).

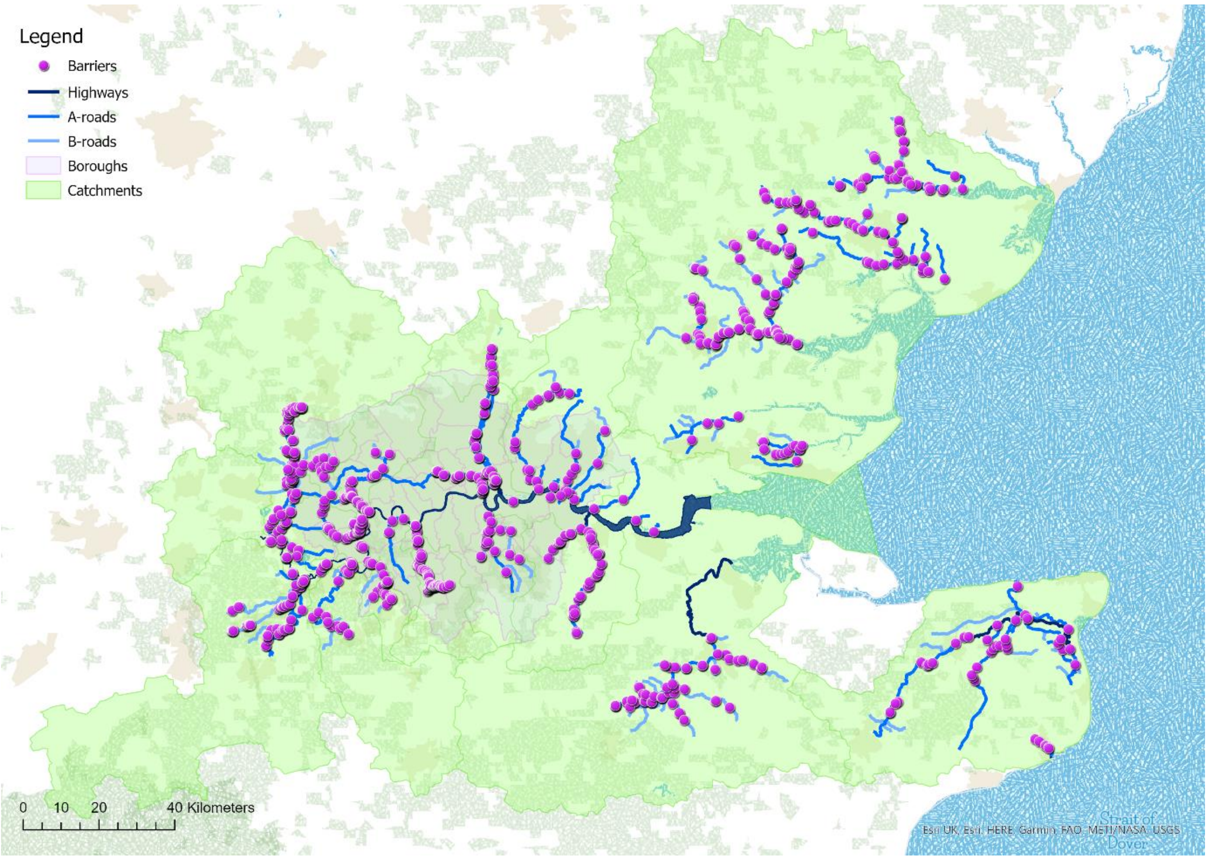


Figure 5: The finalised barrier dataset with the migratory routes (map made in ArcGIS Pro 2.6.3)

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 fish pass	Number of eel pass	Number of multi-species pass	Total river length (km)
Beverely Brook	1	0	0	1	14.34
Brent	46	0	3	0	41.66
Colne	108	18	0	3	151.44
Combined Essex	215	3	24	4	437.81
Crane Valley	43	0	1	0	52.4
Darent & Cray	53	3	3	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	66	16	0	0	158.7
Mole	18	0	6	1	45.81
Ravensbourne	20	1	0	0	41.71
Roding, Beam & Ingrebourne	21	1	3	0	97.94
South Essex	4	1	0	0	19.97
Wandle	50	0	5	0	27.83
Wey	60	2	0	3	93.82
Your Tidal Thames	16	1	1	0	91.25
Total	**945**	**73**	**64**	**18**	**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

The RCI calculated for each catchment highlights the percentage of fragmentation in relation to the total river length, as well as their rank with the presence of fish pass (Table 5a and Figure 6a) and eel pass (Table 5b and Figure 6b) considered. (Note that the barriers with multi-species pass were incorporated into the fish and eel connectivity.)

Rank	Catchment	RCI (%) (with fish pass)
N/A	*Beverely Brook*	*0%*
N/A	*Maidenhead to Teddington*	*0%*
N/A	*Your Tidal Thames*	*0%*
1	Combined Essex	1.52%
2	East Kent	2.76%
3	Medway	2.90%
4	Colne	3.02%
5	Wey	3.42%
6	Darent & Cray	4.90%
7	Hogsmill	4.93%
8	London Lea	5.49%
9	Mole	5.90%
10	Roding, Beam & Ingrebourne	6.85%
11	Wandle	7.62%
12	Ravensbourne	16.14%
13	Brent	21.21%
14	Lower Lea	27.73%
15	Marsh Dyke & Thamesmead	28.86%
16	South Essex	30.00%
17	Crane Valley	100.00%

Table 5a: Summary table of the RCI (%) with fish pass in each catchment. The calculation assumed that barriers with fish pass are passable.

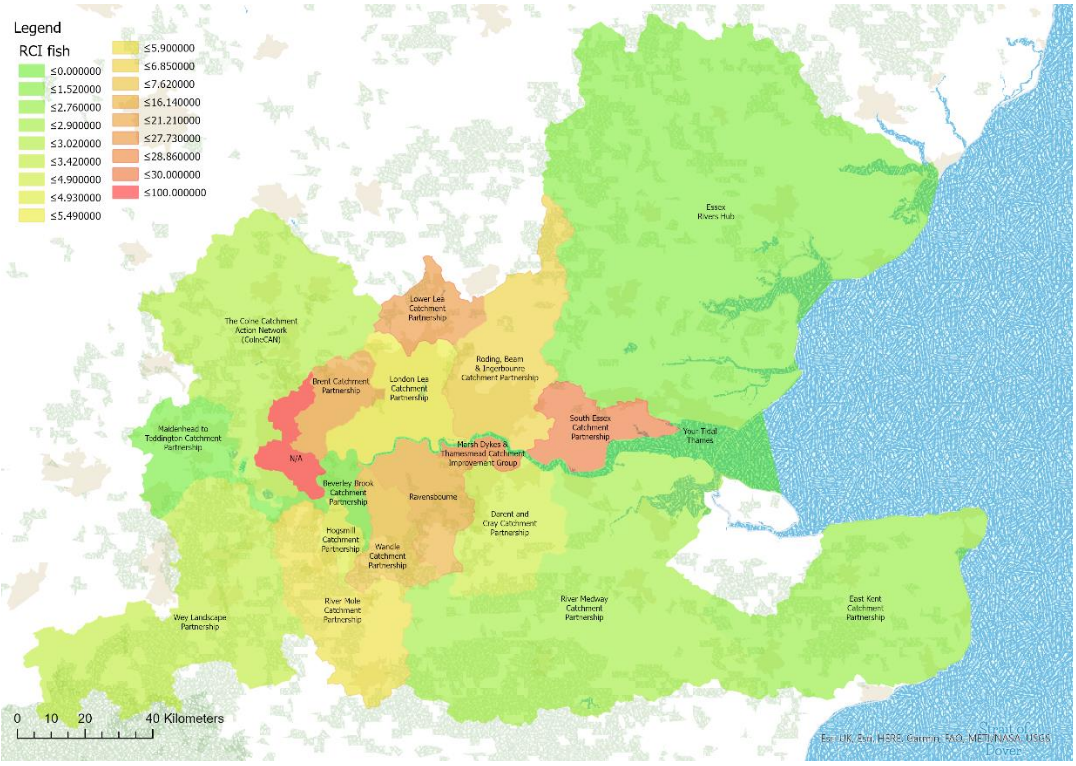


Figure 6a: Map of the RCI (%) with fish pass in each catchment. The calculation assumed that barriers with fish pass are passable (map made in ArcGIS Pro 2.6.3).

Rank	Catchment	RCI (%) (with eel pass)
N/A	*Beverely Brook*	*0%*
N/A	*Maidenhead to Teddington*	*0%*
N/A	*Your Tidal Thames*	*0%*
1	Combined Essex	1.47%
2	East Kent	2.97%
3	Colne	3.31%
4	Mole	4.07%
5	Medway	4.24%
6	Wey	4.26%
7	Darent & Cray	4.98%
8	London Lea	5.27%
9	Roding, Beam & Ingrebourne	5.52%
10	Wandle	7.55%
11	Hogsmill	10.37%
12	Crane Valley	11.02%
13	Ravensbourne	16.41%
14	Brent	20.80%
15	Marsh Dyke & Thamesmead	28.86%
16	South Essex	100.00%
17	Lower Lea	100.00%

Table 5b: Summary table of the RCI (%) with eel pass in each catchment. The calculation assumed that barriers with eel pass are passable.

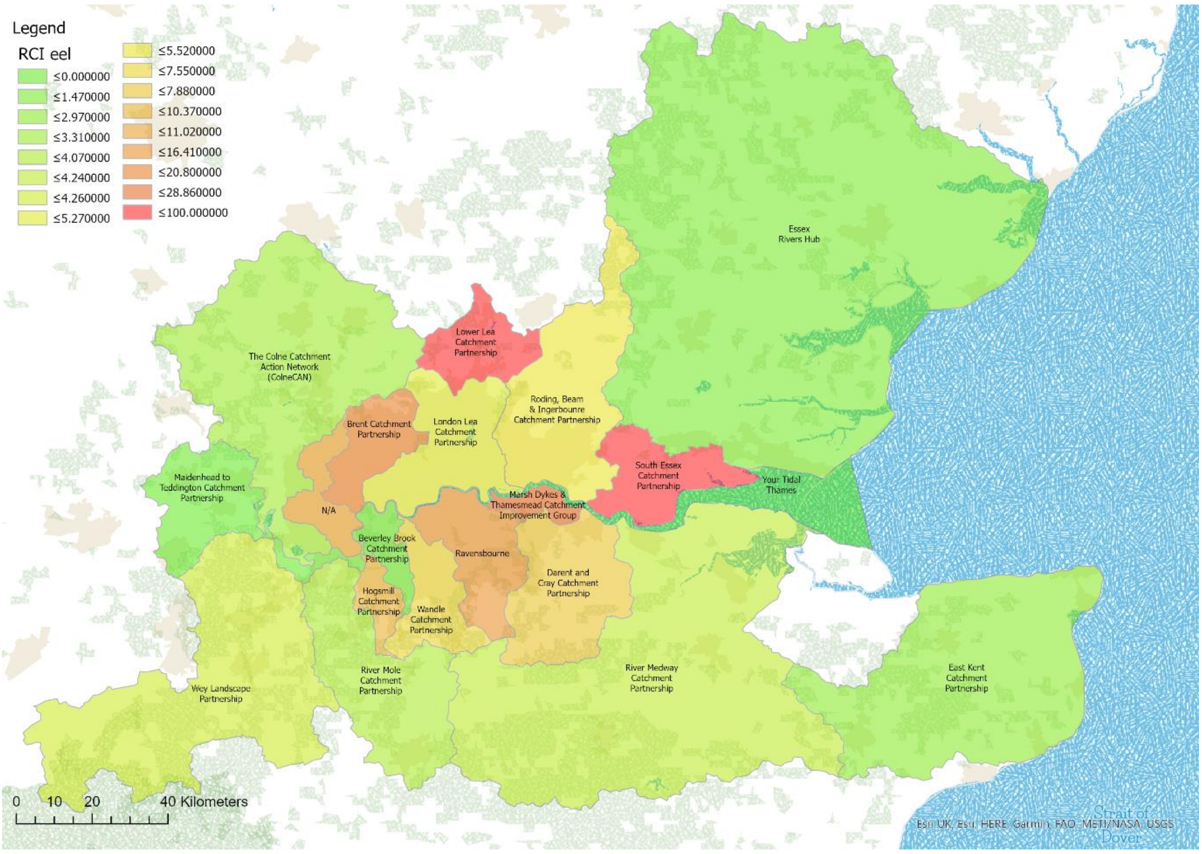


Figure 6b: Map of the RCI (%) with eel pass in each catchment. The calculation assumed that barriers with eel pass are passable (map made in ArcGIS Pro 2.6.3).

Accompanying the results of the RCIs, the upstream river connectivity maps for fish (Figure 7a) and for eel (Figure 7b) visualise the extent of connectivity.

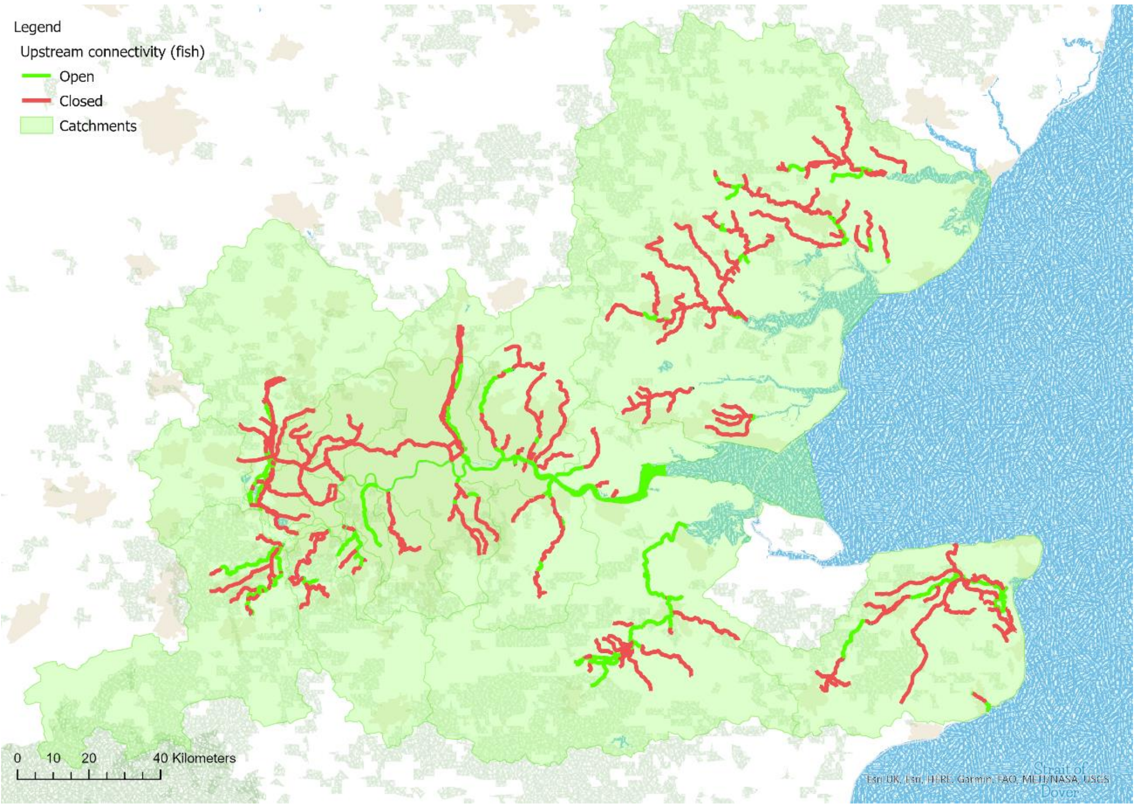


Figure 7a: Upstream river connectivity for fish (map made in ArcGIS Pro 2.6.3).

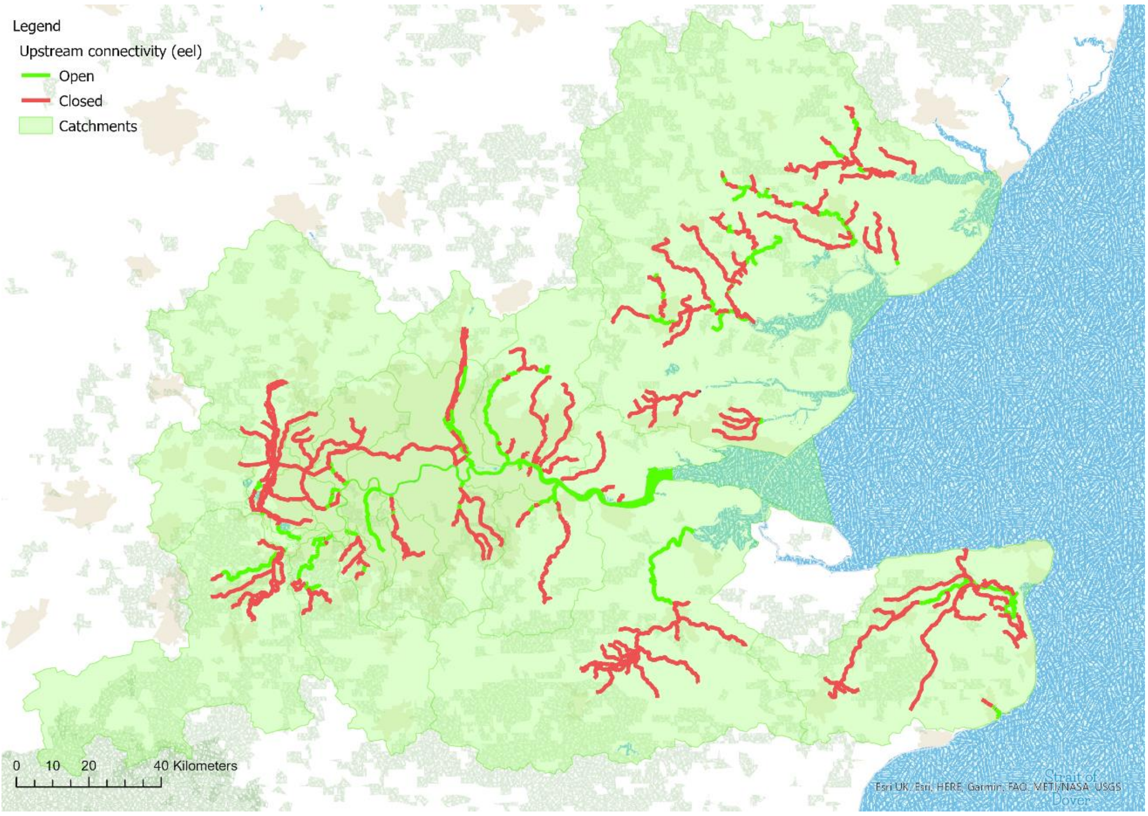


Figure 7b: Upstream river connectivity for eel (map made in ArcGIS Pro 2.6.3).

Based on the data gained and gathered, a website was set up with an interactive Roadmap with the following main functionalities:

- All datasets (see 2.1.5. Data visualisation for more info) are displayed with clear legend and the possibility to tick on and off each layer using the 'Layers and legend' widget (Figure 8a).

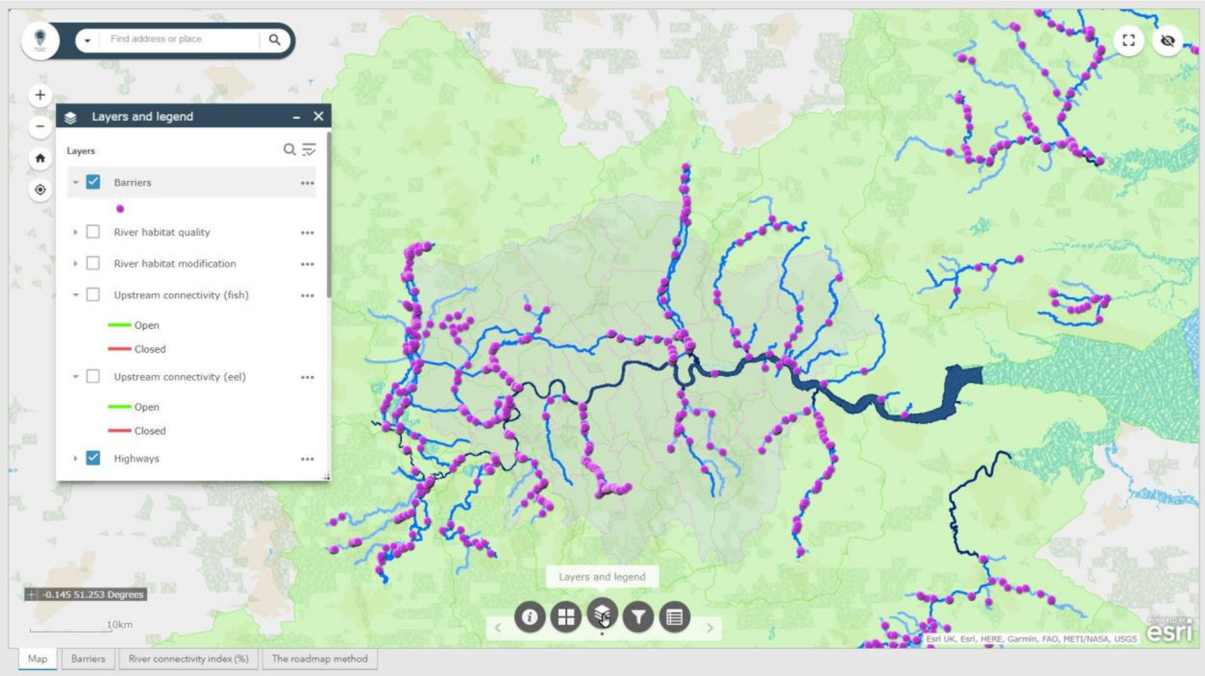


Figure 8a: Screenshot of the interactive map showing the data layers

- The 'Layers and legend' widget also allows to see the river connectivity layers (Figure 8b).

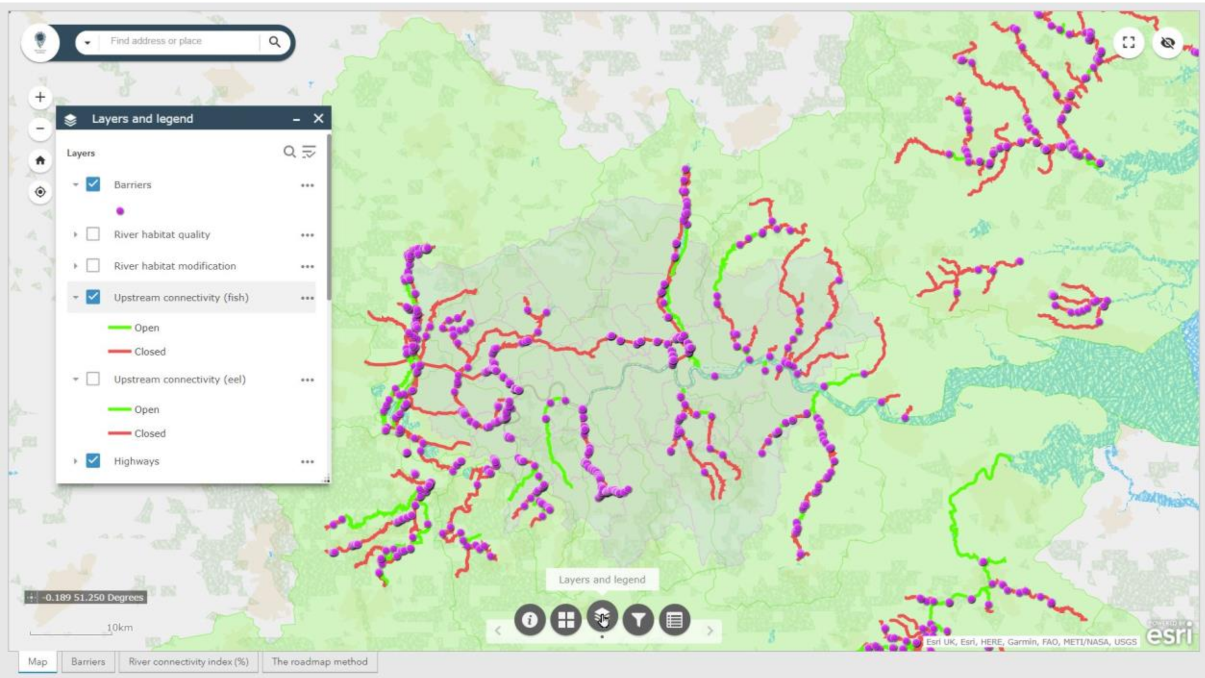


Figure 8b: Screenshot of the interactive map showing the river connectivity layers

- The 'Filter' widget allows the barrier data to be filtered based on barrier type, priority, pass type, river, category and upstream river habitat quality/modification (Figure 8b).

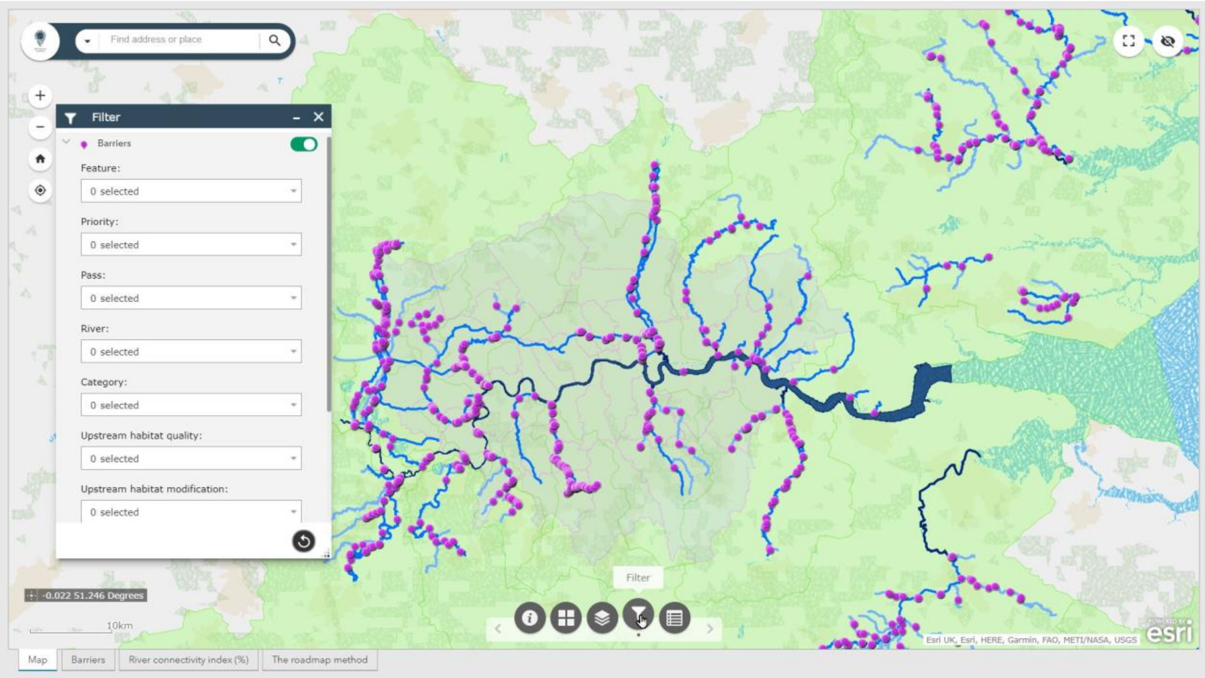


Figure 8c: Screenshot of the interactive Roadmap showing the filter widget

The attribute table also allows the viewer to inspect the datasets used (Figure 8d).

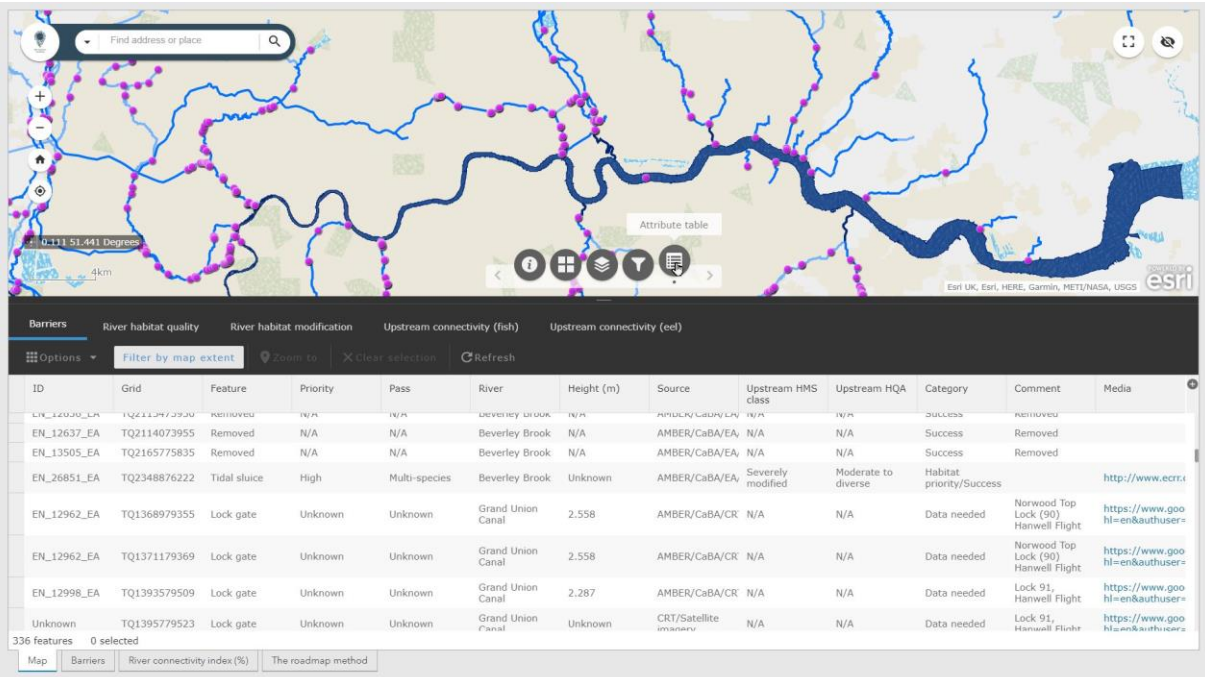


Figure 8d: Screenshot of the interactive Roadmap showing the attribute table

3.1. Using the Roadmap

The example screenshots below highlight the River Wandle and the River Roding on the Roadmap. Considering habitat priority, using the map's filter functionality and the river connectivity layers suggestions were made for possible targeted fish and eel passage works (Figure 9a and b). The recalculated RCI is presented in data tables (Table 6a and b).

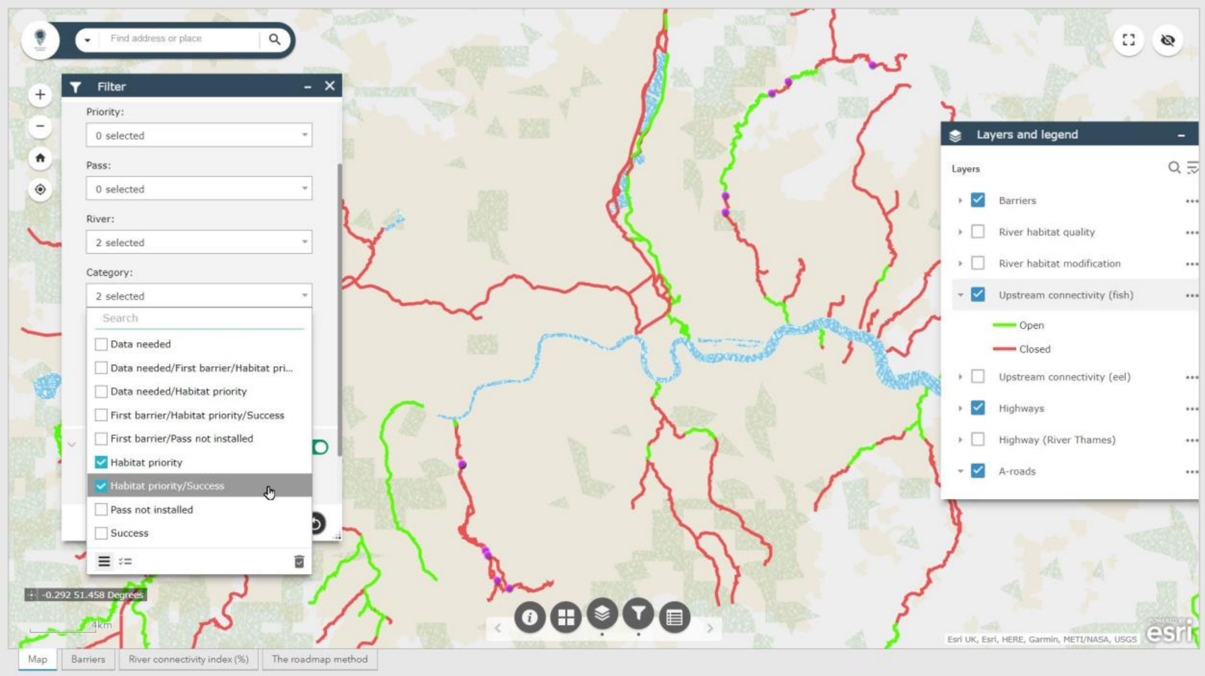


Figure 9a: Screenshot of the interactive Roadmap showing habitat priority areas and the upstream river connectivity layer for fish

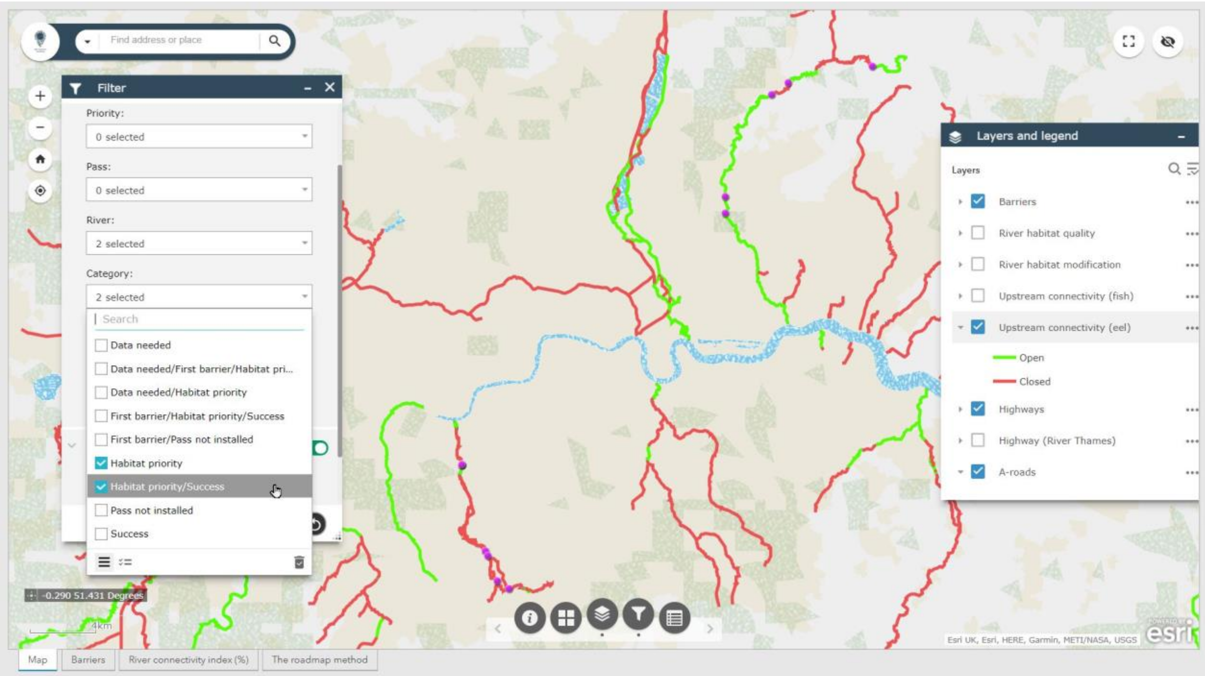


Figure 9b: Screenshot of the interactive Roadmap showing habitat priority areas and the upstream river connectivity layer for eel

River	Barrier type	Name	Category	Location (NGR)	Comment	RCI (%) (with fish pass)
River Roding	Weir	N/A	Habitat priority	TQ5017297459	Suggestion based on using the Roadmap	5.91% (-0.94%)
River Roding	Weir	N/A	Habitat priority	TQ4413895571	Suggestion based on using the Roadmap	
River Roding	Gauging Station	Redbridge weir	Habitat priority	TQ4150088331	Suggestion based on using the Roadmap	
River Wandle	Weir	N/A	Habitat priority	TQ2595872709	Suggestion based on using the Roadmap	5.05% (-2.57%)
River Wandle	Weir	N/A	Habitat priority	TQ2594672683	Suggestion based on using the Roadmap	
River Wandle	Weir	N/A	Habitat priority	TQ2596172700	Suggestion based on using the Roadmap	
River Wandle	Weir	N/A	Habitat priority	TQ2596372693	Suggestion based on using the Roadmap	
River Wandle	Sluice	N/A	Habitat priority	TQ2750367508	Suggestion based on using the Roadmap	
River Wandle	Weir	N/A	Habitat priority	TQ2768167212	Suggestion based on using the Roadmap	
River Wandle	Weir	N/A	Habitat priority	TQ2828465700	Suggestion based on using the Roadmap	
River Wandle	Weir	N/A	Habitat priority	TQ2901365265	Suggestion based on using the Roadmap	

Table 6a: Recalculated RCI (%) with fish pass with suggested barrier locations to improve connectivity

River	Barrier type	Name	Category	Location (NGR)	Comment	RCI (%) (with eel pass)
River Roding	Weir	N/A	Habitat priority	TQ4413895571	Suggestion based on using the Roadmap	5.49% (-0.02%)
River Wandle	Sluice	N/A	Habitat priority	TQ2750367508	Suggestion based on using the Roadmap	5% (-2.55%)
River Wandle	Weir	N/A	Habitat priority	TQ2768167212	Suggestion based on using the Roadmap	
River Wandle	Weir	N/A	Habitat priority	TQ2828465700	Suggestion based on using the Roadmap	
River Wandle	Weir	N/A	Habitat priority	TQ2901365265	Suggestion based on using the Roadmap	

Table 6b: Recalculated RCI (%) with eel pass with suggested barrier locations to improve connectivity

3.2. Essex Fish Migration Roadmap

By considering stakeholder suggestions for barrier works in Essex, the recalculation of the RCIs for fish and eel, respectively, is presented in a data table (Table 7a and b).

River	Barrier type	Name	Category	Location (NGR)	Comment	RCI (%) (with fish pass)
River Blackwater	Mill	Little Braxted Mill	Major fish project	TL8341914800	Stakeholder's suggestion	1.47% (-0.05%)
River Blackwater	Mill	Wickham Bishops Mill	Major fish project	TL8234911722	Stakeholder's suggestion	
River Blackwater	Weir	Blue Mills	Major fish project	TL8308213207	Stakeholder's suggestion	
River Blackwater	Mill	Greys Mill	Major fish project	TL8609218211	Stakeholder's suggestion	
River Colne	Mill	Ford Street Mill	Easy barrier	TL9196127072	Stakeholder's suggestion	
River Colne	Mill	Earls Colne Mill	Easy barrier	TL8650029000	Stakeholder's suggestion	
River Colne	Mill	Cook's Mill	Easy barrier	TL9482926989	Stakeholder's suggestion	

Table 7a: Recalculated RCI (%) with fish pass after barrier reprioritisations

River	Barrier type	Name	Category	Location (NGR)	Comment	RCI (%) (with eel pass)
River Colne	Mill	Ford Street Mill	Easy barrier	TL9196127072	Stakeholder's suggestion	1.47% (0%)
River Colne	Mill	Earls Colne Mill	Easy barrier	TL8650029000	Stakeholder's suggestion	

Table 7b: Recalculated RCI (%) with eel pass after barrier reprioritisations

4. Discussion

The main objectives of the Greater Thames Estuary Fish Migration 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 945 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. Thus, a data pre-processing and merging process had to be developed and carried out over a series of steps which highlighted a few discrepancies.

For example, only the CaBA, EA and Essex datasets held information on barrier prioritisation. In addition, the prevailing methodology used for barrier assessment in the UK is the 'WFD111 (2a) Coarse resolution rapid assessment methodology to assess barriers to fish migration' or SNIFFER method, and the information on assessment methodology was not available in the metadata of either of the barrier datasets received (SNIFFER, 2017). Moreover, based on the follow up information received, the South East Rivers Trust (SERT) used the SNIFFER method, while the Combined Essex Catchment Partnership followed a different barrier assessment methodology to adhere for the standards set out by the Water Framework Directive (WFD) and The Eels Regulations (2009). These differences 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.

The data merging process highlighted that those stakeholder barrier datasets that had been ground-truthed (e.g. Essex or SERT) helped verify 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 existence of a pass could not be confirmed.

It is important to highlight that the finalised barrier dataset does not hold information on fields such as date of last assessment, barrier dimensions for all (e.g. height and width), river width, river flow at a barrier, the ability for both coarse fish and eels to pass upstream and downstream, and the condition of passes. These parameters may be considered for inclusion in future works.

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

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

To achieve this objective, user interactivity and the ability to filter the data was extremely important. These functionalities were developed to the highest standard using up-to-date GIS technology, resulting in the finalised website being user friendly and fully accessible by everyone regardless of technical expertise. Feedback has been good, and the website has been functioning well without any problems.

With the help of the interactive Roadmap, suggestions could also be made to identify barrier locations to improve river connectivity whilst targeting habitat priority areas. For example, on the River Wandle, the RCI recalculated showed that by targeting eight barriers the RCI value could be significantly improved by 2.57% for fish, and by targeting four barriers the RCI value could be significantly improved by 2.55% for eel.

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

The steps of this are summarised in Figure 10, indicating the importance of stakeholder input in several steps, specifically in the reprioritisation process and the development of the Fish Migration Vision.

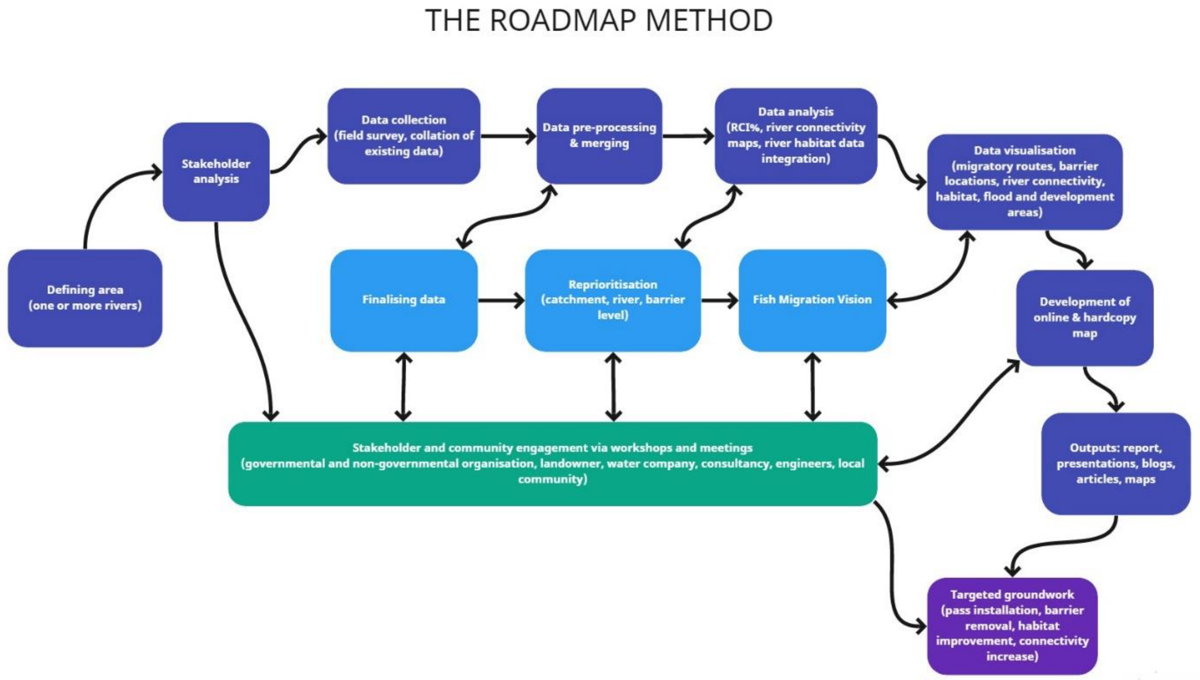


Figure 10: The Roadmap Method

To develop the method with community end-users in mind, it was crucial to work with an active Catchment Partnership to pilot the approach. The enthusiasm from the Combined Essex Catchment Partnership and regional EA team allowed to trial a new approach to accelerate barrier passage work. Therefore, both stakeholder engagement and a reprioritisation process could be progressed easily. A generic reprioritisation process was developed as follows:

- Calculation of RCI and visualisation of river connectivity that could help highlight the level of fragmentation.
- Stakeholder engagement that could help gather local knowledge and understand local needs, subsequently leading to the development of the Fish Migration Vision.
- The introduction of the 'Category' field that could help the barrier reprioritisation process.
- Coupled with the stakeholder engagement, the barrier reprioritisation could help pinpoint priority barrier locations, for example, closed river sections with diverse habitat.

The recalculation of the RCIs in Essex showed that by targeting eight barriers river connectivity for fish could be improved by 0.05%. Whilst the removal of these barriers would not have a statistically significant difference in improving the river connectivity, these are locations that the stakeholder identified to implement mitigation works.

5. Fish Migration Vision

The completed Roadmap, particularly the visualisation of river network connectivity and habitats, helped to develop the Fish Migration Vision concept.

The Fish Migration Vision is a shared, ambitious long-term goal that envisions what a healthy river and connected river corridor could be with collective action across sector initiatives e.g. catchment management, flood asset management and land development. The Vision contains key messages, a characterisation of the catchment through a connectivity lens and a description of the prioritised areas for short term action. The Vision complements and sits within any Catchment Plan developed by the local Catchment Partnership.

The Vision is a useful engagement tool alongside the hardcopy map. It deepens understanding of the need to improve our river corridors, restore habitats, help prioritise migration barriers and accelerate action for shared goals. It can also 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 vision exercise, planning and prioritisation can be carried out locally within a catchment or on a single river. This engages stakeholders and communities so that they and authorities understand local needs and can find commonalities towards a shared conservation concept. This pragmatic approach has multiple benefits, such as flood risk assessment, river restoration and environmental enhancement, helping with land development projects and enabling riverside communities to reconnect with their local waterways.

The reprioritisation process forms a major part of the vision. Accompanying the connectivity maps, barrier reprioritisation can help understand:

- Which species to get back into the system (based on species ecology and the number of suitable habitats);
- Which river section needs to be opened up;
- Which barriers need to be ground-truthed;
- Which barriers can be removed;
- Which barriers can be bypassed;
- Which barriers need passage work.

See the Fish Migration Vision outlined for the Combined Essex Catchment in Appendix 4.

5.1. 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.

6. Conclusion

The Fish Migration Roadmap aims to improve river connectivity and fish migration whilst achieving other benefits for riverside communities.

This is the first time that this kind of strategic approach has been developed in the UK, and because of its ground-breaking nature, both the map and the method may require improvements and will evolve over time. It will be a useful tool to assist with the Government's targets within the 25 Year Environment Plan, helping to identify areas where Net Gain can be achieved and contributions towards Net Zero targets. Crucially, it can be developed to achieve a truly 'wholescape' approach ensuring that solutions are implemented where they can achieve the maximum environmental and social benefits for the Catchment as a whole. It is a first successful step towards more joined-up environmental river management works across the land and water, sea to source.

7. Project outcomes

Here is the list of outcomes to date:

- Creation of replicable a roadmap methodology (Figure 10).
- Up-to-date barrier and river connectivity data covering the Thames River Basin and adjacent catchments.
- Website with interactive map and generic project information.
- Listing of the project on AMBER's website.
- Hardcopy map for raising awareness and for education (*in development*).
- Rolling out of the re-lunch of River Obstacle app (*in development*).
- Fish Migration Vision.
- Rolling out of the Fish Migration Vision and the Roadmap in Essex (to be led by the Essex Rivers Hub).
- Inclusion of the Roadmap project into the 'River restoration in London: A 20-year review' report.
- Creation of a StoryMap (submitted for the 2020 ArcGIS StoryMaps Competition for Sustainable Development Goals).
- Project promotion:
    - Presentation at 8th Annual IFM Specialist Conference,
    - Article in TEP's Talk of the Thames Spring/Summer edition 2018,
    - Article in the IFM FISH Magazine 130 Summer 2018,
    - Presentation at the 20th RRC Annual Network Conference 2019,
    - Presentation at the Essex Coastal Forum 2020,
    - Blog on Thames Estuary Partnership's website.
    - Article in the IFM FISH Magazine 138 Fall 2020.

8. Future project plans

The pandemic of 2020 delayed progress within the project. However, the Roadmap will continue to develop as lessons are learned from supporting the Essex Catchment Partnership as they start to use the Roadmap to deliver fish passage work on the ground. The Roadmap approach will be replicated on more London rivers as opportunities arise and further lessons learned from more urban catchments. Below are the objectives of the project from 2020 – 2022:

- Using the online platform, StoryMap and the completed hardcopy map as an education tool for members of the public to communicate habitat fragmentation and fish migration.
- Extending the study areas to include the entire length of migratory routes in each catchment.
- Inclusion of waterways as 'C-roads'.
- Extending the study area and inclusion of three more catchments (South Chiltrens, Kennet and Loddon) with Highways, A-roads, B-roads, 'C-roads' (Appendix 5.).
- Stakeholder and community engagement in a chosen London catchment(s):
    - 'Thames Catchment Community Eel Project' with Thames Rivers Trust (funded by Defra's Green Recovery Challenge Fund)
        - Focus on 5 rivers: River Pang, River Kennet, River Mole, River Brent and River Ravensbourne
        - Stakeholder and community engagement, and training
        - Use of River Obstacle app (Appendix 6.) – currently being finalised in partnership with the Rivers Trust, Zoological Society of London, the River Restoration Centre, the Wildlife Trust, the RECONNECT project (Ireland)
        - Implementation of the Roadmap Method including the Fish Migration Vision
        - Development of hardcopy map
- Using data from the Environment Agency's Fish & Ecology Data Survey website:
    - Collation and creation of Roadmap specific fish database in each river (addition of info box to the map to highlight key/priority species on each river),
    - Temporal analysis of fish survey data near eel/fish pass locations.
- Downstream river connectivity assessment.
- Inclusion of waterways as 'D-roads'.
- Historic data collection on barrier removal and pass installation to visualise waterway connectivity over time.
- Barrier assessment at those locations where data is needed and where extra stakeholder information was not available (use of River Obstacles app via citizen science).
- A pathway for linking into other local plans and strategies.
- Promotion of the Roadmap as a strategic approach nationally through the Coastal Partnerships Network, partnership with the Rivers Trust in the EMFF funded

Wholescape Approach to Marine Management (WAMM) linking Coastal Partnerships and Catchment Partnerships.

- Developing into a multi-level data integration project to work towards the UK Government's 25 Year Environment Plan (Figure 11).

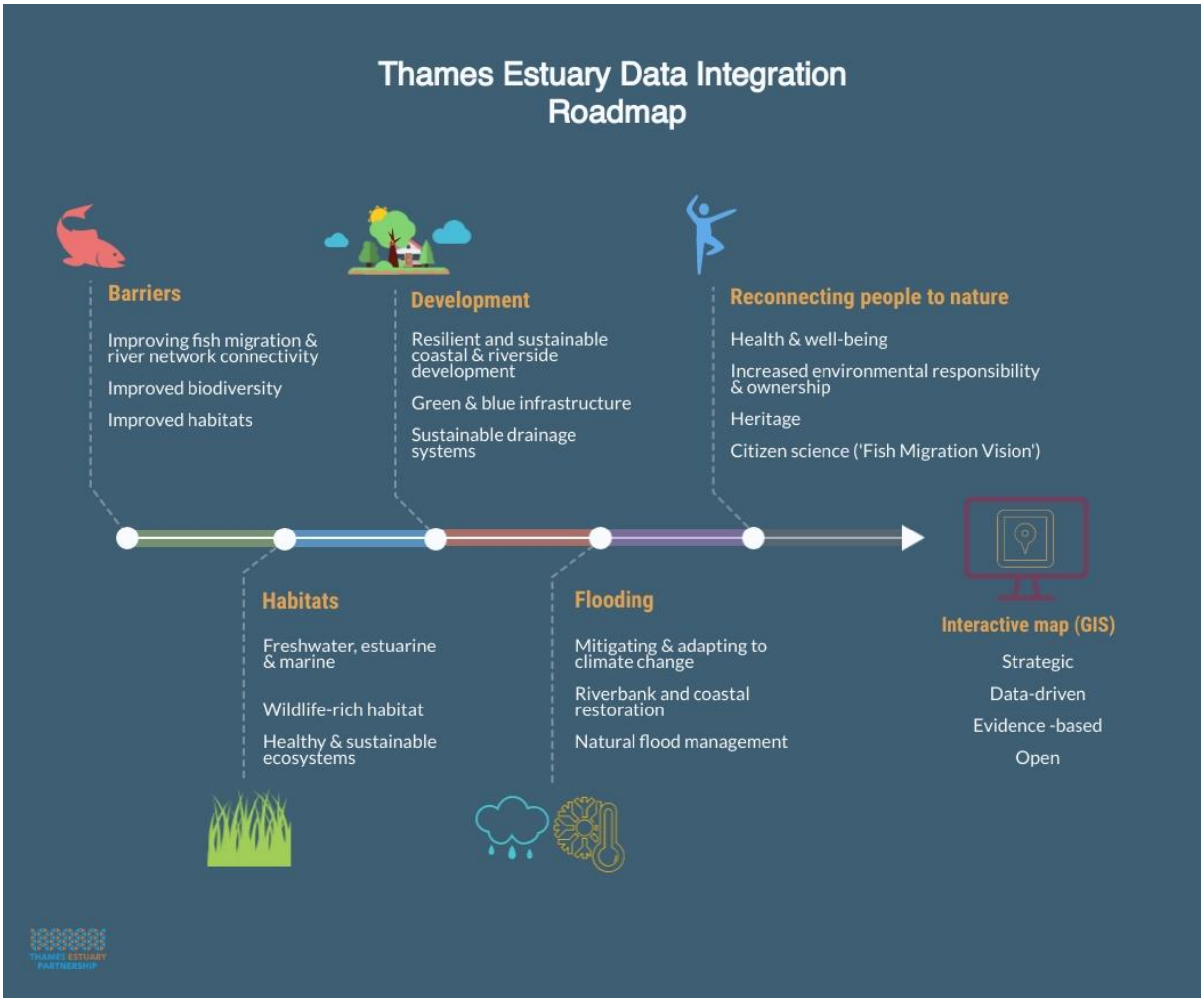
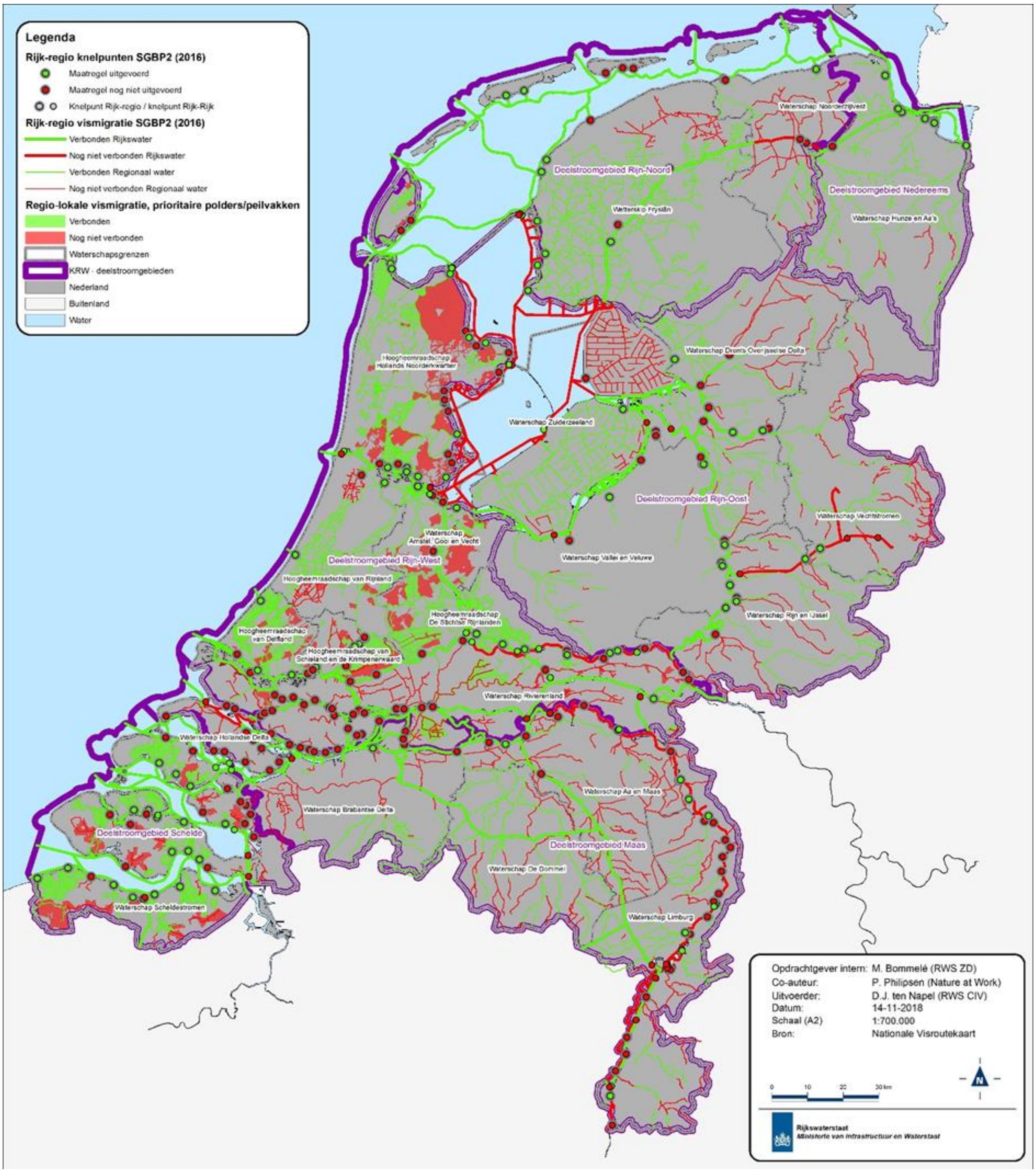


Figure 11: Infographic explaining the 'Thames Estuary Data Integration Roadmap'

Appendices

Appendix 1.



Roadmap for Fish Migration in the Rhine West Delta

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	13/07/2019	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	16/01/2018	None

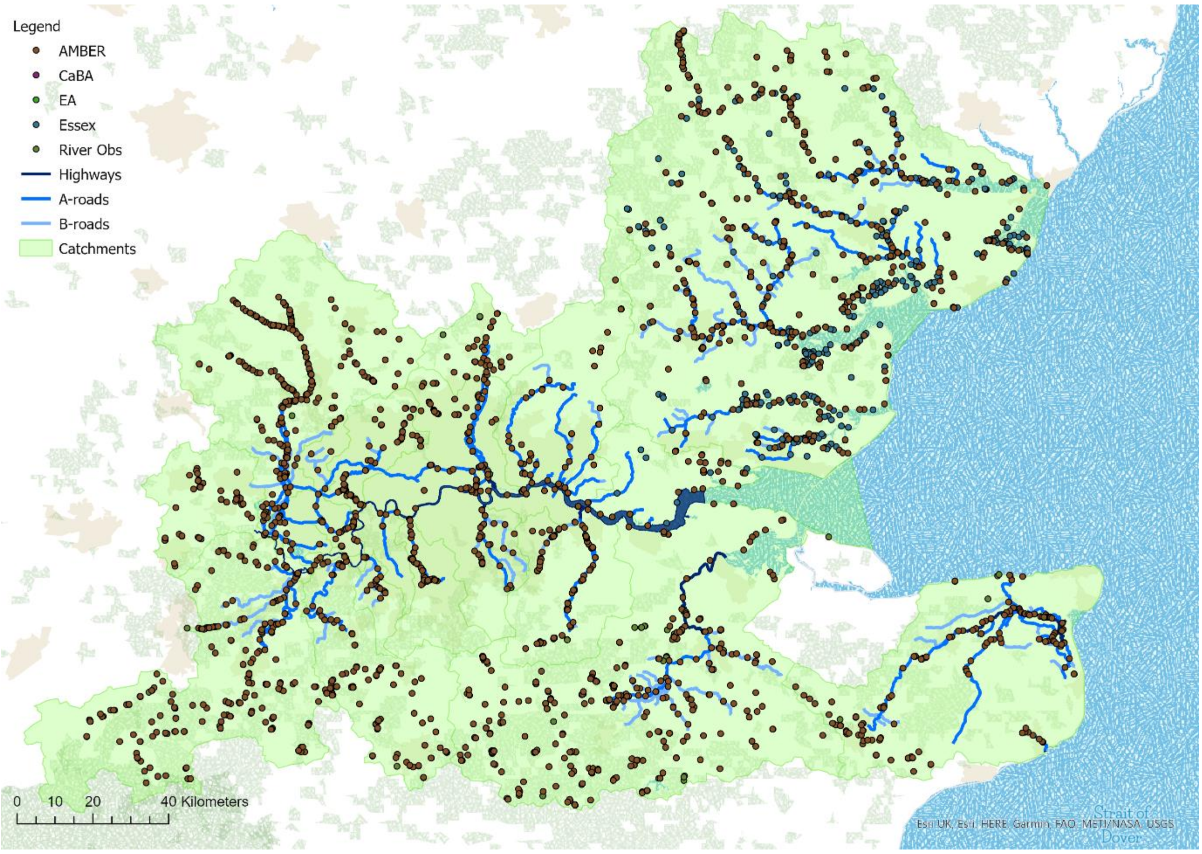
Data table showing the sources of data used for the Roadmap

OTHER							
Type of data	**Project acronym**	**Name**	**Area covered**	**Data collection method**	**Source**	**Date**	**Note**
Shapefile	N/A	OS Open Rivers	20 catchments	N/A	Ordiance Survey website	01/05/2020	N/A
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
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
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	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.

Data table showing the sources of data used for the Roadmap

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 the all the barrier data 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.

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

Buffer	Number of barriers
200m	1221
150m	1194
100m	1173
75m	1155
50m	1127

Appendix 4.

Fish Migration Vision

Essex Combined Catchment Partnership

Re-opening the Essex catchment for migratory fish, restoring healthy, connected and climate resilient rivers

Over many centuries, we have shaped and harnessed our rivers to meet our needs. From water mills and navigation to land drainage and water supply, we have modified our river channels and built structures that hold back or divert water. We have grown to realise that these structures can prevent fish and eels from moving freely in our rivers. It is important for species to reproduce and migrate to maintain healthy populations that are not isolated.

We want to work with others to remove redundant structures, modify those that need to stay in place, or bypass them to open up the migration highways throughout Essex.

Reimagining Our Rivers – key messages

- **Restoring our rivers from straight channels to a more natural river corridor.** For many, a manmade channel is seen as the 'real river' but actually a 'stream' or 'back channel' is often the real river. If we took the straight walls of the channel away it would revert to what it was. *We will build in solutions to re-connect the real river as it meanders and restore it to a state as natural as possible.*
- **As natural as possible is best** – not only because the river functions better and looks nicer, but because using natural solutions often means very little maintenance. *We will raise funds for the right solution, not just the cheapest.*
- **Natural water flows for resilience in wet and dry weather.** A natural river corridor requires little water management. In the face of a climate crisis, Essex will experience periods of dry weather and drinking water will be a priority. *We will restore or enhance rivers to function in wet and dry weather.*
- **Understanding our rivers.** Rivers do not flood, they follow a seasonal ebb and flow: in winter swelling to fill the river and floodplain, and in summer shrinking to a smaller river channel. *We will communicate with the wider community to improve the understanding of how a river runs.*
- **Partnership work is key.** No one organisation can achieve what needs to be done alone. Partnerships can pull in expertise and funds from across Government, charity and private sources and deliver more with less. *We will work in partnership to deliver fully connected rivers.*
- **Working with communities**. Change can be challenging, particularly for those who live nearby. *We will work with the community to build their understanding and needs into any plans.*

Why now?

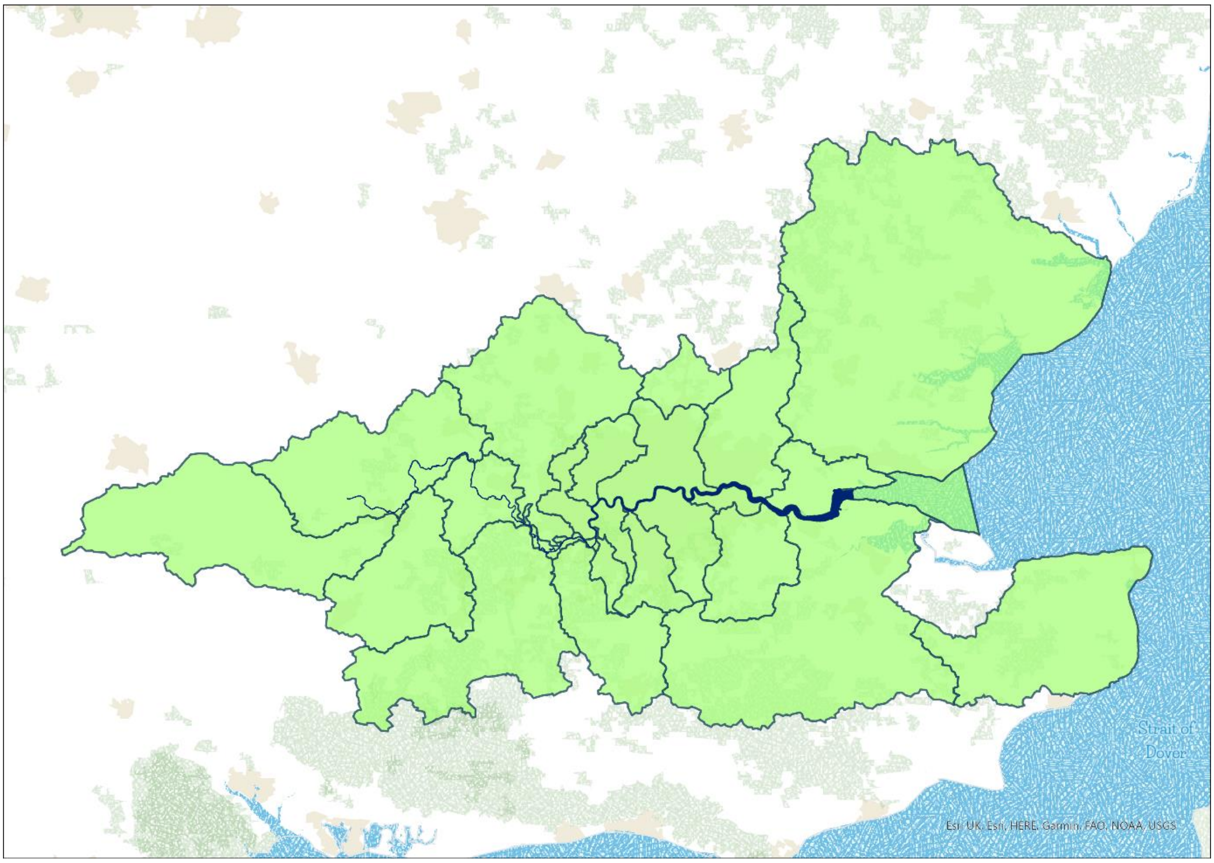
Essex is set to see a large amount of development over next 10-20 years. To achieve sustainability in the face of the climate crisis, it is vital to work with natural processes and ensure that multiple benefits to the environment and to society are realised through economic development. The Catchment Partnership Plan is the key document for this and is linked into local initiatives, conservation strategies and County level development and regeneration plans.

The Fish Migration Roadmap provides an excellent opportunity to highlight where Net Gain can be achieved and maximised by developers and Local Authorities through barrier passage and habitat restoration work. With Green Finance becoming more accessible, the Vision can help to accelerate river restoration and climate resilience through blended private and public financial partnerships, including Net Gain and Flood Asset Management investments.

Why is it important?

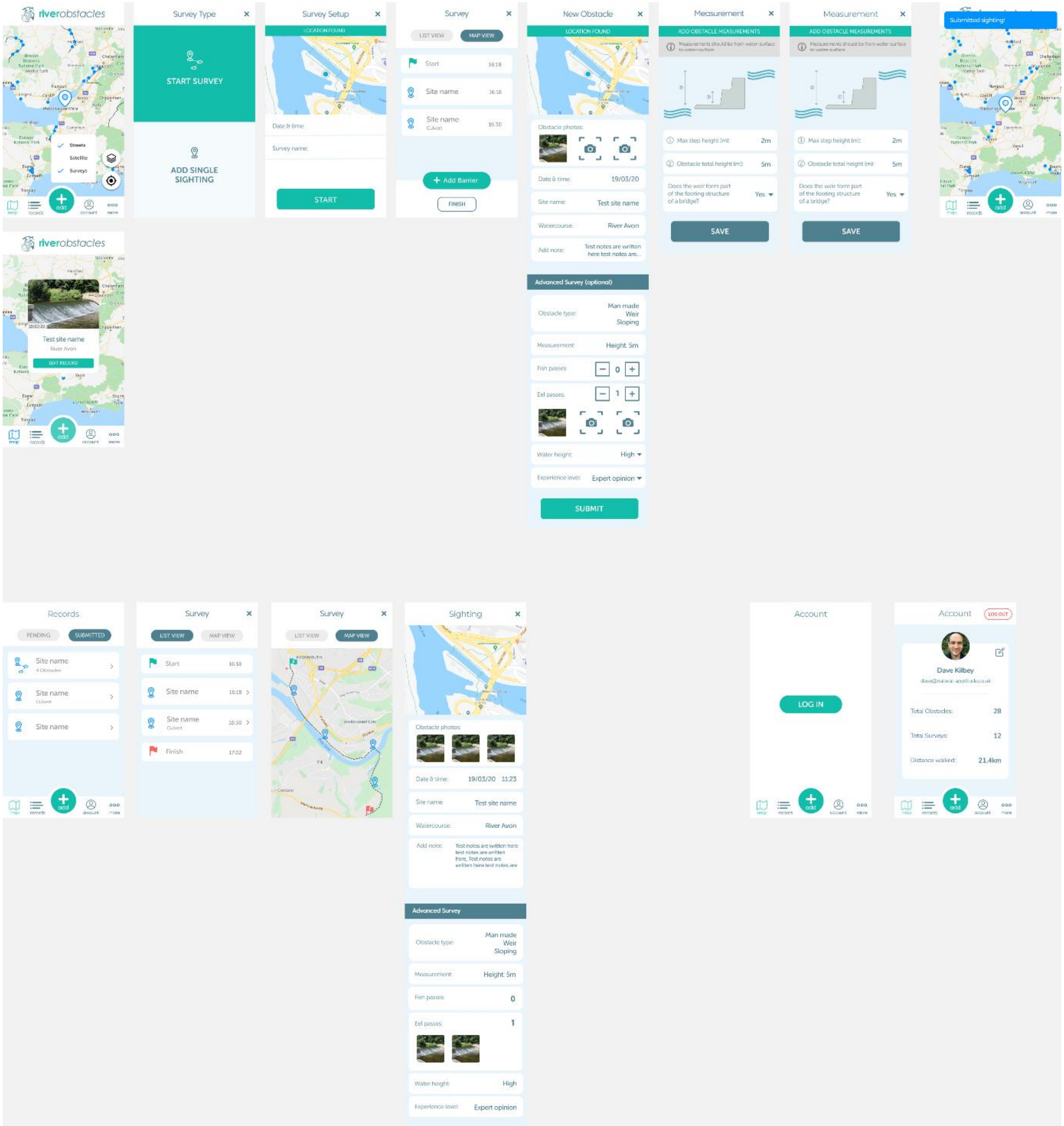
- **People**: access to nature, health and wellbeing, education and recreation
- **Environment**: connected land and seascape for healthy wildlife populations and climate resilience
- **Economy**: working with natural solutions brings the best return on investment in the long term and makes better places for work and life

Appendix 5.



Extent of project area with the integartion of three more catcments as part of the Thames Catchment Community Eel Project

Appendix 6.



Screenshot of the updated River Obstacle app

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