Larval and juvenile fish in the Thames: Investigating early life history stages (ELHS) to understand ecological function of the tidal Thames and the impact of improved water quality

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Executive Summary

It is globally acknowledged that estuaries perform an array of vital functions in determining the recruitment potential of a broad range of freshwater and marine fishes. However; due to tidal dynamics and logistical challenges associated with data collection they remain one of the most poorly studied ecosystems on earth.

In 2016 the Zoological Society of London, Bournemouth University and SC^2 were commissioned by Tideway to collect a pre-Thames Tideway Tunnel baseline on fish in the Thames. This study uniquely focused on the most abundant, vulnerable and understudied life stages of fish utilising the tidal Thames; the early life history stage fish (ELHS, i.e. eggs, larvae and juveniles). The consortium designed a study capable of producing a pre-Thames Tideway Tunnel baseline, while also gathering data to develop our understanding of the inter- and intra-species developmental shifts which determine the 3D utilisation of space, tidal transport and temporal distributions in abundance of ELHS fish.

An innovative multi-method approach was used to collect samples which included deploying ichthyoplankton nets in the mid-channel and both seine and intertidal sweep nets from the foreshore. Two locations along the Thames, Greenwich and Putney, were sampled approximately every two weeks over low spring tide from March to October in 2017 and 2018. Captured fish were identified and fixed (only 35 individuals of each species in each sample were fixed, any others were identified, measured and released) and examined in the laboratory to confirm species identification and developmental state.

Between March and October 2017 and 2018, 33 survey days were conducted, 22 of which included mid-channel surveys and 31 of which included foreshore surveys. Total effort included 512 mid-channel nettings, 708 intertidal nettings and 116 seine nettings. Over the two-year study period a total of 8,263 individual fish were caught comprising of 25 species of freshwater, marine, estuarine resident, anadromous and catadromous fish. Many more fish were caught at the Putney surveys site (n=7,206) than at Greenwich (n=1,055) although the species diversity at both sites were similar (Putney n=21, Greenwich n=19). The composition of species caught at both sites also varied with more freshwater species being found at the upstream site of Putney. A few more-unusual species caught included the short-snouted seahorse (*Hippocampus hippocampus),* a roach bream hybrid and a pipefish *(Syngnathus sp.).*

In general, total abundance and species diversity of ELHS fish peaked towards mid-summer, reducing to lowest observed numbers through the late spring and autumn months. Three marine species (common goby, flounder and bass) and three freshwater species (roach, three-spined stickleback and dace) dominated the catch, representing 66% and 22% of the total catch respectively. As expected, ELHS fish presence varied throughout the survey seasons with clear variations in species spawning time demonstrated with, for example, smelt appearing to spawn in March / April, flounder entering the estuary around May, roach spawning in May / June and sea bass entering the estuary in June – August.

While the general pattern of recruitment timing for each species was generally consistent between the two survey years (2017 and 2018), some fundamental differences in species recorded at each site were evident. Perhaps the most striking contrast was following capture of newly hatched smelt larvae at Putney in 2017, this species was not recorded at Putney during 2018. This is the area previously identified as a key spawning ground for this anadromous species and this was the first time in at least three years smelt were not recorded spawning here. Also, in contrast to 2017, smelt were captured in relatively high numbers at Greenwich in 2018. The smallest fish recorded at Greenwich was however 14 mm, meaning the fish were already several weeks old, thus providing no indication as to where on the estuary spawning may have occurred in 2018. The

total absence of smelt larvae from Putney in 2018, does however suggest that habitats elsewhere on the tidal Thames and/or its tributaries may also function as spawning sites for this high priority species.

The intertidal zone generally demonstrated higher numbers of fish diversity and abundance across both sites than the mid-channel area. ELHS with limited swimming capabilities have adapted various strategies for utilising tidal flows to facilitate their locomotion towards estuarine nursery grounds. This is known as selective tidal stream transport (STST) and can involve vertical and lateral orientation to strategically use tidal flow to achieve net upstream and downstream movements. To understand how changes in ontogeny (development) influence 3D positioning and STST in the Thames, a detailed analysis on the following three model species: flounder, smelt and bass was conducted.

Flounder were found to arrive in Greenwich exclusively in the midchannel with an eye either side of their head and without a functional mouth or gut. Somewhere between Greenwich and Putney a significant morphological development occurred – their eye migrated to the top of the body and the gut and mouth began to function. This change was synchronised with a switch to the estuary margins by the time they had reached Putney. Despite being more developed and already ingesting food, sea bass similarly arrived in the Thames at Greenwich in the mid-channel. However, the results from this study clearly show a habitat shift to the intertidal zone as the sea bass grow. Unlike the clear morphological shift seen in flounder, sea bass appear to change their habitat choice based on their size, moving to the margins when above 17-20mm. It was expected that smelt would demonstrate the same lateral habitat shift at some point in their development, however this was not the case, with smelt primarily observed in the mid-channel throughout the entire survey period. From these examples the entire water column, both mid-channel and intertidal is essential habitat throughout the development of ELHS.

Inter annual variations in temperature, salinity and flow were recorded in the Thames in 2017 and 2018, which may go some way to explaining the fluctuations in smelt spawning observed in this study. With reference to water temperature and water salinity, the conditions during the smelt spawning season showed considerable inter-annual variation at Putney. The conditions at Greenwich in 2018 however, were more closely aligned with those recorded at Putney in 2017. Therefore, it is possible the environmental conditions in the lower parts of the estuary around Greenwich in 2018 (particularly reduced salinity) may have presented smelt with the option of using alternative spawning grounds, negating their need to migrate as far upstream as Putney. However, it must also be noted that percussive piling was being conducted at a number of sites along the Thames in 2018 during and before the smelt spawning season. This kind of percussive piling has been linked to avoidance behaviour in certain fish species of up to 250 m upstream and downstream of the piling site. Although no piling occurred directly around the assumed spawning site, it is possible that the upstream migration of smelt, or other fish species, were impacted by this piling activity.

A considerable amount of public engagement was conducted throughout this project to inspire and engage Londoners about the river Thames. Over 140 volunteers took part in our fish surveys, 250 members of the general public attended a ZSL science event on the Thames, four public engagement events were attended by ZSL staff and over 40 messages about the surveys and catch went out on our social media channels reaching over 90,000 people. Citizen science fish surveys were also conducted at Blackfriars using a simplified methodology using just the intertidal sweep nets. These events were very popular, with all events being over-subscribed, and reports of amazement of the species and diversity caught. Additionally, two MSc students were involved in the survey fieldwork and conducted their research on Thames related topics.

The multi-method, multi-location, multi-year methodology developed for this study has allowed us to begin to understand the temporal and spatial variation in how ELHS fish use the Thames. It is important to note a snapshot survey would not have illustrated the same results. Furthermore, the simplified citizen science methodology has provided a safe and effective way to engage citizen scientists and already this methodology has been used in other estuaries.

This study represents the most comprehensive ELHS research on any UK estuary to date and has clearly demonstrated the importance of the Thames as a nursery habitat for over 20 species of fish. Further research is needed in the Thames to continue to monitor these critical early life stages and answer the many questions which have been raised through this study, such as the potential of multiple spawning grounds for smelt and the causes of inter annual species diversity and abundance. Now that a suitable multi-method approach has been designed to research ELHS, it is hoped that this study will be replicated, both on the Thames in the years to come, but also on other estuaries in the UK and beyond.

Acknowledgements

This project has been funded by Tideway. The research consortium would like to thank the AHOY Centre and the Dulwich and Globe Rowing Clubs for helping us with boat launching facilities / safe access to the foreshore. We would also like to thank the Port of London Authority and Environmental Agency for help with licensing. Lastly, we are very grateful to the over one hundred ZSL volunteers and staff who gave their time over the last two-years to help with this ambitious survey.

List of Abbreviations

BU – Bournemouth University

CPUE – Catch Per Unit Effort

CSO – Combined Sewage Outflow

ELHS - Early Life History Stage fish i.e. eggs, larvae and juveniles.

Inter – Intertidal netting

Ichthy – Ichthyoplankton netting

PDC - Passive Debris Collector

SC^2 – Colclough Coates Consultancy

STST – Selective Tidal Stream Transport

WFD – EU Water Framework Directive

ZSL – Zoological Society of London

Aims and Objectives

- To produce a pre-Thames Tideway Tunnel baseline of early life history stage fish (ELHS, i.e. eggs, larvae and juveniles) abundance, distribution and species diversity, against which future improvements can be quantified;
- To develop state-of-the-art knowledge pertaining to inter- and intra-species ontogenetic shifts in behaviour, 3D utilisation of space, tidal transport and temporal distributions and abundance;
- To gather information on the seasonal and spatial vulnerability of ELHS to anthropogenic impacts;
- To train up to 150 Londoners in ELHS survey techniques and recruit a suite of Masters students from London colleges to actively contribute to conservation in the tidal Thames;
- To develop a long-term ELHS monitoring methodology for the tidal Thames to secure a lasting legacy of the Thames Tideway Tunnel, and
- To communicate the past, present and future ecological value of the Thames Estuary to international audiences, including scientific meetings facilitated by ZSL, open to the public and Tideway guests.

1 Introduction

It is globally acknowledged that estuaries perform an array of vital functions in determining the recruitment potential of a broad range of freshwater and marine fishes. However; due to tidal dynamics and logistical challenges associated with data collection they remain one of the most poorly studied ecosystems on earth.

Estuaries provide a critical migratory pathway for fish species requiring access to both marine and freshwater habitats to complete their life cycles. Furthermore, the sub and intertidal zones of estuaries provide niche habitats and the environmental conditions needed, to support the spawning, nursery and foraging requirements of numerous species of commercial, recreational and conservation value.

This study aimed to uniquely focus on the most abundant, vulnerable and understudied life stages of fish utilising the tidal Thames and collect data which will start to fill this significant knowledge gap. ELHS have a limited ability to swim against the river flow, and thus, rely on low flow refuge areas and/or the synchronised utilisation of tides to govern their distribution within the estuary. As ELHS fish experience elevated sensitivity to poor water quality, construction noise and channel encroachment, this study aimed to enhance the level of knowledge pertaining to how ELHS fish utilise the three-dimensional space of the Thames Estuary over time, to offer vital evidence that currently constrains effective management, robust impact assessment and sustainable development practice in the Tideway and throughout the estuaries of northern Europe.

London's sewerage system designed in the 1850s is a combined system carrying both foul and surface water. During periods of wet weather, the system discharges untreated sewage into the River Thames to prevent flooding elsewhere. When originally built this happened rarely, but now London's combined sewer overflows (CSOs) open more than fifty times a year. The Thames Tideway Tunnel, currently under construction, will capture and store the sewage which currently discharges into the Thames removing this pollution from the river and improving water quality.

As well as enhancing the temporal and spatial understanding of ELHS fish utilisation of the Thames Estuary, the study aimed to provide an essential pre-Thames Tideway Tunnel baseline. This baseline can be used to compare ecological improvements such as fish abundance and biodiversity and can be temporally tracked against significant future betterments in water quality. Furthermore, it is intended that the knowledge gained from this research will allow effective management decisions to be made to further improve conditions for aquatic ecology in the tidal Thames in the context of future development.

In addition to the scientific and conservation purpose of this study, local volunteers have been involved in the survey work throughout, in an effort to inspire Londoners about the ecological value and importance of, the tidal Thames.

2 Methodology

The project focused on three sites distributed along the tidal part of the river; Putney (upper), Blackfriars (mid) and Greenwich (lower) (See Figure 2.1). Putney and Greenwich were the focal sites where a multi-method approach incorporating seine netting, intertidal netting and mid-channel sampling using ichthyoplankton trawl nets was applied. The Blackfriars site was used for citizen science monitoring where a more simplified foreshore-based methodology was used. Sampling took place during spring tides (approximately every two weeks), from April through to October and was conducted over a two-year period in 2017 and 2018.

At each focal site both foreshore and mid-channel sampling took place.

Figure 2.1: Survey sites. Blue: Putney; Red: Blackfriars; green: Greenwich.

2.1 Foreshore Sampling

At both focal sites (Greenwich and Putney), on every survey date, the foreshore sampling included both intertidal and seine netting.

2.1.1 Intertidal netting

For four hours either side of low tide, a 3m x 1.5m rectangular intertidal net with a 1.5 mm mesh was deployed at the margins of the river (Figure 2.2). The net was deployed by one side of the net being held stationary at the edge of the water, while a second person walked the net out to either a 3m distance perpendicular to the water line or knee-height (whichever is the first limiting factor). The second person then swept the net back to the shore, against the flow of the tide. The net was then inspected for ELHS fish, any found were placed into oxygenated buckets for later identification and sampling. Water velocity was measured between each netting. The number of intertidal nettings per day varied between one and twenty, due to the number of fish caught. This variation in effort was accounted for by calculating catch per unit effort (CPUE) in the final analysis.

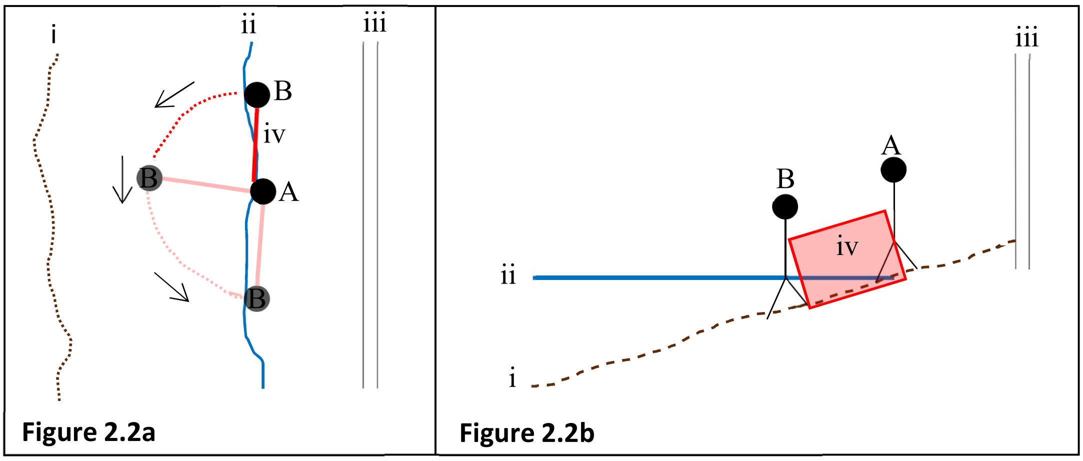

Figure 2.2a shows an aerial schematic of the intertidal netting, Figure 2.2b shows a cross section schematic of the intertidal netting. (i = lower tidal limit, ii = water line, iii = river wall, iv = intertidal net, A = PERSON A, B=PERSON B)

2.1.2 Seine netting

During low tide slack, a ten-metre seine net with 3 mm knotless mesh was deployed by hand by two people. The net was walked out to hip height or a distance of 3m perpendicular to shore (whichever came first) and was deployed parallel to the foreshore. The net was slowly walked back to the foreshore while drawing the ends together to create a U-shaped curtain of net to catch the fish (Figure 2.3). Any fish caught were washed into a central segment before being carefully transferred using hand nets into oxygenated water in buckets on the foreshore for further processing.

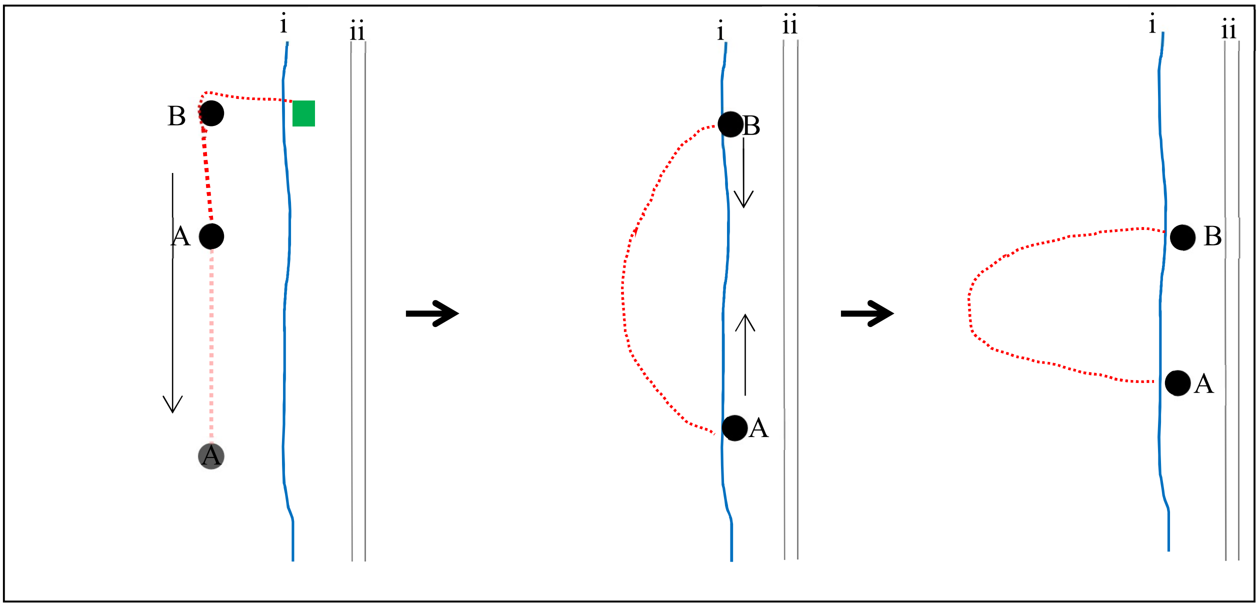

Figure 2.3 shows an aerial schematic of the seine netting. (i = water line, iii = river wall, A = PERSON A, B=PERSON B)

2.2 Midchannel Sampling

Every other spring tide, mid-channel sampling, in the form of ichthyoplankton netting would be conducted at each focal side. Concurrent with the foreshore sampling, ichthyoplankton netting was conducted for approximately 4 hours (covering at least the last 1.5 hours of the ebb tide and the first 1.5 hours of the flood tide) while tied to either the PLA Putney Passive Debris Collector (PDC) for the Putney sampling site or PLA Greenwich barge for the Greenwich sampling site (Figure 3). One ichthyoplankton net was deployed at the surface of the water and the other deployed at a depth of approximate 2m (Figure 2.4) using a weighted depressor. The ichthyoplankton nets had a 250 µm mesh narrowing into a cod end, with a 1.5m total length. The opening of the net was maintained by a 30 cm square steel collar and rope cradle, with a Hydro-bios 438 110 mechanical flow meter for horizontal operations attached to calculate the volume of water sampled. Each net (surface and 2m) was deployed for a total of 5 minutes with the start and end flows noted. Upon recovery the contents of the cod end were washed into a marked bucket of water for further processing. Up to 5 netting events (a netting event included one surface and one 2 m ichthyoplankton net deployed) occurred in the 2 hours before / after low water.

Water quality information including temperature, salinity and dissolved oxygen was measured during each netting both at the surface and at an approximate depth of 2m using a YSI Professional series Pro 2030.

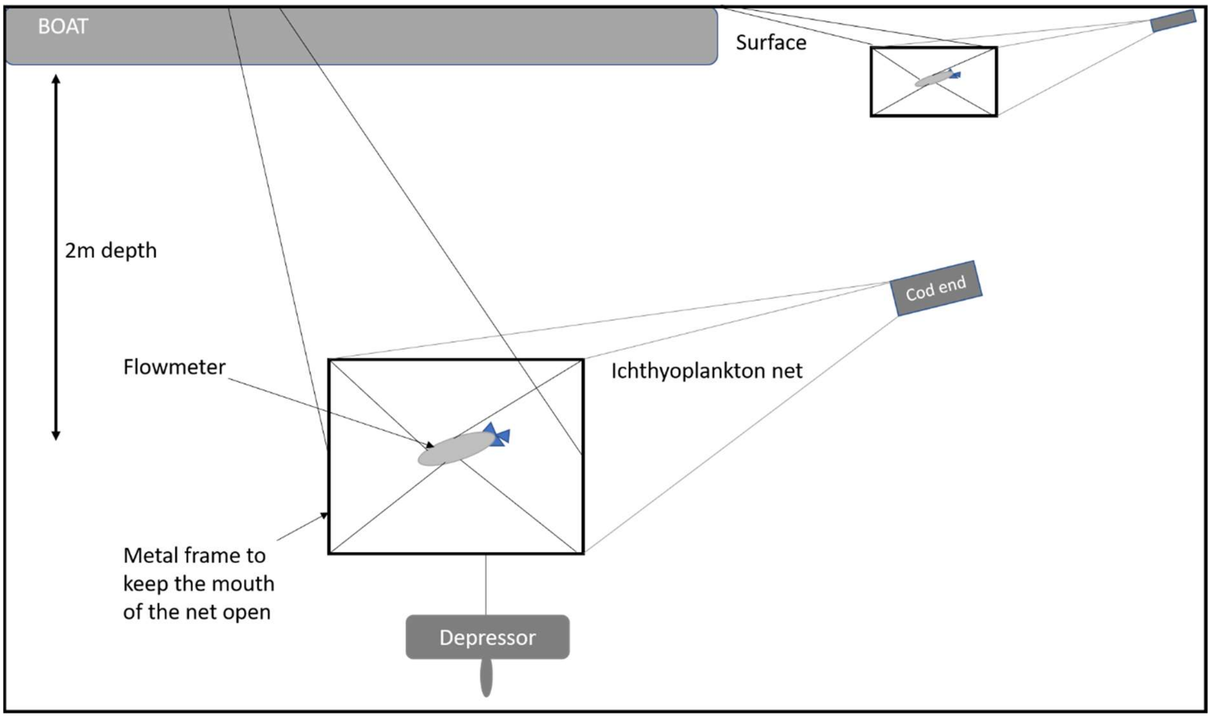

Figure 2.4: a schematic showing the surface and 2m depth ichthyoplankton nets deployed from a rib for mid-channel sampling.

2.3 Processing of catch

Data was collected on all juvenile fish species encountered during the sampling, except for threatened species, such as the Critically Endangered European eel (*Anguilla anguilla*) and Twaite Shad (*Alossa fallax*), or species protected under the Wildlife and Countryside Act including the long-snouted seahorse (*Hippocampus guttulatus*) and short-snouted seahorse (*Hippocampus hippocampus*). If any of these species were caught, they were released immediately back into the tidal Thames and no samples were taken.

The catch from each netting event was processed separately, during or just after the sampling period.

2.3.1 Foreshore samples

When *fewer* than 100 individual fish were caught, the survey team identified all remaining ELHS fish and fixed up to 35 individuals of each species for each netting. All the remaining fish were counted, recorded and released back into the Thames.

When over 100 individual fish were caught, a random but representative subsample of the total catch was taken with a hand net and removed to a separate container. The remaining fish from the catch were released without processing. By counting the number of hand nets used to remove all the fish from the holding container, a rough estimate of the proportion of fish in the subsample compared to the total catch was made.

2.3.2 Mid-channel samples

Due to the challenging nature of working on a small research boat, the samples collected from the mid-channel were only briefly examined to record and release any species of conservation concern and adults / large juveniles. The samples were then examined to assess the quantity of fish, if over 100 fish, the subsampling procedure explained above was conducted. Once these criteria were satisfied, the rest of the sample was fixed for further analysis.

2.3.3 Fixing procedure

The larval fish to be fixed were gathered in a single hand net which was dipped into clove oil solution to humanely euthanise the fish. The sample was then transferred to a sample pot, clearly labelled and fixed 4% formaldehyde.

The fixed fish were sent to Bournemouth University for species identification, enumeration, length measurement and assessment of ontogenetic development stage.

2.3 Laboratory Analysis

All larval fish were washed in freshwater and viewed using a zoom binocular microscope to define species identity using the keys of Pinder (2001) and Munk & Nielsen (2005) for freshwater and marine species respectively. Individual fish were measured to the nearest 0.5 mm using either an eye-piece mounted graticule or a pair of Mahr digital callipers. In addition to fish length (recorded as total length or fork length for species with a concave caudal fin), the ontogenetic stage of development of each individual was also noted in accordance with staging models proposed by Pinder (2001; 2004).

2.4 Citizen Science

At least four times over the survey season each year, six members of the public would be invited to help conduct a citizen science survey from the foreshore at Blackfriars. These surveys were run for just one hour before and one hour after low tide to coincide with the surveys at the focal locations. Intertidal nettings only were conducted from the foreshore. All fish caught were identified, measured and released back into the tidal Thames. No fish were fixed for further analysis from this survey site.

3 Results

33 survey days were conducted in 2017 and 2018, 22 of which included mid-channel surveys and 31 of which included foreshore surveys between March and October (Table 3.1). Total effort included a total of 512 mid-channel nettings, 708 intertidal nettings and 116 seine nettings.

Table 3.1. A summary table of the survey effort during the 2017 and 2018 juvenile fish surveys.

Date	Putney	Greenwich
21/03/2017	Foreshore and Mid-channel	Foreshore only
03/04/2017	Foreshore only	Foreshore and Mid-channel
19/04/2017	Foreshore and Mid-channel	Foreshore only
02/05/2017	Foreshore only	Foreshore and Mid-channel
17/05/2017	Foreshore and Mid-channel	Foreshore only
31/05/2017	Foreshore only	Foreshore and Mid-channel
16/06/2017	Foreshore and Mid-channel	Foreshore only
28/06/2017	Foreshore only	Foreshore and Mid-channel
14/07/2017	Foreshore and Mid-channel	Foreshore only
27/07/2017	Foreshore only	Foreshore and Mid-channel
11/08/2017	Foreshore and Mid-channel	Foreshore only
29/08/2017	Foreshore only	Foreshore and Mid-channel
13/09/2017	Foreshore and Mid-channel	Foreshore only
26/09/2017	Foreshore only	Foreshore and Mid-channel
11/10/2017	Foreshore and Mid-channel	Foreshore only
26/10/2017	Foreshore only	Foreshore and Mid-channel
05/03/2018	Mid-channel only	No survey
20/03/2018	Mid-channel only	No survey
05/04/2018	Foreshore and Mid-channel	Foreshore only
20/04/2018	Foreshore only	Foreshore and Mid-channel
04/05/2018	Foreshore and Mid-channel	Foreshore only
21/05/2018	Foreshore only	Foreshore and Mid-channel
05/06/2018	Foreshore and Mid-channel	Foreshore only
18/06/2018	Foreshore only	Foreshore and Mid-channel
04/07/2018	Foreshore and Mid-channel	Foreshore only
17/07/2018	Foreshore only	Foreshore and Mid-channel
02/08/2018	Foreshore and Mid-channel	Foreshore only
15/08/2018	Foreshore only	Foreshore and Mid-channel
30/08/2018	Foreshore and Mid-channel	Foreshore only
13/09/2018	Foreshore only	Foreshore and Mid-channel
1/10/2018	Foreshore only	Foreshore only
16/10/2018	Foreshore only	Foreshore only
30/10/2018	Foreshore only	Foreshore only

Across the two-year study period, a total of 1,402 individual nettings (all methods combined) were conducted across the two survey sites (Greenwich and Putney). This survey effort produced a total catch of 8,263 individual fish, of which 47% were fixed and retained for laboratory. Table 3.2 provides an absolute overview of sample numbers, fish numbers and CPUE between years and between sampling methods. These data are further explored throughout Sections 3 to 6.

Table 3.2. Total number of samples by survey method and number of fish captured per year for Greenwich and Putney combined.

	Number of samples		Number of fish		CPUE	
	2017	2018	2017	2018	2017	2018
Ichthyoplankton Surface	154	110	107	161	0.69	1.46
Ichthyoplankton 2 m	155	103	121	209	0.78	2.03
Intertidal Net	380	339	2150	2567	5.66	7.57
Intertidal Seine	85	76	1636	1312	19.25	17.26
TOTAL	**774**	**628**	**4014**	**4249**	**5.19**	**6.77**

3.1 Species list by site and survey method

A total of 24 fish species (excluding hybrids) were recorded among both sites over the two-year sampling period (Table 3.3). A total of 1,055 fish comprising 19 species were recorded at Greenwich. Eight of these species were classed as freshwater fish species, with freshwater fish comprising 10.2 % of the total fish captured (Table 3.3). A total of 7,206 fish comprising 20 species (excluding hybrids) were recorded at Putney. Twelve of these species were classed as freshwater fish species, with freshwater fish comprising 28.1 % of the total fish captured (Table 3.3).

Table 3.3. Total number of each species captured by each survey method for Greenwich and Putney (both years combined). Freshwater fish species are highlighted blue.

Year	Greenwich (2017 + 2018)					Putney (2017 + 2018)					
Number of samples	46	40	173	41	300	64	63	163	38	328	628
Survey method	Ich S	Ich 2m	IN	S	TOTAL GREENWICH	Ich S	Ich 2m	IN	S	TOTAL PUTNEY	GRAND TOTAL
Common Goby *Pomatoschistus microps*	41	31	66	109	**247**	0	6	2076	1007	**3089**	**3336**
Flounder *Platichthys flesus*	10	67	8	22	**107**	2	4	844	717	**1567**	**1674**
Roach *Rutilus rutilus*	1	0	12	3	**16**	9	0	650	220	**879**	**895**
3-spined Stickleback *Gasterosteus aculeatus*	0	1	25	17	**43**	1	0	403	136	**540**	**583**
Bass *Dicentrarchus labrax*	29	9	88	88	**214**	27	13	68	186	**294**	**508**
Smelt *Osmerus eperlanus*	73	130	24	8	**235**	61	54	0	3	**118**	**353**
Dace *Leuciscus leuciscus*	0	0	9	3	**12**	0	0	189	132	**321**	**333**
Perch *Perca fluviatilis*	0	0	14	1	**15**	0	1	32	118	**151**	**166**
Sand Goby *Pomatoschistus minutus*	5	7	4	4	**20**	0	2	83	37	**122**	**142**
Eel *Anguilla anguilla*	0	2	31	65	**98**	1	2	10	4	**17**	**115**
Chub *Leuciscus cephalus*	1	0	8	1	**10**	4	0	30	9	**43**	**53**
Common Bream *Abramis brama*	0	0	4	4	**8**	0	0	7	22	**29**	**37**

Year	Greenwich (2017 + 2018)					Putney (2017 + 2018)					
Number of samples	46	40	173	41	300	64	63	163	38	328	628
Survey method	Ich S	Ich 2m	IN	S	TOTAL GREENWICH	Ich S	Ich 2m	IN	S	TOTAL PUTNEY	GRAND TOTAL
Sand Smelt *Atherina presbyter*	0	0	3	9	**12**	0	0	9	10	**19**	**31**
Thinlip Mullet *Chelon ramada*	0	0	1	8	**9**	0	0	2	0	**2**	**11**
Minnow *Phoxinus phoxinus*	0	0	0	0	**0**	1	0	5	0	**6**	**6**
9-spined Stickleback *Pungitius pungitius*	0	0	2	1	**3**	0	0	2	0	**2**	**5**
Bullhead *Cottus gobio*	0	0	0	0	**0**	0	0	3	0	**3**	**3**
Sprat *Sprattus sprattus*	1	1	1	0	**3**	0	0	0	0	**0**	**3**
Barbel *Barbus barbus*	0	0	0	0	**0**	0	0	1	0	**1**	**1**
Mirror Carp *Cyprinus carpio*	0	0	0	0	**0**	0	0	0	1	**1**	**1**
Pike *Esox lucius*	0	0	0	0	**0**	0	0	1	0	**1**	**1**
Pipefish *Syngnathus sp.*	0	0	0	1	**1**	0	0	0	0	**0**	**1**
Roach x Bream Hybrid	0	0	0	0	**0**	0	0	1	0	**1**	**1**
Short Snouted Seahorse *Hippocampus hippocampus*	0	0	0	1	**1**	0	0	0	0	**0**	**1**
Tench *Tinca tinca*	0	0	0	1	**1**	0	0	0	0	**0**	**1**
TOTAL NUMBER	**161**	**248**	**300**	**346**	**1055**	**106**	**82**	**4416**	**2602**	**7206**	**8261**
TOTAL CPUE	**3.50**	**6.20**	**1.73**	**8.44**	**3.52**	**1.66**	**1.30**	**27.09**	**68.47**	**21.97**	**13.15**
SPECIES RICHNESS (excluding hybrids)					**19**					**20**	**24**

3.2 Greenwich summary

3.2.1 Greenwich species composition

The total number of fish captured by each survey method at Greenwich for both 2017 and 2018 are shown in Table 3.4 below. A total of 511 fish comprising 18 species were recorded during 2017, and a total of 544 fish comprising 16 species were recorded during 2018. (Table 3.4, Figure 3.1 to Figure 3.4).

Table 3.4. Total number of fish captured by each survey method for 2017 and 2018 at Greenwich.

Year	2017					2018					
Number of samples	71	72	203	46	392	46	40	173	41	300	692
Survey method	Ich S	Ich 2m	IN	S	TOTAL 2017	Ich S	Ich 2m	IN	S	TOTAL 2018	GRAND TOTAL
Common Goby *Pomatoschistus microps*	20	17	54	102	**193**	21	14	12	7	**54**	**247**
Smelt *Osmerus eperlanus*	0	2	0	0	**2**	73	128	24	8	**233**	**235**
Bass *Dicentrarchus labrax*	18	8	54	62	**142**	11	1	34	26	**72**	**214**
Flounder *Platichthys flesus*	5	47	2	10	**64**	5	20	6	12	**43**	**107**
Eel *Anguilla anguilla*	0	1	19	16	**36**	0	1	12	49	**62**	**98**
3-spined Stickleback *Gasterosteus aculeatus*	0	0	23	17	**40**	0	1	2	0	**3**	**43**
Sand Goby *Pomatoschistus minutus*	0	3	1	3	**7**	5	4	3	1	**13**	**20**
Roach *Rutilus rutilus*	0	0	1	0	**1**	1	0	11	3	**15**	**16**
Perch *Perca fluviatilis*	0	0	1	0	**1**	0	0	13	1	**14**	**15**
Dace *Leuciscus leuciscus*	0	0	1	0	**1**	0	0	8	3	**11**	**12**
Sand Smelt *Atherina presbyter*	0	0	2	2	**4**	0	0	1	7	**8**	**12**
Chub *Leuciscus cephalus*	1	0	1	1	**3**	0	0	7	0	**7**	**10**
Thinlip Mullet *Chelon ramada*	0	0	1	7	**8**	0	0	0	1	**1**	**9**
Common Bream *Abramis brama*	0	0	1	2	**3**	0	0	3	2	**5**	**8**
9-spined Stickleback *Pungitius pungitius*	0	0	1	0	**1**	0	0	1	1	**2**	**3**
Sprat *Sprattus sprattus*	1	1	1	0	**3**	0	0	0	0	**0**	**3**
Pipefish *Syngnathus sp.*	0	0	0	1	**1**	0	0	0	0	**0**	**1**
Short Snouted Seahorse *Hippocampus hippocampus*	0	0	0	1	**1**	0	0	0	0	**0**	**1**
Tench *Tinca tinca*	0	0	0	0	**0**	0	0	0	1	**1**	**1**
Barbel *Barbus barbus*	0	0	0	0	**0**	0	0	0	0	**0**	**0**
Bullhead *Cottus gobio*	0	0	0	0	**0**	0	0	0	0	**0**	**0**
Minnow *Phoxinus phoxinus*	0	0	0	0	**0**	0	0	0	0	**0**	**0**
Mirror Carp *Cyprinus carpio*	0	0	0	0	**0**	0	0	0	0	**0**	**0**
Pike *Esox lucius*	0	0	0	0	**0**	0	0	0	0	**0**	**0**
Roach x Bream Hybrid	0	0	0	0	**0**	0	0	0	0	**0**	**0**

Year	2017					2018					
Number of samples	71	72	203	46	392	46	40	173	41	300	692
Survey method	Ich S	Ich 2m	IN	S	TOTAL 2017	Ich S	Ich 2m	IN	S	TOTAL 2018	GRAND TOTAL
TOTAL NUMBER	45	79	163	224	511	116	169	137	122	544	1055
TOTAL CPUE	0.63	1.10	0.80	4.87	1.30	2.52	4.23	0.79	2.98	1.81	1.52
SPECIES RICHNESS					18					16	19

Figure 3.1 provides a summary of the species composition across all sampling methods at Greenwich in 2017 only. In terms of absolute numbers, five species dominated, making up 93 percent of the total catch. In order of abundance, these were common goby (38%), bass (28%), flounder (12%), three-spined stickleback (8%) and eel (7%). Each of the remaining 13 species represented no more than 1.4% of the total catch.

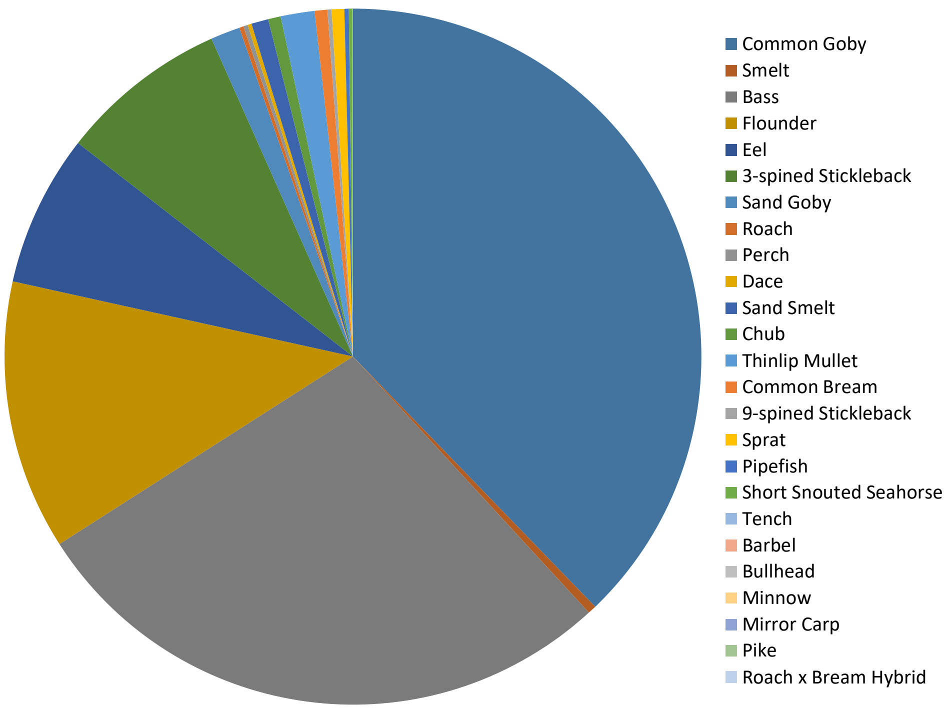

Figure 3.1. Proportion of each fish species captured at Greenwich (all survey methods combined) during 2017 (n = 511).

Of the 511 individual fish captured at Greenwich in 2017, only 24% of fish were caught from the sub-tidal zone (ichthyoplankton surface and 2m combined), compared to 76% from the inter-tidal zone (intertidal net and intertidal seine combined). Species richness was also considerably greater in the intertidal zone. Here, 17 species were recorded, compared to just eight from the sub-tidal zone (Figure 3.2).

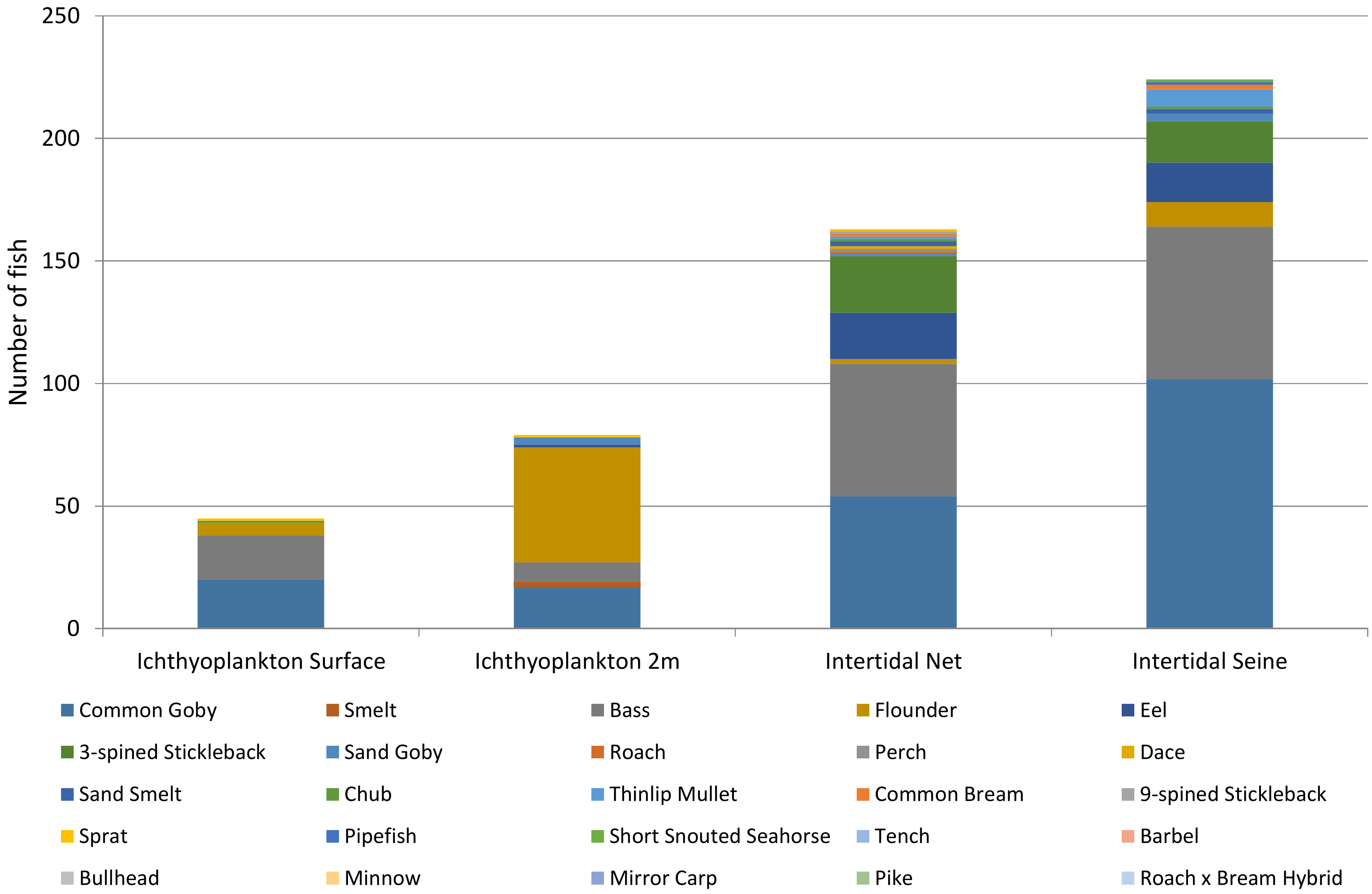

Figure 3.2. Proportion of each fish species captured at Greenwich (split by survey method) during 2017 (n = 511).

Figure 3.3 provides a summary of the species composition across all sampling methods at Greenwich in 2018 only. In terms of absolute numbers, five species dominated, making up 85 percent of the total catch. In order of abundance, these were smelt (43%), bass (13%), eel (11%), common goby (10%) and flounder (8%). Each of the remaining 11 species represented no more than 3% of the total catch.

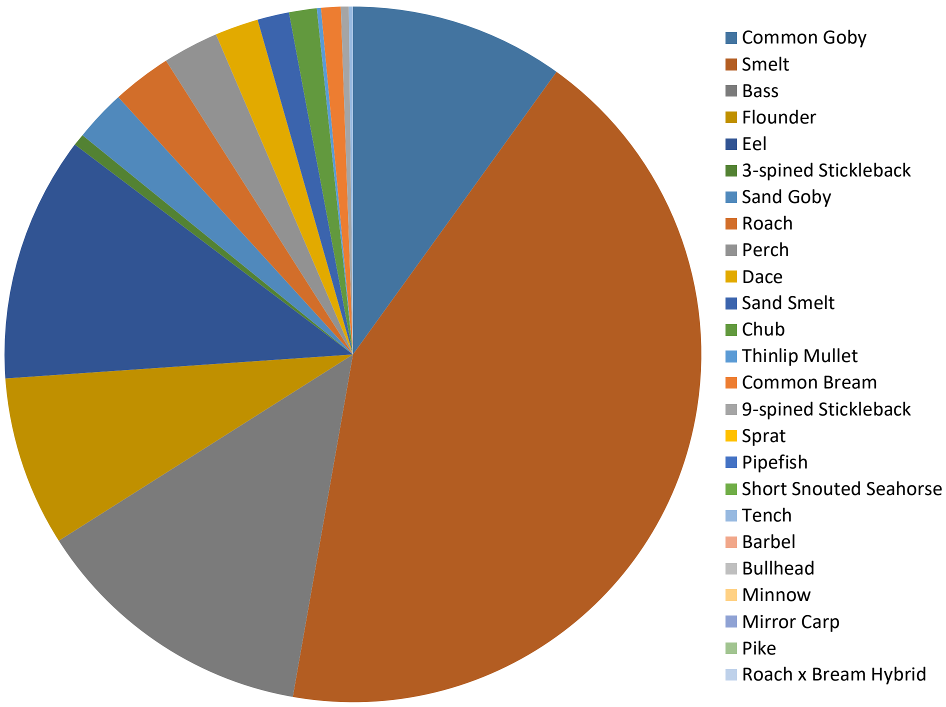

Figure 3.3. Proportion of each fish species captured at Greenwich (all survey methods combined) during 2018 (n = 544).

Of the 544 individual fish captured at Greenwich in 2018, fish numbers were split more evenly between sub-tidal and inter-tidal zones, where 52% and 48% of the catch was recorded respectively. Consistent with observations from 2017 at Greenwich, species richness was considerably greater in the intertidal zone. Here, 18 species were recorded, compared to just eight from the sub-tidal zone (Figure 3.4Figure 3.3).

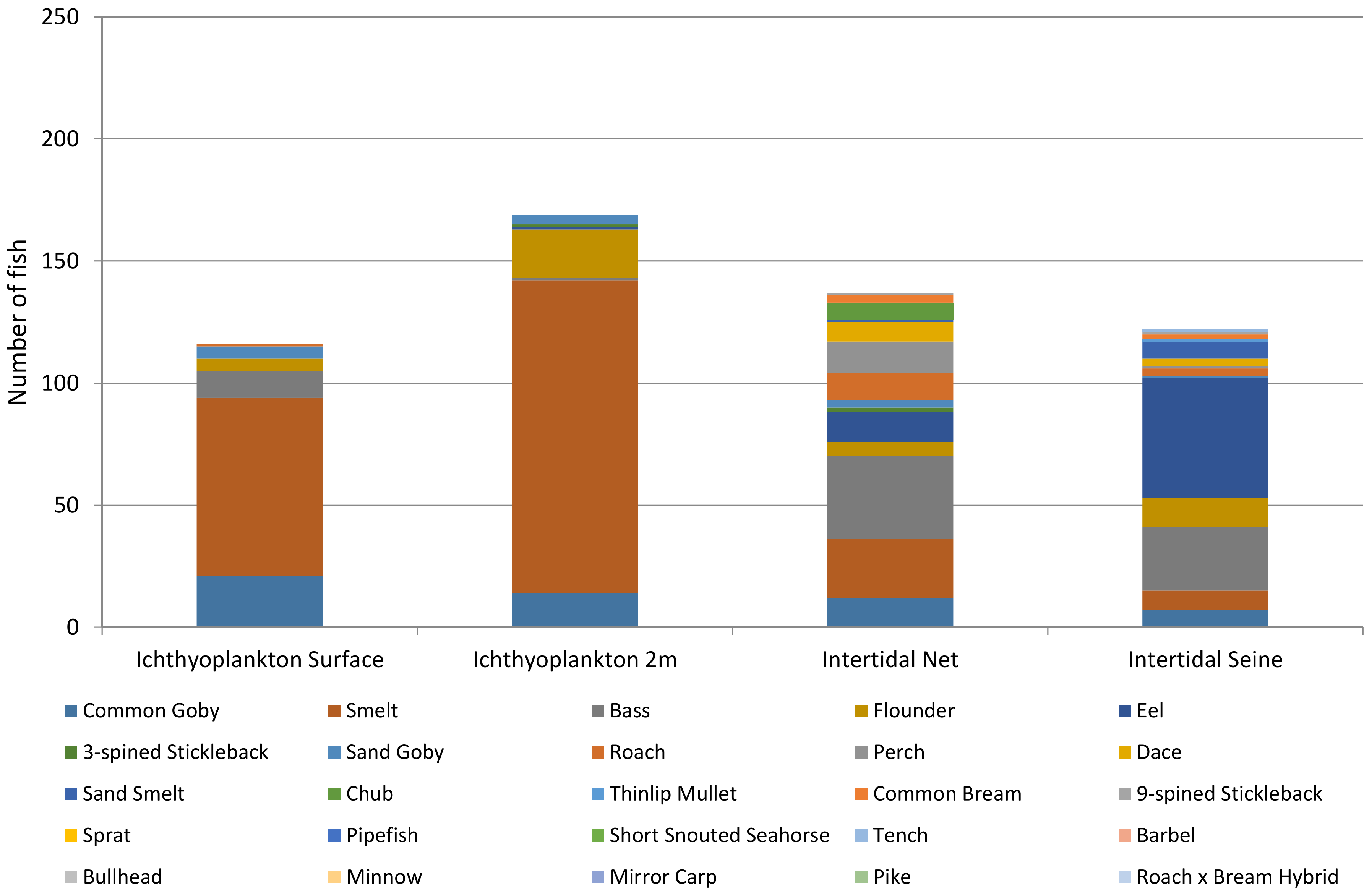

Figure 3.4. Proportion of each fish species captured at Greenwich (split by survey method) during 2018 (n = 544).

3.2.2 Greenwich temporal species richness

To further examine temporal species richness at Greenwich, all data (sub-tidal and inter-tidal) were combined. In 2017, across sampling dates, species richness ranged between one and 14. Reduced species richness was observed in March, with peaks evident in May and June (Figure 3.5). In 2018, species richness ranged between 0 and 21 (Figure 3.6). Temporal patterns of species richness were generally observed to be consistent with 2017, with the lowest diversity (0) recorded in April and 14 species recorded in May and June. In 2018, a further peak of 21 species was recorded in August.

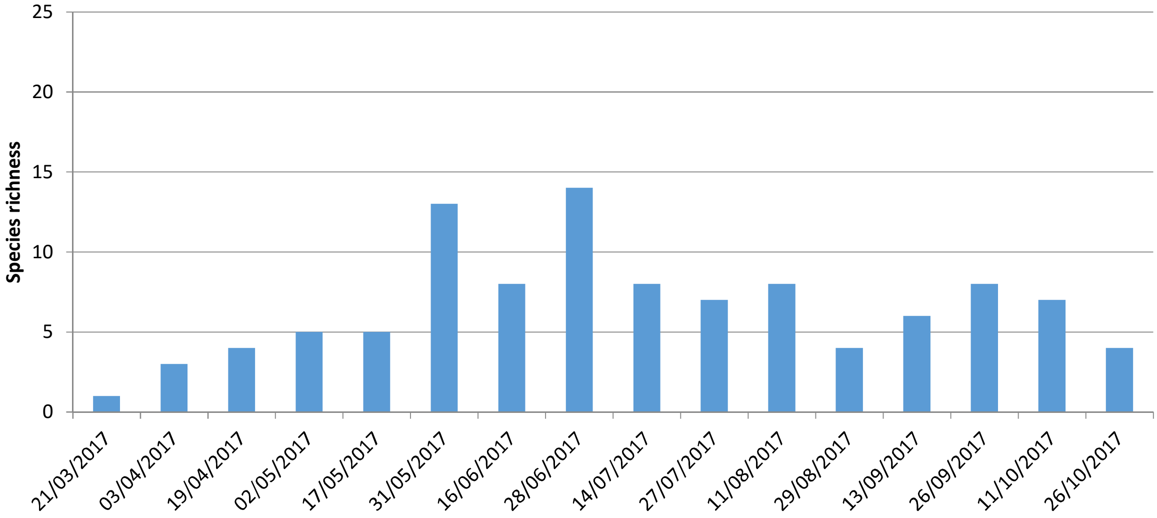

Figure 3.5. Temporal species richness (CPUE) for Greenwich during 2017.

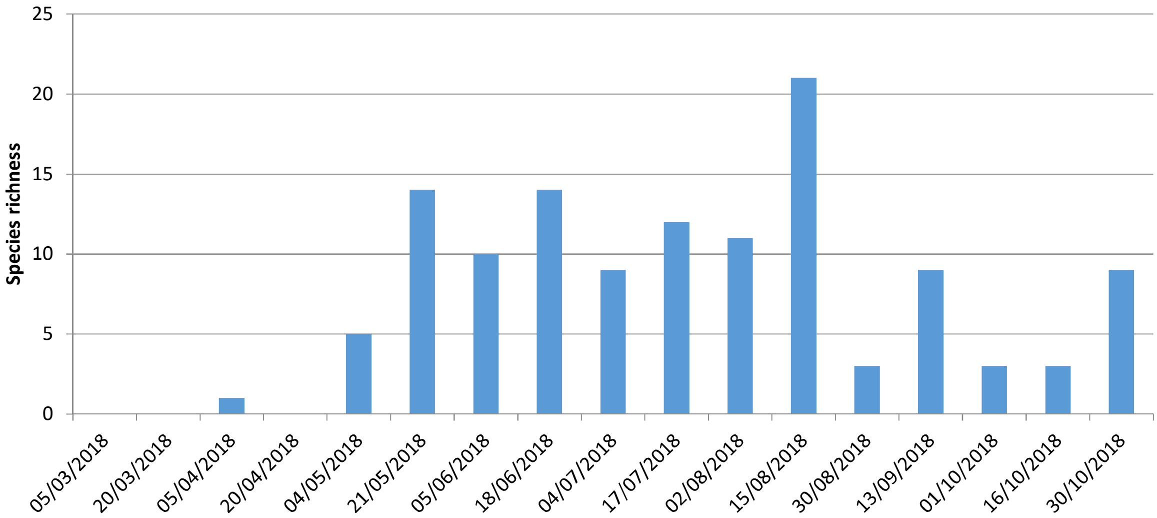

Figure 3.6. Temporal species richness (CPUE) for Greenwich during 2018.

3.3 Putney summary

3.3.1 Putney species composition

The total number of fish captured by each survey method at Putney for both 2017 and 2018 are shown in Table 3. below. A total of 3,500 fish comprising 17 species (excluding hybrids) were recorded during 2017, and a total of 3,706 fish comprising 17 species were recorded during 2018. (Table 3.5, Figure 3.7 to Figure 3.10).

Table 3.5. Total number of fish captured by each survey method for 2017 and 2018 at Putney.

Year	2017					2018					
Number of samples	83	83	175	41	382	64	63	163	38	328	710
Survey method	Ich S	Ich 2m	IN	S	TOTAL 2017	Ich S	Ich 2m	IN	S	TOTAL 2018	GRAND TOTAL
Common Goby *Pomatoschistus microps*	0	6	1093	783	**1882**	0	0	983	224	**1207**	**3089**
Flounder *Platichthys flesus*	0	4	270	186	**460**	2	0	574	531	**1107**	**1567**
Roach *Rutilus rutilus*	0	0	135	87	**222**	9	0	515	133	**657**	**879**
3-spined Stickleback *Gasterosteus aculeatus*	1	0	307	95	**403**	0	0	96	41	**137**	**540**
Dace *Leuciscus leuciscus*	0	0	53	58	**111**	0	0	136	74	**210**	**321**
Bass *Dicentrarchus labrax*	15	13	63	164	**255**	12	0	5	22	**39**	**294**
Perch *Perca fluviatilis*	0	1	7	11	**19**	0	0	25	107	**132**	**151**
Sand Goby *Pomatoschistus minutus*	0	0	13	4	**17**	0	2	70	33	**105**	**122**
Smelt *Osmerus eperlanus*	41	17	0	0	**58**	20	37	0	3	**60**	**118**
Chub *Leuciscus cephalus*	0	0	13	5	**18**	4	0	17	4	**25**	**43**
Common Bream *Abramis brama*	0	0	5	10	**15**	0	0	2	12	**14**	**29**
Sand Smelt *Atherina presbyter*	0	0	9	8	**17**	0	0	0	2	**2**	**19**
Eel *Anguilla anguilla*	0	1	6	3	**10**	1	1	4	1	**7**	**17**
Minnow *Phoxinus phoxinus*	1	0	4	0	**5**	0	0	1	0	**1**	**6**
Bullhead *Cottus gobio*	0	0	3	0	**3**	0	0	0	0	**0**	**3**
9-spined Stickleback *Pungitius pungitius*	0	0	2	0	**2**	0	0	0	0	**0**	**2**
Thinlip Mullet *Chelon ramada*	0	0	2	0	**2**	0	0	0	0	**0**	**2**
Barbel *Barbus barbus*	0	0	0	0	**0**	0	0	1	0	**1**	**1**
Mirror Carp *Cyprinus carpio*	0	0	0	0	**0**	0	0	0	1	**1**	**1**
Pike *Esox lucius*	0	0	0	0	**0**	0	0	1	0	**1**	**1**
Roach x Bream Hybrid	0	0	1	0	**1**	0	0	0	0	**0**	**1**
Pipefish *Syngnathus sp.*	0	0	0	0	**0**	0	0	0	0	**0**	**0**
Short Snouted Seahorse *Hippocampus hippocampus*	0	0	0	0	**0**	0	0	0	0	**0**	**0**

Year	2017					2018					
Number of samples	83	83	175	41	382	64	63	163	38	328	710
Survey method	Ich S	Ich 2m	IN	S	TOTAL 2017	Ich S	Ich 2m	IN	S	TOTAL 2018	GRAND TOTAL
Sprat *Sprattus sprattus*	0	0	0	0	**0**	0	0	0	0	**0**	**0**
Tench *Tinca tinca*	0	0	0	0	**0**	0	0	0	0	**0**	**0**
TOTAL NUMBER	**58**	**42**	**1986**	**1414**	**3500**	**48**	**40**	**2430**	**1188**	**3706**	**7206**
TOTAL CPUE	**0.70**	**0.51**	**11.35**	**34.49**	**9.16**	**0.75**	**0.63**	**14.91**	**31.26**	**11.30**	**10.15**
SPECIES RICHNESS (excluding hybrids)					**17**					**17**	**20**

Figure 3.7 provides a summary of the species composition across all sampling methods at Putney in 2017 only. In terms of absolute numbers, five species dominated, making up 91 percent of the total catch. In order of abundance, these were common goby (54%), flounder (13%), three-spined stickleback (11%), bass (7%) and roach (6%). Each of the remaining 13 species represented no more than 3% of the total catch.

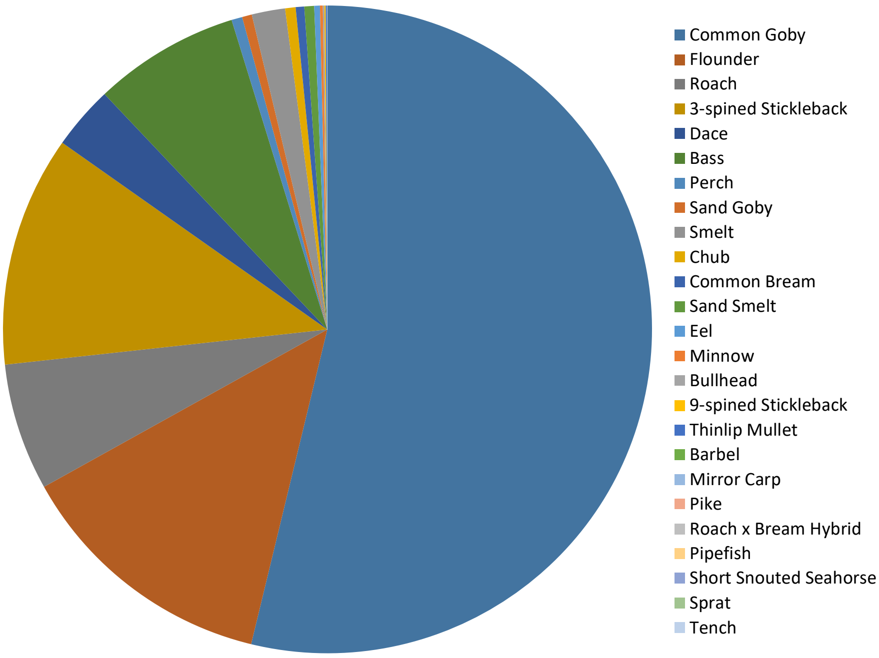

Figure 3.7. Proportion of each fish species captured at Putney (all survey methods combined) during 2017 (n = 3,500).

Of the 3,500 individual fish captured at Putney in 2017, only 3% were caught from the sub-tidal zone (Ichthyoplankton surface and 2m combined), compared to 97% from the inter-tidal zone (intertidal net and intertidal seine combined). Species richness was also considerably greater in the intertidal zone. Here, 17 species were recorded, compared to just eight from the sub-tidal zone (Figure 3.8).

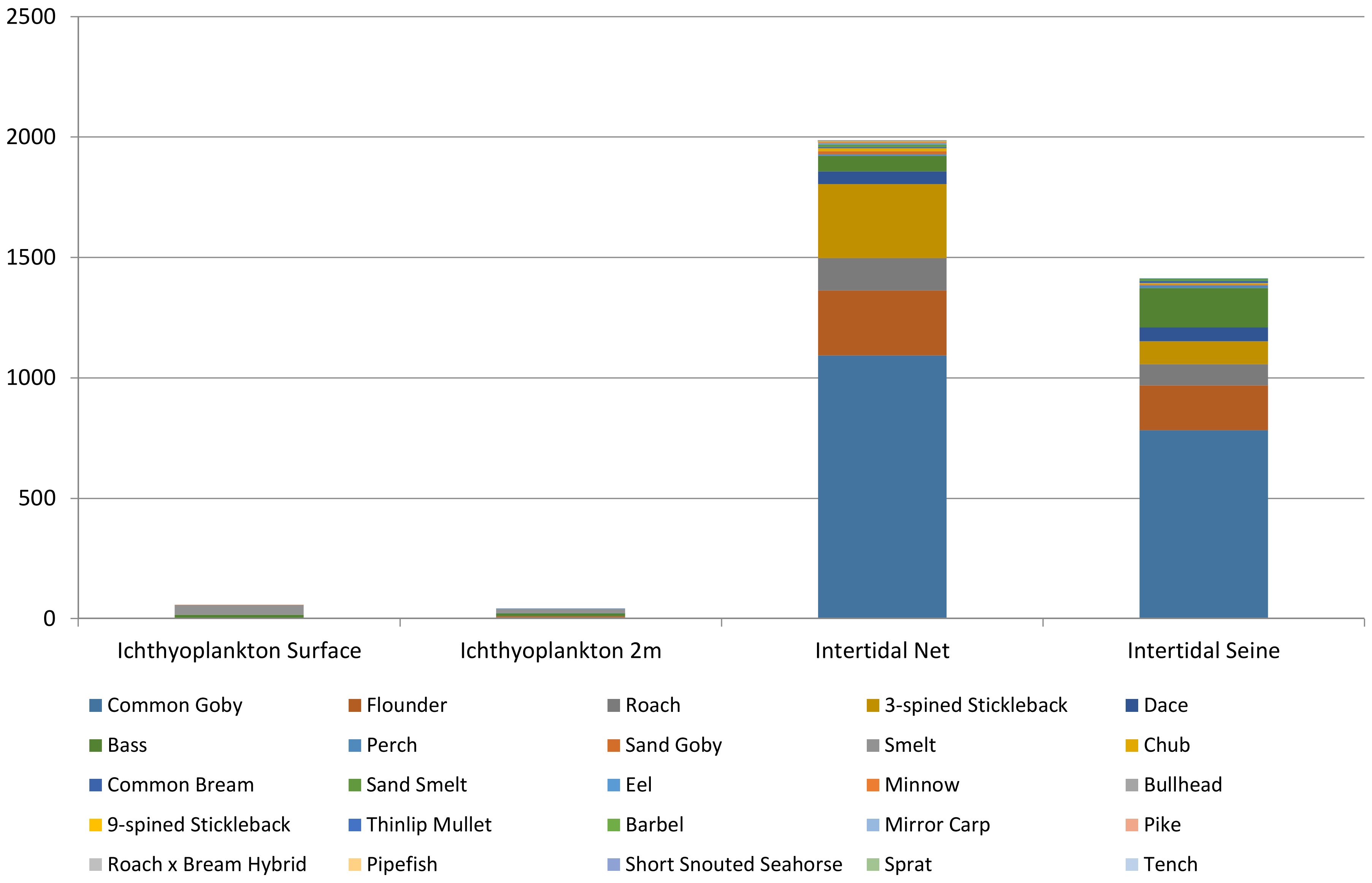

Figure 3.8. Proportion of each fish species captured at Putney (split by survey method) during 2017 (n = 3,500).

Figure 3.9 provides a summary of the species composition across all sampling methods at Putney in 2018 only. In terms of absolute numbers, four species dominated, making up 85.5 percent of the total catch. In order of abundance, these were common goby (32%), flounder (30%), roach (18%) and dace (5.5%). Each of the remaining 13 species represented no more than 4% of the total catch.

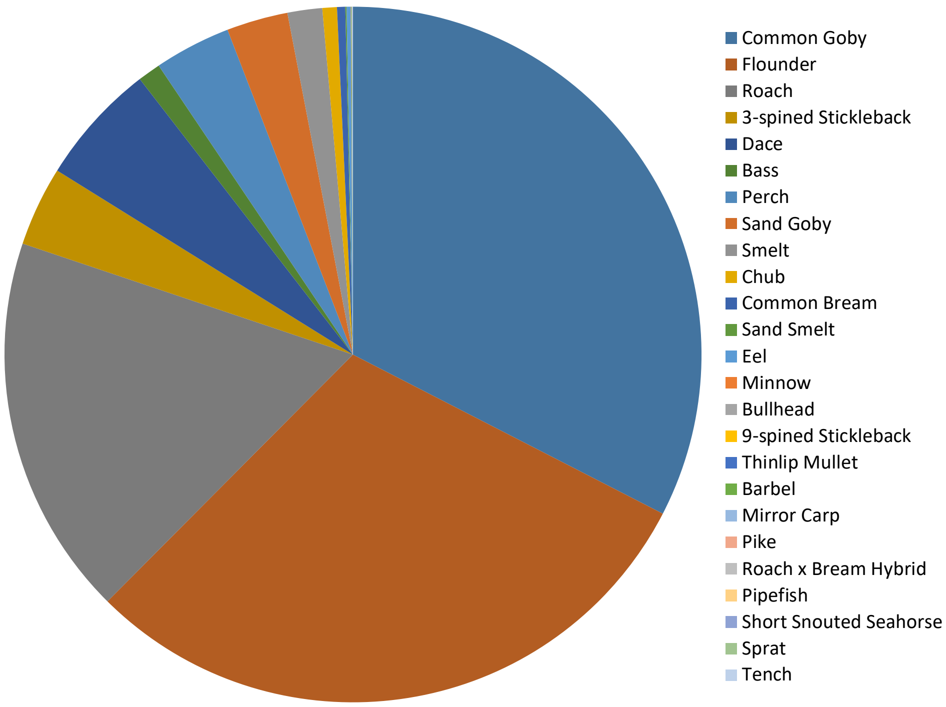

Figure 3.9. Proportion of each fish species captured at Putney (all survey methods combined) during 2018 (n = 3,706).

Of the 3,706 individual fish captured at Putney in 2018, only 2.5% of fish were caught from the sub-tidal zone (ichthyoplankton surface and 2m combined), compared to 97.5% from the inter-tidal zone (intertidal net and intertidal seine combined). Consistent with the 2017 sampling season, species richness was also considerably greater in the intertidal zone. Here, 17 species were recorded, compared to just seven from the sub-tidal zone (Figure 3.10).

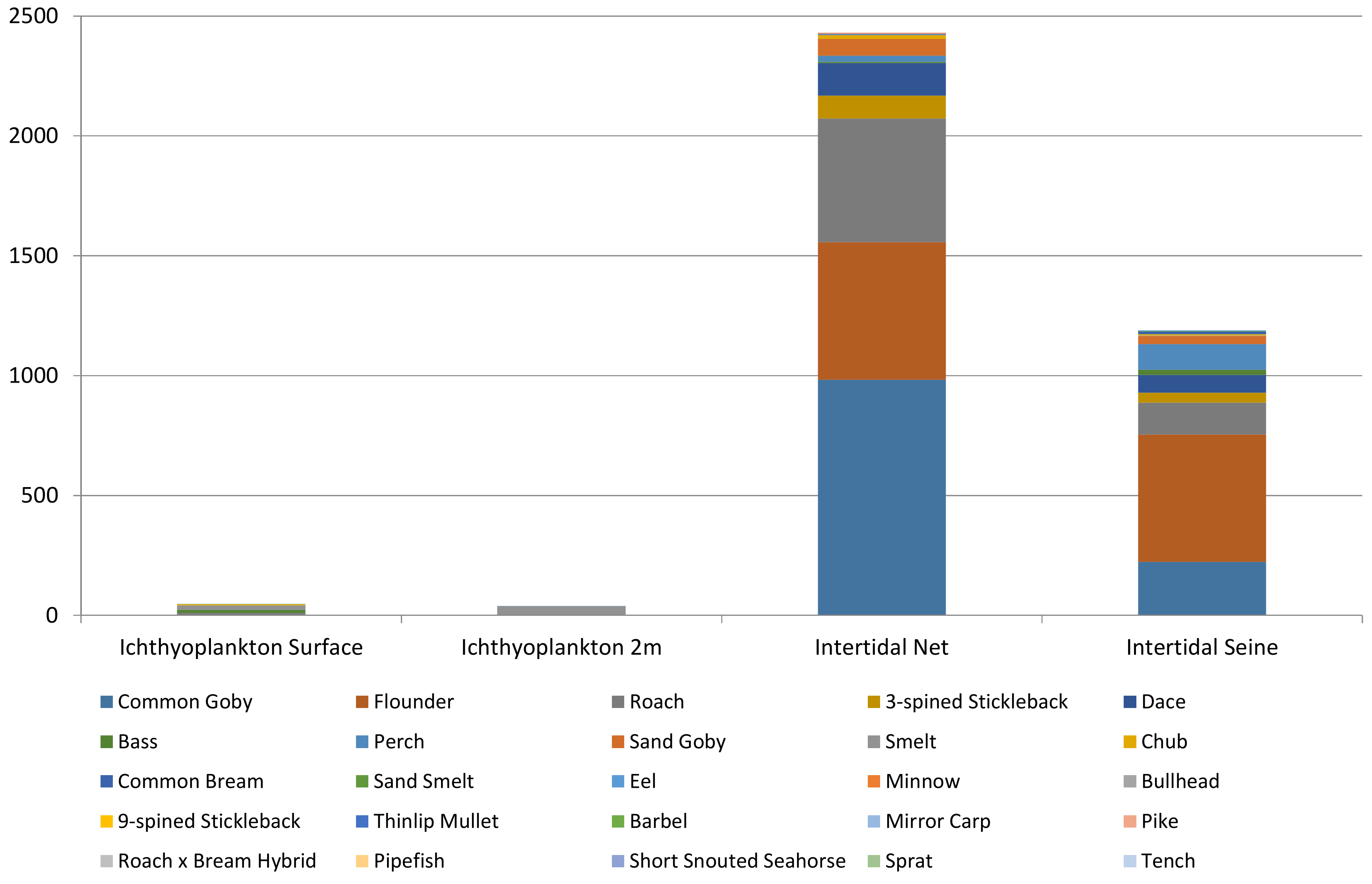

Figure 3.10. Proportion of each fish species captured at Putney (split by survey method) during 2018 (n = 3,706).

3.3.2 Putney temporal species richness

To further examine temporal species richness at Putney, all data (sub-tidal and inter-tidal) were combined. In 2017, across sampling dates, species richness ranged between two and 21. Reduced species richness was observed in March and April (maximum = two species), with species richness peaking at 21 in late June (Figure 3.11). In 2018, species richness ranged between 0 and 21 (Figure 3.12). Temporal patterns of species richness were observed to be generally consistent with 2017, with the lowest diversity (0) recorded in March and April and peaking at 21 in early August.

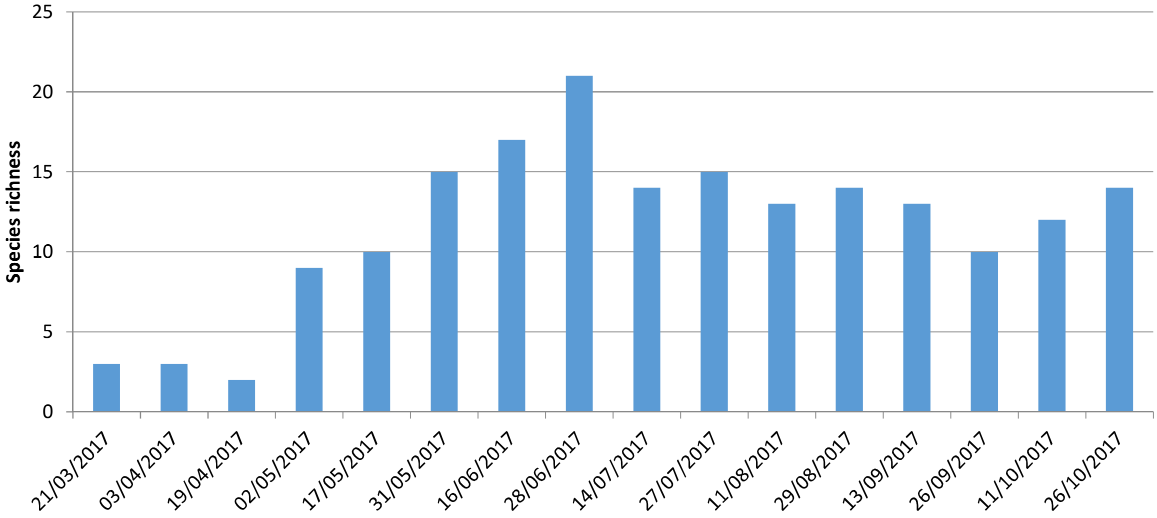

Figure 3.11. Temporal species richness (CPUE) for Putney during 2017.

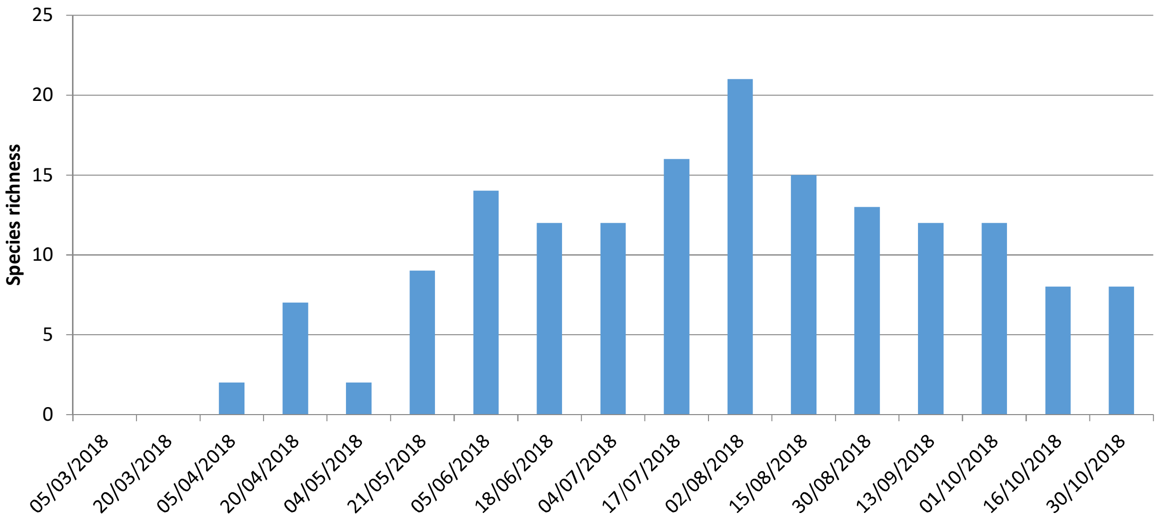

Figure 3.12. Temporal species richness (CPUE) for Putney during 2018.

4 Species Summary – Flounder

In Sections 4, 5 and 6, we have applied more detailed focus to flounder, smelt and bass respectively. These three species were selected based on their elevated commercial / conservation status and because satisfactory numbers were recorded, both temporally and spatially, to undertake meaningful statistical analyses. For each of these three species, the following results present:

- catch-per-unit-effort (CPUE) by date, site and sampling method;
- a temporal comparison of total numbers recorded from both sub-tidal (ichthyoplankton) and inter-tidal zones;
- Temporal and spatial length and growth; and
- Comparison of mean fish length between sites and sub-tidal (ichthyoplankton) and inter-tidal zones.

4.1 Flounder temporal abundance

Temporal Catch-Per-Unit-Effort (CPUE, calculated as the number of fish divided by the number of samples) of flounder for both sites over both years is shown in Figure 4.1 to Figure 4.4 below.

Note: temporal and spatial CPUE for individual intertidal methods (seine and nets) cannot be directly compared due to fundamental differences in sample area and efficiency. Likewise, comparison of ichthyoplankton CPUE versus intertidal CPUE is not valid. Ichthyoplankton samples (2m and surface) are however directly comparable across time and sites, due to consistency in the sampling method.

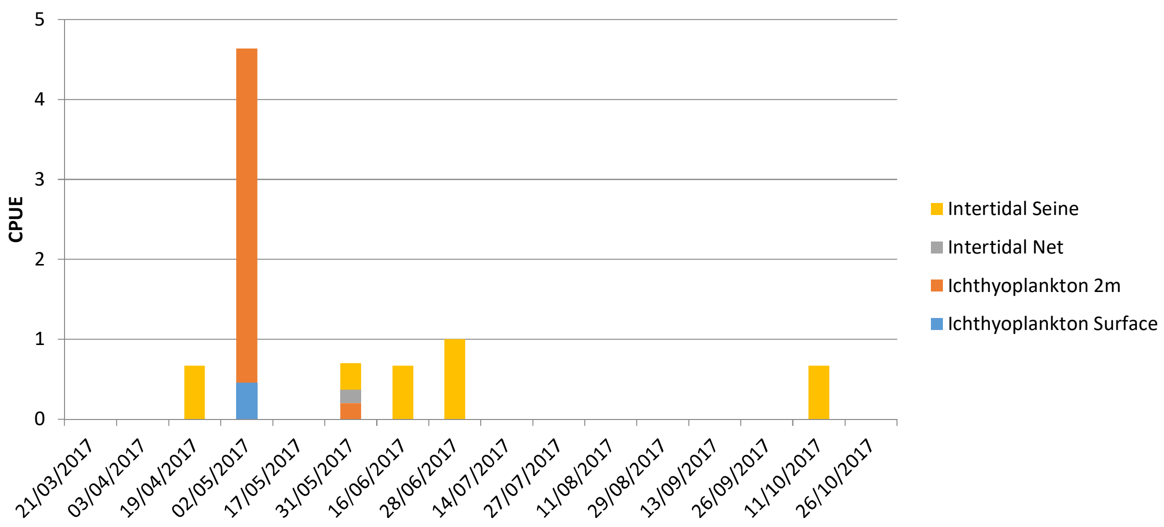

Figure 4.1. Temporal abundance (CPUE) of flounder at Greenwich during 2017.

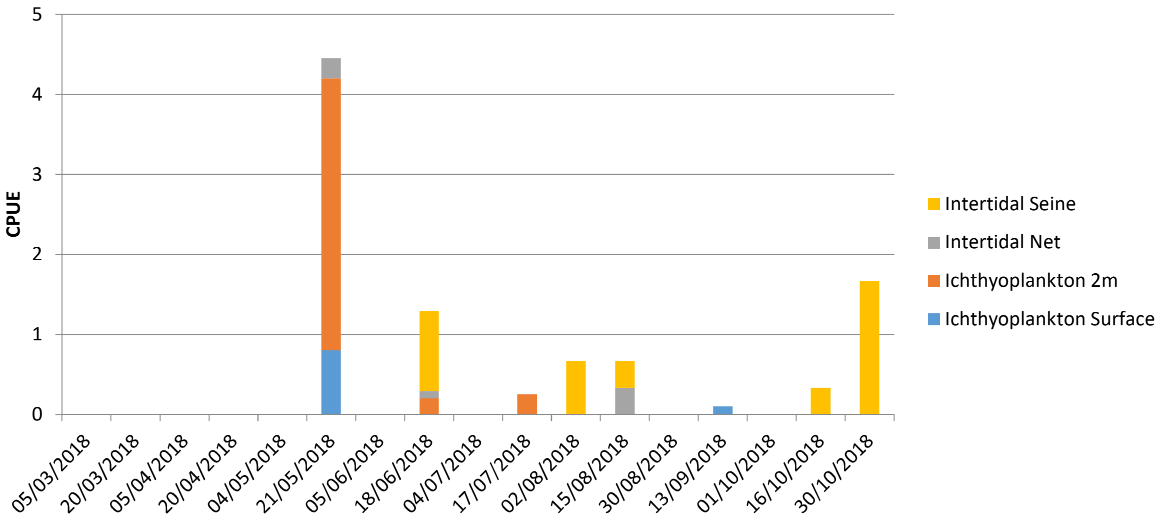

Figure 4.2. Temporal abundance (CPUE) of flounder at Greenwich during 2018.

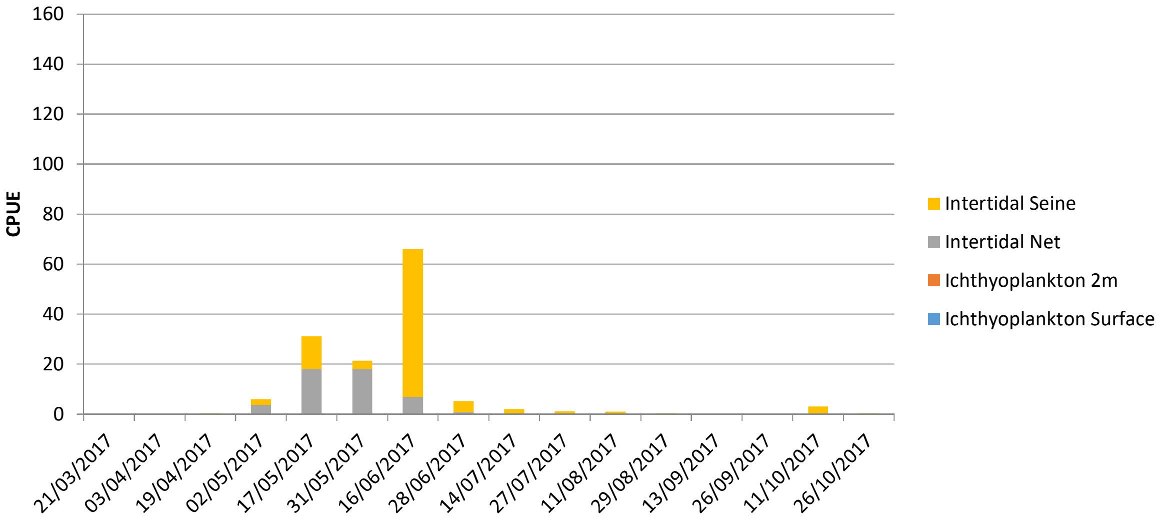

Figure 4.3. Temporal abundance (CPUE) of flounder at Putney during 2017.

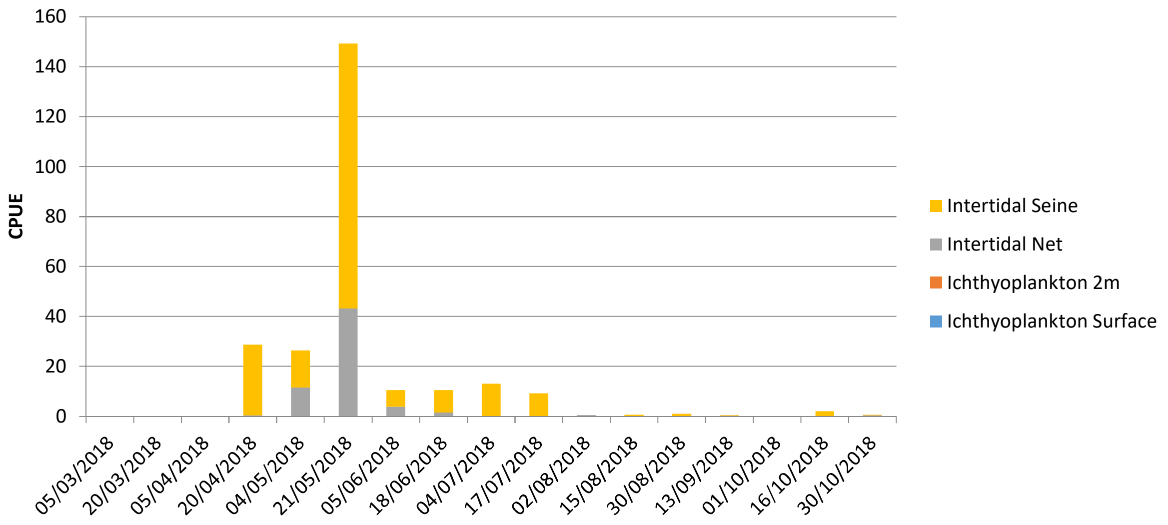

Figure 4.4. Temporal abundance (CPUE) of flounder at Putney during 2018.

4.2 Flounder spatial distribution

To understand temporal habitat utilisation of flounder, total abundance (i.e. absolute numbers of individuals recorded) was compared between sub-tidal (ichthyoplankton) and inter-tidal zones. Results are presented for both sites and both years (2017 & 2018) in Figure 4.5 to Figure 4.8 below. At Greenwich, in both years, the number of flounder captured from the sub-tidal zone peaked in May. Further upstream at Putney, flounder were only captured within the inter-tidal zone. These results are further explored and explained in Section 4.4.

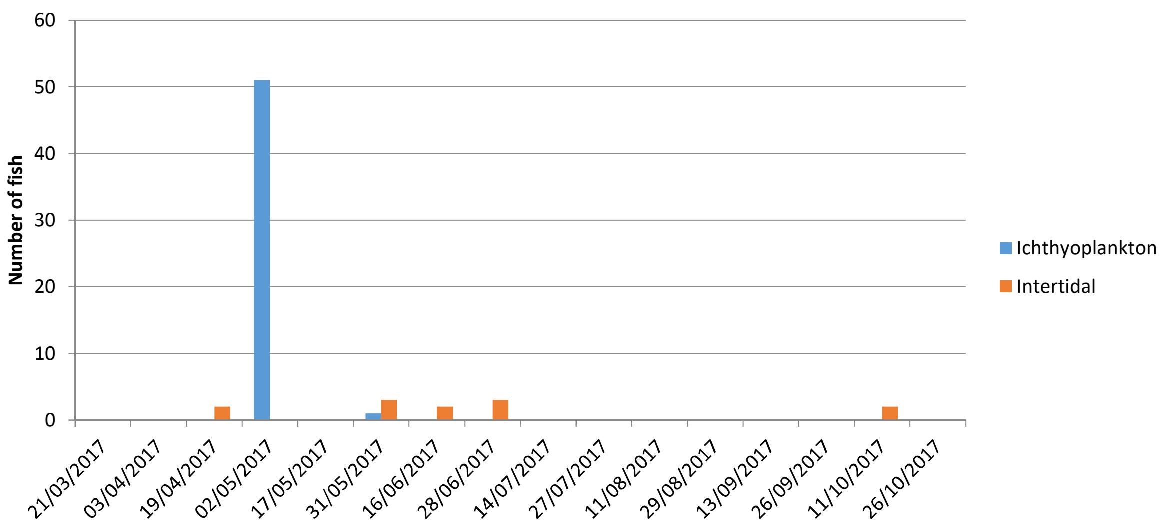

Figure 4.5. Temporal abundance of flounder at Greenwich during 2017, distributed between ichthyoplankton nets and intertidal nets.

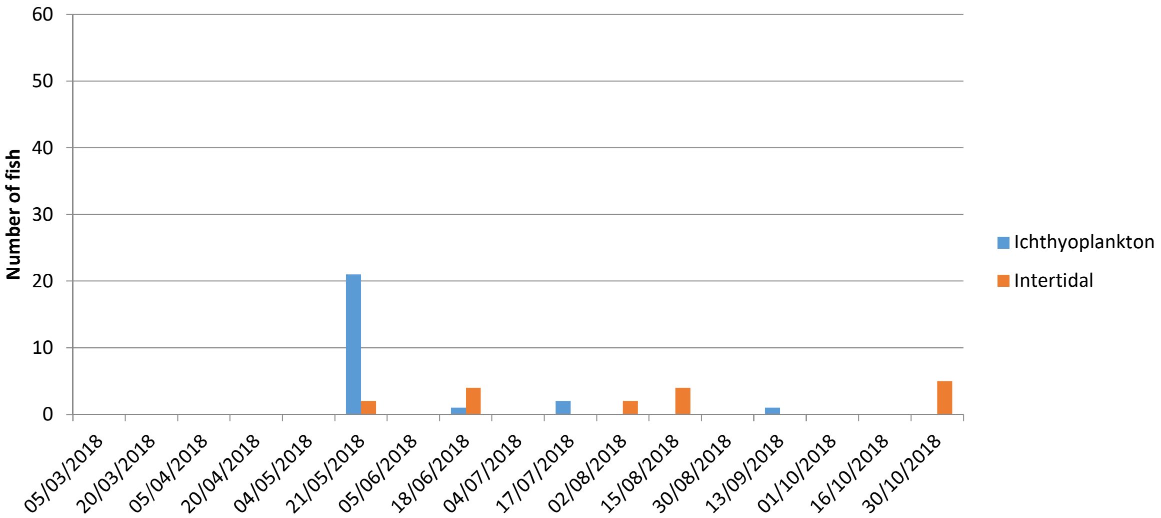

Figure 4.6. Temporal abundance of flounder at Greenwich during 2018, distributed between ichthyoplankton nets and intertidal nets.

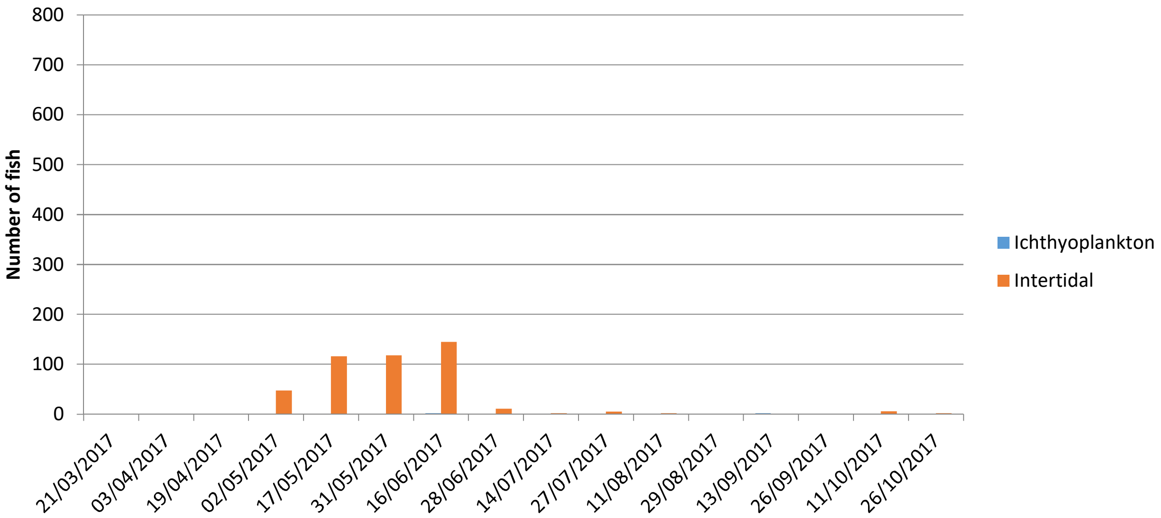

Figure 4.7. Temporal abundance of flounder at Putney during 2017, distributed between ichthyoplankton nets and intertidal nets.

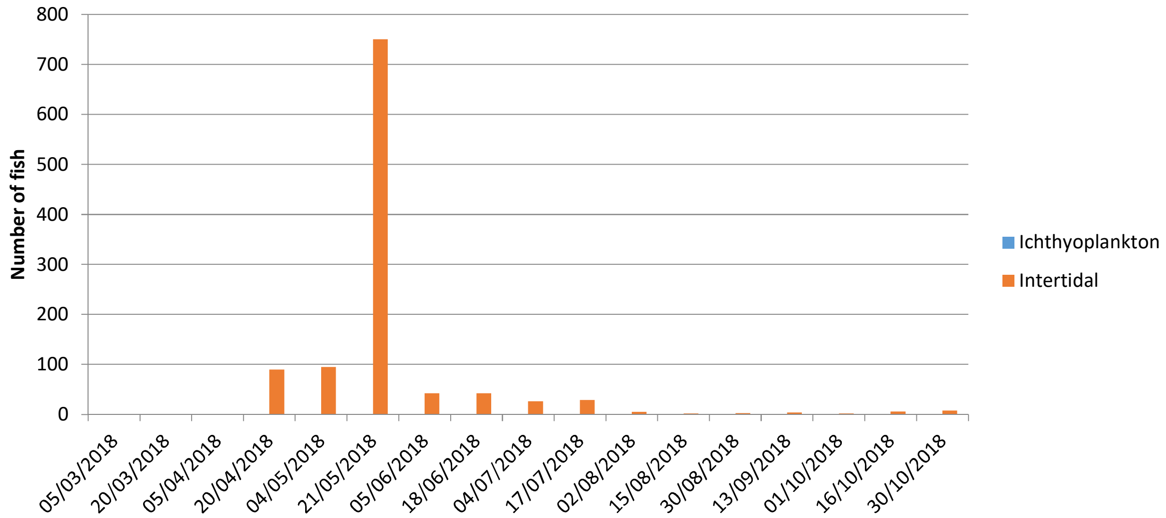

Figure 4.8. Temporal abundance of flounder at Putney during 2018, distributed between ichthyoplankton nets and intertidal nets.

4.3 Flounder length and growth

Mean length, inclusive of minimum and maximum values were calculated for all flounder recorded across all sampling methods. Figure 4.9 to Figure 4.12 present the results by site and year.

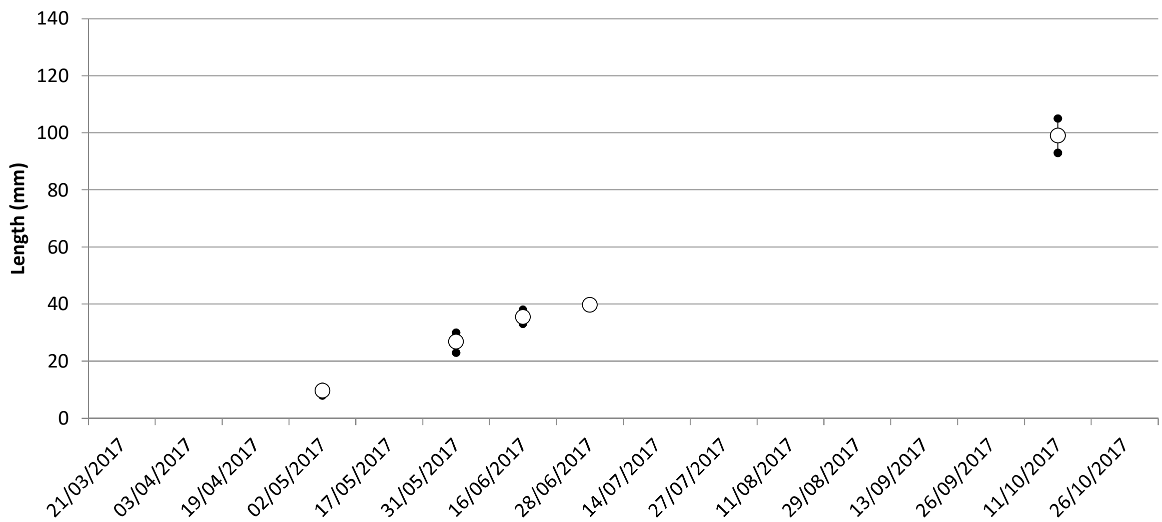

Figure 4.9. Mean, max and min length of 0+ flounder at Greenwich during 2017.

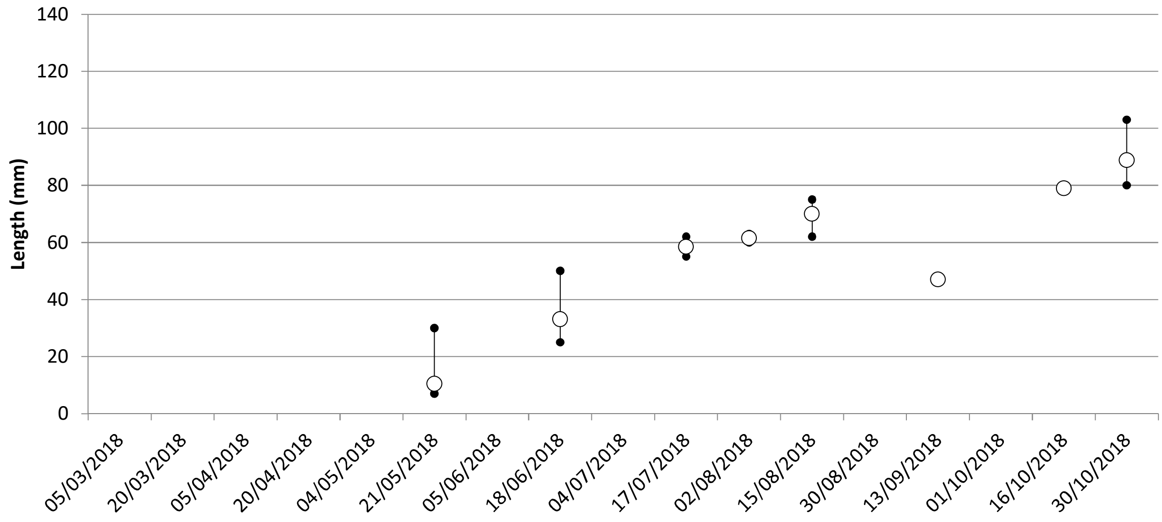

Figure 4.10. Mean, max and min length of 0+ flounder at Greenwich during 2018.

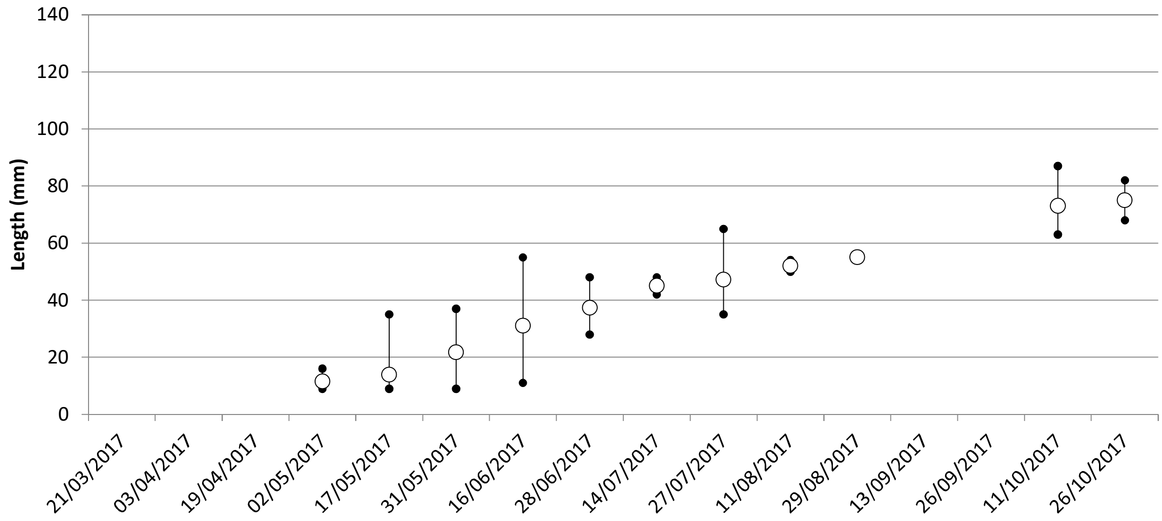

Figure 4.11. Mean, max and min length of 0+ flounder at Putney during 2017.

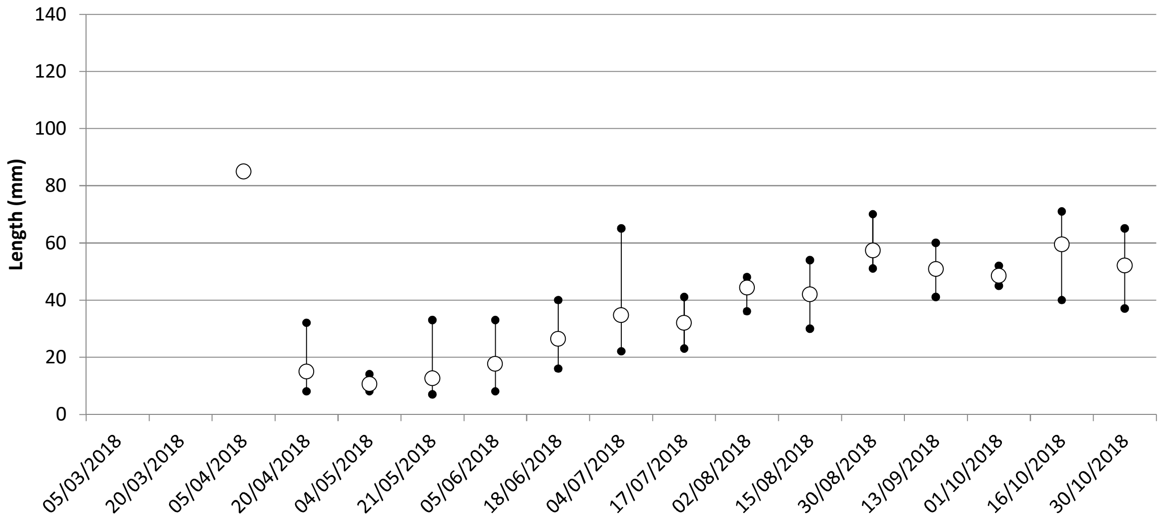

Figure 4.12. Mean, max and min length of 0+ flounder at Putney during 2018.

4.4 Flounder length comparison of ichthyoplankton versus intertidal

To examine whether fish size, or ontogenetic development stage of flounder (see discussion) had any influence on spatial (lateral) habitat utilisation, minimum and maximum length of flounder captured throughout each year are presented for sub-tidal (ichthyoplankton) and intertidal surveys at each site and each year Table 4.1. These data are further refined to compare mean length (± min/max) of flounder recorded between sub- and inter-tidal zones at both sites in 2017 and 2018 in Figure 4.13 and Figure 4.14 respectively.

Table 4.1. Min and Max length (mm) of flounder captured at Greenwich and Putney.

Site / Method	2017		2018	
	Min (mm)	Max (mm)	Min (mm)	Max (mm)
Greenwich - Ichthyoplankton	8	29	7	62
Greenwich - Intertidal	23	105	8	103
Putney - Ichthyoplankton	11	135	8	8
Putney - Intertidal	9	100	7	85

With the exception of the very small sample size from ichthyoplankton trawls at Putney (n=4 in 2017 and n=2 in 2018) (Figure 4.13), mean lengths of flounder captured in the sub-tidal zone (ichthyoplankton trawls) were significantly smaller than those fish captured in the inter-tidal zone. These differences were particularly pronounced at the Greenwich site in both 2017 and 2018.

The ontogenetic thresholds responsible for driving this habitat shift in flounder corresponded with a definitive metamorphic shift in body shape. This was at the point of departure from the symmetrical larval form when the second eye had migrated onto the top of the body. This also corresponded with the opening of the mouth, the first ingestion of exogenous food and a shift from pelagic to benthic habitat. Ontogenetic stage was a better predictor of habitat utilisation than fish length in flounder, with metamorphosis taking place between 9 – 10.5mm.

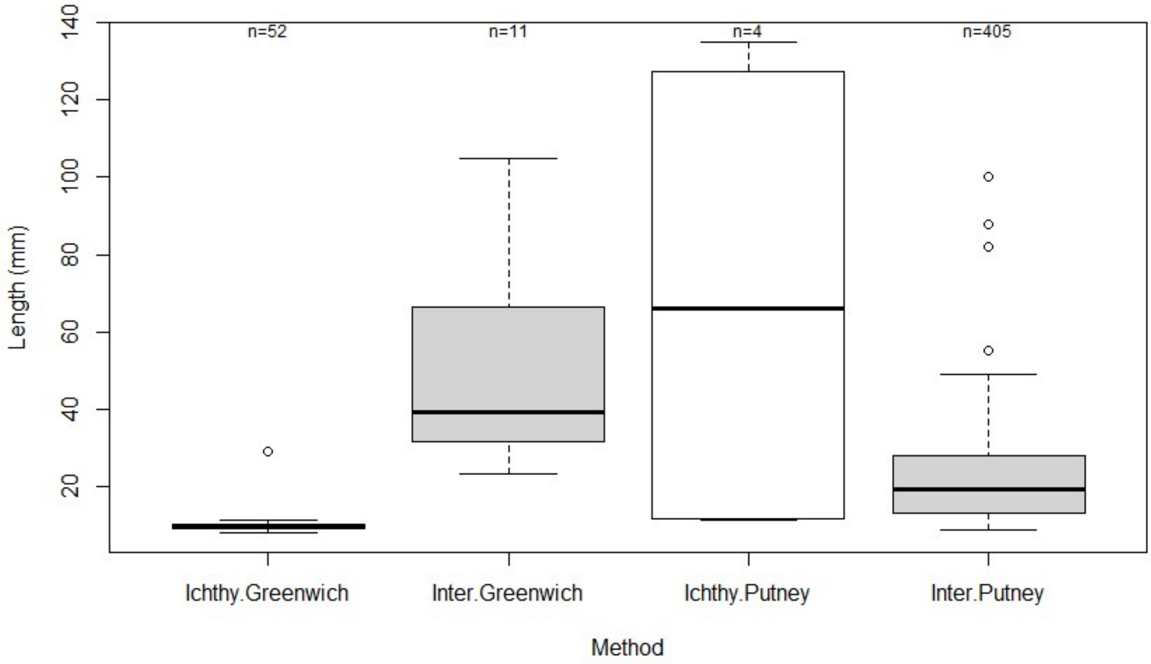

Figure 4.13. Boxplot of flounder length versus sampling method for both Greenwich and Putney during 2017. Ichthy = Ichthyoplankton, Inter = Intertidal.

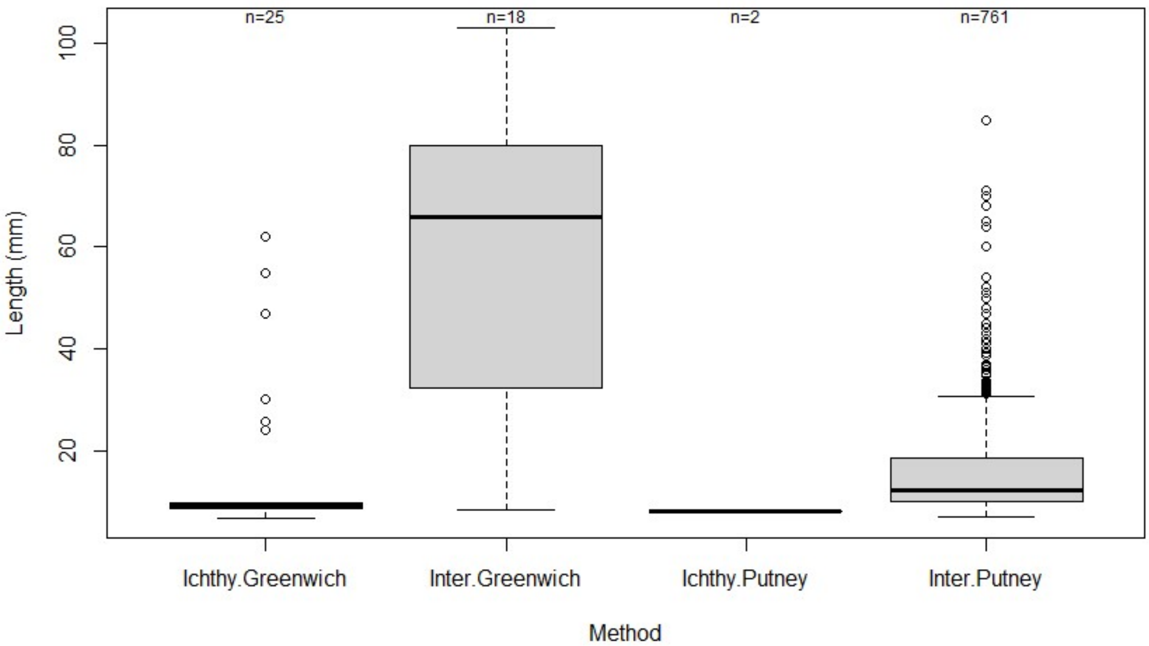

Figure 4.14. Boxplot of flounder length versus sampling method for both Greenwich and Putney during 2018. Ichthy = Ichtyoplankton, Inter = Intertidal.

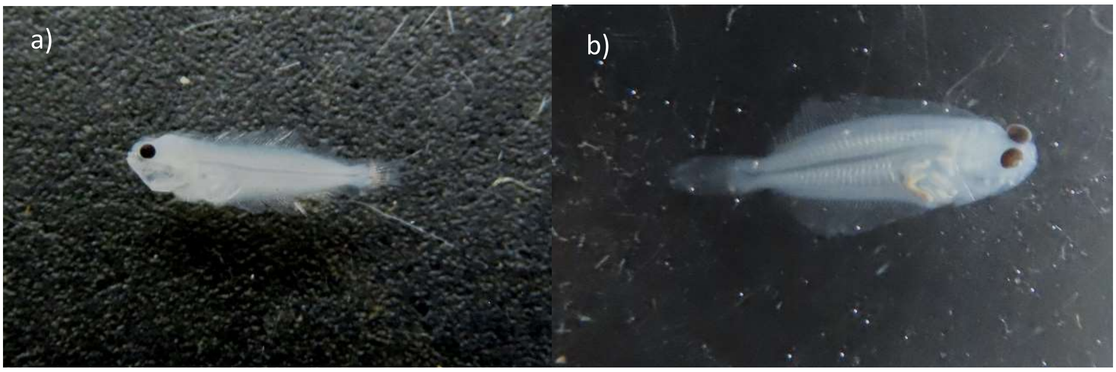

Figure 4.15. Photographs showing the different ontogenetic stages of flounder a) an ELHS flounder with eyes on both sides of its head b) an ELHS flounder whose eyes have migrated to the top of their head – note food visible in digestive tract.

5 Species Summary - Smelt

5.1 Smelt temporal abundance

Temporal Catch-Per-Unit-Effort (CPUE, calculated as the number of fish divided by the number of samples) of smelt for both sites over both years is shown in Figure 5.1 to Figure 5.4 below.

Note: temporal and spatial CPUE for individual intertidal methods (seine and nets) cannot be directly compared due to fundamental differences in sample area and efficiency. Likewise, comparison of ichthyoplankton CPUE versus intertidal CPUE is not valid. Ichthyoplankton samples (2m and surface) are however directly comparable across time and sites, due to consistency in the sampling method.

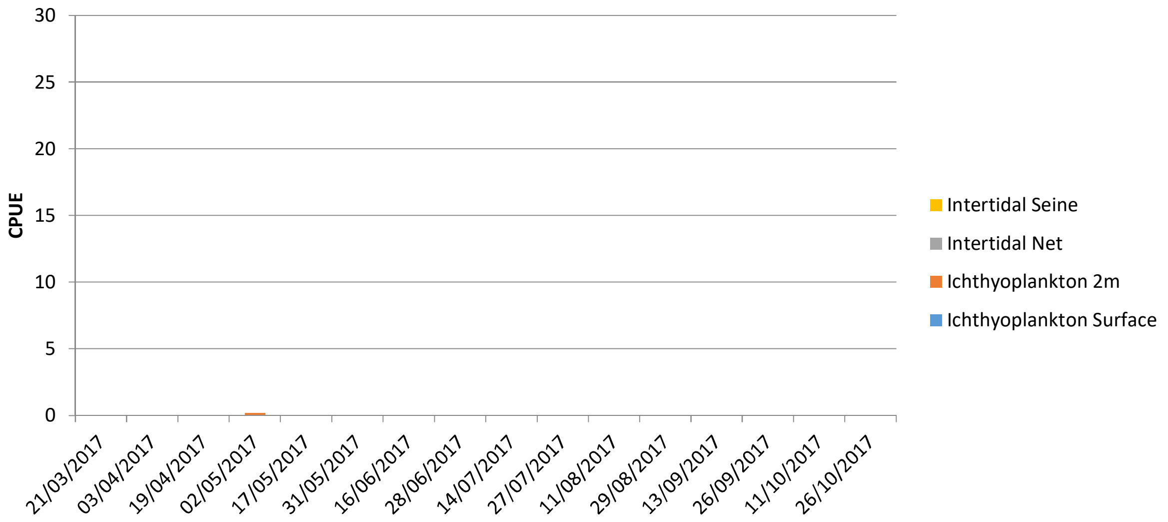

Figure 5.1. Temporal abundance (CPUE) of smelt at Greenwich during 2017.

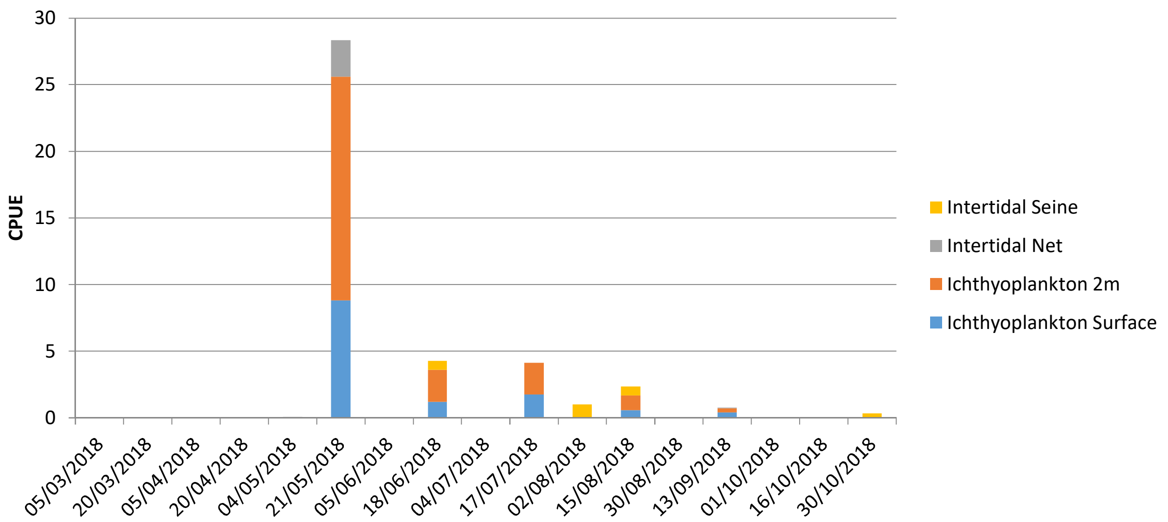

Figure 5.2. Temporal abundance (CPUE) of smelt at Greenwich during 2018.

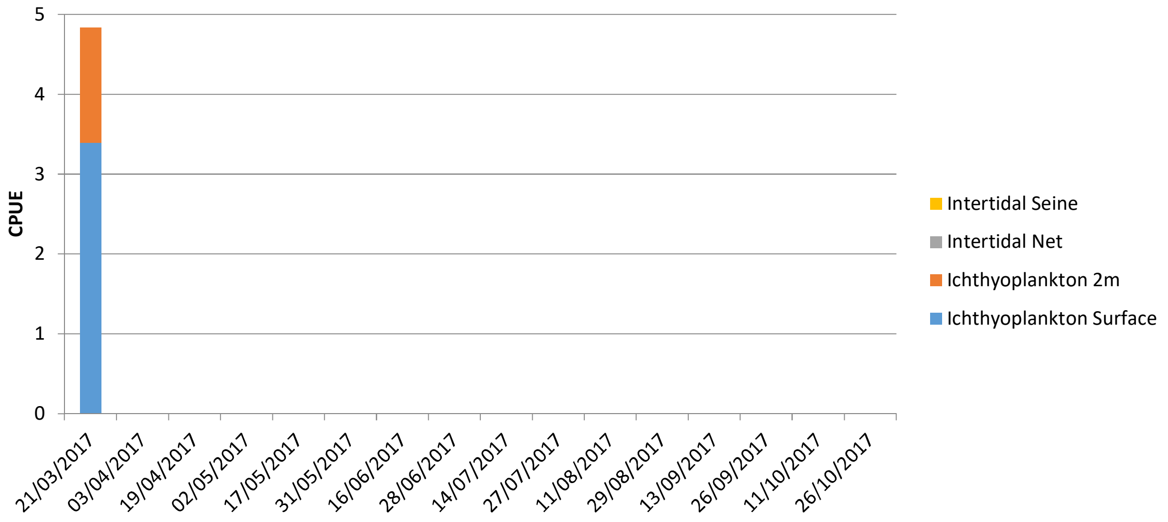

Figure 5.3. Temporal abundance (CPUE) of smelt at Putney during 2017.

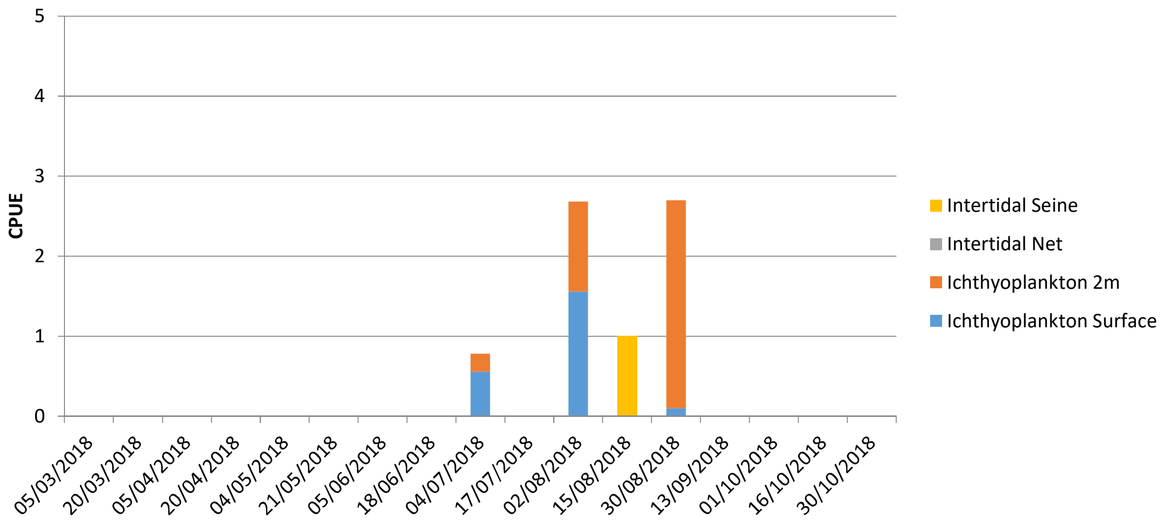

Figure 5.4. Temporal abundance (CPUE) of smelt at Putney during 2018.

5.2 Smelt spatial distribution

To understand temporal habitat utilisation of smelt, total abundance (i.e. absolute numbers of individuals recorded) was compared between sub-tidal (ichthyoplankton) and inter-tidal zones. Results are presented for both sites and both years (2017 & 2018) in Figure 5.5 to Figure 5.8 below. At Greenwich, in both years, the number of smelt captured from the sub-tidal zone peaked in May. Further upstream at Putney, smelt were only captured within the inter-tidal zone. These results are further explored and explained in Section 5.4.

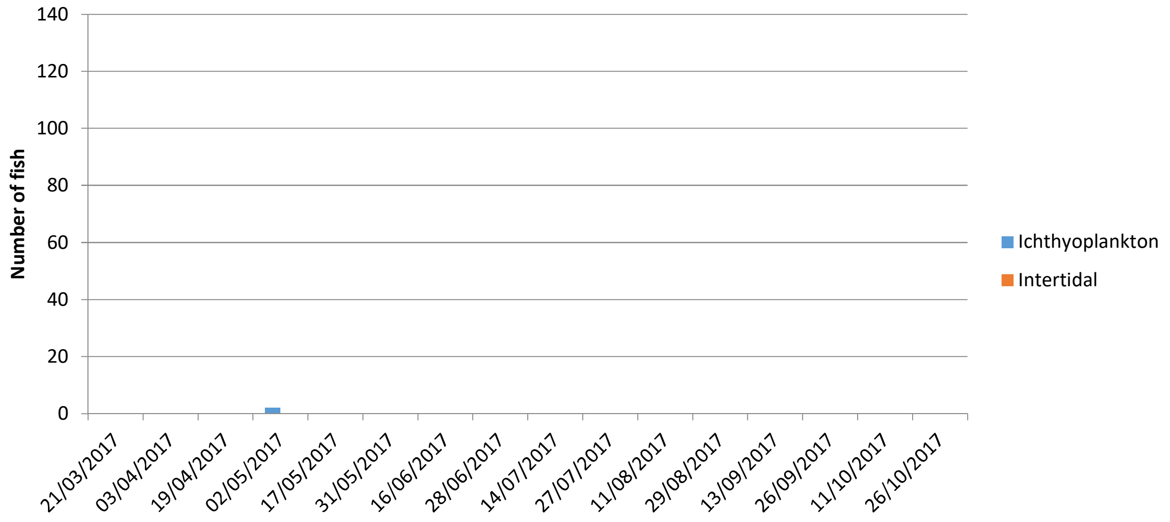

Figure 5.5. Temporal abundance of smelt at Greenwich during 2017, distributed between ichthyoplankton nets and intertidal nets.

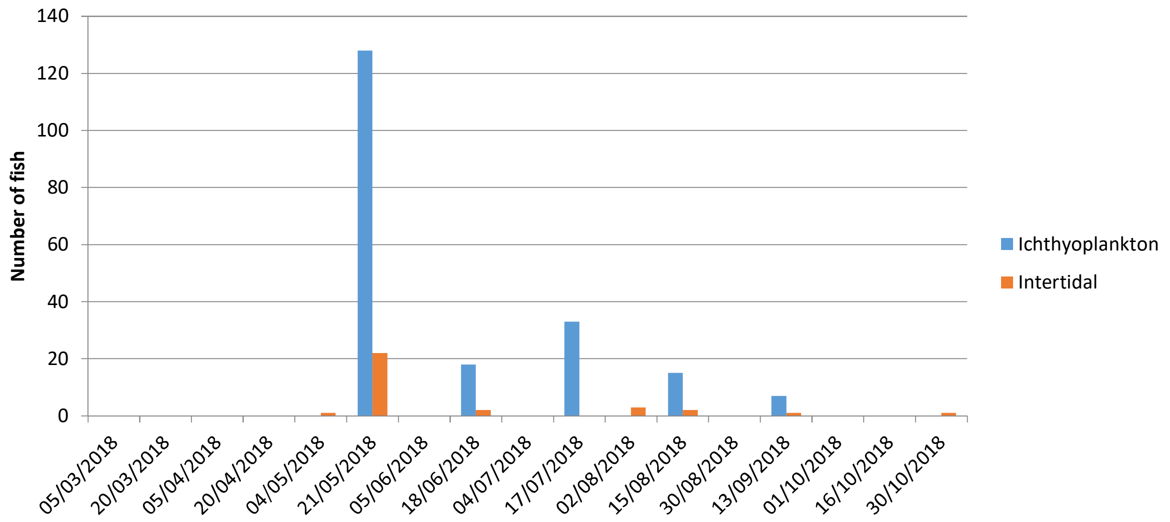

Figure 5.6. Temporal abundance of smelt at Greenwich during 2018, distributed between ichthyoplankton nets and intertidal nets.

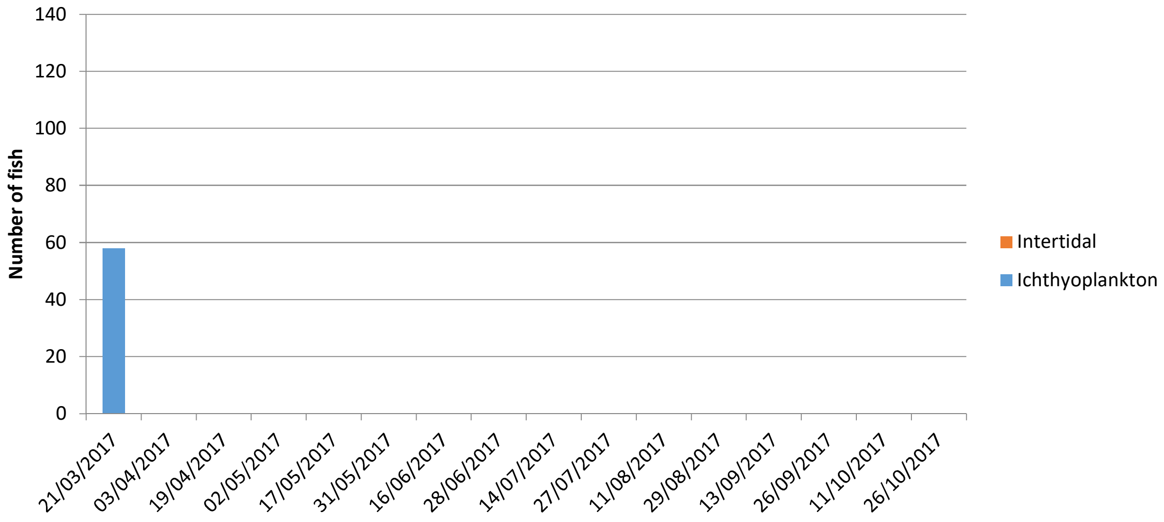

Figure 5.7. Temporal abundance of smelt at Putney during 2017, distributed between ichthyoplankton nets and intertidal nets.

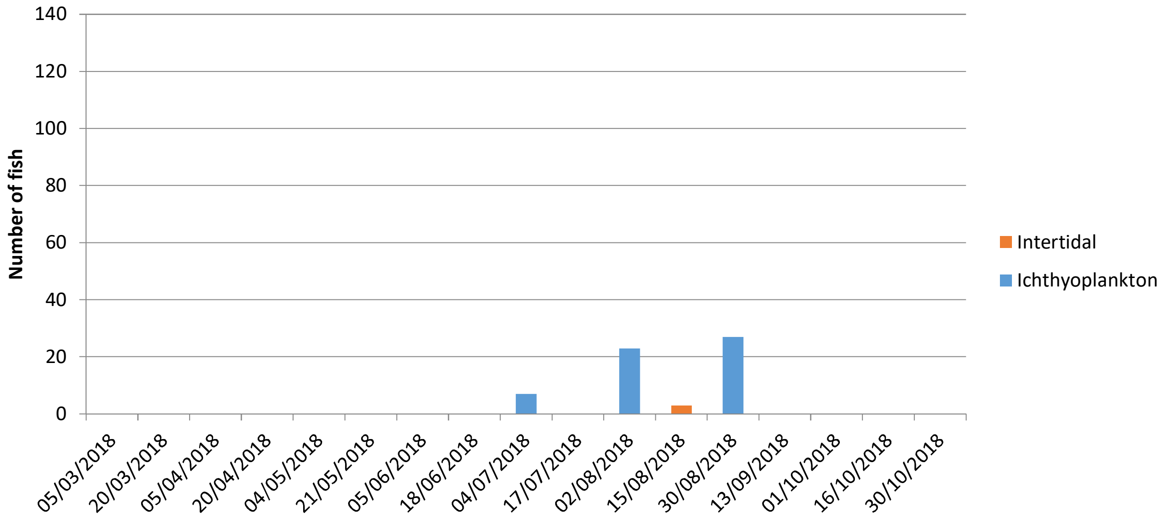

Figure 5.8. Temporal abundance of smelt at Putney during 2018, distributed between ichthyoplankton nets and intertidal nets.

5.3 Smelt length and growth

Mean length, inclusive of minimum and maximum values were calculated for all smelt recorded across all sampling methods. Figure 5.9 to Figure 5.12 present the results by site and year.

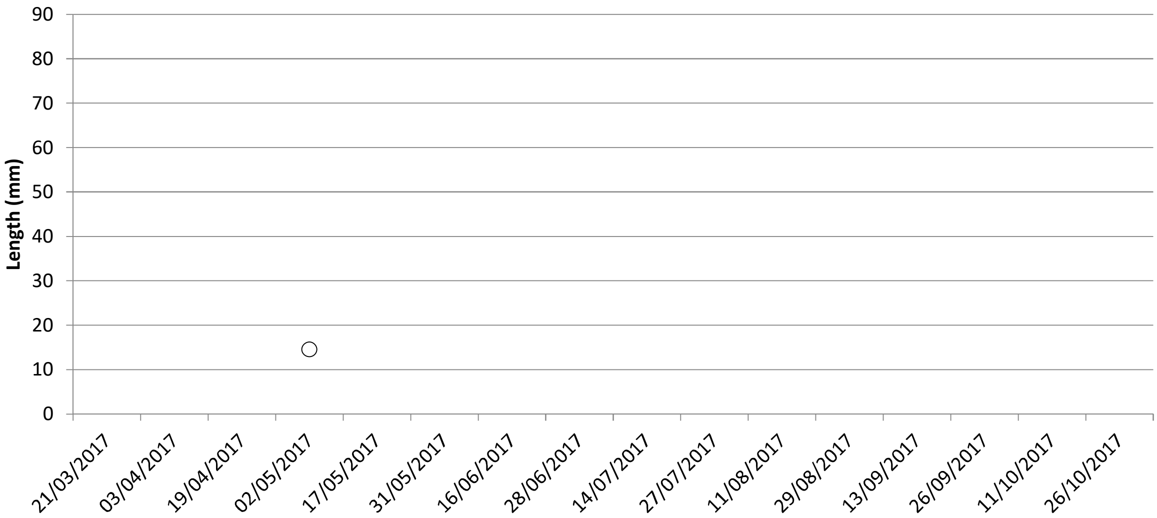

Figure 5.9. Mean, max and min length of smelt at Greenwich during 2017.

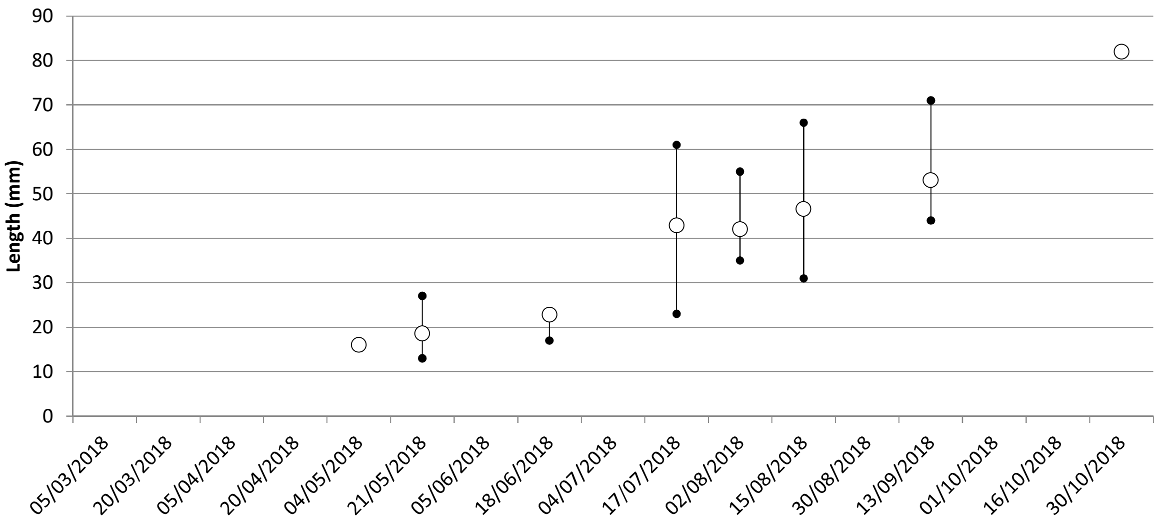

Figure 5.10. Mean, max and min length of smelt at Greenwich during 2018.

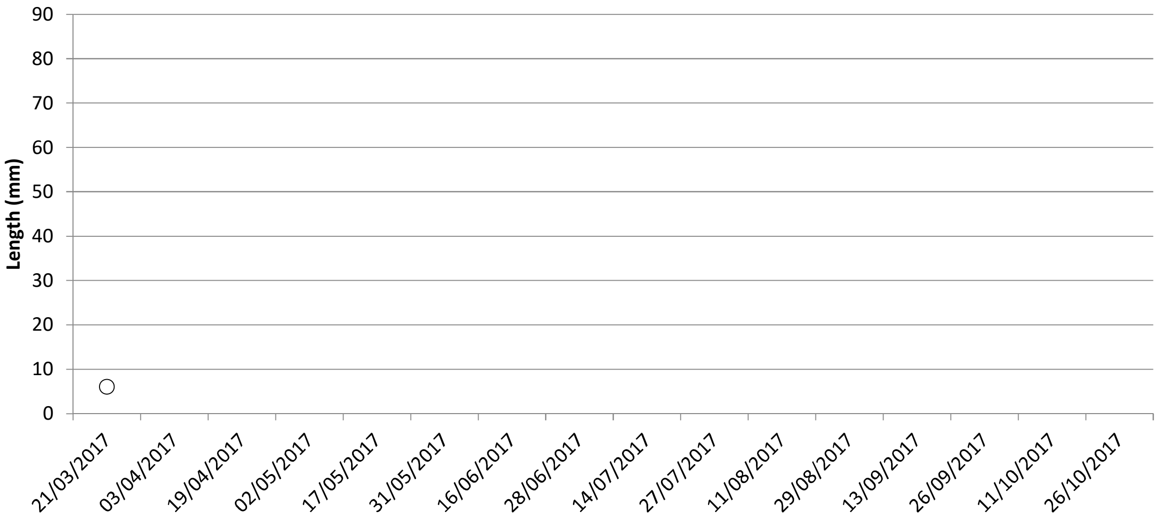

Figure 5.11. Mean, max and min length of smelt at Putney during 2017.

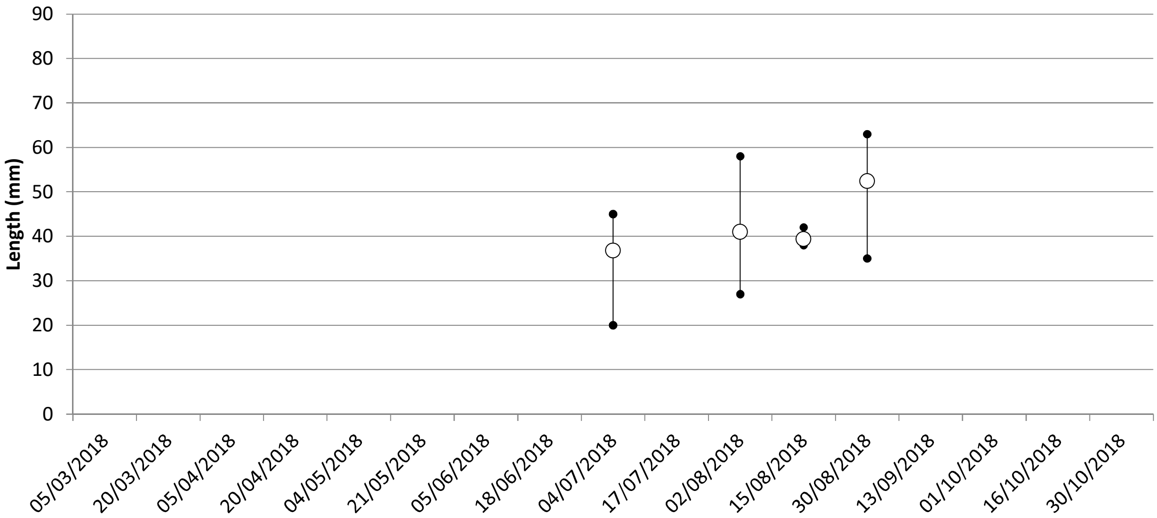

Figure 5.12. Mean, max and min length of smelt at Putney during 2018.

5.4 Smelt length comparison of ichthyoplankton versus intertidal

To examine whether fish size, or ontogenetic development stage of smelt (see discussion) had any influence on spatial (lateral) habitat utilisation, minimum and maximum length of smelt captured are presented for sub-tidal (ichthyoplankton) and intertidal surveys for 2018 only (Table 5.1). These data are further refined to compare mean length (± min/max) of smelt recorded between sub- and inter-tidal zones at both sites in 2018 in Figure 5.13 and Figure 5.14 respectively. Due to the low number of smelt captured in 2017, meaningful comparisons have not been possible.

Table 5.1. Min and Max length (mm) of smelt captured at Greenwich and Putney during 2018.

Site / Method	Min (mm)	Max (mm)
Greenwich - Ichthyoplankton	13	71
Greenwich - Intertidal	15	82
Putney - Ichthyoplankton	20	63
Putney - Intertidal	38	42

Despite a greater range in smelt size recorded in ichthyoplankton (sub-tidal) samples at Greenwich in 2018, the data collected indicate no obvious relationship between ontogenetic stage of development and habitat utilisation. Indeed, the results demonstrate that the sub-tidal zone remains a critical habitat for smelt throughout their early development within the estuary (Figure 5.13).

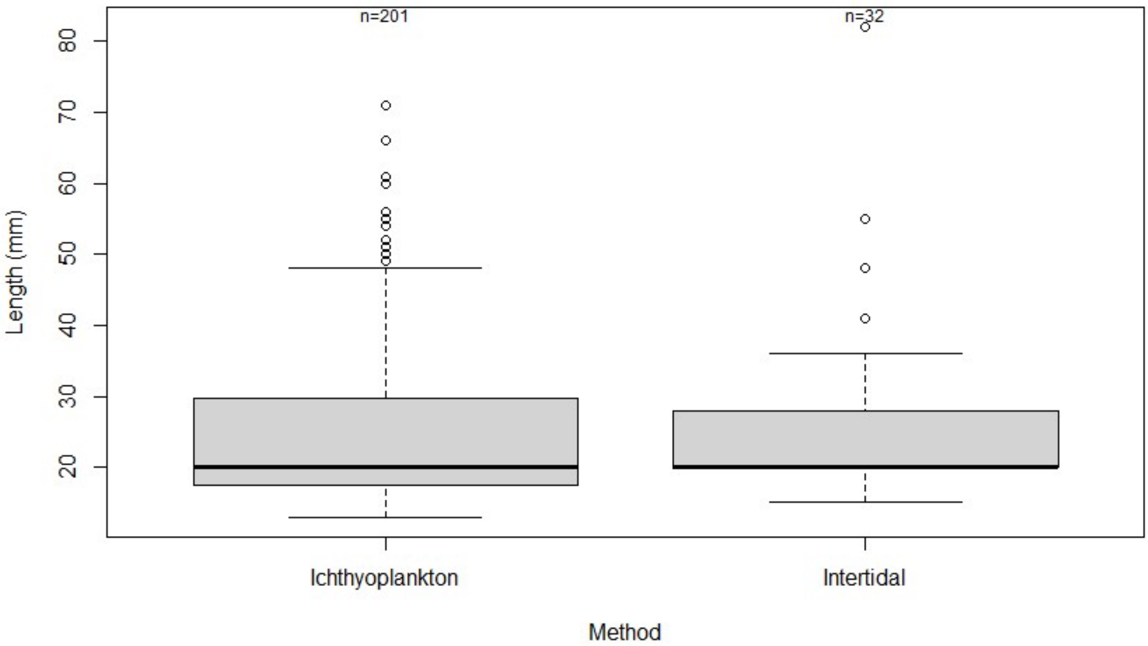

Figure 5.13. Boxplot of smelt length versus sampling method at Greenwich during 2018.

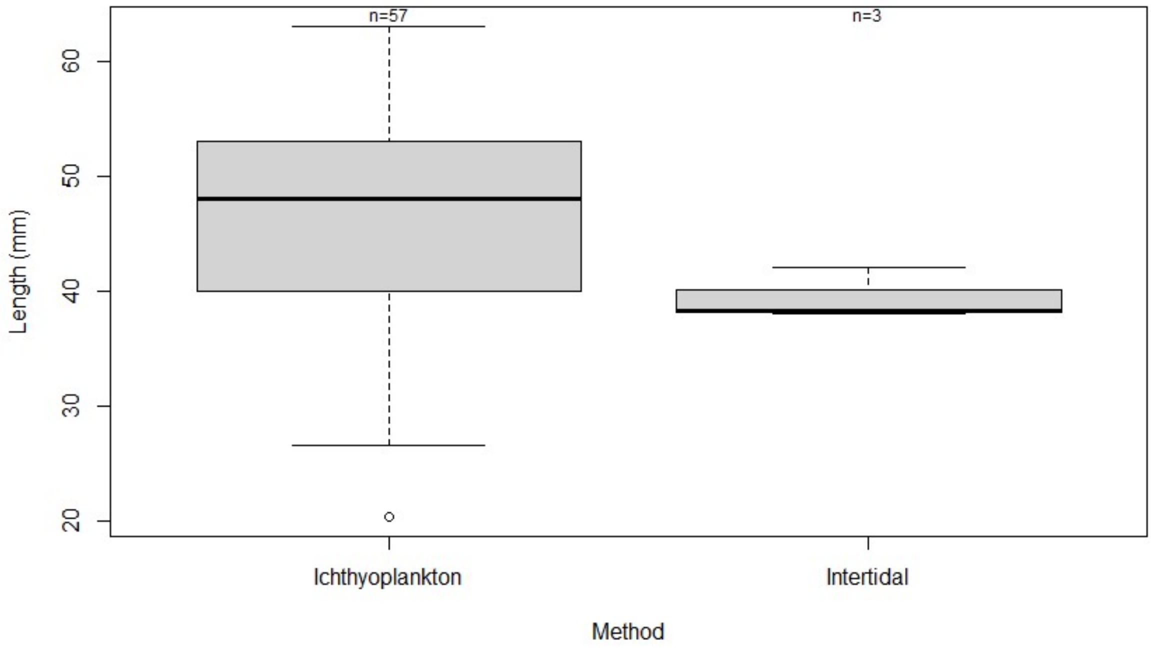

Figure 5.14. Boxplot of smelt length versus sampling method at Putney during 2018.

6 Species Summary - Bass

6.1 Bass temporal abundance

Temporal Catch-Per-Unit-Effort (CPUE, calculated as the number of fish divided by the number of samples) of bass for both sites over both years is shown in Figure 6.1 to Figure 6.4 below.

Note: temporal and spatial CPUE for individual intertidal methods (seine and nets) cannot be directly compared due to fundamental differences in sample area and efficiency. Likewise, comparison of ichthyoplankton CPUE versus intertidal CPUE is not valid. Ichthyoplankton samples (2m and surface) are however directly comparable across time and sites, due to consistency in the sampling method.

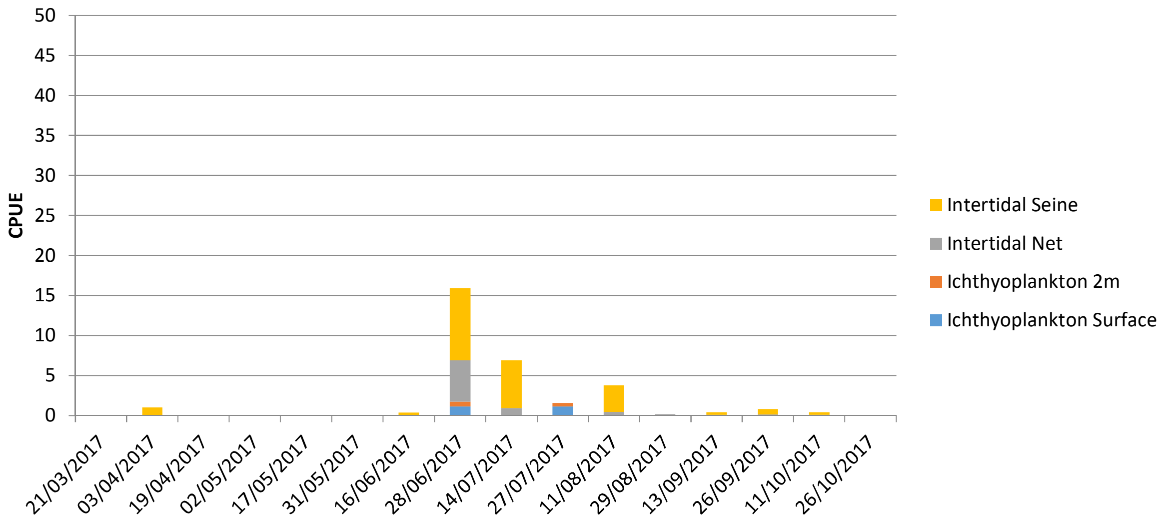

Figure 6.1. Temporal abundance (CPUE) of bass at Greenwich during 2017.

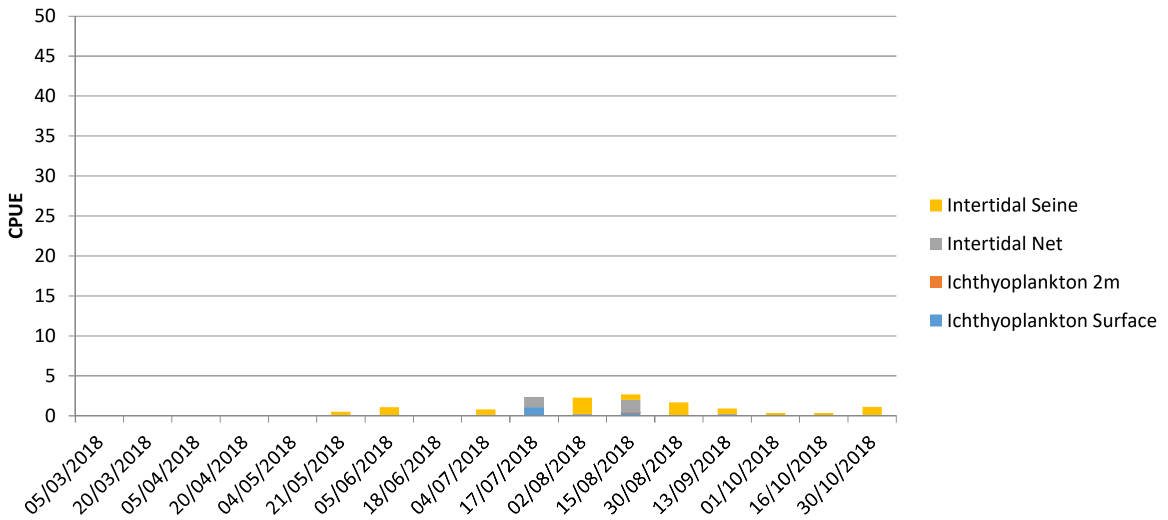

Figure 6.2. Temporal abundance (CPUE) of bass at Greenwich during 2018.

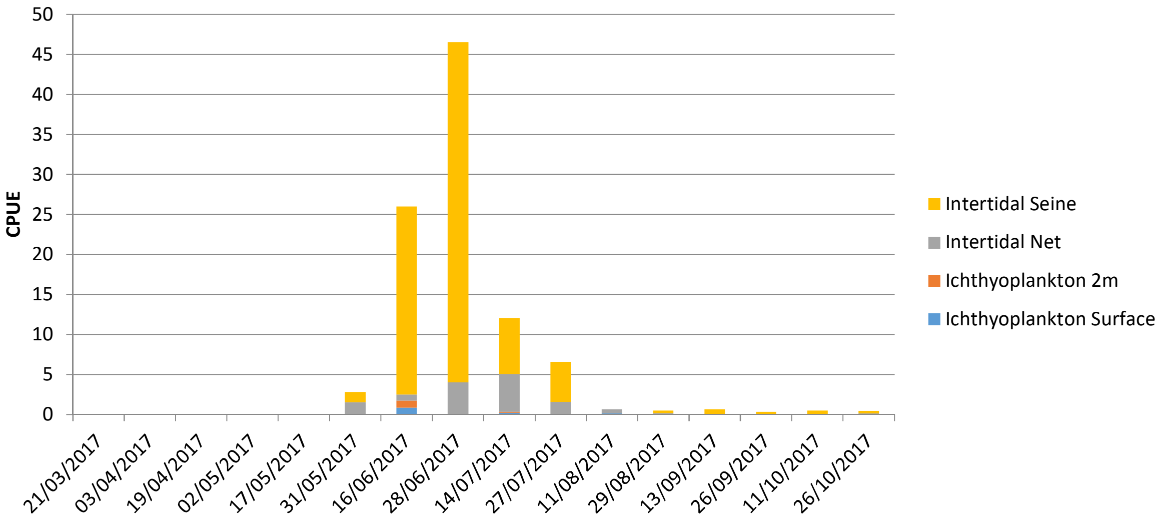

Figure 6.3. Temporal abundance (CPUE) of bass at Putney during 2017.

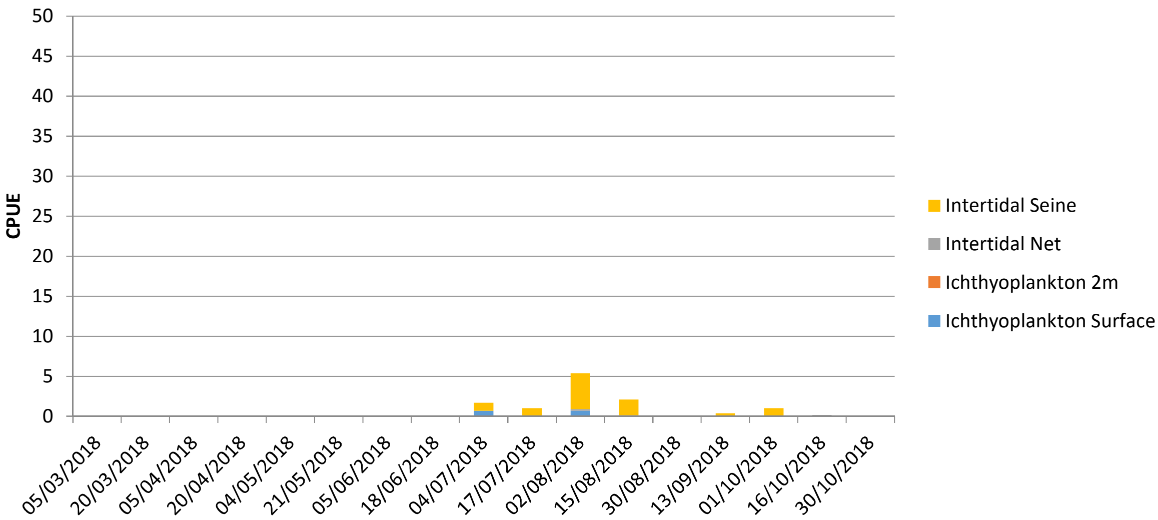

Figure 6.4. Temporal abundance (CPUE) of bass at Putney during 2018.

6.2 Bass spatial distribution

To understand temporal habitat utilisation of bass, total abundance (i.e. absolute numbers of individuals recorded) was compared between sub-tidal (ichthyoplankton) and inter-tidal zones. Results are presented for both sites and both years (2017 & 2018) in Figure 6.5 to Figure 6.8 below. Consistent between sites and across years, the majority of bass captured were recorded from the inter-tidal zone (>78%). At both sites, young bass first arrived as ichthyoplankton in mid to late June in 2017, but their arrival was notably later in 2018, with no larvae being recorded in advance of early July. In 2017, numbers of bass captured from the intertidal zone peaked during late June. Consistent with the later arrival of ichthyoplankton in 2018, the number of bass captured from the intertidal zone did not peak until August. These results are further explored and explained in Section 6.4.

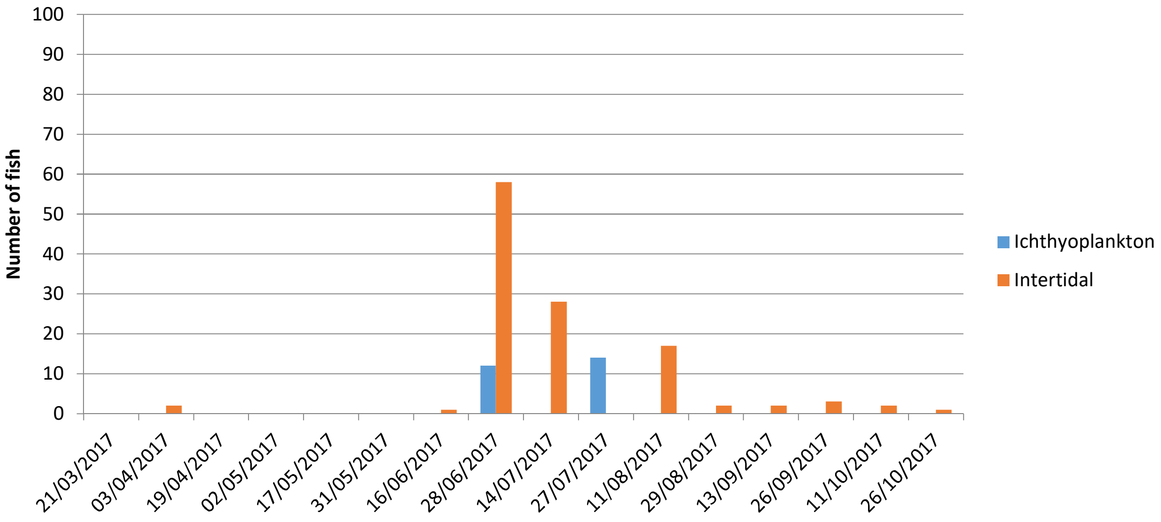

Figure 6.5. Temporal abundance of bass at Greenwich during 2017, distributed between ichthyoplankton nets and intertidal nets.

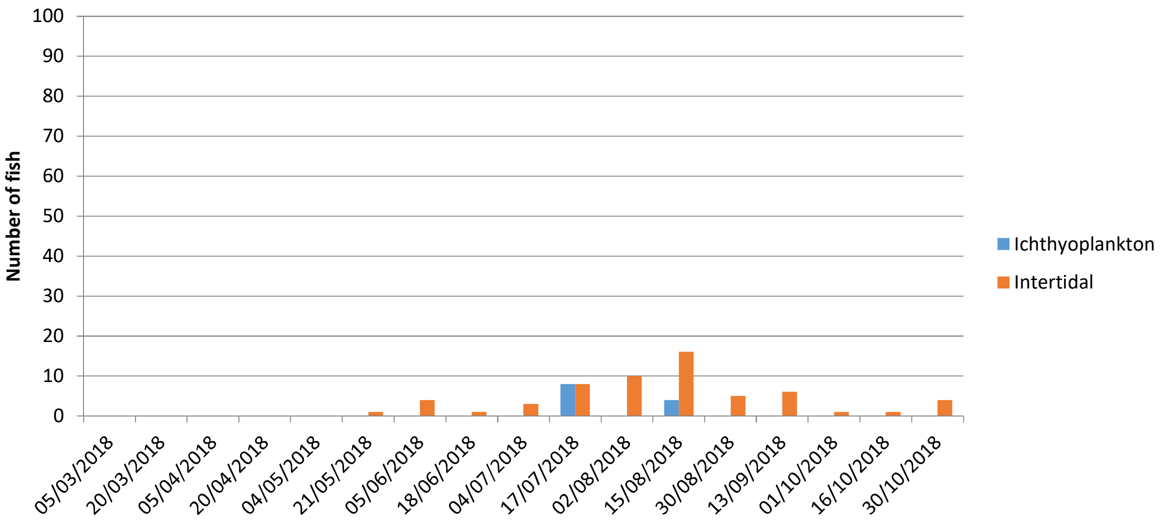

Figure 6.6. Temporal abundance of bass at Greenwich during 2018, distributed between ichthyoplankton nets and intertidal nets.

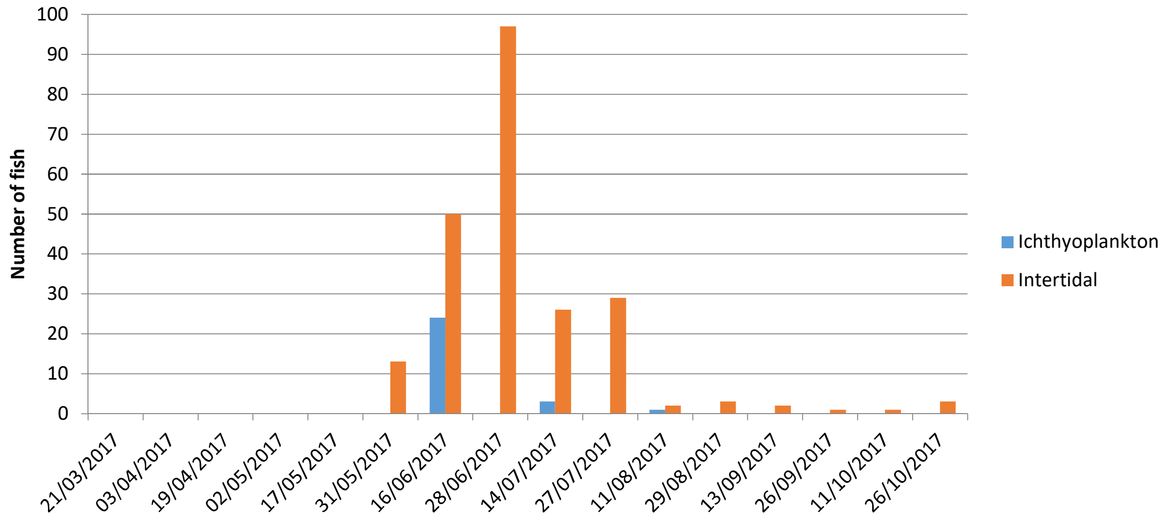

Figure 6.7. Temporal abundance of bass at Putney during 2017, distributed between ichthyoplankton nets and intertidal nets.

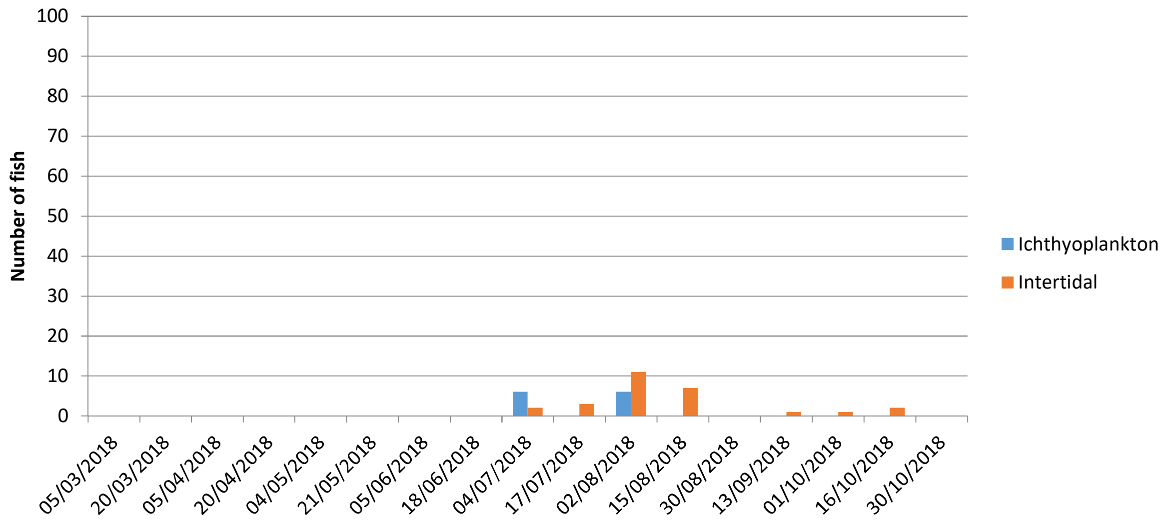

Figure 6.8. Temporal abundance of bass at Putney during 2018, distributed between ichthyoplankton nets and intertidal nets.

6.3 Bass length and growth

Mean length, inclusive of minimum and maximum values were calculated for all bass recorded across all sampling methods. Figure 6.9 to Figure 6.12 present the results by site and year.

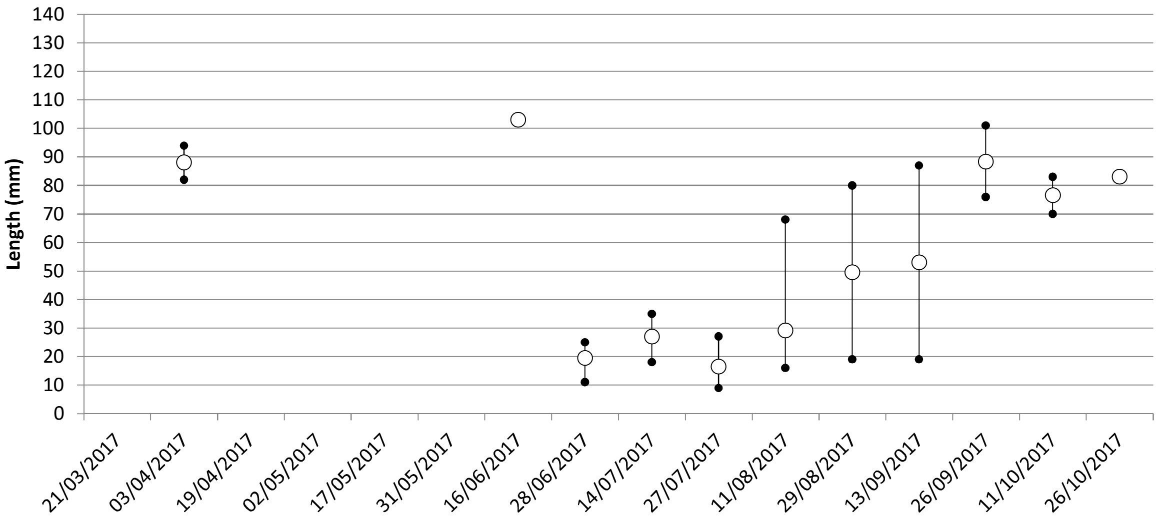

Figure 6.9. Mean, max and min length of bass at Greenwich during 2017.

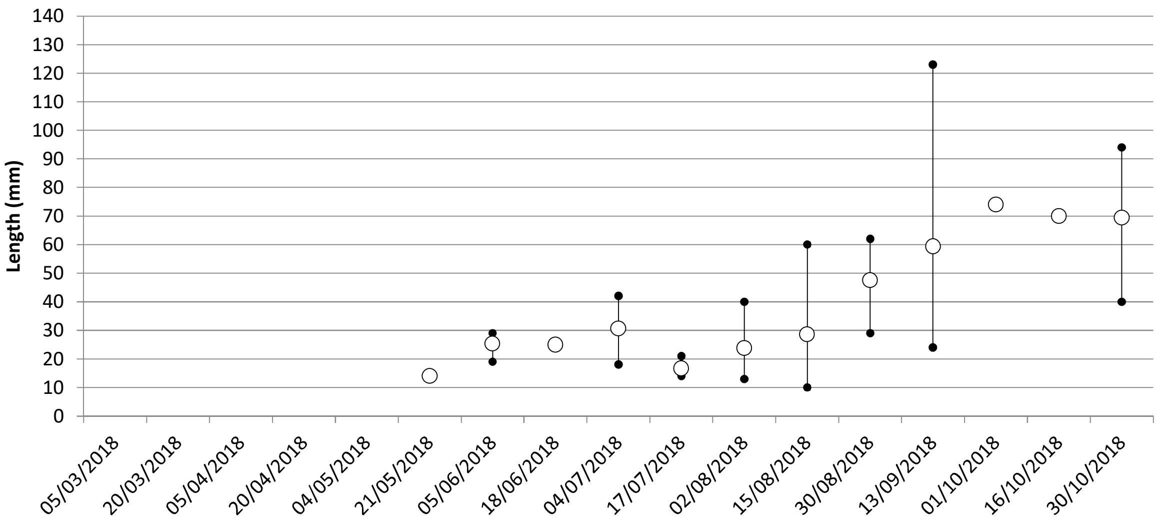

Figure 6.10. Mean, max and min length of bass at Greenwich during 2018.

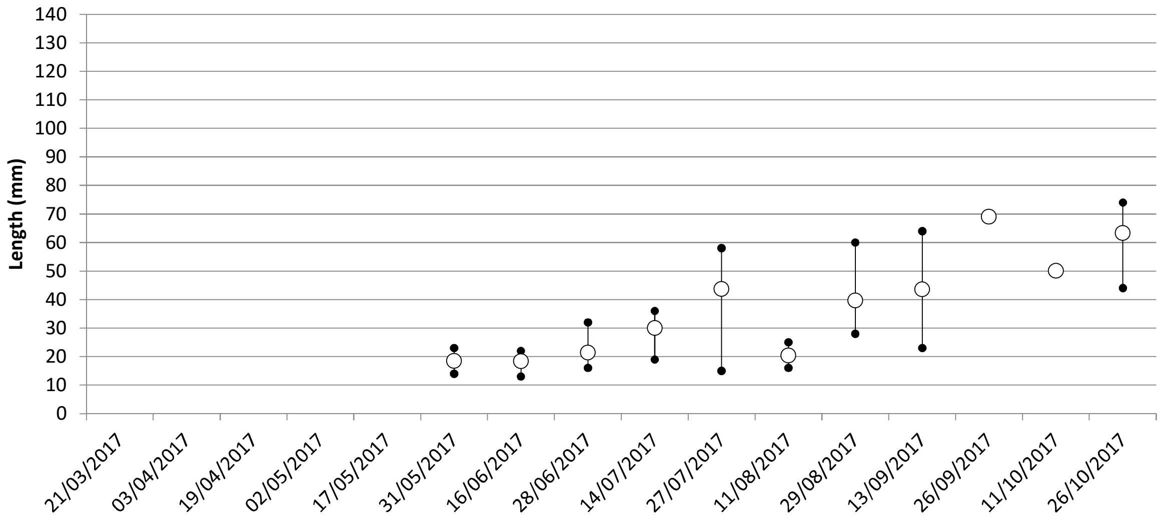

Figure 6.11. Mean, max and min length of bass at Putney during 2017.

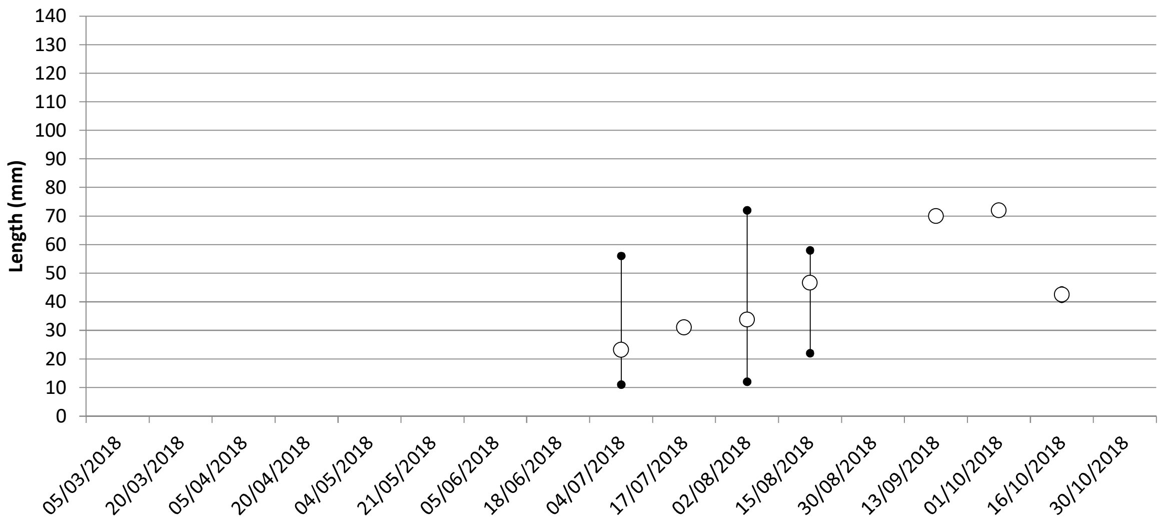

Figure 6.12. Mean, max and min length of bass at Putney during 2018.

6.4 Bass length comparison of ichthyoplankton versus intertidal

To examine whether fish size, or ontogenetic development stage of bass (see discussion) had any influence on spatial (lateral) habitat utilisation, minimum and maximum length of bass captured are presented for sub-tidal (ichthyoplankton) and intertidal surveys for 2017 and 2018 (Table 6.1). These data are further refined to compare mean length (± min/max) of bass recorded between sub- and inter-tidal zones at both sites in 2017 and 2018 in Figure 6.13 and Figure 6.14 respectively.

Table 6.1. Min and Max length (mm) of bass captured at Greenwich and Putney.

Site / Method	2017		2018	
	Min (mm)	Max (mm)	Min (mm)	Max (mm)
Greenwich - Ichthyoplankton	9	27	10	43
Greenwich - Intertidal	14	103	12	123
Putney - Ichthyoplankton	13	28	11	19
Putney - Intertidal	14	74	20	72

Consistent across both sites and both years, mean lengths of bass captured in the sub-tidal zone (ichthyoplankton trawls) were significantly smaller than those fish captured in the inter-tidal zone. The ontogenetic thresholds responsible for driving this habitat shift in bass were not observed to be as abrupt or as well defined as in flounder. The shift from sub-tidal to inter-tidal zones in bass corresponded with the latter stages of final fin formation, specifically, the completion of the anterior dorsal fin, which occurs between fish lengths of 17 and 20 mm.

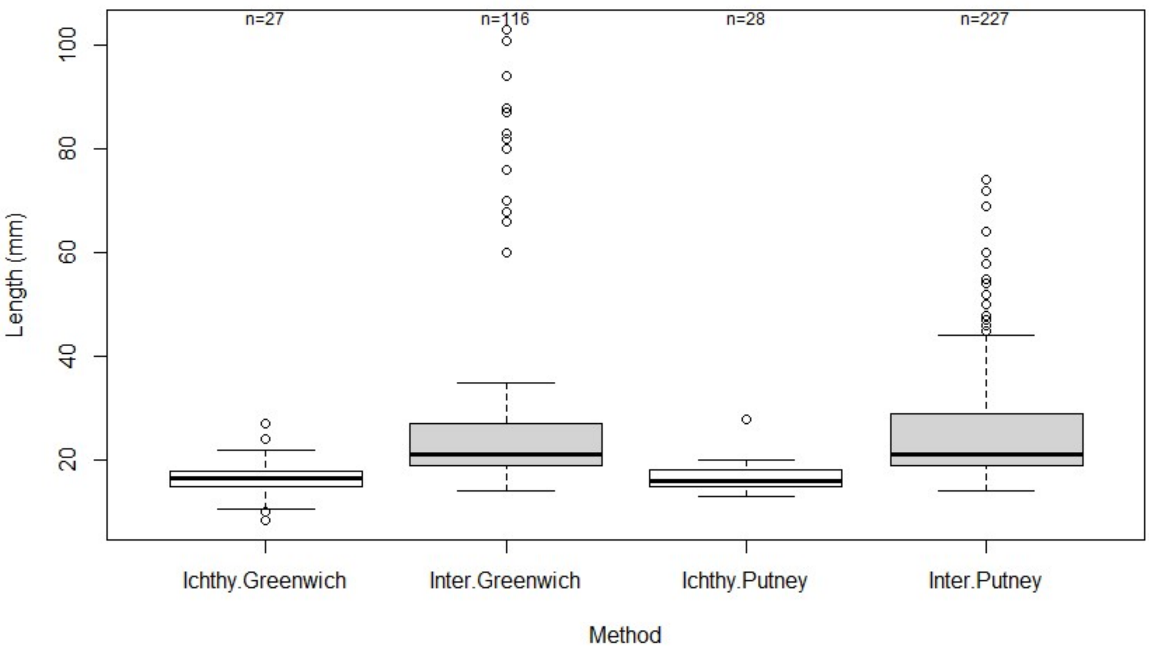

Figure 6.13. Boxplot of bass length versus sampling method for both Greenwich and Putney during 2017. Ichthy = Ichthyoplankton, Inter = Intertidal.

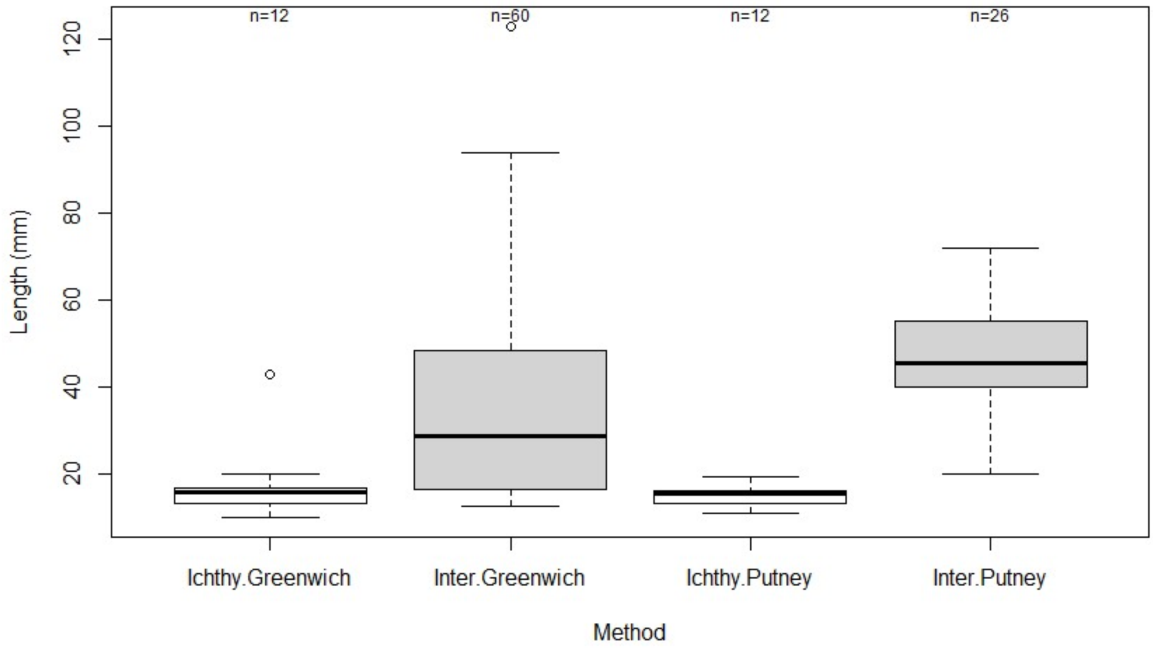

Figure 6.14. Boxplot of bass length versus sampling method for both Greenwich and Putney during 2018. Ichthy = Ichthyoplankton, Inter = Intertidal.

7 Citizen science

The citizen science events, based at Blackfriars, proved very popular and each one was over-subscribed by members of the public interested in taking part. Over 40 people attended the 10 citizen science surveys across 2017 and 2018.

In addition, we also opened up our dedicated foreshore surveys at the focal sites to ZSL-based volunteers and MSc students. In 2017 and 2018 a total of 99 volunteer days were donated to help us in our dedicated surveys. In addition, two MSc students assisted with data collection; Hayley Swanlund from Imperial College, London, who completed her MSc titled, "Environmental changes and seabass, *Dicentrachus labrax*, in the tidal Thames, UK: Are juvenile populations in decline?" in September 2017, and Kate Rowley from Royal Holloway University, London, who completed her MSc titled, "Microplastics in the River Thames water column" in December 2018. Kate Rowley used the samples collected during the 2017 mid-channel ichthyoplankton nettings to analyse the microplastic content of the water samples. Her research has measured microplastic load comparable to the highest ever recorded, and as such her research is currently being submitted to a scientific journal.

In the 113 samples collected at Blackfriars in 2017 and 2018, a total of 110 individual fish were recorded, belonging to nine different species. A full overview of catch, catch per unit effort (CPUE) and species richness, both for the individual year and over the entire survey season, can be found in table 7.1. Four of the species caught were freshwater fish and comprised 46.4% of the total catch.

In 2017, bass dominated the catch, making up 58% of the total catch, whereas in 2018 bass made up just 12% of the catch. Conversely in 2018 Dace dominated, making up 65% of the catch, while only making up 8% of the total catch in 2017.

Table 7.1 Total number of each species captured at Blackfriars in 2017 and 2018 citizen science surveys. Freshwater fish species are highlighted blue.

Year	2017	2018	Total
Samples	63	50	113
Dace *Leuciscus leuciscus*	4	39	**43**
Bass *Dicentrarchus labrax*	29	7	**36**
European Eel *Anguilla anguilla*	7	5	**12**
Flounder *Platichthys flesus*	1	4	**5**
3-spined Stickleback *Gasterosteus aculeatus*	1	2	**3**
Common Goby *Pomatoschistus microps*	0	3	**3**
Perch *Perca fluviatilis*	3	0	**3**
Smelt *Osmerus eperlanus*	3	0	**3**
Unidentified Cyprinidae	2	0	**2**
TOTAL NUMBER	**50**	**60**	**110**
TOTAL CPUE	**0.79**	**1.20**	**1.03**
SPECIES RICHNESS	**8**	**6**	**9**

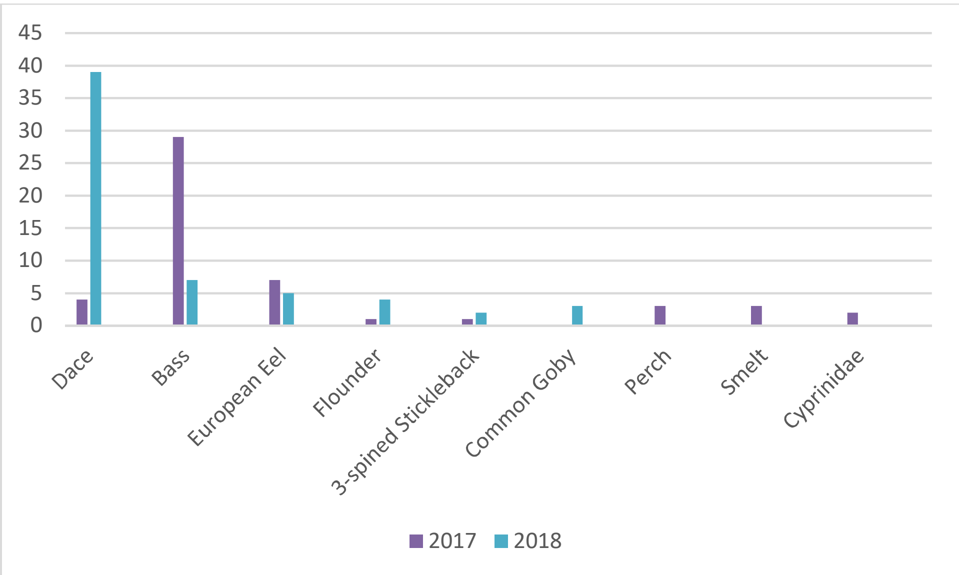

Figure7.1 Species composition at Blackfriars in 2017 and 2018.

8 Environmental Parameters

Readings of temperature, dissolved oxygen and salinity were recorded for each netting during the mid-channel sampling (Figure 8.1). Data were recorded at the surface and at 2m depth, however results were similar from these two depths and so only surface readings have been displayed below.

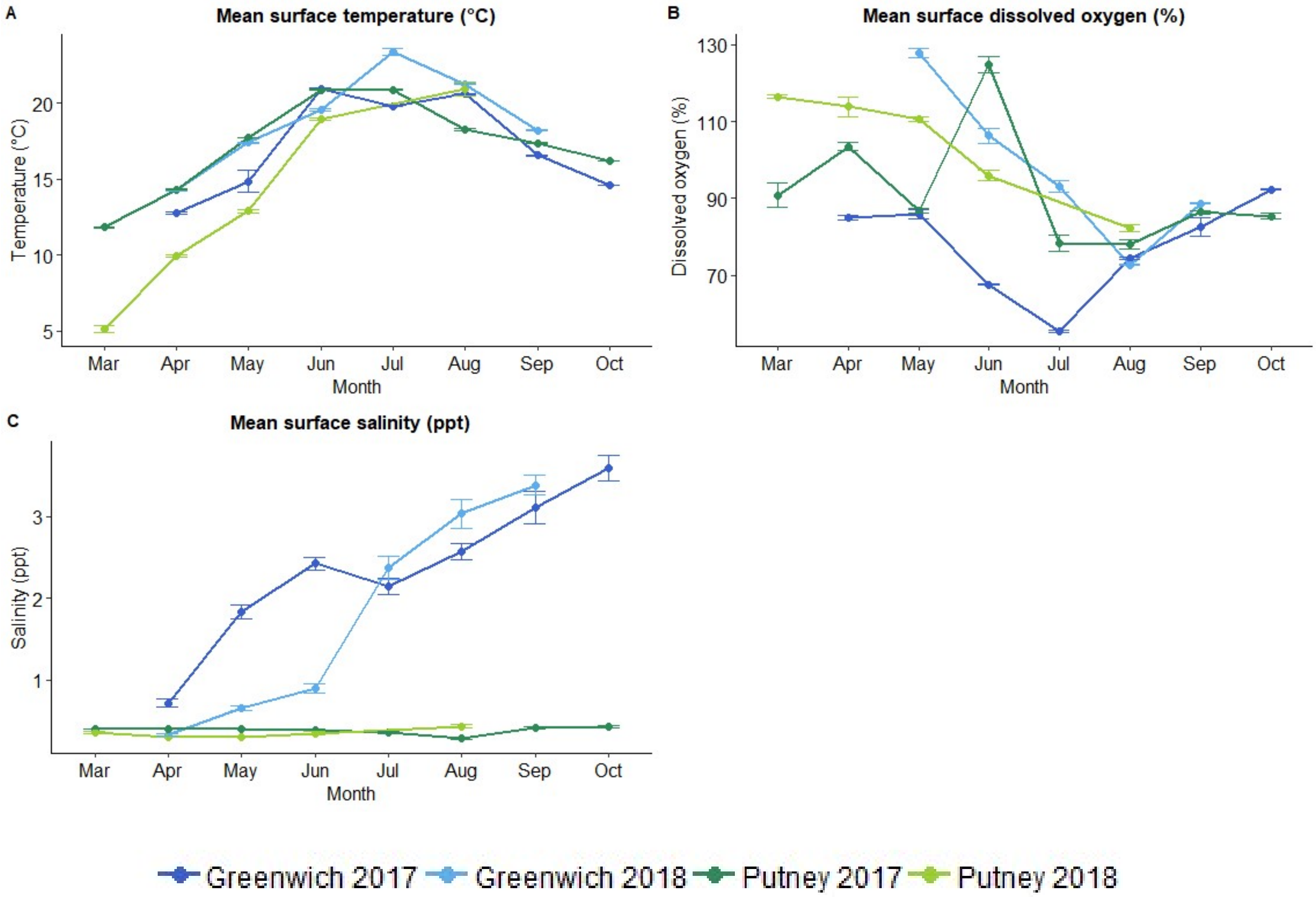

Figure 8.1. Monthly means of environmental data during the survey season at sites Greenwich and Putney in 2017 and 2018. Error bars display standard error. A: Temperature (°C); B: Dissolved oxygen (%); C: salinity (ppt).

The mean water temperature across sites and years followed the expected seasonal temperature fluctuations, with the lowest temperatures recorded in March steadily increasing and reaching its peaks in June or July followed by a subsequent decrease during the autumn months. Water temperature in Putney was in general marginally cooler than Greenwich. The coolest water temperature was recorded in March 2018 at Putney at just 4.2°C and the warmest recorded water temperature was in July 2018 in Greenwich at 25.1°C. The ambient air temperature broadly mimicked the water temperature patterns (Figure 8.3).

In general, the dissolved oxygen levels demonstrated a decrease between spring and summer before increasing again in the autumn months. The dissolved oxygen levels in 2018 were greater overall than those recorded in 2017, with those at Greenwich showing higher levels than those at Putney.

As expected, the salinity recorded in Greenwich was higher than that recorded in Putney, as the Greenwich survey site is closer to the sea. The salinity levels in Putney remained approximately the same across both years and months, however the salinity levels in Greenwich displayed a steady increase throughout both the 2017 and 2018 survey seasons.

Freshwater flow data from the Kingston gauging weir is recorded by the Environment Agency throughout the year and is available through the National River Flow Archive. Figure 8.2 (and Table 8.1) shows temporal discharge (cumecs) in the Thames across the 2017 and 2018 survey years. As expected, the mean freshwater flow is greatest throughout the winter months when the UK experiences the most rainfall and decreases through the summer. In both 2017 and 2018 the freshwater flow levels were primarily below the mean for the Thames, as both years were considered drought years. It should be noted that the lower flow in spring 2017 is reflected in the higher salinity at Greenwich in the same year.

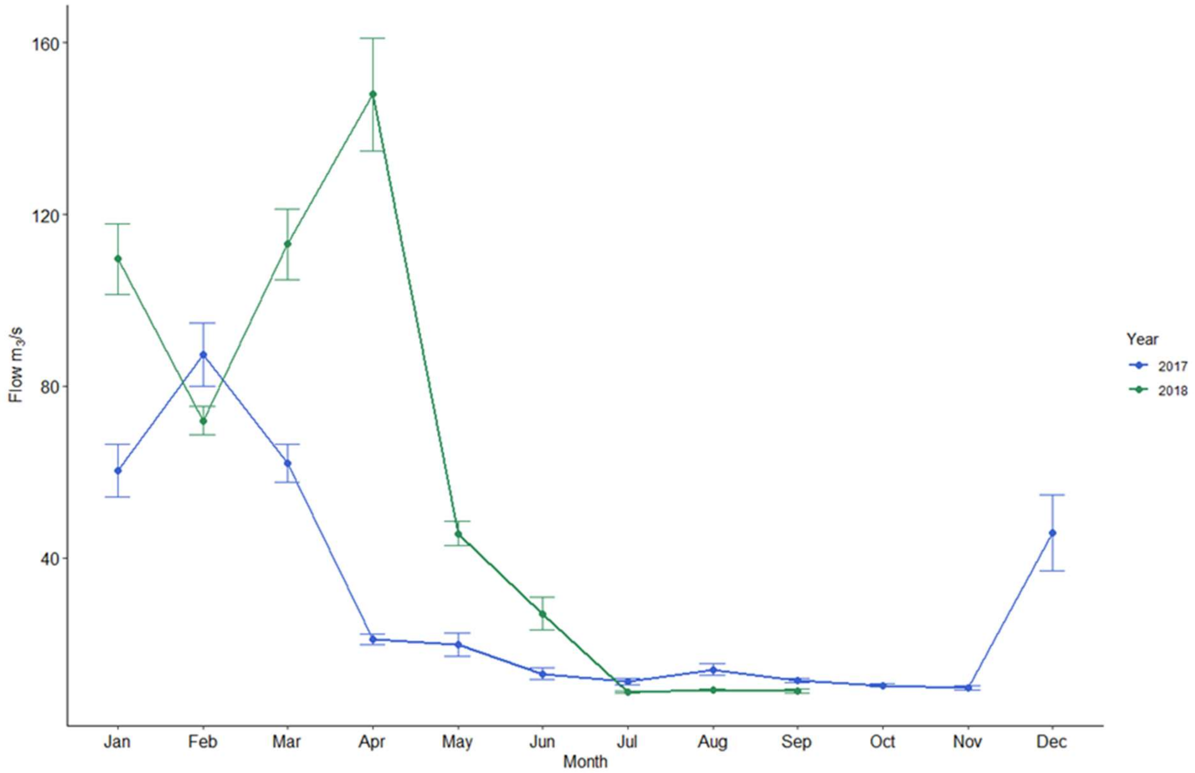

Figure 8.2. Monthly means of freshwater flow (m^3/s) in the tidal Thames from January 2017 to end of September 2018. Error bars in +/- standard error.

Table 8.1 Monthly means of freshwater flow (m³/s), with standard error, in the tidal Thames from January 2017 to end of September 2018.

Month	2017	2018
Jan	60.44 +/- 6.16	109.68 +/- 8.24
Feb	87.39 +/- 7.35	71.94 +/-3.32
Mar	62.07 +/- 4.32	113.06 +/- 8.29
Apr	21.03 +/- 1.13	147.93 +/-13.14
May	19.81 +/- 2.65	45.65 +/- 2.84
Jun	13.05 +/- 1.40	27.03 +/- 3.74
Jul	11.18 +/- 0.79	8.75 +/-0.22
Aug	14.01 +/- 1.30	9.30 +/- 0.25
Sep	11.47 +/- 0.51	9.06 +/- 0.44
Oct	10.29 +/- 0.32	
Nov	9.72 +/- 0.53	
Dec	45.74 +/- 8.86	

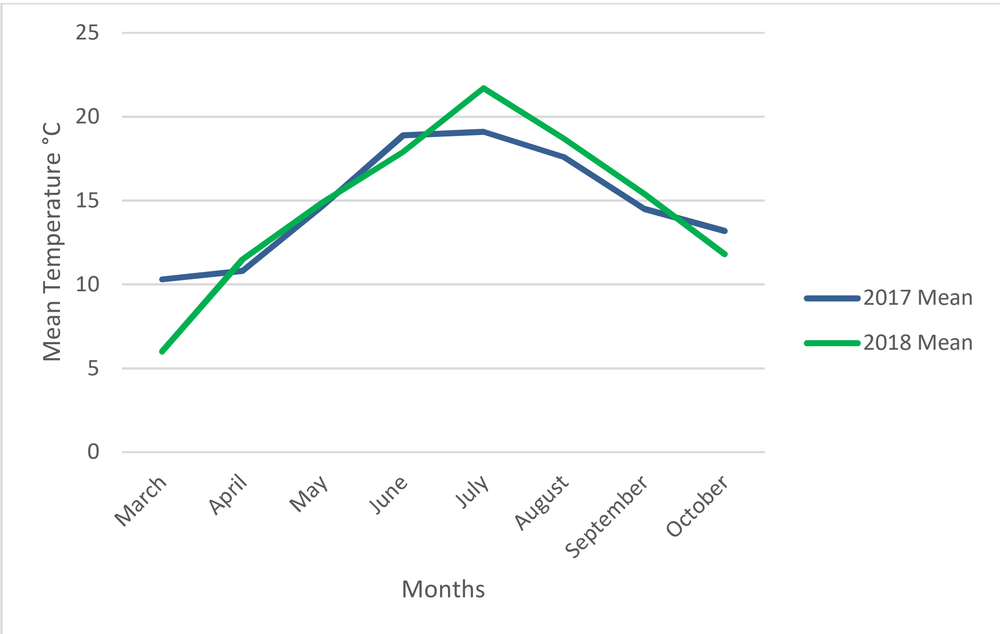

Figure 8.3 Monthly means of ambient temperature recorded by NW3 Weather Hamstead London (http://nw3weather.co.uk).

9 Discussion

Since 1964, the ecology of the tidal Thames has responded positively to dramatic improvements in water quality (Wheeler, 1979). However, due to the challenges associated with monitoring fish populations in large

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estuaries, studies designed to monitor these ecological gains have since been limited. Indeed, much of the work conducted prior to the late 1980's was restricted to the lower estuary, where West Thurrock Power Station provided opportunity to monitor fish via their impingement on cooling water intake screens (Araujo et al., 2000). The first detailed study to focus on the upper estuary between Teddington and Chelsea involved monthly sampling at five sites between February 1989 and August 1990 and attempted to correlate fish diversity with temporal and spatial water quality parameters (Araujo et al., 1999). In recognition of growing concerns over anthropogenic pressures and requirements under the forthcoming EU Water Framework Directive (UKWFD), in 1992, the Environment Agency started to invest effort by establishing a seasonal (four surveys a year) sampling programme at 11 sites (rationalised to six sites in 1994) between Richmond and West Thurrock (Colclough et al., 2002). This study formed the basis of the development of a suite of monitoring and ecological quality assessment tools now enshrined in the WFD fish classification tools for transitional waters (Coates et al., 2007).

One of the primary aims of the current study was to develop a pre- Thames Tideway Tunnel ecological baseline of fish diversity, against which, the ecological response to future improvements in waste water management could be quantified. Due to their elevated sensitivity to water quality and other anthropogenic pressures (e.g. noise and entrainment), ELHS have greater potential than adult life stages to indicate environment change. Accordingly, the study was designed to focus specifically on early life history stages (ELHS, i.e. eggs, larvae and juveniles). They also provide qualification of habitat functionality both in terms of spawning and nursery habitats. One further advantage of monitoring ELHS is their relative abundance and ease of capture in high numbers compared to adult fishes more capable of avoiding sampling gears. Due to the perceived challenges (e.g. effective survey design, resource requirements and species identification), this study represents the most comprehensive ELHS study on any UK estuary to date. The following discussion has been broken down into sub-sections to discuss what has been learned to date and the novel knowledge gaps which are now emerging.

9.1 Species diversity

Excluding the occurrence of a single hybrid (roach x bream), a total of 24 species have been recorded throughout the study period. This diversity has encompassed freshwater, marine, estuarine resident, anadromous and catadromous species. The three numerically dominant marine species (common goby, flounder and bass) and freshwater species (roach, three-spined stickleback and dace) represented 66% and 22% of total fish numbers respectively. This domination of just a few species at each site is typical of that found in the regular Water Framework Directive surveys undertaken by the Environment Agency for adult fish in spring and summer (per comms. Steve Colclough). With the exception of unexpected species such as short-snouted seahorse *Hippocampus hippocampus,* species diversity was slightly higher, but not dissimilar in composition to the earlier studies conducted in 1989 and 1990 by Araujo et al. (1999). This earlier survey reported a total of 23 species, however, the inclusion of souffie *Leuciscus souffia* has not been reported from UK waters from any other studies and suggests that this was an erroneous identification, bringing the species tally of Araujo et al. (1999) to 22.

9.2 Temporal observations

Other studies of estuarine fish populations have clearly demonstrated dynamic seasonal differences in both the abundance and community structure present throughout the year (Colclough et al., 2002; Pinder et al., 2011). These observations have provided considerable assistance in informing the temporal survey design of the current study. The points presented in sections 9.2.1 and 9.2.2 also confirm the vital importance of sampling both throughout and across years to account for natural variations in fish populations.

9.2.1 Intra-annual observations

General total abundance and species diversity of ELHS fish peaked towards mid-summer, reducing to lowest observed numbers through the winter months.

The earliest larvae to appear in surveys were smelt. These were first recorded at Putney in late March. The larvae of early spawning freshwater species such as perch and dace arrived in April, with roach and minnow first recorded in mid-May. Early May also saw the first arrival of flounder in the ichthyoplankton, with some later arrivals extending into mid-June at Putney. Bass and common goby demonstrated extended recruitment periods, with individuals less than 15 mm in length arriving in multiple cohorts between late-May through to mid-August. Later arrivals included common bream and chub in mid-June, with young chub (<12 mm) continuing to recruit to the estuary into July. The recruitment timing of thin-lip mullet was less defined. While Colclough et al. (2002) reported the arrival of (>20 mm) thin-lip mullet during September, our results show fish of 20 – 35mm arriving at Greenwich in mid to late-May, coupled with the appearance of a smaller specimen of 17.4 mm in late October. This suggests multiple cohorts of recruits, which corresponds with reports of the spawning period extending between September and February for this species (Billard, 1997).

9.2.2 Inter-annual observations

While the general pattern of recruitment timing for each species was generally consistent between the two survey years (2017 and 2018), some fundamental differences in species recorded at each site were evident. Perhaps the most striking contrast was following capture of newly hatched smelt larvae at Putney in 2017, this species was not recorded at Putney during 2018. This is the area previously identified as a key spawning ground for this anadromous species (ZSL, 2016). Also, in contrast to 2017, smelt were captured in relatively high numbers at Greenwich in 2018. The smallest fish recorded at Greenwich was however 14 mm, meaning the fish were already several weeks old, thus providing no indication as to where on the estuary spawning may have occurred in 2018. The total absence of smelt larvae from Putney in 2018, does however suggest that habitats elsewhere on the tidal Thames and/or its tributaries may also function as spawning sites for this high priority species.

Beyond the scope of the current study, early observations from ongoing surveys extending into 2019 have recorded high numbers of larval flounder arriving in ichthyoplankton samples at Putney as early as late March. This is particularly noteworthy as ichthyoplankton captures across 2017 and 2018 at Putney were limited to a total of just six individuals. The late-March arrival of flounder in 2019 is also considerably earlier than previously recorded. In 2017-2018 flounder were first recorded during early May, which also corresponds with the earlier observations of Colclough et al. (2002).

9.3 Spatial observations

9.3.1 Longitudinal observations

When comparing catches between Greenwich and Putney across both years combined, species richness was not dissimilar (Putney = 21; Greenwich = 19). Given the higher ambient salinity range at Greenwich, one might expect to observe a higher ratio of marine to freshwater species at this seaward site. This was certainly true for a small number of species which were recorded in very low numbers or just single individuals. For example, marine species which added to the richness count at Greenwich and did not occur at Putney, included a single pipe fish *Syngnathus* sp., a single short-snouted seahorse and a total count of three sprat. At Putney, freshwater species recorded such as minnow, barbel, bullhead, carp, pike and tench were all species not recorded downstream at Greenwich. Despite these small numbers of less common species contributing to differences in total species richness counts, 87% of all fish recorded during the study were captured at Putney. This included 92.6% of all common goby (n=3089), 94% of all flounder (n=1667) and 58% of all bass (n=294). This is perhaps surprising due to all of these species spawning downstream of Greenwich, meaning they would have to pass through the Greenwich site before reaching Putney. This may be explained by the larger size of the estuary at Greenwich reducing the likelihood of encountering these fish in the ichthyoplankton. Our results also indicate that many of the marine species which enter the estuary in the pelagic zone (e.g. flounder and bass) have developed sufficiently to switch to the estuary margins by the time they reach Putney, thus increasing their susceptibility to capture within the intertidal zone. This is further discussed in Section 9.3.2 below. With the exception of odd individual species (discussed above), two species only were recorded in higher numbers at Greenwich than at Putney. Specifically, 85% of all eel (n=98) and 66% of all smelt (n=235) were recorded from Greenwich.

9.3.2 Lateral observations and selective tidal stream transport

The intertidal zone generally demonstrated high numbers of fish diversity and abundance across both sites. Elliot and Taylor (1989) described a similar trend in the Forth Estuary with intertidal fish and invertebrate production being twice as large as that in the immediate sub tidal zone.

ELHS with limited swimming capabilities have adapted various strategies for utilising tidal flows to facilitate their locomotion towards estuarine nursery grounds. This is known as selective tidal stream transport (STST) and can involve vertical and lateral orientation to strategically use tidal flow to achieve net upstream and downstream movements. The current survey was designed to capture fishes at two defined depths in the drift of the central channel and within the estuary margins to determine the 3D positioning of individual species and their respective developmental (ontogenetic) staging. While the migratory behaviour of glass eels is well understood (Figure 9.1) and an excellent example of STST (see Harrison et al., 2013), this accounts for a species which is not undergoing dramatic ontogenetic remodelling during the migration process. To understand how changes in ontogeny influence 3D positioning and STST in the Thames, we have focused our detailed analysis on the following three model species: flounder, smelt and bass.

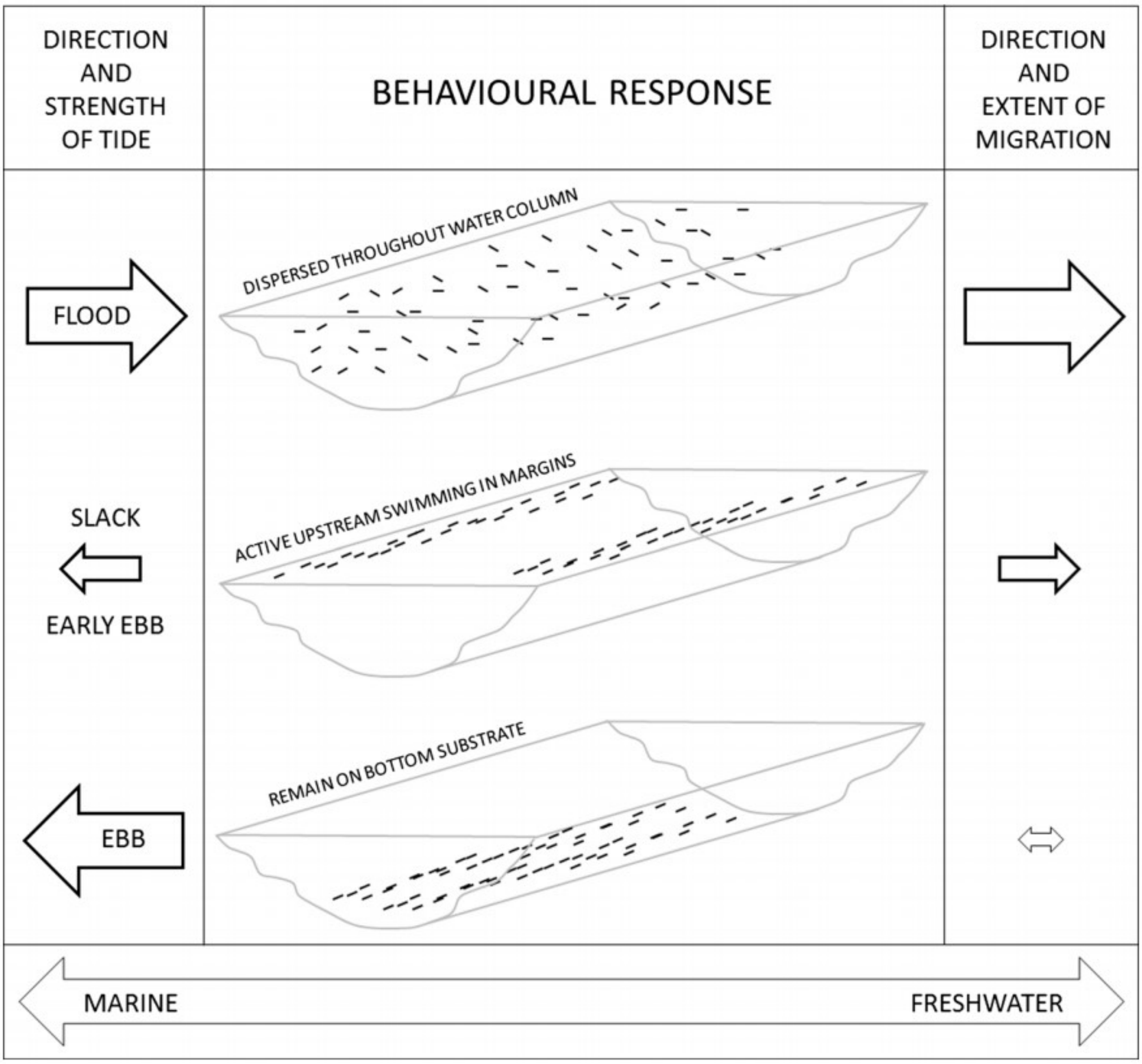

Figure 9.1. Generalised summary of glass eel migration in upper estuaries. Flood tide; glass eels spread throughout water column. Slack/early ebb tide; glass eels move to margins and actively swim upstream. Ebb tide; glass eels remain on or in the bottom substrate (from Harrison et al., 2013).

Arriving at Greenwich in their symmetrical body form, with one eye on either side of the head, flounder were not sufficiently well developed for their mouth and gut to be functional. At this stage they were exclusively found to be using the middle of the river and only recorded in ichthyoplankton nets. However, somewhere between Greenwich and Putney, a significant morphological development occurred. The migration of the eye to the top of the body also corresponded with the first functioning of the mouth and gut meaning that these fish could take in exogenous nutrition. This was synchronised with a switch to the estuary margins and by the time they had reached Putney, flounder were almost exclusively recorded from the intertidal nets with their guts full of food. The few individuals (n=6) caught in ichthyoplankton nets at Putney were still of symmetrical form and not yet feeding. In flounder, ontogenetic stage was found to be a better predictor of habitat utilisation than fish length, with metamorphosis driving the ontogenetic threshold taking place between 9 – 10.5 mm. Once in the intertidal zone, the compressed body form of these young juveniles allows them to hold position on the riverbed during the ebbing tide and swim up into the flow during the flooding tide to facilitate further upstream migration.

Bass were another species which arrive in the mid channel. Despite being more developed and already ingesting food, the results presented within this report (see Figure 6.14) clearly show a shift from the sub-tidal to the intertidal zone. The specific ontogenetic developments driving this habitat shift are less obvious than with flounder, but corresponded with the latter stages of final fin formation, specifically, the completion of the anterior dorsal fin, which occurs between fish lengths of 17 and 20 mm. Considering the less definitive ontogenetic changes driving this shift in habitat utilisation and the fact that bass were captured in varying stages of dorsal fin development in both the sub-tidal and intertidal zones, fish length (17 – 20 mm) is considered to provide a better predictor of lateral habitat shift towards the richer feeding prospects of the intertidal zone.

Based on the knowledge that intertidal habitats in estuaries provide high quality nursery habitat for many species of fish, the expectation was that smelt would demonstrate the same lateral habitat shift at some point during their early ontogeny. This was not the case and may be explained by the fact that the largest smelt captured during the present study (maximum = 82 mm) were still undergoing morphological transition towards the adult morphotype. Also still lacking body pigmentation, it is possible that smelt may delay a shift to the intertidal zone until their development is more advanced. With data limited to just two years, further focussed research would be required to better understand the lateral movements of smelt. However, the results to date, indicate that the subtidal zone is of key importance to smelt throughout their first few months of development.

9.4 Environmental drivers

Abiotic variables driven by the weather can impact quite dramatically on temporal environmental conditions within an estuary. This creates the potential to drive temporal (intra- and inter-annual) variance in fish population performance and may assist in explaining why differences occur in the survey results between years.

With specific reference to the environmental data summaries presented in Section 8, freshwater river discharge recorded at Kingston, was notably higher between the months of January to June in 2018, than the flows recorded for the same months in 2017. It is important to note that Kingston gauging station has been used as a proxy for freshwater flows for all other tributaries entering the Thames downstream of this point. This input of additional freshwater therefore has the potential to dilute the salinity and also impact on the physicochemical characteristics of the estuary. The temporal trends in salinity between years and sites (see Figure 8.1), do however indicate that while monthly surface water salinity remained relatively constant between years at Putney, considerable differences were evident between years at Greenwich from when monitoring started in April until June, thus tying in with the elevated influx of freshwater into the estuary during this same period in 2018. It is particularly noteworthy that in April 2018 (and probably March), the salinity at Greenwich was no higher than the salinity recorded at Putney for the same month in either 2017 or 2018. Water temperature (see Figure 8.1) also corresponds with these observed inter-annual differences, particular between March and May. Again, due to the influx of additional freshwater and colder ambient air temperatures during the same period in 2018 (Figure 8.3), water temperature at Putney in March 2018 was more than 50% lower (~5.1^{o}C) than the temperature recorded for the same month in 2017 (~12^{o}C). At Greenwich, inter-annual temperatures were relatively consistent. Despite lacking any temperature data for Greenwich during the month of March 2018, trends appear to broadly track the same trajectory as Putney in 2017 and indicate that the temperature at Greenwich in March/April 2018 would have been similar to the temperatures recorded for the same months at Putney in 2017.

So how might these observed differences in environmental conditions impact of fish? Firstly, it's important to consider the seasonality of these changes and the fish species known to be present in the estuary during this early part of the year. This reduces the potential impacts to one species in particular; the smelt.

Remarkably, smelt also demonstrated dramatic differences in their population performance and distribution between years. The results from the 2017 survey show the presence of newly hatched smelt fry at Putney in March 2017. Indeed previous surveys have detected smelt spawning activity in this part of the estuary for the preceding two years, with smelt fry recorded in 2015, 2016 and 2017. In 2018, smelt were absent from Putney, but appeared in relatively high abundance in more advanced stages of development at Greenwich. With reference to water temperature and water salinity, the conditions during the smelt spawning season showed considerable inter-annual variation at Putney. The conditions at Greenwich in 2018 however, were more closely aligned with those recorded at Putney in 2017. It does seem unlikely that the colder temperatures recorded at Putney in 2018 would have prevented smelt from spawning, as previous studies have documented spawning activity at temperatures greater than 4°C (Belyanina, 1969; Inland Fisheries Trust, 1972). It is however possible that the environmental conditions in the lower parts of the estuary around Greenwich in 2018 (particularly reduced salinity) may have presented smelt with the option of using alternative spawning grounds, negating their need to migrate as far upstream as Putney.

It is very important to note that the results from this study represent a 'snapshot' of water quality during each fish survey and therefore, do not show the detail which would have been provided by constant monitoring throughout the full tidal cycle. These preliminary inferences between environmental drivers and the inter-annual behaviour and performance of smelt must therefore be considered with appropriate caution. The results do however demonstrate considerable inter-annual variation and the need to incorporate these factors into guiding future fisheries survey design.

9.5 Habitat considerations

The results from this study clearly show that the entire water column is important for ELHS fish. With smelt needing the mid-channel throughout their development, and flounder, seabass and eels using the margins and deeper water for selective tidal stream transport and feeding. It is therefore concerning that so many of the margins on the Thames are altered from their natural state, with shallow water over foreshore in some areas entirely lacking. Brief examination of two areas along the Thames at Putney and Tower Bridge demonstrated shallow water above foreshore for just five and three hours of the day respectively. It is difficult to know the short- or long-term impact that could be caused by the lack of shallow, sheltered places to escape the current for ELHS fish, but it must be assumed that there would be an energetic cost as they would be forced to swim against the current or be washed further downstream, potentially to a less favourable feeding area. It is therefore imperative when designing further developments in the Thames that foreshore area is maintained and ideally enhanced (Estuary Edges 2018, ZSL Guidance Document, 2016).

Furthermore, the discovery of a potential second spawning site for Smelt further downstream must be further examined. Smelt, once common in the UK have suffered significant declines since the 19th Century. The tidal Thames holds one of the largest-known breeding populations of smelt in the UK and their spawning site is rightly protected during the spawning season from impacts from developments. It is important that the policies used to protect Smelt in the Thames are updated to reflect this potential second spawning site and further research is undertaken to identify and protect it. Additionally, throughout early 2018 limited percussive piling was undertaken around Chelsea Embankment, Albert Embankment, Victoria Embankment and Blackfriars Bridge, linked to the construction of the Thames Tideway Tunnel. This piling was strictly controlled, time limited and only took place during daylight hours. Percussive piling has been linked to avoidance behaviour in certain fish species of up to 250 m upstream and downstream of the piling site (THA Aquatic, 2017). Although no piling occurred directly around the assumed spawning site, it is possible that the upstream migration of smelt, or other fish species, were impacted by this piling activity which could account for the apparent lack of spawning in Wandsworth in 2018.

9.6 Effective stakeholder engagement

Stakeholder engagement was woven into the survey plan throughout the two years of this project. Over 140 volunteers were in our fish surveys, 250 members of the general public attended a ZSL science event on the Thames, four public engagement events were attended by ZSL staff and over 40 messages about the surveys and catch went out on our social media channels reaching over 90,000 people. These activities were very important in engaging Londoners, and those further afield, in the importance of the Thames estuary for fish. The citizen science fish surveys at Blackfriars were particularly popular, with all events being over-subscribed, and reports of amazement of the species and diversity caught.

Due to the limited effort and simplification of techniques used, the data from Blackfriars is of limited use for this study. However, as these surveys are an important tool in engaging stakeholders of the Thames, further surveys are planned for 2020 and beyond (funding allowing). With a longer-term dataset, using similar methods, the information collected from Blackfriars by citizen scientists in this study and others, will have more worth in demonstrating trends in species composition over time at this site.

10 Conclusion and suggested further research

The results of this study clearly demonstrate that the Thames is an important spawning and nursery ground for over 20 species of marine and freshwater fish. Furthermore, the data show that the way ELHS fish use the Thames, specifically their temporal and spatial use of the river channel, varies depending on the species and their stage of development. By examining the lateral use of the estuary by species as they develop, it is clear that the entire width of the channel functions as an essential nursery habitat, with some species like smelt appearing to favour the mid-channel, and others, such as flounder and seabass moving into the margins as they develop.

The data collected through this study has provided a strong pre-Thames Tideway Tunnel baseline of ELHS relative abundance, distribution and species diversity against which future improvements can be quantified. Follow up surveys after the Thames Tideway Tunnel is launched are therefore strongly recommended.

The multi-method, multi-location, multi-year methodology developed for this study allowed us to understand the temporal and spatial variation in how ELHS fish use the Thames. It is important to note a snapshot survey would not have provided the same insight. As the results from the 2017 and 2018 surveys were found to be very different it is important that further comparable research is conducted to further develop our understanding of the causes of these fluctuations. Preliminary analysis suggests environmental variables may account for some of the observed variations, however it is also possible anthropogenic impacts, such as percussive piling from development, may have also played a role in determining the inter-annual performance. Each year the Environment Agency conduct two adult fish surveys at specific sites along the river and estuary to report on the Water Framework Directive requirements. Despite representing snapshot surveys, the long-term dataset built up over 25 years provides some valuable information on temporal trends in species presence and their relative abundance. We propose a similar plan of regular surveys year-on-year for ELHS fish would be an excellent way to continue to monitor this aspect of Thames fish populations.

From the data collected it appears that for the first time in at least three years, smelt did not succeed in spawning at Wandsworth in 2018. However, ELHS smelt were caught further downstream suggesting a second spawning site on the river. As smelt are a species of principle importance (Marine and Coastal Access Act 2009) it is essential that further research is conducted to understand firstly, why there was a lack of spawning in Wandsworth and secondly where additional second spawning sites on the tidal Thames and its lower tributaries may be located.

Citizen scientist surveys proved an effective way to engage members of the public with Thames wildlife, with the methodology developed already replicated in other estuaries. However, due to snapshot nature of these surveys, the data were of limited use for this study. If a long-term comparable dataset were collected however, sampling the same location at the same time of year with the same nets, citizen science sampling has the potential to provide us with useful data on general trends of juvenile fish species at Blackfriars over time.

This study represents the most comprehensive ELHS research on any UK estuary to date and clearly demonstrates the importance of the tidal Thames as a nursery habitat for fish. Now that a suitable multi-method approach has been designed to research ELHS, it is hoped that this study will be replicated, both on the Thames in the years to come, but also on other estuaries in the UK and beyond.

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