Improving Fish Migration in the Crane Catchment

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UK Conservation Programme

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1. Background

1.1 The River Crane Catchment

The Crane catchment is situated in west London and is a lowland catchment that drains an area of approximately 127km^2. The catchment is largely urban yet provides a belt of semi-natural habitat, with the river originating from the low hills west of Harrow as the Yeading Brook West before flowing south where it joins the Yeading Brook East. The river then continues to flow south through Hillingdon and becomes the River Crane before it reaches Cranford Park (Deane and Tricklebank, 2018).

The River Crane then passes through Hounslow and Hillingdon where it is joined at North Feltham by the artificial waterway, the Duke of Northumberland's River (DNR). This connection links the Crane Valley system to the Colne Valley to its west. The River Crane then continues its path flowing south-east and east through Richmond (with a tidal section stretching for 1km) before reaching its confluence with the River Thames in Isleworth. At Kneller Gardens, the DNR splits off and flows north-east to supply water to the ornamental ponds at Syon Park where sluices control its flow into the park and into the River Thames (LWT, 2013, The Crane Valley Partnership, 2019).

The Longford River, another artificial waterway in the catchment, diverts water from the River Colne to Bushy Park and Hampton Court Palace where it reaches the River Thames above Teddington Lock. In the northern reaches of the Longford, the river runs side by side with the upper DNR (UDNR) around the perimeter of Heathrow Airport before these rivers diverge after the Two Bridges at Hatton Road (Talling, 2011).

Over the last 300 years, much of the catchment and large sections of the rivers have been modified for industrial purposes such as Heathrow Airport, roads including the M4 and M40, as well as for mainline westbound rail services. Water from rivers in the catchment was also historically used to power a significant number of mills for processes such as flour milling, copper production, paper making and more famously gunpowder. Remains of these mill structures can be found in places such as Donkey Woods, Brazil Mill Woods and in Crane Park, with some dating back to the 16th Century (FORCE, 2015). Prior to the modifications made to facilitate these developments, the Crane would have looked very different to its current state, once a meandering river with good flows and depths. Now, the Crane has been artificially straightened across much of its course, artificially widened, lined and reinforced - all of which limits the river's natural function. In addition, there are a number of operational and redundant structures across the catchment such as weirs, sluices, mill races and culverts which have the potential to act as barriers to the movement and migration of fish between habitats, and throughout the catchment (LWT, 2013).

1.2 Habitat connectivity

Fish in rivers and streams depend on connectivity along longitudinal (upstream-downstream), lateral (connectivity to the floodplain), vertical (below the streambed), and temporal (yearly, seasonal, generational) dimensions. These drive the migratory patterns of fish that shape their ecology (Cowx and Welcomme,1998). To complete their lifecycle and survive in aquatic environments, many species of fish require chronological access to a range of habitats to provide for life stages and facilitate key life functions such as feeding and spawning (Roy and Le Pichon, 2017). Coarse fish species such as barbel, dace, minnow, chub, bullhead, stone loach and gudgeon typically spawn in fast flowing, shallow beds of clean (silt-free) gravel or scatter their eggs on sand or under rocks usually found in riffles and runs. Often, coarse fish fry can only tolerate slower flows and therefore favour the shallow, vegetated channel margins and backwaters which warm quickly in the summer and can support a diversity of suitable food and provide refuge from predators. In contrast, the larger adult fish often migrate to deeper, more sheltered areas of the channel such as pools and glides or between habitats in search of feeding, spawning and refuge habitats (Pike, 2014, Deacon, 2020 and Everard, 2015).

Variation of flow dynamics, bed morphology, vegetation and temperature create dynamic mosaics of habitats for fish and in turn help to maintain heterogeneity of complementary habitats for fish. The presence of marginal and partially connected backwater habitats, areas connected to the main river but with reduced velocities and shallower depths, can also be very valuable in providing areas in which fish can take refuge during short-term pollution event and flooding or high flow periods (Courtneidge, 2020 and Slipke, 2005).

The way in which these functional habitats are configured affects the ability of fish to disperse and migrate between them, with connectivity having a strong impact on the diversity of species, community composition and fish population dynamics in different areas. Reductions in connectivity among individual populations may reduce fitness and weaken the ability of fish to resist catastrophic change (Fullerton *et al*., 2010). Artificial river and stream alterations such as weirs, sluices, dams, culverts and channelisation diminish the natural connectivity of the river from its flood-plain, decrease sinuosity, homogenise river profiles and limit or completely impair the movement and migration of species (Roy and Le Pichon, 2017).

To tackle this issue and subsequent biodiversity decline, it is important for conservation and management planners to consider not only the removal (or improvement) of potential barriers to migration, but also to focus on river restoration aimed at the understanding of species habitat preferences. Furthermore, particular focus should be placed on reducing habitat fragmentation to connect areas of habitat suitable for facilitating the different life stage requirements of a range of fish species (Bernhardt and Palmer, 2007, Merenlender and Matella, 2013).

1.3 Fish population in the Crane Rivers

Environment Agency (EA) fish data was analysed to gain an understanding of what species are living in the catchment at present and to better understand whether fish population structure and diversity differed in the past, particularly prior to major pollution events in the catchment. Analysis of these data was also used to determine the absence of key species that could typically be expected within similar river catchments to inform the management and improvement of barriers structures and habitat to facilitate the movement of these absent species into the Crane catchment rivers. The ZSL Habitats and Biodiversity in the Crane Catchment Report (2022) explores the trends in these data in more detail and statistical analyses of EA fish monitoring data is presented where possible.

Environment Agency electric fishing data shows a total of 17 species of fish caught between 2000-2018 in the Crane catchment over a total of 12 monitoring sites. Some of the most common species caught in the most recent data (2016-2018) include: stone loach, minnow, bullhead, 3-spined stickleback, roach, gudgeon and chub. Fish species recorded within the upper estuary and tidal Crane include flounder, sea trout, European eel, sea bass, European smelt, thin lipped grey mullet and common goby (FORCE, 2018).

It should be noted that although electric fishing is the sampling method of choice in smaller rivers with the potential to be very efficient under optimal conditions, its effectiveness for calculating accurate population estimates for eel is often recognised as being less efficient. Eels can be under-represented in electric fishing catches due to this method being size selective for eel with catch efficiency being lower for smaller eel (Knights *et al*., 2001, Baldwin and Aprahamian, 2012). See Appendix 2 for information about general behaviours and habitat preferences of fish species identified within the Crane catchment or those that could be expected to enter the system should a suitable environment be made available.

Fish populations within the catchment have been significantly affected by pollution in the last decade and are reflected within the EA electric fishing data. Two major pollution events have taken place in the Crane Catchment, the first in 2011, followed by another in 2013. The 2011 incident was a direct result of infrastructure failure during routine maintenance by Thames Water at an outfall where the A4 road crosses the Crane River in Cranford. Sewage was discharged into the river, and it is estimated that during the incident, all river invertebrates and over 10,000 fish were killed. Evidence collected by the Environment Agency showed this pollution event devastated the aquatic life on the Crane for 20km downstream of the source, with different ages and species of fish being impacted, including mature eels, pike and carp. The pollution event in 2013 occurred due to work at a site in Cranford resulting in the fracturing of a pipe that was transporting sewage sludge between two sewage works, causing significant fish kills but with invertebrate communities not impacted as badly as they were during the previous event.

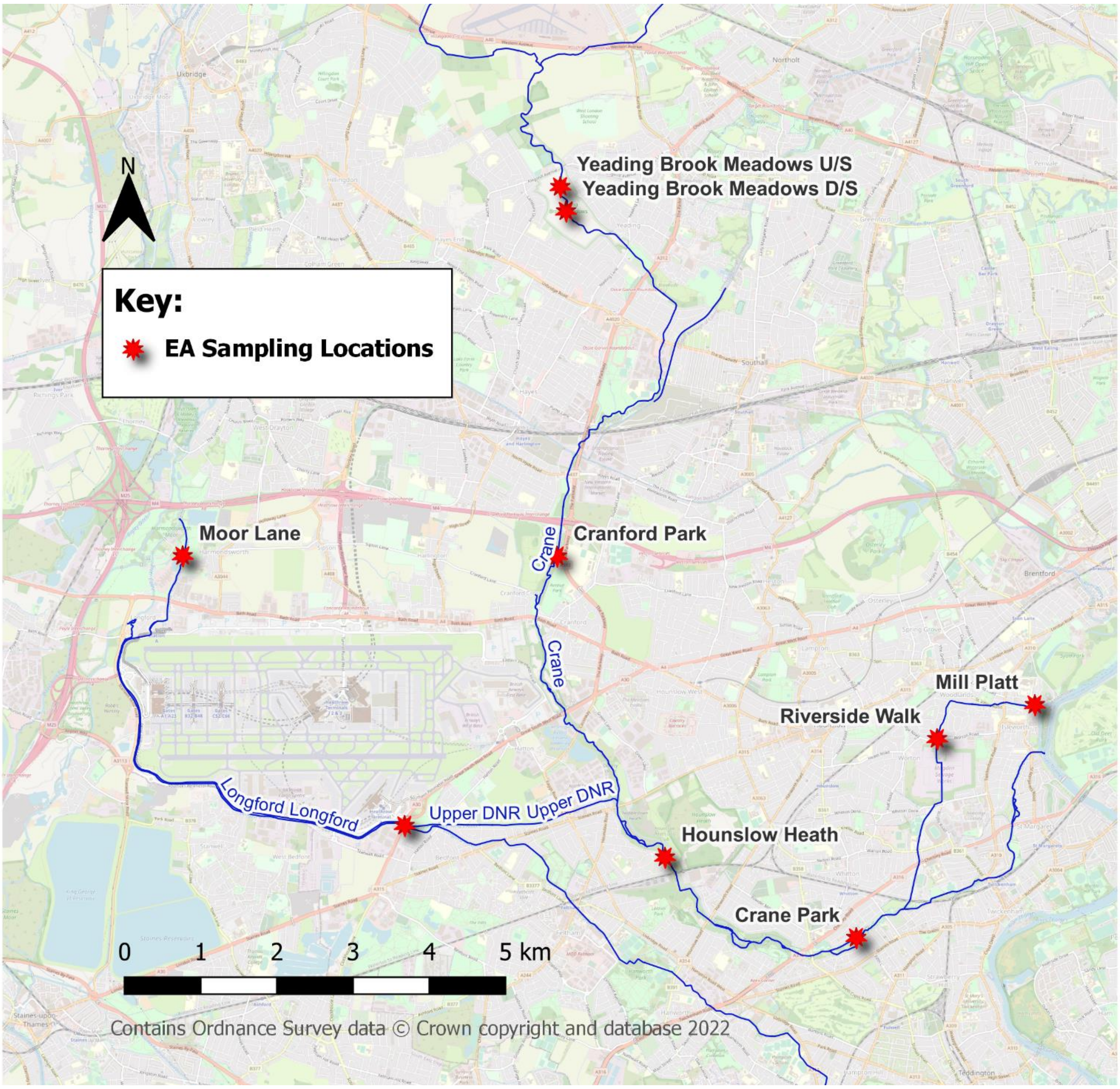


Figure 4.5: Map of Environment Agency electric fishing sampling sites.

Looking at the area just north of the Crane catchment boundary, (Moor Lane), where the Upper DNR splits from its source at the River Colne, the most recent EA electric fishing survey data (2017) in the Upper DNR showed predominantly roach and minnow with some gudgeon, chub, bleak, and pike recorded. In previous years when this site was surveyed (2000, 2005 and 2010), fewer fish were caught per m^2, however data shows the presence of species including bullhead, stone loach, tench, perch and European eel (see Figure 4.6). This aligns with ZSL (2022) analysis of fish diversity which shows an overall average decline in diversity index values since 2000.

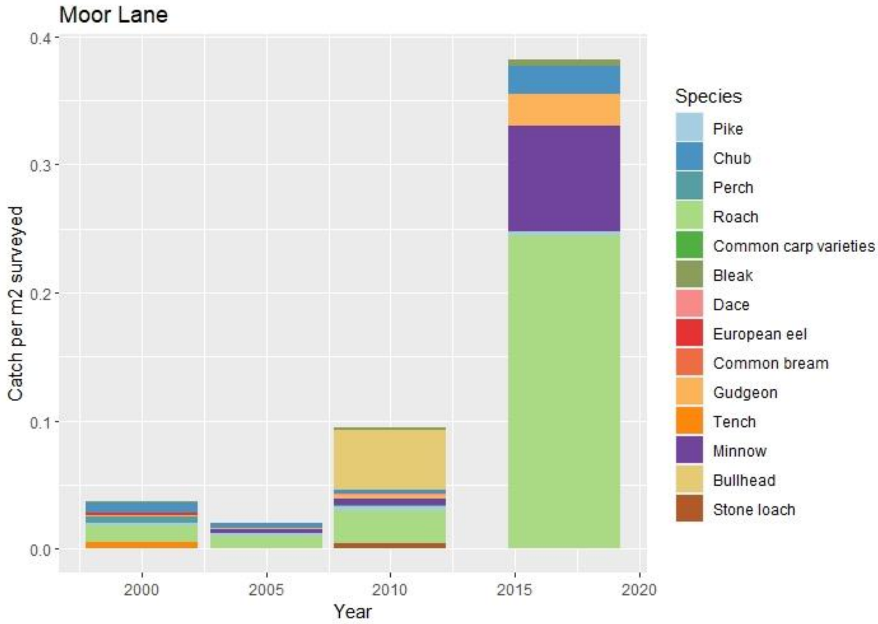


Figure 4.6: Electric fishing catch per m² of area surveyed across monitoring years at Moor Lane sampling site.

Overall, the Hatton Road site shows consistently lower fish diversity than the Moor Lane site that is further upstream on the Upper DNR. Most recent EA Hatton Road 2016 site data shows that the middle reaches of the Upper DNR predominantly contain roach with the presence of tench, perch, European eel and chub also recorded. As with the upper reaches (Moor Lane), this data differs from previous years, with 2010 data for example showing less fish caught per m², no presence of roach, however with much larger catch diversity and additional species such as minnow, stone loach, pike, bullhead and 3-spined stickleback being recorded (see Figure 4.7). This is explored in more detail in the ZSL (2022) report that highlights most recent sampling years' diversity index scores as being the lowest recorded for the two Upper DNR sites.

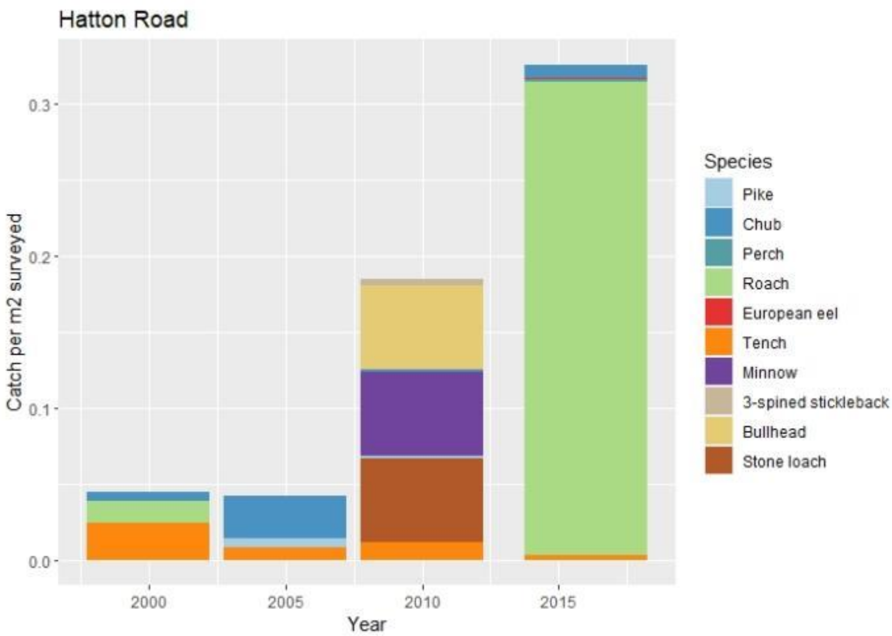


Figure 4.7: Electric fishing catch per m² of area surveyed across monitoring years at Hatton Road sampling site.

EA data from the two sites on the Yeading Brook (Yeading Meadows US and DS) was only collected in 2013 and therefore, due to a lack of monitoring statistical analysis was not carried out on these data in the ZSL (2022) report. However, for the purpose of this investigation, species composition was observed and result of the 2013 survey can be seen to show populations dominated by smaller species, 3-spined stickleback and minnow, with the DS site showing presence of a small number of gudgeon.

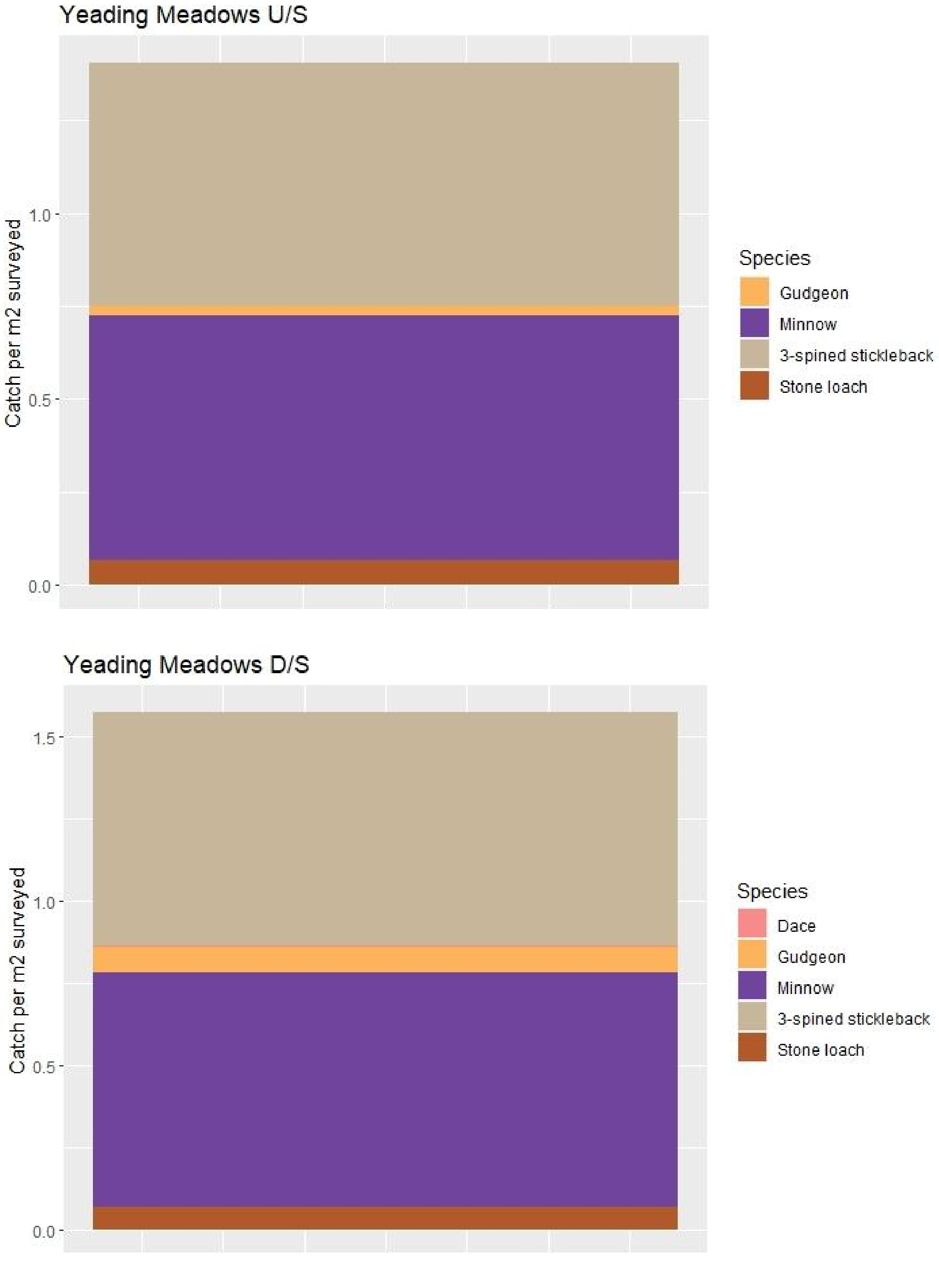


Figure 4.8: Electric fishing catch per m^2 of area surveyed in 2013 at Yeading Brook Meadows sampling sites.

Interestingly, over time, significant changes in species composition at the Cranford Park monitoring site can be seen in the River Crane. Lower abundances were recorded in 2000, however fish diversity was at its highest with roach, perch, gudgeon, dace and chub recoded. Following this, data for 2010 and 2015 showed an increase in catch per m^2 but a decline in diversity and a shift to fish populations dominated by minnow, with the presence of other small species such as stone loach and 3-spined stickleback being recorded. Most recent data (2016) at this site shows not only a decline in catch per m^2 to levels more similar to 2000 data, but also the absence of the previously dominant species minnow and a change to populations dominated by roach, dace and chub which had not been recorded at this site since 2000.

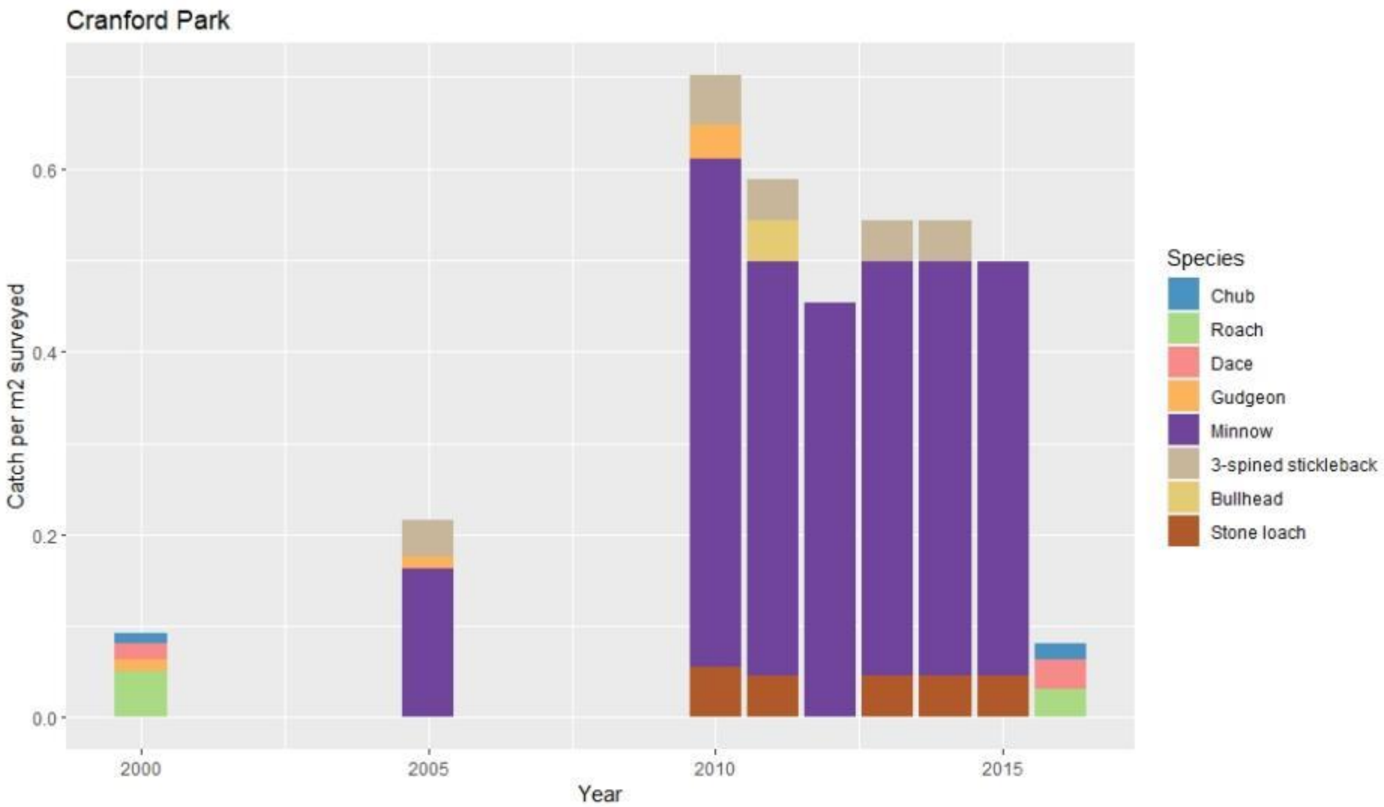


Figure 4.9: Electric fishing catch per m^2 of area surveyed across monitoring years at Cranford Park sampling site.

Further downstream on the River Crane, at Crane Park, species composition can be seen to shift following two large pollution events taking place upstream of this monitoring site in 2011 and 2013. Data from years following the pollution events show populations comprising of mainly smaller species such as 3-spined stickleback, bullhead and minnow. In surveys prior to these pollution events (pre-2010), populations were more diverse and made up of larger species such as chub, dace, roach and gudgeon. Very low densities of fish were recorded in the years that the pollution events took place. The statistical trends in diversity are explored in more detail in the ZSL (2022) report.

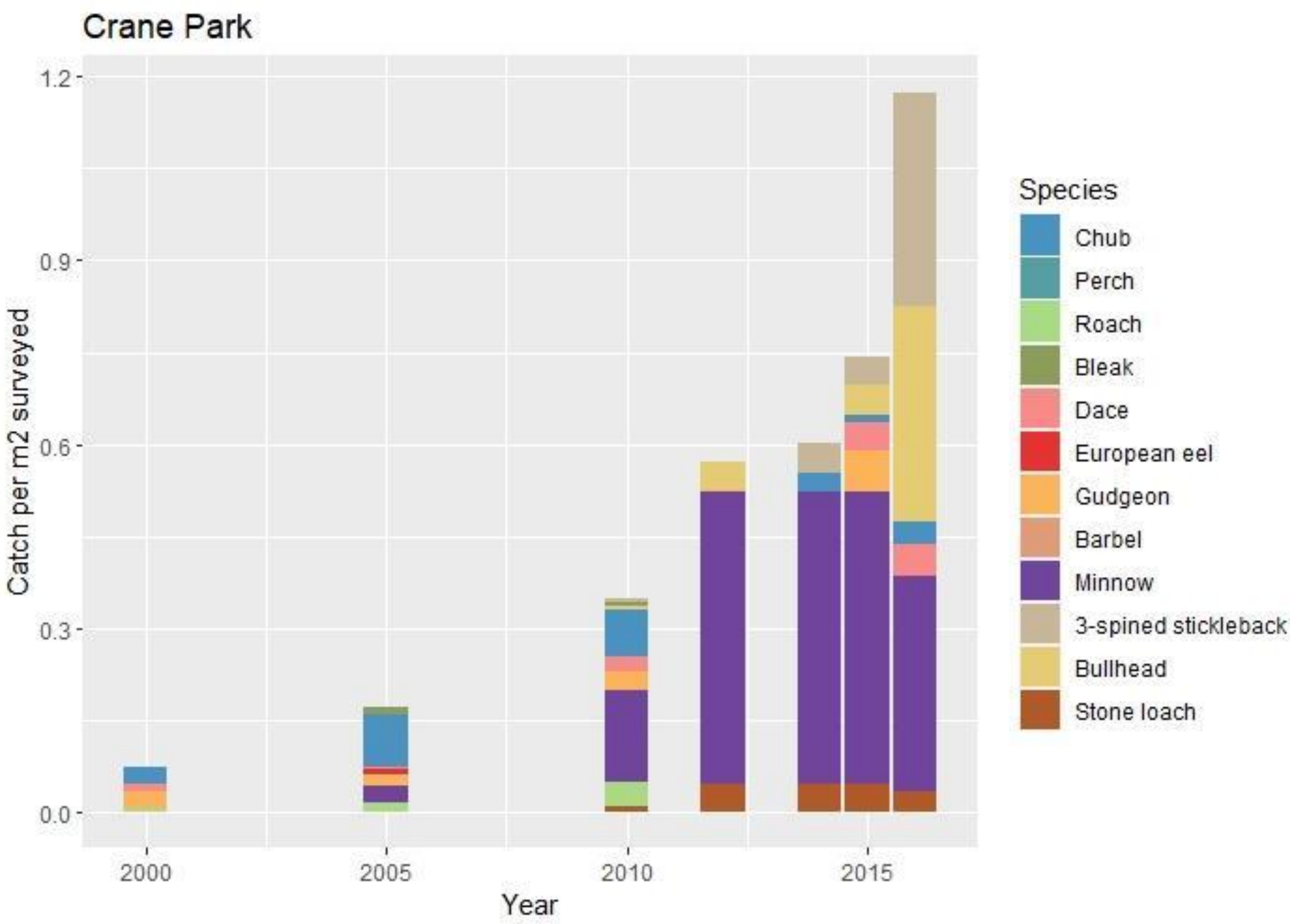


Figure 4.10: Electric fishing catch per m^2 of area surveyed across monitoring years at Crane Park sampling site.

Most recent data collected from the Riverside Walk site (2016) on the lower DNR, show populations dominated by 3-spined stickleback and minnow. In 2016, unlike previous survey years (2005 and 2010) and following the installation of eel passes to two structures on the lower DNR (at Kidd's Mill and Mogden Sewage Treatment Works), the presence of small numbers of European eel were recorded. Chub and gudgeon were also caught in small numbers at the Riverside walk site in 2016. In previous survey years, bullhead and stone loach presence was recorded, however unlike further upstream, even prior to the two large pollution events, none of the larger fish species were recorded at this site.

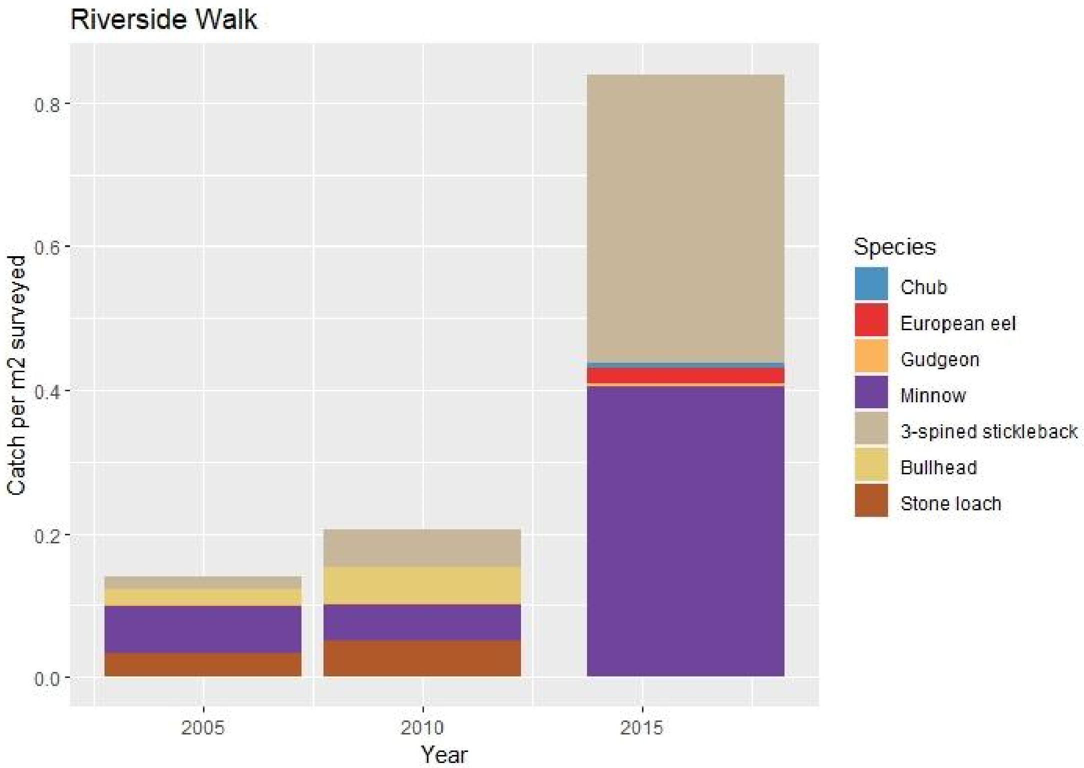


Figure 4.11: Electric fishing catch per m^2 of area surveyed across monitoring years at Riverside Walk sampling site.

Overall, across all species and sites, there is significant variation in the number of individuals caught during sampling, with the ZSL (2022) report demonstrating that the same trend can be seen in species length distributions. This suggests that fish populations within the catchment are unstable. Monitoring in 2005 for example across the Crane catchment shows relatively low catches and diversity, while 2016 monitoring shows generally higher catches and an increase in species diversity despite almost complete decimation of fish populations following the major pollution events in 2011 and 2013. This fluctuation between catch, length distribution and population structure could be indicative of low stability and low resilience of fish populations to factors such as spate flows and lack of refuge habitats, pollution events, and unbalanced predator prey relationships due to poor habitat (limited cover). These factors are often intensified by the alteration of natural flow regimes, poor longitudinal connectivity and the lack of functional habitat for species to complete their lifecycles.

2. Aims of this study

1. Review and update the London Wildlife Trust (LWT) 2016 report 'An Assessment of Barriers to Fish Passage in the Crane River Catchment'.
2. Assess and map barriers to the upstream migration of fish in the Crane Catchment rivers not within the scope of the 2016 LWT report. Analyse findings and feed geo-referenced data into the project 'StoryMap'.
3. Describe fish diversity and biomass in the Crane catchment rivers.
4. Produce preliminary evaluations of the approaches to fish migration for the Crane system and Longford.

3. Methods

3.1 Desk-based research

A review was carried out of the LWT 2016 Assessment of Barriers to Fish Passage in the Crane River Catchment to help identify any gaps, key areas of concern, barriers that have been improved or removed and next steps for this investigation. Information on changes made to barriers identified by the LWT (2016) report and other structures not covered by the study area of the report was obtained through a mixture of online sources and personal communications with a number of stakeholders in the SWC project.

Methods for the scoring of the passability of barriers were reviewed and adapted to cover the key aspects of both the Scotland & Northern Ireland Forum for Environmental Research (SNIFFER, 2010) Coarse Resolution Rapid-assessment Methodology and the Zoological Society London's Eel Barrier Assessment Tool (EBAT). These were used to ensure that structure assessments could be applied fish passage but also used to assess passability to European Eel (more information is provided in Section 3.2).

3.2 Field-based research

Following the initial desk-based research, sections of the catchment that had not been surveyed for barriers to fish and eel movement were identified and surveyed. This included the Longford River (that was not surveyed as part of this investigation, see Appendix 1) and the Upper Duke of Northumberland's River from its offtake from the River Colne to Baber Bridge where it joins the Crane.

EpiCollect was used to log data in line with the River Obstacles App and ObstacEELS methodology. Measurements of barriers were based on bankside estimations. Where applicable, the following parameters were recorded for each barrier to carry out an assessment of the passability of structures to coarse fish and eels:

- **Type of structure** (e.g. Sluice, weir (vertical, sloping, stepped), culvert (perched or not perched), ford, flap gate (side hung or top hung) etc.
- Whether the barrier is **natural or man-made**
- The presence of **multiple barriers**
- **Owner and purpose** of the barrier (e.g. flow control)
- **Structure material** (e.g. concrete, wood, metal, rock etc.)
- **Barrier dimensions** (m): Total height, maximum step height, slope shape, slope length, head loss (hydraulic head), width, length, gap dimensions.
- **Water depth** over the crest of the structure (m) and immediately downstream of the structure.
- **Width** – Total wetted width at the crest of the structure and immediately downstream of the structure.
- **Presence of limiting or damaging features** (e.g. lip at base of structure, debris blockages, tall vertical drops etc.)
- **Turbidity** associated with the structure.
- **Approximate water velocity.**
- Presence of a continuous path of **crawling media**. Crawling media is a wetted rough substrate (such as algae, moss, other vegetation, roughened rock, decaying wood, etc.) that eels can climb or crawl across. This crawling media must be uninterrupted across the structure's length (downstream to upstream).
- The presence of **fish or eel passes** installed at the structure.

Images were taken of each structure as well as other key details such as the GPS location, date, time, weather conditions and relevant additional details were recorded. Based on this information, fish passability scores and EBAT scores were calculated where applicable.

Surveys were carried out by ZSL staff with assistance from Historic Royal Palaces and Heathrow Biodiversity and Conservation Team staff in areas of land with private or restricted access.

Culverts and trash screens, which can also impact fish migration, were also recorded. The methods for scoring passability of these structures is explained below.

<u>Culverts:</u>

As with the LWT (2016) report, culverts with physical attributes that do not obstruct the dimensions of the river channel were assessed based on water depth, water velocity and length. The SNIFFER Coarse Resolution Rapid-assessment Methodology states that for upstream migration, barriers are passable for cyprinids if water depth is

>10cm throughout, and velocity is <1m/s. For juvenile eels, and if no crawling media is present, water depth should be >5cm throughout and velocity <0.3m/s. Therefore, if depth and flow was sufficient, the culvert was scored as 'No Impact', and if depth or flow was limiting the culvert was scored as 'Impassable'.

The LWT (2016) report methodology was followed to account for culvert length and the negative impact that this can have on upstream migration of fish. Culverts with lengths <50m were scored based only on their depth and flow while those with lengths >50m were identified as having the potential to present a barrier and were scored as 'Low Impact 'structures.

<u>Trash Screens:</u>

SEPA (2008) recommends a bar spacing of at least 230mm to avoid negative effects on fish migration. CIRIA (2019) state that a minimum gap size between screen bars of 100mm is suitable for coarse fish such as roach, dace, chub and species <250mm in length. CIRIA (2019) notes that gap sizes of between 100mm and 200mm are required for larger coarse fish species (>250mm length), and species such as brown trout, sea trout and salmon >500mm. Therefore, trash screens with gap sizes between bars of ≥100mm were scored as 'Potential Low Impact 'barriers and those with gap sizes <100mm were scored as 'Potential High Impact 'barriers.

Fish passability scoring range:

Fish passability score range	
No impact	Not an obstacle to the upstream migration of fish. Does not present a significant impediment to coarse fish and the majority of the population of the target species should be able to pass during the majority of the period of migration/movement.
Partial Low Impact	A partial, low impact structure that represents a significant impediment to the target species, but most of the population will pass eventually; or the obstacle is passable for a significant proportion of the time.
Partial High Impact	A partial high impact obstacle is a structure that represents a significant impediment to target fish species but that some of the population will be able to pass eventually; or the obstacle is impassable for a significant amount of time.
Impassable	A complete barrier to upstream fish movement/migration. A structure that cannot be passed by coarse fish species.

Eel Barrier Assessment Tool scoring range:

Eel Barrier Assessment Tool (EBAT) score range	
10-15	Unlikely to represent a major barrier to upstream migration
5-9	Partial impact, obstacle may impede passage
<5	Likely to be a complete obstacle to eels migrating upstream

4. Results of desk-based investigation

4.1 Improvements to fish and eel passage since 2016

Improvement 1

Figure 4.1: Image of improvements made to Mereway Barrier 1.

Structure Name: Mereway Barrier 1, ID: 192274 (LWT, 2016)

Location: (GPS) 51.448698, -0.33983994

Description: Concrete sloping weir

LWT 2016 Priority for action: Medium

Date of improvements: Completed June 2020

Improvements: Installation of baffles and eel tiles

Improvement 2

Figure 4.2: Image of Mereway Barrier 4 taken prior to improvement works commencing (10/03/2022).

Structure Name: Mereway Barrier 4, ID: 192278 (LWT, 2016)

Location: (GPS) 51.446956, -0.34702656

Description: Large vertical tilting weir made from pre-cast concrete and metal. The structure is responsible for the flow split between the Lower Crane and Duke of Northumberland's River

LWT 2016 Priority for action: Medium

Date of improvements: Work due to start Spring 2022 with an estimated completion in Autumn 2022.

Improvements: Management of the weir has changed to ensure that there is continuous flow in the lower Crane. In addition, the Environment Agency are in the process of adding a new 50m channel incorporating a spill way and Larinier fish pass to this structure to link the lower Crane to the upstream river system for the first time.

Improvement 3

Figure 4.3: Image of improvement works (fish pass installation) being carried out by FishTek at Mogden Barrier 3. Photo Credit: Rob Gray

Structure Name: Mogden Barrier 3, ID: 262984 (LWT, 2016)

Location: (GPS) 51.463991, -0.34024958

Description: Sloping weir made from poured concrete and steel at the Mogden Treatment Sewage Works. Used as Environment Agency Telemetry Station. An eel pass is present at this site.

LWT 2016 Priority for action: High

Date of improvements: Completed November 2021

Improvements: Fish pass installed by Fishtek (original eel pass still in place). Baffles being installed in a chevron shape.

5. Results of field assessment barrier survey of the Upper Duke of Northumberland's River

5.1 Structures assessed

Approximately 9.3km of river were surveyed for this report, identifying 13 structures overall. Of these, five structures received an EBAT score of <10, indicating that they have the potential to be either a partial or complete barrier to upstream eel migration. Ten of the structures identified received scores that would indicate partial low, high, or complete impassability to fish. The locations of all structures surveyed can be seen below in Figure 5.1 with their scorings listed in Table 5.1.

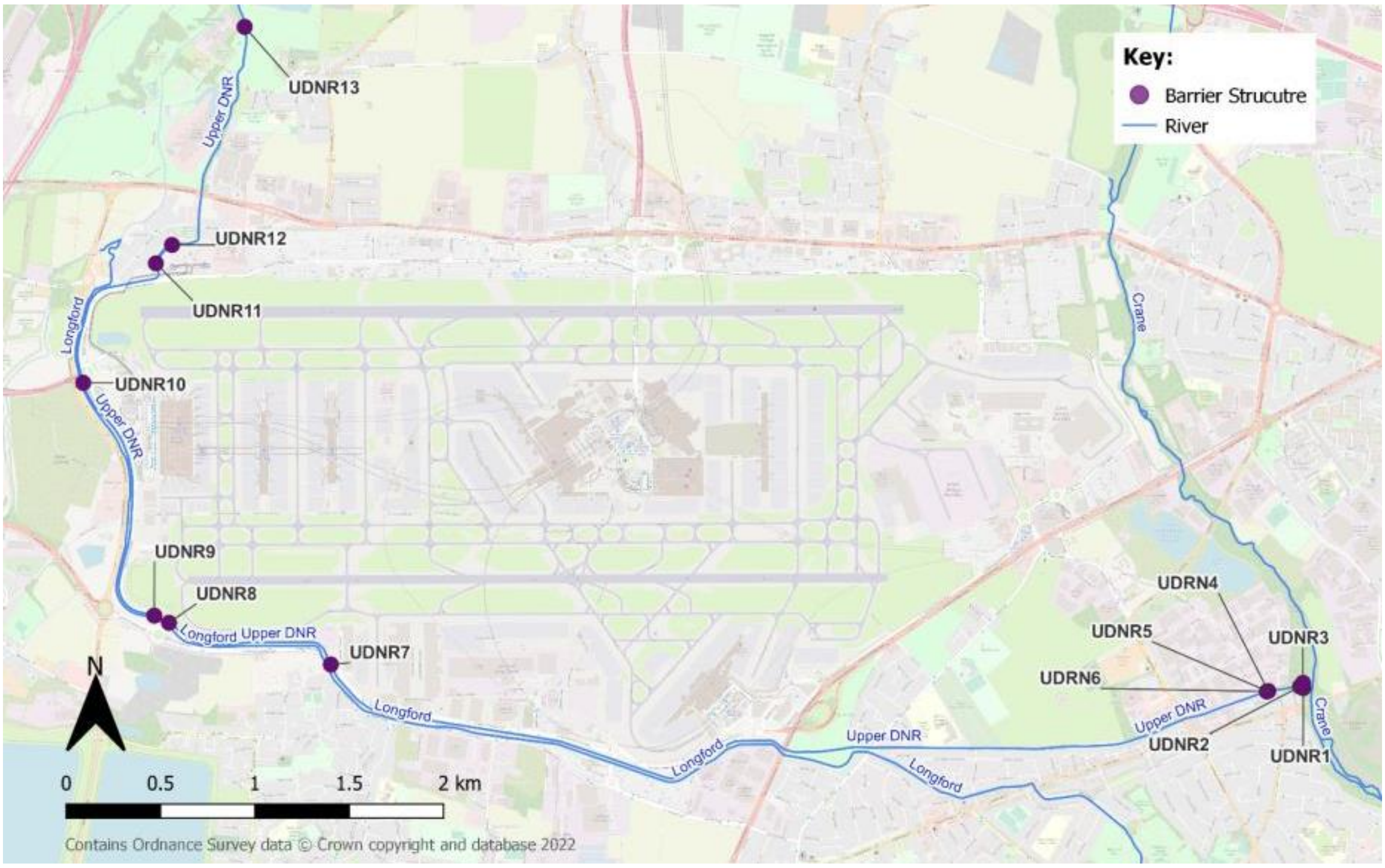
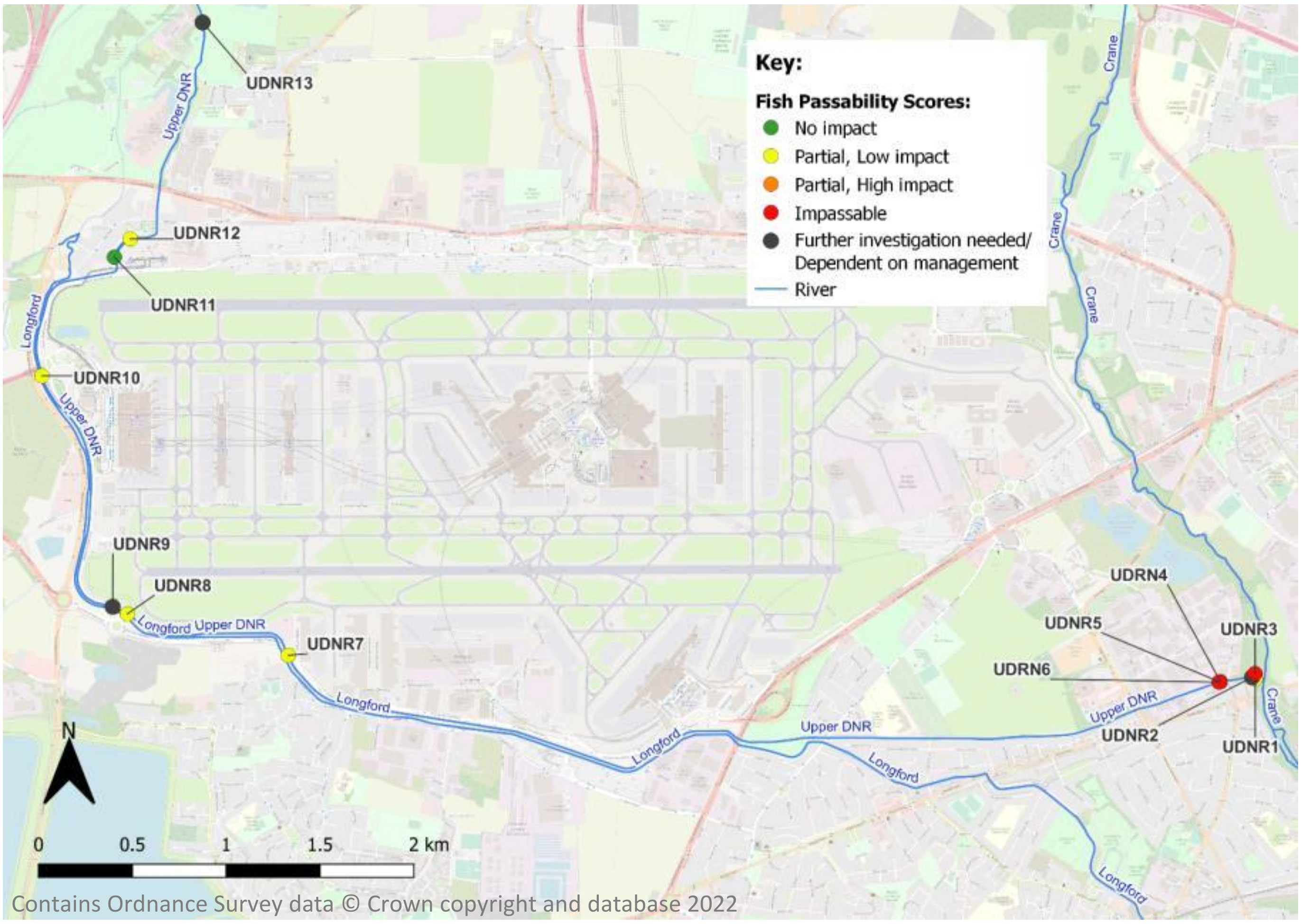


Figure 5.1: Map of all structures surveyed under the scope of this investigation on the Upper Duke of Northumberland's River. Structure ID corresponds to Table 5.1.

Table 5.1: Summary of structures on the Upper Duke of Northumberland's River. Structure ID corresponds to Figure 5.1, with score colouration corresponding to the EBAT and fish passability score ranges.

Structure ID	Structure Name	Location	Structure Type	Fish Passability	EBAT Score
UDNR1	Donkey Wood Lip	51.45971, -0.40201	Concrete lip	**Partial low impact**	**6**
UDNR2	Donkey Wood Sluice	51.45978, -0.40226	Sluice (small opening)	**Dependent on management**	**Dependent on management**
UDNR3	Donkey Wood Weir	51.45996, -0.40203	Vertical weir (slope at crest)	**Impassable**	**1**
UDNR4	River Gardens Downstream Weir	51.45957, -0.40468	Sloping weir	**Partial high impact**	**8**
UDNR5	River Gardens Middle Weir	51.45956, -0.40473	Sloping weir	**Impassable**	**5**
UDRN6	River Gardens Weir	51.45955, -0.40479	Stepped weir	**Impassable**	**4**
UDNR7	Seaford Road Culvert	**DS:** 51.46083, -0.47615 **US:** 51.46157, -0.47672	Culvert with trash screens at openings.	**Partial low impact**	**15**
UDNR8	Perimeter Roads Roundabout Culvert (DS)	51.46281, -0.48849	Culvert	**Partial low impact**	**15**
UDNR9	Perimeter Roads roundabout culvert (US) – Inverted Siphon	51.46315, -0.48958	TBC	**Further investigation needed**	**Further investigation needed**
UDNR10	T5 Roundabout Culvert	**DS:** 51.47419, -0.49503 **US:** 51.47512, -0.49539	Culvert (~100m) no trash screens	**Partial low impact**	**15**
UDNR11	Heathrow pod sluices	51.47986, -0.48949	Open Sluice no screen	**No Impact**	**15**
UDNR12	White Horse sluices	51.48073, -0.48826	Open Sluice with screen	**Partial low impact**	**15**
UDNR13	Saxon Way Sluice	51.49107, -0.48272	Closed sluice no screen	**Dependent on management**	**Dependent on management**

a) 

b) 

Figure 5.2: a) Map of all structures surveyed under the scope of this investigation with corresponding fish passage scores shown, b) Zoomed in view of structures UDNR 1-6.

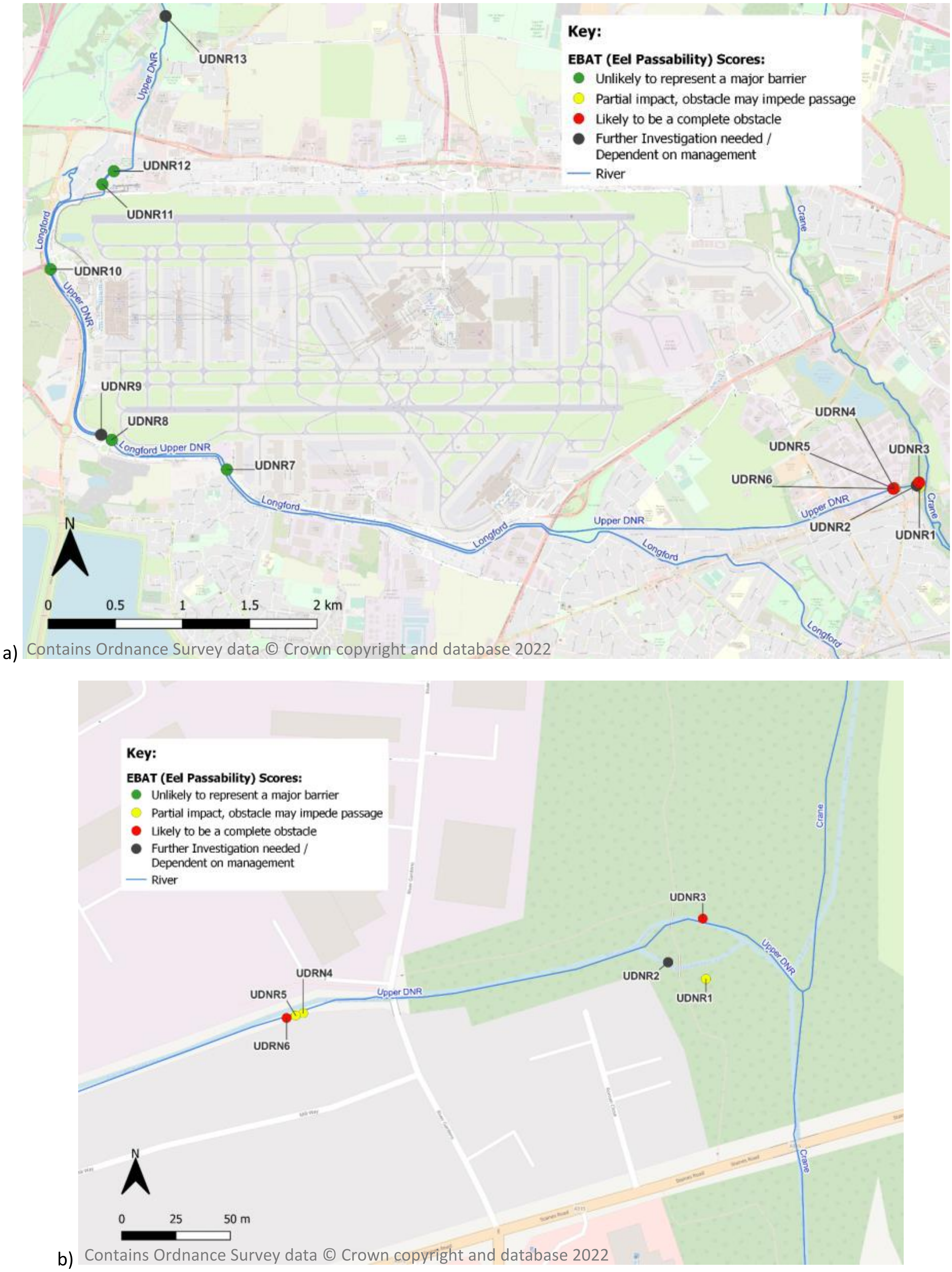


Figure 5.3: a) Map of all structures surveyed under the scope of this investigation with corresponding EBAT scores shown, b) Zoomed in view of structures UDNR 1-6.

<u>Structure UDNR1:</u> Donkey Wood lip

Location: 51.45971, -0.40201

Fish passability: Partial low impact (Partial high impact potential at low flows)

EBAT Score: 6

This concrete lip is approximately 3cm high with a depth of water at the base of the structure measuring ~30cm. Downstream of the lip is a wetted channel width of ~4m and upstream of the lip is a smooth concrete channel leading to the base of a sluice gate (UDNR2). Crawling media was present across the edged of the structure with some woody and plant debris coverage across the surface. This structure is likely not a barrier to elver and small eel that could take advantage of the crawling media or to fish at high flows when the lip would likely be submerged, however this could be a barrier to larger eel and fish at low flows when the lip is exposed. Similarly for coarse fish, at high flows and therefore greater water depth in the channel downstream, the impact of this structure would be low, however at low flows, the impact score would be high.

<u>Structure UDNR2:</u> Donkey Wood Sluice

Location: 51.45978, -0.40226

Fish passability rating: Impassable

EBAT Score: 0 (Sluice gate in closed position at the time of survey but if opened would receive and EBAT score of 15)

This sluice is located on the southern channel that splits from the Upper DNR and joins the River Crane. At the time of surveying, one of the gates of the sluice was completely closed with the other gate having a small opening (~1-2cm gap) at the base of the structure. The difference in water level between upstream and downstream of this structure was ~2.5m. There was some turbidity associated with this structure with water flowing very fast from the opening. The channel directly downstream of the structure is made of smooth concrete with some cover of crawling media which also extends up the sides of the brick channel walls. This structure is likely a complete barrier to the upstream migration of fish and eel. *Information regarding the management of structure could not be found.*

<u>Structure UDNR3: </u>Donkey Wood Weir

Location: 51.45996, -0.40203

Fish passability rating: Impassable

EBAT Score: 1

This structure is a vertical weir with a sloped section at the crest measuring ~50cm in length. The head loss (difference in upstream to downstream water level) of the structure is approximately 2m. At the time of survey there was turbulence associated with the structure with fast flows and very little presence of crawling media. This structure forms part of a footing bridge and connects the Upper DNR to the River Crane. The channel immediately downstream of this structure is approximately 7m wide with a water height of ~3cm. This structure is likely a complete barrier to elver, larger eel and coarse fish under all flow conditions due to the head loss and turbulence associated with this structure.

<u>Structure UDNR4:</u> River Gardens Downstream Weir

Location: 51.45957, -0.40468

Fish passability score: Partial high impact

EBAT Score: 8

This structure is located upstream of Donkey wood and is part of a series of three weirs. This first structure is the smallest of the three weirs and is a sloping weir with a head loss of approximately 20cm. Fast flows were present at the time of survey however there was no turbulence associated with this structure. There was not a continuous path of crawling media across this structure and both the channel bed and walls are concrete/brick. This barrier has the potential to act as a barrier to elver and larger eel migration. Due to the lack of resting locations for fish immediately downstream of this structure and the gradient of the slope, it is likely that this barrier would have a high impact on coarse fish migration under conditions observed at the time of survey. Under high flow conditions, this barrier could potentially become submerged, and its impact would be reduced.

<u>Structure UDNR5:</u> River Gardens Middle Weir

Location: 51.45956, -0.40473

Fish passability score: Impassable

EBAT Score: 5

This is the second structure in the series of weirs upstream of Donkey Wood. This structure is a sloping weir ~10m upstream of Structure UDNR4. This structure is roughly double the height of UDNR4 with a head loss of approximately 1m, with a steeper slope that has a more curved shape (steeper at the crest). As with UDNR4, there is no continuous path of crawling media across this structure and water velocity was high at the time of survey. The channel directly downstream of this structure is channelised with a concrete base and sides with a width of approximately 5m. This barrier has the potential to act as a complete barrier to elver and larger eel migration and is likely to be impassable to coarse fish due to the gradient of its slope.

<u>Structure UDNR6:</u> River Gardens top weir

Location: 51.45955, -0.40479

Fish passability score: Impassable

EBAT Score: 4

This structure is a concrete stepped weir directly upstream (~10m) of structures UDNR4 and UDNR5. This structure is the largest of the three with an overall head loss of approximately 1.5m. The height of each step measures approximately 15cm. Due to large amounts of turbidity at the structure the number of steps could not be counted as the base of the structure was not visible, but it can be assumed that there are approximately 8-10 steps present. The structure is curved across the width of the channel measuring approximately 7m, leading downstream to a channel width at the base of the structure of approximately 5m. Some debris/crawling media was present in the centre of the structure consisting of woody debris and wooden planks upon which some vegetation had become stuck. This barrier is likely a complete barrier to elver and larger eel as well as being impassable to coarse fish due to the turbidity associated with the structure and lack of resting areas for fish immediately downstream.

<u>Structure UDNR7: </u>Seaford Road culvert

Location: DS: 51.46083, -0.47615, US: 51.46157, -0.47672

Fish passability score: Partial low impact

EBAT Score: 15

This structure is a concrete culvert located at the downstream section of Heathrow land. Trash screens are present at both the entrance and exit of this structure that has an approximate length of 90m. At the point at which the culvert begins, the total channel width is approximately 10m. The culvert spans the width of the cannel (~10m) and is split into two adjacent sections (both ~5m). The height of the culvert is ~1.5m and the depth of water at the time of survey at this structure was approximately 10cm at both the DS and US openings. The trash screens were well maintained at the time of survey with little debris at the US opening and no debris at the DS opening. The distance between metal trash screen bars is approximately 10cm. One of the trash screen gates at the DS opening was left open. The Heathrow Biodiversity and Conservation Team confirmed that all trash screens on their site are maintained and cleared regularly by their maintenance team year-round. This structure is unlikely to be a barrier to the upstream migration of elver or larger eel. Due to the length of this culvert, this structure has the potential to act as a partial low impact barrier to fish.

<u>Structure UDNR8:</u> Perimeter Roads roundabout culvert (DS)

Location: DS: 51.46281, -0.48849

Fish passability score: Partial low impact

EBAT Score: 15

This structure is an ~80m long culvert built to divert water under the perimeter roads roundabout, similar to UDNR 7 with a height of ~1.5m and a total width of ~7m (split into two culverts each with ~3.5m width). The US opening of the culvert has been logged as a separate barrier structure (UDNR9). The water depth at the DS opening of this structure measures approximately 25cm. The DS section structure is unlikely to be a barrier to the upstream migration of elver or larger eel. Due to the length of this culvert, this structure has the potential to act as a partial low impact barrier to fish.

<u>Structure UDNR9:</u> Perimeter Roads roundabout culvert (US) – Inverted Siphon

Location: US: 51.46315, -0.48958

Fish passability score: Further investigation needed

EBAT Score: Further investigation needed

This structure is the US opening to the UDNR8 culvert structure. Trash screens have been installed across the entire channel width with gaps between metal bars of approximately ~10cm. The trash screens were clear of debris at the time of survey with water flowing slowly through this structure. The water depth measured approximately 25cm at the time of survey. Heathrow have provided information that this structure contains an inverted siphon and have supplied structural diagrams/design plans. Based on the diagrams provided, it appears that the siphon is contained within a perched culvert which has the potential to impact fish and eel passage. At the time of survey this structure could not be investigated in further detail as it is encased within an open culvert structure that is obscured by trash screens. Further investigation is required to establish the potential that this structure has on fish and eel migration.

Structure UDNR10: T5 Roundabout culvert

Location: DS: 51.47419, -0.49503, US: 51.47512, -0.49539

Fish passability score: Partial low impact

EBAT Score: 15

This structure is a ~100m culvert with a width of ~approximately 7m and a height of approximately 1.5m. Water depth at the US and DS openings of the culvert measured approximately ~15cm at the time of survey. This culvert diverts water underneath the Terminal 5 roundabout. This structure is unlikely to be a barrier to the upstream migration of elver or larger eel. Due to the length of this culvert, this structure has the potential to act as a partial low impact barrier to fish.

<u>Structure UDNR11:</u> Heathrow pod sluices

Location: 51.47986, -0.48949

Fish passability score: No Impact

EBAT Score: 15

This structure is a set of four sluice gates built across the width of the channel (~8m) each with a width of ~2m. At the time of survey all four gates were in an open position and water flowing through the structure had a depth of approximately 10cm. There was no turbidity associated with this structure. Heathrow Biodiversity and Conservation Team have said that these sluices always remain open. With the sluices in a completely open position, this structure does not act as a barrier to fish or eel migration.

<u>Structure UDNR12:</u> White Horse sluices

Location: 51.48073, -0.48826

Fish Passability Score: Partial low impact

EBAT Score: 15

This structure has the same dimensions as Structure UDNR 11 with the only difference being that there is a trash screen at the US end of the sluice gates. Gaps between the metal bars of the trash screen measure approximately 10cm. At the time of the survey some leaf litter was seen to be trapped in the trash screen however water was still flowing with ease through this structure. As with Structure UDNR 11, Heathrow Biodiversity and Conservation Team have said that these sluices always remain open and therefore, in this current position, these sluice gates do not act as a barrier to elver or eel migration.

<u>Structure UDNR13:</u> Saxon Way Sluice

Location: 51.49107, -0.48272

Fish Passability Score: Impassable (no impact when open)

EBAT Score: 0

This structure is a set of four undershot sluice gates with a total width of ~8m (each sluice gate measing ~2m) that were all closed at the time of survey. A small gap at the base of the structure is likely present as a small, slow flow could be seen to be flowing downstream. The depth of water held US by the sluice gates was approximately 10cm. The water depth downstream of the structure was the same as that upstream, measuring approximately 10cm. There was no crawling media present at this structure, however there was a lot of plant material and vegetation being held upstream by this structure. *Information regarding who manages this structure could not be found, but the structure is located within parkland owned by British Airways.*

6. Discussion

The LWT 2016 report did not cover the Longford River and therefore, it was initially planned that this river would be surveyed for barriers to fish and eel migration as part of this investigation. However, due to the complexity of this channel (particularly the hydrology of Home Park and Bushy Park), and the lack of available and specific barrier data, it was decided that only the Upper Duke of Northumberland's would be surveyed as a priority channel for this investigation. This decision was made following a review of both the available online data as well as personal communications with Royal Parks, Historic Royal Palaces and Phil Belfield (Environment Agency) and the Smarter Water Catchments Steering Group. Please see Appendix 1 for further information. However, outside of the scope of this investigation, ambition remains to survey the Longford River for barriers to fish and eel passage to gain a complete picture of limits to migration across the entire Crane catchment.

6.1 Evaluation of approaches

This report, like the 2016 LWT report, identifies the key physical barriers to fish and eel migration within the Crane catchment. However, as discussed, migration is not solely dependent on or influenced by physical barrier structures within rivers and not all fish species have the same migratory needs. In the Crane catchment, habitat and water quality are key considerations when it comes to improving fish abundance, diversity, migration and predator-prey relationships/ratios.

Water quality, ecology, fishery and pollution impact assessments have been carried out across the Crane catchment and a number of significant factors have been identified that could be limiting habitat and water quality and in turn impacting fish abundance and diversity within the hydrological system (Radbone *et al*., 2016, Jennings *et al*., 2010, Winter, 2013). These include:

- Scarcity of habitat complexity, physical niches and refuges needed for key requirements such as resting, juvenile growth phase, and shelter from predators and extreme flow conditions.
- Insufficient water depths, often due to the over-widening of channels, for larger fish and species with a preference for deeper waters (for feeding, over-wintering, hiding etc.) to migrate to and between.
- Absence of clean gravel substrates for fish spawning due to much of the rivers within the catchment having been highly engineered and channelised.

It is therefore fundamental that wider restoration initiatives be designed with fish in mind. Key improvements that should be considered to improve habitat are listed in the recommendations.

6.2 Strategic priorities for fish passage

We advocate improving links with the Thames and Colne over action in the upper catchment at this time. As the channel widths of the Yeading Brooks reduce towards their sources, the fish communities predictably shift to being dominated by smaller species. Fish data are limited for the Yeading Books but what is available shows low biomass and the dominance of a smaller suite of species such as 3-spined stickleback and minnow. Although carrying out improvements to barriers in this part of the catchment would bring benefits to these species, particularly the more mobile minnow, fewer species will benefit from investment in improving connectivity in this part of the catchment compared to investing in the lower catchment. Connectivity is also probably not the limiting factor for fishes in the Yeading Books either, with water quality having been consistently poor with damaging concentrations of ammonium recorded by both the Environment Agency (Atkins, 2022) and Citizen Crane.

Several locations along the Yeading Brook West have been identified as offering good habitat quality in comparison to other areas of the Yeading Brook (LWT 2016), with areas of river being sinuous in nature with suitable light levels and diverse aquatic flora. In contrast, extensive habitat improvement works are recommended throughout the

Yeading Brook East, which is heavily urbanised, culverted, straightened, channelised and over-shaded. The Yeading Brook East also routinely shows the highest concentrations of ammonium in the catchment.

6.2.1 Improve links with the Tidal Thames

The 2016 LWT report identifies two possible routes for movement of fish in and out of The River Thames: the lower Crane and lower Duke of Northumberland's Rivers. These rivers differ dramatically in terms of the number of obstructions to fish migration they contain, the quality of the habitat and their hydromorphology (LWT, 2016). The LWT survey found six obstructions in the lower DNR, four of which were impassable obstructions for coarse fish. The lower Crane was identified as having 17 obstructions in total, 16 of which were impassable for coarse fish and five of which are impassable for juvenile eels at the time of survey. Although more numerous, the structures in the lower Crane are relatively low-profile sloping or vertical weirs that could be improved through the installation of modifications such as baffles and rock ramps and may well be more cost effective and have additional benefits for wildlife than focusing on installing a single costly technical pass at Kidd's Mill on the lower DNR.

The LWT report recommended that until significant improvements are made to habitat and water quantity in the lower Crane, improving fish passage on the DNR and specifically at the Kidd's Mill be prioritised due to the higher quality habitat that it provides. However, developments that have been carried out since 2016 in the lower Crane have altered its potential as a link to the tidal Thames.

Improvements to the management of Mereway Weir have ensured that there is now continuous flow in the lower Crane which is the essential precursor to considering habitat improvements for fish passage. The 'Test lowering of Mereway Weir November 2017 to November 2018' report (Environment Agency 2019) has confirmed that changing the split of water from the Lower DNR and River Crane has not adversely impacted the Lower DNR but has significantly improved the River Crane. These changes have allowed fish to be present for longer periods of the year than before the weir was lowered. Result of this report show that within a concrete section of the channel at Marsh Farm in 2017, only 5 fish were caught (three stone loach and two 3-spined stickleback), whereas in 2018 at the same site, much higher catches and more species were recorded. Catch counts were based on estimates with between 100-999 stone loach and 10-99 stickleback recorded in 2018. In addition, other minor species caught included bullhead, and minnow (10-99) with dace, roach and chub recorded in a variety of sizes.

Furthermore, a pilot scheme is underway to improve habitat availability on the lower Crane River and has the potential to be scaled up through the Smarter Water Catchments (SWC) initiative, and/or through other funding mechanisms. Improvements (baffle installation) at Mereway Barrier 1 (ID 192274) and delivery of a fish pass at Mereway Barrier 4 (ID 192278) (see Section 4.1) will further improve connectivity by allowing fish to pass upstream from the lower Crane into the upper sections of the river. The installation of the pass at Mereway will have a particular impact on the cost/benefit ratio of focusing future investment on the lower Crane as an alternative link between the Thames and the Crane to the lower DNR.

A fish survey carried out by FORCE, ZSL, the IFM and Friends of Northcote Nature Reserve in 2017, using a sweep net, in the tidal section of the Crane recorded eight fish species: stickleback, dace, chub, stone loach, common goby, flounder, minnow and European eel. The species caught in highest abundance were stickleback, with over 100 individuals recorded in the pool habitats on either side of the Northcote Nature Reserve (NNR). Habitat of the tidal Crane is set to be enhanced in 2022 with the creation of a tidal inlet backwater within the NNR.

Figure 6.1: Fish, likely juveniles, gathering around the limited habitat available in this section of the lower River Crane near London Road Bridge, Twickenham. Photo Credit: John Waxman.

Addressing the numerous small barriers in the lower Crane coupled with more habitat improvements would increase the accessibility for fishes found in the tidal Thames. This includes species such as flounder, dace and brown/sea trout that rely on tidal currents to move upriver and spawn as well as European eel that migrate upstream on estuarine tides in search of habitat in which to grow and feed (Wheeler, 1980). Brown/sea trout are found in the tidal Thames and we are aware of a report of one individual recently caught by an angler at the mouth of the Crane. Brown/sea trout migrate to improve growth and survival with life histories being dependant on a number of complex and interacting factors including the availability and connectivity of functional habitats (Nevoux *et al*., 2019). They migrate upstream in autumn/ winter to spawn on clean gravels. The apparent lack of this species within the lower Crane could indicate that migration into the catchment is limited by a lack of suitable habitat.

6.2.2 Improving links between the Colne and the Crane via the Upper DNR

The importance of linking the Crane and Colne Valleys has been well documented. A Green Infrastructure Strategy published in 2019 highlights the considerable potential benefits for wildlife that could be provided through better linking the two catchments and improving hydrological connectivity from the River Thames in West London with the Colne Valley and Chilterns AONB. From the perspective of fish passage specifically, improving the links between these two catchments would facilitate the mixing of fish populations between the Colne River system and the Crane, and support the recolonization and resilience of the Crane system that is still suffering from the impacts of large pollution events in 2011 and 2013.

This report has identified a number of structures on the Upper Duke of Northumberland's River that have the potential to impact fish and eel migration and thereby limit the links between the Colne and Crane catchments. Five of these barriers were scored as being completely impassable to fish passage, three as being 'Partial, High Impact' barriers, five as 'Partial, Low Impact' and one barrier was scored to have 'No Impact' on fish migration. In terms of eel migration, three of the barriers identified were scored as complete barriers to eel migration, four as partial barriers and five as unlikely barriers to eel migration. Based on these results, the following priority structures for removal or improvement have been identified to best improve fish passage through the Upper DNR section of the Crane catchment (see Table 6.1).

Table 6.1: Proposed priority barrier structures to be improvement or removed within the survey area. Corresponding improvement recommendations are provided.

Structure ID	Location	Structure Type	Fish Passability	EBAT Score	Recommended Improvement
UDNR1	51.45971, -0.40201	Concrete lip	**Partial low impact**	**6**	Chip off a section of the concrete lip.
UDNR2	51.45978, -0.40226	Sluice (small opening)	**Impassable**	**8**	Ensure management of sluice to enable fish and eel upstream migration. Improvements of structures UDNR1 and UDNR2 will enable fish and eel to bypass the large weir at Donkey Wood (UDNR3) and access habitat upstream.
UDNR3	51.45996, -0.40203	Vertical weir (slope at crest)	**Impassable**	**1**	If management requirements of UDNR2 mean that this structure cannot be opened for fish and eel passage, improvements to this structure will be required. For eel, an 'up and over' gravity fed pass in a notched section of the vertical weir. For coarse fish, installation of a Larinier fish pass or equivalent is recommended. *Further expert opinion required.*
UDNR4	51.45957, -0.40468	Sloping weir	**Partial high impact**	**8**	For eel, installation of eel passes/eel tiles. For coarse fish, pre-baffle installation downstream of the structures to raise water levels, in addition to baffle installation on the structures. *Further expert opinion required.*
UDNR5	51.45956, -0.40473	Sloping weir	**Impassable**	**5**	
UDRN6	51.45955, -0.40479	Stepped weir	**Impassable**	**4**	
UDNR13	51.49107, -0.48272	Closed sluice no screen	**Impassable**	**0**	Find out who owns this structure and ensure management allows for fish and eel upstream migration.

Improving passage and migration pathways for eel through this section of the catchment would be more straightforward and lower cost than for coarse fish, with fewer barriers to European eel highlighted in the upper DNR. Therefore, it could be beneficial to address and improve UDNR6, UDNR13 and potentially UDNR3 (depending on the management of UDNR2) as a priority. However, as discussed, the removal of physical barriers for all fish species should be coupled with significant habitat improvements. Lack of functional habitat (see Figure 6.2) can be considered a barrier in itself, and habitat improvement works should be viewed as a priority activity to be carried out alongside structural works on barriers within the Crane catchment. The benefits of habitat improvement, coupled with improving connectivity with the Colne catchment will in turn help to build resilience at a catchment level and overall, act as a sustainable solution to improving fish diversity and abundance within the Crane system.

Figure 6.2: A channelised section of the Upper Duke of Northumberland's river at the entrance to a box culvert, reflective of conditions across large sections of the river. Concrete bed and banks, low water levels, with no presence of aquatic macrophytes or quality habitat and only a small covering of moss, algae and leaf litter.

Some habitat improvements have been carried out within this section of the catchment already, particularly within the Twin Rivers system (Longford and Upper Duke of Northumberland's Rivers) to try to improve the heterogeneity of habitats and flows and reduce the mobilisation of fine sediments through the installation of gabions, the strategic placement of large woody material and the planting of marginal vegetation (see Figure 6.3). However, throughout much of its reaches, the Upper Duke of Northumberland's remains heavily channelised, culverted and lacks key habitats such as the deeper pools and gravel riffle habitats that are required by many fish species to complete their lifecycle.


Figure 6.3: (Left) Image of gabions and large woody material installed in the Upper Duke of Northumberland's River by Heathrow Conservation and Biodiversity Team. (Right) Image showing the growth of marginal vegetation planted in the Upper Duke of Northumberland's River at Heathrow.

7. Limitations

- Due to time constraints, barriers were surveyed once between November and December 2021. Barriers were scored based on flow conditions at the time of survey passsability may vary under different flow conditions such as summer low flows.
- Scoring and subsequent passability ratings of structures are therefore based on best estimates. Although aspects of both the SNIFFER and EBAT methodologies were used to account for the varied abilities of different species to pass structures, there is no one size fits all when it comes to fish habitat and flow preferences and the abilities of different species to scale barriers.
- The report identified the potential of long culverts, those with insufficient water levels or those with high velocities to have the potential to act as a barrier to fish migration. However, as little information exists as to the conditions within these structures, a more accurate estimation of how these structures will impact fish migration cannot be provided at this stage.
- Structure measurements were based on estimates. In the 2016 LWT report, structures were measured where possible, with parameters such as water depth and velocity measured along transects. In this report, specific measurements could not be collected, and bankside estimates were used instead. This limited the accuracy of the assessments but provided enough information for priority structures to be identified. These can be measured at a later date should improvements be undertaken.
- Recent fish data from the Environment agency is lacking across the catchment largely due to limited monitoring being able to take place since 2019 due to COVID-19 disruptions.

- Due to data access issues, access to fish data gathered by Heathrow was unavailable at the time of reporting and therefore understandings of fish abundance and diversity within the Upper Duke of Northumberland's River was limited.

8. Recommendations

- Consult stakeholders on the findings and recommendations made in this report and collectively agree a strategy for fishes in the Crane catchment. Collate any additional information on fish presence and barriers and review the findings accordingly.
- Conduct a detailed feasibility study for improving fish passage in the lower Crane. This will include consultation with stakeholders, such as the London Borough of Richmond and the Environment Agency, to co-develop a staggered plan for improving in-channel habitat in the sections that are currently in open culvert.
- Conduct a detailed feasibility study for improving fish passage and habitat between the Crane and Colne. This will include mapping functional habitat in the UDNR, investigating the impact of the siphon (UDNR9) on fishes, identifying who owns and operates UDNR13 and outline design and costs to mitigate the impacts of the structures identified in this report.
- Consider the impact on fish when reviewing SWC hydrogeomorphology/ habitat improvement proposals. Key improvements that should be considered to improve habitat and restore fish populations in the River Crane and DNR include:
    - The narrowing of the over-widened sections of the river channel to encourage natural scouring and help create a more varied bed topography.
    - The creation of pool and riffle habitats with gravel substrate at appropriate river locations to help provide necessary substrate for riffle spawning fish which will also benefit plants and invertebrates.
    - The creation of backwaters and bays to provide valuable refuge habitat for fish during pollution incidents or periods of high flows and add to the range of habitats in the rivers including spawning and rearing habitats.
    - The daylighting of excessively shaded sections and planting of marginal aquatic vegetation (local species) that provides shelter habitat for juvenile fish to develop, provides bank protection and acts as a buffer zone to trap sediments and pollution.
    - The addition of large woody debris and flow deflectors to provide additional habitat and promote flow diversity.

- Improve understanding of fish populations in the Crane catchment by,
    - Conducting surveys on the impact of the lower crane restoration pilot on fishes (ZSL plan to conduct a sweep/seine netting of the new habitat in the lower Crane in summer 2022) and the new tidal refuge in Northcote Nature Reserve.
    - Liaise with the Environment Agency to highlight the need for an area-controlled monitoring programme to repeat electric fishing surveys at long-term monitored sites impacted by the pollution events of 2011 and 2013. The Environment Agency (pers comms. Phil Belfield) highlighted that their programme of fish surveys is now largely 'nationally controlled', but that areas can have some influence on local priority sites. Understanding how and if populations of fishes in the Crane have reestablished since being decimated by pollution should be a sufficient reason to prioritise Crane fish surveys, but at the time of writing repeat electric fishing surveys have not been confirmed.
    - Propose the consideration of running fisheries surveys of the upper reaches of the river (Yeading Brook East and Yeading Brook West - above the confluence) to assess the current fish numbers and the potential for fish to colonise these reaches.
    - At the time of writing there is provision for CCTV monitoring fish window at the Mereway fish pass. This has the potential to provide valuable insight into the diversity and abundance of fish within this section of the catchment and with planning, analysis of the data could be supported by members of the local community.
    - Better understand the distribution of spawning sites for different fishes in the Crane. There is potential for this to be done with citizen scientists in a project developed by ZSL and delivered by the Citizen Crane Project Officer.

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10. Appendices

Appendix 1: The Longford River

Background

The Longford River is an artificial waterway originally constructed to divert water from the River Colne and built for King Charles I in 1638 as a water supply for Bushy Park and Hampton Court. The Longford River flows through a mixture of private and public land and is managed by Historic Royal Palaces, Royal Parks and Heathrow. Although it flows through the Crane Valley, the Longford River is not connected at any point to the River Crane.

In 2014, APEM was appointed to carry out a hydromorphological survey of the Longford River for The Royal Parks (TRP). The final report compiled existing reports and surveys on the Longford River to provide both management and environmental information specific to the River Longford. APEM carried out a hydromorphological field survey and mapping exercise to provide an up-to-date record of the river condition which included information on key barriers and flow control structures (see Figure A1.1)

The report recommended that a feasibility study be carried out into the provision of eel passage at Watermill Weir, Cascade Weir and Waterhouse Pond and that connectivity to the Thames should also be assessed. Although this report was extensive and a number of barriers were recorded and mapped, details of their dimensions and other key parameters that could enable a passability score to be derived were not recorded.

Pryor (2013) carried out an investigation that assessed the hydrological connectivity of the interface between the Longford River and the lower freshwater River Thames just above the Tidal limit at Teddington Lock and identified several potential barriers to fish and eel migration. This report made recommendations for future hydrological and conservation management as well as for habitat improvement, access improvement for European eel and for future monitoring plans to better understand the Home Park site and its role in the wider riverscape.

Figure A1.1: Home Park potential barriers to fish and eel upstream migration (culverts not accounted for).

Many of the known structures identified by Pryor (2013) and APEM (2014), are highly complex and many of the sluices, weirs and other structures have been built to regulate river levels and water supply to important features such as ponds, fountains and reed beds. Therefore, the recommendations that could be made to improve fish passage in these areas through either the modification or removal of barriers would be very limited, with many of the existing structures being critical to flow control.

As a result of the findings of Pryor (2013), Joe Pecorelli (ZSL) and Ken Mackenzie (Thames Landscape Strategy) conducted a site visit on 20/11/2013, to reflect on the suggestion made by Pryor (2013) to make specific recommendations on key structures to allow eels to move into a large section of the 'main ditch' and up into Rick Pond. Based on these recommendations and those made by Pryor (2013), a number of improvements were made to key barrier structures within Home Park (see Figure A1.2 and Figure A1.3). However, during a site visit carried out as part of this investigation, it was clear that a number of structures with a high potential to act as a complete barrier to both fish and eel migration were still present due to their key function in controlling flow to the Rick's Pond, the Longwater Canal and other key features such as the pond networks and the reed bed.

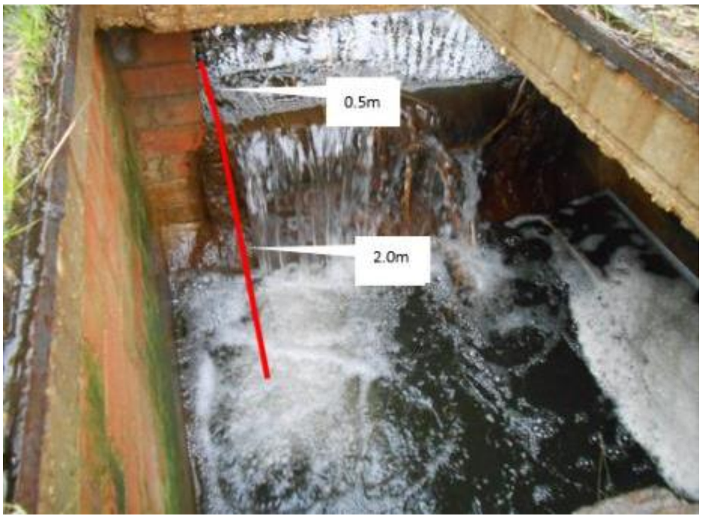

Figure A1.2: Before (left) and after (right) images of an eel pass installed to the sump of the off-take of Rick Pond.

Figure A1.3: Before (left) and after (right) images of an eel pass installation to a vertical weir in Home Park.

Existing knowledge of fish populations in the Longford River

There is very limited and inconsistent fish data available for the Longford River. For example, the Ecological Appraisal of the Longford River that was carried out in conjunction with the APEM hydromorphological survey did not systematically survey fish in the river, stating that it was not within the scope of the survey. The report highlights that the Longford River is likely to support a fish assemblage typically found in lowland rivers with anecdotal records of fish species occurring in the Longford including chub, minnow, bream, roach, stickleback, eel (juvenile silver and yellow eels) and bullhead.

Pryor (2013) sampled fish populations using a range of fishing methods. Species found were analysed by location and hydrology to identify lateral links with the river. No historic data existed with which to compare the results. Sample locations can be seen in Figure A1.4 taken from Pryor 2013, with the most upstream sample being Sample 10, at the lower end of the Long Water Canal. The report highlights that at this site, the 'apex 'of the network is connected by a culvert between to the Overflow Pond (Sample 11) which has a drop of approximately 3m and is impossible for any fish to pass upstream. Therefore, fish data collected by Pryor (2013) that can be seen in Table A1.1 is likely not reflective of fish populations present upstream of the Long Water Canal.

Figure A1.4: Map of sample sites and sampling method used by Pryor (2013) within Home Park and surrounding paddocks.

Table A1.1: Total number of all fish sampled in Home Park Ponds and Paddock ditches. Totals include fish captured using electrofishing (20th May 2013), total number of fish caught using large meshed fyke nets (3rd – 7th June, 2013), all fish captured using small meshed fyke nets (3rd – 7th June, 2013) and all *Anguilla anguilla* (European eel) captured in an elver trap (7th June – 1st July, 2013).

Common name	Total Number caught
European Eel	90
Bream	2
Chub	6
Dace	1
Gudgeon	10
Roach	15
Rudd	72
Tench	4
Roach/Rudd hybrid	3
3-Spined Stickleback	7
9-Spined Stickleback	87
Perch	90

Recommendations for improving fish migration in the Longford River

- Large sections of the Longford River, particularly where it splits into multiple channels through Bushy Park, are highly complex. A full barrier and hydrological assessment of Bushy Park was deemed outside the scope of this project. We recommend that a survey be commissioned by Royal Parks to map and assess potential barriers to fish migration, understand where potential habitat (ponds, ditches and sections of naturalised channel) for different fish species are available and how these habitats might be connected.
- Flow regimes within the Longford are carefully controlled to ensure that water levels remain at desired levels to feed into the fountain and pond systems. It would be important that a report on the survey documents the ownership, management and function of water control structures.
- Opportunities to alter flow regimes to significant heritage structures in Bushy Park and Hampton Court are limited and improvements/removal of barriers would need to involve more in-depth analysis of the dimensions and function of the structures as well as the potential cost of development. Consequently, surveying the Longford and making recommendations for fish passage is multifaceted.
- In addition to the lack of connectivity in the lower sections of the Longford River through Bushy and Home Park, the OHES (2016) analysis of fish data indicated that the Longford was less productive than the Upper Duke of

Northumberland's, its neighbour watercourse, with considerably lower and poorer biomass and density. This was attributed to a lack of suitable fish habitats due to the absence of submerged macrophytes throughout much of the upper reaches of the Longford River, with the UDNR comparatively containing an abundance of submerged vegetation. In the UDNR, submerged vegetation has provided more areas of refuge, food and breeding opportunities for fish with the UDNR recording high number of juvenile fish (small roach) and the presence of particular species with a preference for these conditions, such as tench. Significant habitat improvement works would therefore be needed in addition to any barrier remediation works, particularly in the upper section of the Longford River.

- Overall, from a cost-benefit perspective, and considering the various challenges presented by restoring connectivity for the upstream migration of fish from the Tidal Thames through the rivers of the Crane catchment, focussing resources and improvement works across the Crane and Duke of Northumberland's rivers would likely yield more benefits for fish populations at a lower cost. As discussed in the main body of this report, works to improve flows and habitat quality within the lower Crane River are already underway, as well as the removal and improvement of several barriers to fish migration, in turn improving the connection between the Colne and Crane catchments.

Appendix 2: The behaviours and habitat requirements of fish species.

Table A2.1: General behaviours and habitat preferences of fish species present within the Crane Catchement system (based on EA data) or that could be expected to occur if suitable habitat was made available.

Species	Behaviour	Habitat requirements	References
3-spined stickleback *Gasterosteus aculeatus*	Tend to be sedentary, staying in the same place for their whole lives.	General preference for slow flowing or still, shallow waters and can inhabit small streams, river edges, ditches and estuaries. Juveniles predominantly found in shallow reaches or near banks with moderate flow, adults found in depths greater than 20cm with slow flows. This species often migrates within rivers or up to breeding areas, to spawn and downstream in estuarine waters to overwinter. Spawning occurs in a constructed nest in shallow waters, usually within vegetation, weeds, silt, sand and sediments in late spring/early summer.	AMEC (2014) and Everard (2013).
Barbel	Large home range. Migrate to	Generally found within the middle reaches.	Cowx *et al*. (2004),

Barbus barbus	spawn. Live in small shoals or groups, often solitary when large.	Barbel are capable of migrating long distances in search of functional habitats such as well flushed, shallow gravel beds and riffles for spawning (with substrates of specific size), deep areas for overwintering, complex marginal habitat for refuge and warm, slow -flowing food-rich areas for juvenile nursery.	Everard, (2013), DVWK and F.A.O. (2002).
Bleak *Alburnus alburnus*	Sometimes form dense shoals.	Middle and lower reaches (still and moving waters) of moderate to high productivity rivers. Preference for silt/sand/gravel substratum. Frequent open water and prefer river stretches containing varied habitat providing a diverse range of food and refuge from spates and predation. Spawning typically occurs on gravel, stones and aquatic macrophytes in spring /early summer. Juveniles have a preference for warm, shallow, marginal habitats.	AMEC (2014), Everard, (2013).
Brown/Sea trout *Salmo trutta*	Migrate to spawn and dependent on unimpeded migration.	Clean, well-oxygenated flowing waters with cobble and gravel substrates in cooler, upper reaches and with cover provided by deeper pools, undercut banks and vegetation. Spawning occurs in gravel/pebble substrate in flowing water.	AMEC (2014), DVWK and F.A.O. (2002), Nevoux *et al.,* 2019.
Bullhead *Cottus gobio*	Restricted home range. Active at night, rest under cover during the day.	Relatively adaptable species with a wide distribution in a range of flowing and still waters but with distinct habitat preferences. Adult fish prefer river reaches with rapid current and correspondingly coarse substrate. Young fish, during their growing phase, find their optimal habitat in areas with gentle currents and fine-grained substrates. General preference for wooded riparian zones or open chalk streams with abundant macrophytes offering shade and refuges from predators and flow, lacking obstructions with appropriate channel structure (e.g. riffle/pool sequence).	DVWK and F.A.O. (2002), Tomlinson and Perrow (2003).
Carp	Usually found in small groups although larger	Inhabit lowland, slow flowing rivers with abundant vegetation and often found on or near the bed of pools and rivers.	Everard, (2013),

Cyprinus carpio	fish solitary. Peak activity in summer.	Tolerant of a range of conditions e.g. larger backwaters, productive rivers, occasionally brackish conditions. Spawning usually occurs on dense vegetation (macrophytes/roots) and firm substrates in river margins and rapidly warming shallows.	Cowx *et al*. (2004).
Chub *Leuciscus cephalus*	Juveniles shoal, Adults are solitary. Migrate to spawn.	Middle and lower river reaches. Strong preference for tree and macrophyte cover, large woody debris, rocks and moderate to high productivity. Generally prefer gravel/cobble substratum. Fry require warm, shallow, marginal waters and juveniles occupy slower flowing pools in shoals, adults occupy deeper water and are often solitary.	Everard, (2013), Cowx *et al*. (2004).
Common bream *Abramis brama*	Home range. Shoaling.	This species prefers nutrient-rich slow flowing rivers/lowland reaches with silt/mud substrate. This species is slow growing, requires a range of habitats from vegetated shallow waters for spawning and nursery areas and deeper silt-bedded waters for refuge and feeding areas as adults. Common bream are known to carry out long migrations.	Everard, (2013), Cowx *et al*. (2004), DVWK and F.A.O. (2002).
Dace Leuciscus leuciscus	Home range. Migrate to spawn.	Dace generally prefer varied habitats with good water quality and adequate flows. Known to undertake very large migrations to shoal over winter. Prefer shallow, well-flushed, gravel substrate areas are used for spawning whereas adults overwinter in deeper waters and are known to inhabit faster flowing well oxygenated areas. Young fish require warm, food-rich, shallow waters in the river margins.	Everard, (2013).
European eel Anguilla anguilla	Catadromous.	Undertake migration through freshwaters as part of a complex life cycle. Adults migrate downstream to reproduce in the open sea. Reproduction takes place exclusively in the Sargasso Sea, and larvae are carried by sea currents into coastal regions. After metamorphosis, young migrate upstream, where they develop until they are sexually mature. European eel generally avoid fast flowing waters, but otherwise occurs everywhere. This species is	Ibbotson *et al.* (2002), DVWK and F.A.O. (2002).

		nocturnal, spending day seeking refuge and cover in benthic mud and dense vegetation.	
Gudgeon *Gobio gobio*	Shoaling.	Generally found in the middle and lower reaches and have a preference for slow to moderate flow. Bottom dwelling and bottom feeding on silt/sand/gravel substrata in moderate to high productivity rivers. Spawning occurs on gravel and macrophytes in shallow water.	Cowx *et al*. (2004), AMEC (2014), Everard, (2013).
Minnow *Phoxinus phoxinus*	Shoaling.	This species typically requires good water quality, in well oxygenated waters in the upper and middle reaches. Preference for a range of aquatic habitats for feeding and for refuge from predators. Young prefer food-rich, shallow margins, and spawning takes place on well-flushed gravel/pebble runs.	Everard, (2013), DVWK and F.A.O. (2002).
Perch *Perca fluviatilis*	Shoaling.	Found in a range of habitats, in both standing and slow-flowing waters, occasionally those with moderate flow. Preference for habitat with submerged vegetation. Migrate to spawn on vegetation or hard surfaces and require areas of deep water for overwintering. Require good habitat complexity to evade predators and to provide opportunities for efficient hunting.	Everard, (2013), Cowx *et al*. (2004).
Pike *Esox lucius*	Solitary. Peak activity at dawn and dusk.	Typically found in the middle and lower reached in slow to moderate flows and occupy a range of habitats. This species spawns in shallow areas with submerged vegetations. Juveniles often found in weed beds and more shallow and sheltered areas with plenty of emergent vegetation whereas adults have a preference for more turbid waters.	Pauwels, 2017, Cowx *et al*. (2004).
Roach *Rutilus rutilus*	Home range. Migrate to spawn.	Usually found in lowland rivers in bankside vegetation but can also be found in open waters with a preference for both standing and flowing waters. Roach require good water quality and a range of complex habitats to migrate between on a daily and seasonal basis to support a variety of food, shelter and suitable young nursery	AMEC (2014), DVWK and F.A.O. (2002),

		habitat. Roach stick their eggs to rocks and plants and newly hatched fish stay attached to the vegetation. Juveniles prefer vegetation cover and lower velocities whereas larger fish occupy deeper less turbulent river reaches.	Cowx *et al*. (2004).
Stone loach *Barbatula barbatula*	Restricted home range.	Require good water quality and well-oxygenated conditions. Preference for with cobble/gravel/sand/silt substrate in moderate flows. Roach seek refuge habitats under cobbles, dead wood and boulders, spawn on well-flushed gravel runs, stones and aquatic vegetation.	Everard, (2013), Cowx *et al*. (2004).
Tench *Tinca tinca*	Congregate to spawn in late spring. Dormant in winter. Live in small groups/pairs and can be solitary when large.	Still or slow flowing water species typically found in lowland reaches. Tench are adapted to life in waters and backwaters with soft mud/silt substrates with abundant and dense vegetation required for refuge from predators and strong flows. Shallow, warm margins required for successful breeding.	DVWK and F.A.O. (2002), Cowx *et al*. (2004).