Estuary Edges 2018

Fish Survey Programme

October 2017

A survey of fish populations associated with a series of artifical habitat structures in the Thames Estuary

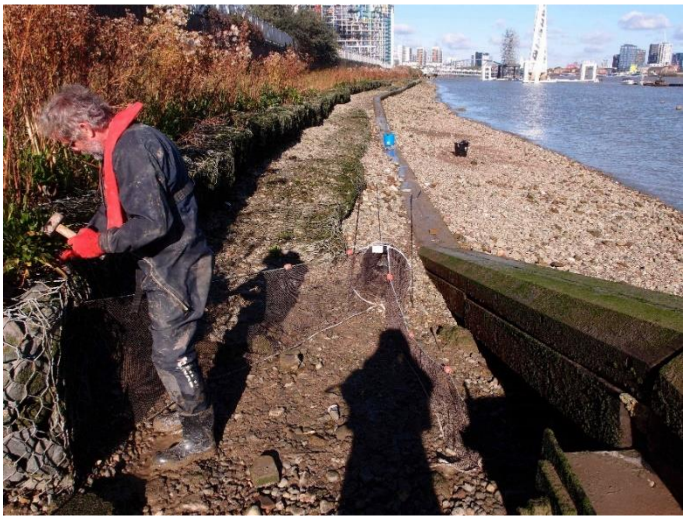

Plate 1 Winged fyke net set at downstream end of the Greenwich Millennium Terraces North East, on October 6th 2017.

(ZSL)

Plate 2 Bass taken in a winged fyke from the artificial creek habitat adjacent to Becton STW on Barking Creek on 17th October, 2017

(ZSL)

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Executive Summary

The Tidal Thames is a heavily modified estuary running through the heart of London. Over the last 15 years, mitigation measures to help address the impact of modification have been implemented, varying from timber bolt on structures, to sloping pre-planted terraces where the flood defence has been set back. Planning guidance for developers called Estuary Edges was produced and published in 2008, featuring many of these sites as case studies and details of the different designs that could be used to soften the hard-engineered flood walls. That guidance is now out of date and not fit for purpose. In addition, the mitigations featured in Estuary Edges and others delivered since have never been revisited to understand their true habitat value or structural integrity with time.

The Environment Agency have secured funding to complete post project appraisals of these mitigation measures. Through a wider partnership project bringing together the engineering, academic, navigation, field and engagement expertise across the tidal Thames, we now have the opportunity to deliver an update on Estuary Edges, produce a user friendly guide, suite of case studies and develop a sustainable and replicable monitoring model through citizen science.

The overall project is managed by the Thames Estuary Partnership (TEP). Colclough & Coates – SC^2 were contracted to deliver a fish survey programme across 11 selected sites in October, 2017. The surveys were executed in conjunction with ZSL, with additional volunteer support through TEP.

In summary, 10 species of fish covering some 767 individual specimens, were captured using a multi-method sampling technique involving winged fyke nets, seine nets and block nets. All fish were identified, enumerated, measured and returned to the water. 39% of the total catch was made up of juvenile bass *Dicentrarchus labrax.*

Capture rates varied considerably between sites. Site design was considered to be a critical element in the degree of fish utilisation. Tidal height, gradient, drainage channel evolution and vegetation cover are all important considerations. A complex of micro-habitats, with low gradients (but not flat), drainage channels and adequate vegetative cover will optimise multiple species fish utilisation of terrace structures.

Ecological studies should take place on those sites not covered in this survey, in particular Point Wharf and Saxon Wharf in Deptford Creek, to advance our understanding further. Further studies should take place at Wandsworth Riverside Quarter and in Wandle Creek adjacent, as site conditions improve, to more fully assess the value of these terraces. This work could form part of wider long-term potential study, to see how the whole creek habitat re-establishes itself after removal of the half-tide weir in early 2017.

The current level of science and understanding of fish utilisation of these sites should be brought to bear on site design for new sites. It may also be possible to adopt subtle design modifications to existing sites to improve fish utilisation. Post project appraisal, including ecological studies, should become a standard element in future site implementation. Each site is unique and continues to improve our understanding.

Several sites have been studied previously. Long term studies of key sites should be undertaken to understand more clearly how these sites evolve over time. This will further inform future design.

A more holistic ecosystem services or even Natural Capital approach should be adopted, to maximise the benefits from future site creation and realise important contributory funding streams.

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1. Introduction

The Tidal Thames is 152 km of heavily modified estuary, running through the heart of London and out to the Essex and Kent marshes. Over the last 15 years, mitigation measures to help address the impact of modification have been implemented, varying from timber bolt on structures which vegetation can cling to, to sloping pre-planted terraces where the flood defence has been set back. These have included sites at: Wandsworth Riverside Quarter, Deptford Creek, Greenwich Peninsula, Barking Creek, Dartford Creek, Gargoyles Wharf, Pipers Wharf, Isle of Dogs (Folly Wall) and Battersea Reach. These were innovative at the time and have set the trend for many heavily modified estuaries throughout the UK (e.g. the Humber). Planning guidance for developers called Estuary Edges was produced and published in 2008, featuring many of these sites as case studies and details of the different designs that could be used to soften the hard-engineered flood walls. This guidance proved very popular and has been used extensively by the Environment Agency (EA) and coastal engineers across the UK and internationally as far afield as the Philippines. However, it is now out of date and not fit for purpose. In addition, the mitigations featured in Estuary Edges and others delivered since have never been revisited to understand their true habitat value or structural integrity with time. With constant development and the promotion of economic growth, the EA and partners need this information to continue to promote these structures and to help achieve Good or Moderate Ecological Potential under the EU Water Framework Directive. Furthermore, with many significant infrastructure projects such as the Thames Tideway Tunnel and flood defence project, Thames Estuary Asset Management 2100, the need for this information is compounded further. EA's national evidence is performing a literature review of worldwide estuary and coastal ecological enhancements (called the Integrated Grey-Green Infrastructure Project (IGGI)) but cannot produce the raw data that is required here.

Therefore, the EA have secured funding through an internal process to complete post project appraisals of these mitigation measures. Through a wider partnership project bringing together the engineering, academic, navigation, field and engagement expertise across the tidal Thames, we now have the opportunity to deliver an update to Estuary Edges, produce a user-friendly guide, a suite of case studies and develop a sustainable monitoring model through citizen science that is replicable in all estuaries.

The overall project is managed by the Thames Estuary Partnership (TEP). A Project Board has been set up to steer the project and bring partners together. TEP will convene the board, produce minute meetings, manage delivery partners, bring together outputs, fundraise for the wider project aspects and produce the final report and guidance in an agreed format.

2. Field Surveys and Data

Surveys of sites featured in Estuary Edges and others delivered since were conducted in October, 2017. Plant, fish and invertebrate density and diversity surveys were conducted in parallel. Site descriptions and observations on structural integrity were made. A social survey of selected sites was also conducted. A broad range of sites were considered for investigation initially. After site inspections, the number of sites was reduced to the suite which appear in Table 1.

3. Fish in intertidal environments

Estuaries provide extremely productive environments, playing a crucial part in the life cycle of many fish species (McHugh, 1967; Haedrich, 1983). They act as key marine fish nursery grounds, as well as vital corridors for migratory species. These are highly dynamic environments, with abrupt changes in oxygen concentration, temperature, turbidity and salinity applying over both the short term and over longer seasonal cycles (Thomas, in Attrill, 1998). This tends to limit the species of fish which survive in these conditions, but those that can do so thrive. (Blaber *et al*, 1989). As a reflection of these challenging conditions, the fish communities associated with estuaries are highly dynamic (Blaber, 1991; Colclough *et al,* 2000 & 2002). Fish are constantly moving in response to the range of environmental forcing factors described. Superimposed on this complex picture are pronounced seasonal rhythms in the movements of the fish species themselves. The sheer dynamic scale of all these processes together has dictated that until recently, the fish communities of many estuaries across Western Europe had been poorly studied in comparison to their freshwater and marine counterparts. Therefore, the importance of these habitats for fish life is still not fully recognised (Elliott M., in Elliott & Hemingway, 2002).

Saltmarshes exist as a natural component of the estuarine system in the more saline reaches, extending as a band of higher plants on the foreshore between mean high-water neap tide level and the mean high water mark. The largest remaining expanses of saltmarsh in Britain lie in the greater Thames estuary along the Essex coast and in Suffolk (Waite, in Attrill, 1998).

Elliott & Taylor (1989) demonstrated that intertidal habitats in estuaries are twice as productive in terms of invertebrate production when compared to subtidal equivalents. The intertidal areas and salt marsh of the estuarine fringes are vitally important refuge and feeding habitats for fish fry (McLusky *et al*., 1992). This is particularly important for round fish fry, and for some species, such as sea bass, saltmarshes may represent the optimal nursery habitat (Laffaille *et al*, 2001). This understanding of the importance of saltmarshes as nursery grounds for marine fish species is well understood in the US (Bell, 1997; Boesch & Turner, 1984; Roundtree & Able, 1992; West & Zedler, 2000) but is very new to Europe (Laffaille *et al*, 2001; Lyndon, 2002; Colclough *et al*, 2005).

Much of the historic saltmarsh habitat has been lost across Europe (Airoldi & Beck, 2007). Two per cent of English saltmarshes are lost to the sea every year as a consequence of sea level rise (Dixon *et al*, 1998). Net saltmarsh loss in the south east of England from 1973 to 1998 was *c.* 1000ha, or 33% of the total area present in 1973 (Wolters *et al*, 2005). In the Thames estuary, less than 1% of the original bank form still exists (Colclough *et al,* 2002). Some of the impacts associated with this substantial loss have been unrecognised until recently. For example, McLusky *et al* (1992) estimated that land-claim and sea defence work in the Forth estuary over the past 200 years have reduced overall fish production in the estuary by 66%.

Saltmarshes are a UK Biodiversity Action Plan habitat and, in England, form part of the Government (Department for Environment and Rural Affairs) High Level Target nine habitat series. Under these initiatives the intention is that there should be no further net loss of habitat and opportunities for environmental enhancement should be sought.

Managed realignment has been developed in the UK since the early 1990's as one of a suite of effective flood risk management measures to meet the challenges provided by storm surges and rising sea levels. There have now been more than 40 such treatments in the UK, with sites in the Humber, Greater Thames and Severn estuaries and on a number of coastal locations on the East, South and West coasts. Dixon *et al,* (2007) provides a review of the early experiences with design and development of some of the first UK sites (Blackwater and Crouch estuaries).

A lot of information on how saltmarshes function and the ecosystem services they provide, including fish utilisation, has been developed over the last 20 years, through the study of managed realignment treatments which develop saltmarsh plant communities over a period of years (Colclough *et al*, 2005; Dixon *et al*, 2007; Fonseca, 2009; Fonseca, *et al*, 2011; Yates, 2012; Nunn *et al*, 2016). Saltmarshes can provide a number of other valuable ecosystem services, including nutrient and micro-pollutant removal and carbon sequestration. (Luisetti, 2011; Viera da Silva,2012). Placing all the currently known functionality of saltmarshes in Water Framework Directive terms, these habitats may prove to be vital components in achieving good ecological status.

Studies of how fish utilise these relatively small new intertidal habitats created in the Thames will add significantly to our overall understanding and help focus more holistic design of new treatments, both large and small.

4. Fish Surveys

Colclough & Coates – SC^2 led the fish survey programme, in partnership with ZSL, under contract to TEP. Each site was visually inspected to determine the most appropriate fish sampling methodologies to apply. Comprehensive generic and site-specific RAMS statements were developed for each site. Staffing to deploy and recover fishing equipment was restricted to SC^2 and ZSL staff. Volunteer assistance from TEP, UCL and elsewhere was harnessed to undertake fish processing and related tasks well away from the sampled area. TEP staff provided safety site cover on all survey days. ZSL staff took photographic records of sites prior and post fish sampling. Plastics samples were taken for a wider ZSL study, wherever fyke nets or seine nets captured these during fish sampling.

5. Fish Sampling Methodologies

A recognised Best Practice multi-method survey approach was employed throughout (Coates *et al,* 2007; Elliot, M. in Elliott & Hemingway, 2002). The actual methodology varied slightly between sites, given local conditions. The methods employed were one 15m * 2.7m * 3mm knotless mesh seine net, four small mesh winged fyke nets (50cm height; trap length 2.75m * 6.5mm knotless mesh; wings 1.5m) and three very small mesh winged fyke nets (30cm height; trap length 3m * 3mm knotless mesh).

Where applicable, seine netting was conducted on a rising tide on the foreshore in front of the terrace structure, just before the tide covered this feature completely. This work was conducted by SC^2 & ZSL only in drysuits and lifejackets. Fish were recovered to the public footpaths above for processing. This sampling was conducted in the light of past studies on the Thames which have demonstrated that small fish follow the head of tide up actively in order to be able to enter vegetation as soon as possible (Amoo-Gottfied, 1998; Colclough et al, 2000 & 2002). Fyke nets were deployed on the terrace structures before water entered onto these features, by SC^2 and ZSL staff only. The nets were recovered on the falling tide just prior to the cod-ends drying out. Again, fish were removed to the footpaths above for processing. The fyke nets were secured with small metal stakes and weights. A telescopic safety ladder was used to permit staff to safely descend onto the terrace structures, in several locations. A safety harness and safety lanyard were deployed on one of these latter sites to protect staff entering onto the terrace by ladder. At the two Barking Creek sites, there was no possibility of seine netting in the main creek adjacent. The intention here was to set a seine as a block net at high water across the mouth of the new creek feature and recover the net and contents as the water left the site. Metal stakes were used to secure the block net. Every care was taken to minimise damage to the vegetation on the habitats sampled. All fish captured were identified to species level, counted, measured and returned to the water as soon as possible. Where vehicular access was remote, equipment trollies delivered equipment to site, via riverside paths.

Table 1 provides details of the final 11 sites which were chosen for the fish, plant and invertebrate surveys. It also contains details of the fish sampling methodology employed at each site. Plates 3-5 illustrate the sampling methods employed.

Table 1 Estuary Edges Fish Survey Fish Survey, October 2017.

	Name	Survey Methodology	Foreshore Access	Date	Tide HW	Sunset	Notes
1	Wandsworth Riverside Quarter	Fyke nets set on terraces. Seine netting in front of terrace.	Possible	2/10/17	12:27pm 6.0m	18:36pm	No safety boat required.
2	Battersea Reach Terracing	Fyke nets set on terrace. Seine netting in front of terrace.	Possible	3/10/17	13:16pm 6.4m	18:34pm	No safety boat required.
3	Royal Wharf Western Terrace	Fyke nets set on terrace.	Possible	4/10/17	13:40pm 6.9m	18:31pm	Foreshore access considered here to be unsafe for seine netting in front of terrace. No safety boat required.
4	Point Wharf Greenwich Peninsular	Fyke nets set on terrace. Seine netting from slipway adjacent to terraces.	Possible	5/10/17	14:19pm 7.1m	18:29pm	4 replicate groyne treatments with varying degrees of habitat creation. Access via adjacent slipway. No safety boat required.
5	Greenwich Peninsular Terraces NE	Fyke nets on terrace. Seine netting in front of terrace.	Possible	6/10/17	14:58 7.3m	18:27pm	No safety boat required.
6	Barking Creek at Becton STW	Fyke nets set in creek habitat structure and on seawall below barrier. Seine net will be deployed as a stop net at high tide across mouth of creek structure	N/A	17/10/17	12:45pm 6.8m	18:03pm	. No safety boat required.
7	Barking Creek at Barking Barrier	Fyke nets set in habitat feature. Seine net used as block net at edge of feature at high tide.	N/A	18/10/17	13:34pm 7.0m	18:01pm	No safety boat required.
8 9 10	Deptford Creek Vertical Wall Renewal, new terrace (North Facing) Saxon Wharf & new terrace (South Facing) Thanet Wharf	A single day of seine netting in the creek is proposed to cover all 3 sites. Fyke nets to be deployed on terraces at Saxon and Thames wharves.	Creekside centre. Access via both wharves available.	19/10/17	14:15pm 7.19m	17:59pm	Small fish associate with vertical habitats. SC to collaborate with other workstreams to use EA boat access to visually assess fish association with vertical structure.
11	West India Dock Phragmites bed	Fyke nets set on terrace.	Not possible	20/10/17	14:51pm 7.2m	1757pm	No possibility of seining on terrace or adjacent on foreshore. No safety boat required.

Plate 3 Small winged fyke net with 1mm cod-end and 3mm micromesh panels and wings.

(SC²)

Plate 4 Larger winged fyke net with 8mm panels, 10mm wings and 6.5mm cod-end

(SC²)

Plate 5 15m micromesh seine net set from the shore.

(J.Sutton)

6. Results

767 fish were captured in total, comprising 10 species. Table 2 provides a summary of the fish captured. The most numerous species taken was the sea bass *Dicentrarchus labax*. (39%). Individual site reports, with observations on habitat structure and other issues appear in Appendix 1. Photographs of most of the species captured appear in appendix 2. Length frequency distributions for bass captured in the survey appear in appendix 3.

Table 2 Fish Captured at the 11 sites sampled

Site Name	Fish Species	Number Captured		Size Range mm	Comments
		Foreshore	Terrace		
Wandsworth Riverside Quarter	Bass Dicentrarchus *labrax*		3	78-83	
	Common Goby Pomatoschistus *microps*		1	46	
Battersea	Bass *Dicentrarchus labrax*	1	2	60-62	
	Common Goby *Pomatoschistus microps*	1	0	48	
	European Eel *Anguilla anguilla*	0	3	216-475	
	Roach Rutilus *rutilus*	2	0	76-78	
Royal Wharf					
Point Wharf	Bass *Dicentrarchus labrax*	21		53-114	
	Common Goby *Pomatoschistus microps*	1		32	
	Thin Lipped Grey Mullet *Liza ramada*	1		144	
	Seahorse *Hippocampus hippocampus*	1		8	
Greenwich 02 NE terraces	Bass *Dicentrarchus labrax*	10	10	62-110	
	Common Goby *Pomatoschistus microps*	6	8		
	Thin Lipped Grey Mullet *Liza ramada*	0	1	18	
	Flounder *Platichthys flesus*	1	1	60-84	
	European Eel *Anguilla anguilla*	0	5	225-425	
	Sand-smelt *Atherina presbyter*	1	0	33	
	Sand Goby *Pomatoschistus minutus*	0	17	48-74	
Barking Creek Becton STW	Bass *Dicentrarchus labrax*		30	35-125	
	Common Goby *Pomatoschistus microps*		84	35-52	
	Flounder *Platichthys flesus*		1	78	
	European Eel *Anguilla anguilla*		1	295	
Barking Creek River Road	Bass *Dicentrarchus labrax*		180	66-128	119 not measured
	Common Goby *Pomatoschistus microps*		2	42-48	
	Flounder *Platichthys flesus*		2	78-125	
Barking Creek Outside Thames Barrier	Bass *Dicentrarchus labrax*		14	65-116	
	Common Goby *Pomatoschistus microps*		1	48	
	Flounder *Platichthys flesus*		4	78-125	
Deptford Creek	Bass *Dicentrarchus labrax*	6	14	54-114	
	Common Goby *Pomatoschistus microps*	326	1	30-48	287 not measured
	Bream *Abramis brama*	2	0	65-75	
	Sand goby *Pomatoschistus minutus*	0	1	70	
West India Dock	European Eel *Anguilla anguilla*		1	160	

As a former Environment Agency (EA) fisheries scientist and subsequently since 2011, the author has over thirty years' experience with the Thames estuary, fish life and habitat creation. He will provide some relevant additional observations from that background in the discussion.

7. Discussion

Fish communities in the Thames estuary have been well described (Thomas in Attrill, 1998; Colclough et al, 2000 & 2002). In addition, there have been a number of relevant MSc theses over the past 25yrs (a number of which were supervised by the current author). Important work has also been conducted by ZSL staff and MSc students and through the EIA development process. The EA current WFD transitional waters surveillance fish monitoring programme provides a means of assessing current fish community status.

The fish communities reported from these surveys accord well with this range of studies. However, there have been few specific studies associate with created marginal habitats. Where these exist, they will be referred to, as relevant.

Wandsworth Riverside Quarter - The terraces at Wandsworth Riverside Quarter, on the mouth of the river Wandle, provide an excellent gradient with mature vegetation which should have seen the capture of many more fish, judging by experiences elsewhere. Informal fish surveys by the former Thames Water Authority in 1988 prior to the barrier construction had demonstrated that the lower parts of Wandle Creek were heavily populated with common goby, flounder and juvenile dace and smelt, in a manner consistent with that seen later in Deptford and Railshead Creeks as well (Colclough, S. pers. obs.). When the half-tide weir had been in place, contaminated silt burdens sat behind the structure, probably originating from foul connections and road runoff from the densely populated urbanised Wandle catchment. On removal of the weir in early 2017, the deposits had been removed by dredging. Staff involved in the current study noted significant movement of black silt burdens in suspension on the ebbing tide. It is reasonable to assume that this site is still too disturbed at present to attract the high-quality fish community that it should support. The original intention to seine the intertidal gravels in front of the terraces could not be implemented on the day. The H & S induction on the building site immediately adjacent took too long for this purpose. By the time the fish survey team were on site, the tide had already moved onto the foot of the terraces. This is particularly unfortunate, since these gravels lie upstream of the mouth of the Wandle. It is reasonable to assume that in an unimpacted state these gravels would support similar fish communities to those reported in regular EA WFD surveys at both Chelsea and Putney.

Battersea Reach Terracing - Very few fish were taken at Battersea. The seine netting was hampered by very large quantities of leaf litter, woody debris and some plastics. The upper half of the terraces provide very little habitat for fish life since the underlying substrate within the gabion baskets has been washed away, to a depth ranging from 5cm up to 30cm in places. There was very little vegetation growing in these exposed areas. The behaviour of the rubber barrier may well have interfered with fish movements across this boundary. On a rising tide the barrier floats and lifts with the incoming tide. The rubber skirt of the barrier is approximately 1m deep. Until a depth of 1m exists above the terrace front edge, there is a continuous wall present, as the barrier rises from its retaining slot. Above this height, there is a free clear gap of water below the barrier skirt. Many studies have shown that fish try to move onto the upper intertidal habitat as soon as they can in the tidal cycle to feed and seek refuge from predators, remain for long as possible, and then exit rapidly (Colclough *et al*, 2004 & 2005). This barrier behaviour tends to frustrate fish migration until well into the rising tide, probably reducing significantly the use of the terraces by fish. On small tides, the free gap may not last for very long. There is also the prospect of fish strandings above the barrier wall. There are no freestanding pools of water on the terrace immediately above the barrier for fish to survive until the next tide. One interesting feature of this survey was the capture of 3 larger eels.

These were taken in one of the larger winged fykes. Given that these are 2.5m in length with 2.5 m wings, much of the terrace depth was taken up by setting the net perpendicular to the shoreline, as per normal practice. At the top of the tide on the day of the survey, there was a maximum of 45cm of water at the top of the wing. The eels must have been actively feeding along the high-water mark in order to have found their way into the net.

Royal Wharf - The survey at Royal Wharf was a complete failure. 3 fykes were set at the edges and in the centre following the only gaps in a very uniform and dense *Phragmites* stand. In practice, water levels on the day only came to the level of the terrace and water did not penetrate. The Port of London Authority later advised that due to prevailing wind patterns, high water had been at least 30cm lower than predicted. They also advised that a Thames Barrier closure was probable on the following day (Point Wharf survey) given the current weather patterns.

This terrace is set very high in the tidal range. In conjunction with Richard Charman of the EA, the author later estimated that even under normal conditions the terrace might not be inundated more often than 1 or 2 days per month. This is borne out by the lack of debris and rubbish on the terrace, so evident on many of the other structures studied. The terrace has no apparent gradient, and so no drainage channels have begun to form. These may develop with time, but without a gradient, this might not be the case. For the very short time in each tidal cycle that fish can enter the terrace feature, they have no channel form to guide entry and exit. Without channel guidance, fish would need 50cm plus of water above them to feel confident to enter the terraces (Colclough *et al*, 2004), although they might associate with the extreme margins. If fish were to enter, without channel guidance and no gradient, fish stranding is quite possible (Colclough *et al,* 2004).

Development work for the WFD fish sampling programme in the early 2000's demonstrated that very few fish in the estuary actually remain at any one particular point for more than a short period. Most are moving on the tidal excursion (up to 13km) attempting to maintain stasis or are actively migrating upstream or downstream on seasonal patterns (Colclough *et al*, 2000 & 2002; Barton, 2006). On this basis, although no foreshore sampling was attempted at Royal Wharf, it is reasonable to suggest that the fish communities found on the shores will be common with those found on the foreshore upstream at Greenwich Millennium terraces and at Point Wharf. A similar case can be made for West India Dock in the same vicinity. The nearest EA WFD sampling station is also close by outside the Royal Naval College at Greenwich.

Point Wharf - At Point Wharf, the habitat created provides a progressive treatment set to sample. The photographs in Appendix 1 demonstrate how the extent of the habitat creation increases progressively moving downstream. Unfortunately, this survey date coincided with the emergency Thames Barrier closure advised a day in advance by the PLA. In practice water did not venture onto any of the terrace structures.

The terraces have established stands of vegetation and should provide good cover for fish life. The vertical campshed face to the terraces will dissuade some species such as flounder from penetrating onto the terraces (Colclough *et al,* 2004). Water drains out through holes in the campsheds, leaving significant ponded areas behind temporarily. Some fish stranding on the terraces is therefore likely.

The seine netting adjacent to the slipway, proved to be very efficient. The community of fish species reported is the community known to be present in these reaches of the river in the late summer/ early autumn and is regularly seen in the routine EA WFD fish survey site outside the Royal Naval College at Greenwich (T.Cousins, pers.comm.). The capture of a sea horse *Hippocampus*

hippocampus was a notable finding. As later described by ZSL, this is one of 6 individuals reported from the estuary at the end of September and beginning of October 2017, itself unusual since these animals are rare locally. (A.Cucknell, pers.comm.)

Greenwich Millennium Terraces North East - What are generally termed the Greenwich Millennium Terraces were constructed in 1998, as a demonstration of setback defences in an urban setting, as part of the site development for the Millennium Exhibition. Amoo-Gottfried (1998) studied the fish associated with a range of artificial marginal features in the Thames estuary including the Millennium Terraces, in the late summer of 1998. These terraces had only been established for several months at that point. *Phragmites* planting had taken place. Pioneer stands of sea - aster *Aster tripolium* were beginning to appear of their own accord. One early lesson from this process was that if the form, gradient, tidal height and structure of the physical habitat being created do mimic natural local intertidal habitat features, then pioneer plants will establish quickly in the Thames estuary, where the in situ seasonal seed bank appears to remain high. Amoo-Gottfreid reported captures of low numbers of dace *Leuciscus leuciscus*, common goby and flounder. His sampling sites were situated close to the present ferry pier and on the separate terrace on the point of the peninsular, at Blackwall Point.

Another study was completed on these terraces in August 2003 (Colclough *et al*, 2004). Sites were fished at Blackwall Point and around the current ferry pier footing, as in 1998. Two further sites were studied. One was only approximately 500m upstream of the current survey. A further control site was fished on the foreshore adjacent to Greenwich Yacht Club. The 2003 study established the rationale of sampling the foreshore in front of the terrace on a rising tide, prior to sampling the terraces themselves. This work established for the first time in the Thames that fish were moving actively close to the leading edge of the tide, to move onto the terrace as soon as possible. This behaviour had been seen elsewhere in saltmarshes (Colclough *et al*, 2005). In summary, the 2003 survey found greater densities of fish present and more species, now including smelt *Osmerus eperlanus* and roach. The greater density and variety of species was believed to be associated with the significant development of vegetation cover on the terraces since 1998. One point of note in both the previous surveys was the presence of freshwater species such as dace and roach. These were the first surveys in the Thames to demonstrate that in tidal waters, all species of fish freshwater, estuarine and marine are capable of selectively using tidal streams to access marginal habitats such as these. The precise mixture of species found at any one point will be dictated by a complex of seasonal bio-rhythms, ambient temperature and salinity. In an elegant study at Millwall, Barton (2006) sampling with a seine net regularly throughout a tidal cycle in July 2006 (repeated one week later) found that the fish community locally changed significantly after low water to a more marine mix of species and that this reversed to a more freshwater/estuarine community as the tide ebbed again. Understanding this dynamic is a cornerstone of the current EA WFD surveillance fish survey programme. For consistency, sampling is always conducted at low water slack tide.

The design intention in 1998 was to create a variety of micro-habitats along the terraces. Much more variety was engineered into the terrace structures on the downstream end of the feature. This can be demonstrated today. The photograph in Appendix 1 taken close to the pier foot shows a dense *Phragmites* bed. Closer inspection of this site on foot will show a flat terrace structure with no obvious gradient or drainage channel development. The remaining photographs are taken further downstream at or near the current sampling station. The greater habitat variety is evident. Further evidence of this intention appears in photographs that feature in the site report for this site, which were taken in 1998 just post-construction. One notable feature on the downstream terraces surveyed in this study is the formation of drainage channels across the site. Although offering a very truncated horizontal profile, parts of the terraces are beginning to develop true saltmarsh characteristics. Since fish access and leave marshes via these channels, this can only benefit fish utilisation.

Barking Creek (Becton STW) and Barking Creek (River Road) - These two sites will be discussed together, since they share some common historical links. The curved intertidal creek habitat adjacent to River Road, Barking was created in 2006. A structure of wooden stakes, coir and brushwood faggots was employed to provide some initial structure and encourage sedimentation. These elements were placed along the base and lower margins of the gently sloping new channel form. Photographs of the site during construction appear in Appendix 1.

Gray (2007) studied fish utilisation of this habitat, using a similar methodology and even some of the same fyke nets as in the current study. There was significant *Phragmites* growth across the upper part of the new creek feature, but an open water channel still existed throughout. Brushwood placed across the mouth of the creek feature was noted to hamper effective drainage from the site to some extent. Gray sampled over several days in July of 2007. In summary, she captured bass, thin lipped grey mullet, sand goby, bream, roach and dace. On one occasion on an ebbing tide with a block net set across the mouth of the new creek habitat (set at high water) 3131 fish were captured. 93% of these were young of the year bass.

In 2012, a similar form of creek habitat was constructed further up Barking Creek adjacent to Becton STW. The design was very similar to the above, with the same use of woody structure. A study of both the earlier site and this new site was conducted in July 2013 (Yates, 2013). Yates reported six species from the 2006 site, but only 36 fish in total. Most of these had been taken in a block net set across the mouth of the new creek habitat. 195 specimens of a total of nine species were then reported from the newly created creek, with good penetration of fish into the new creek system. Yates postulated that the contrast between the two sites might be explained by how the River Road site had evolved since 2007. Extremely dense *Phragmites* stands had developed, with no open water across the whole feature. The woody structure placed across the mouth of the creek feature was now heavily silted, providing no clear entry point for fish to enter. There was no indication of the development of drainage channels within the site. Photographs from this site at the time of the 2013 study appear in the site report in Appendix 1. An open water channel still existed along the whole of the new creek feature at Becton STW. There was significant *Phragmites* growth along both banks. Yates further postulated that if creek evolution followed a similar path in the new creek system, then this too may become less favourable to fish in future years. He recommended that future creek designs should include consideration of the maintenance of an open water channel to maximise, or at least secure, fish penetration. 2013 was a very wet and cold spring and summer. This may explain in part why catches were so much lower than in 2007. For example, 2013 was later recognised by Cefas as a very poor year for bass spawning and subsequent early life stage survival in the southern North Sea, since this is a warm water species (Hyder, K. pers.comm).

In 2017, similar sampling strategies to both Gray and Yates were used at these two sites. At Becton, the open water channel has remained. Significant sedimentation has occurred since 2013, with much of the woody structure now obscured. Drainage channels are developing across the upper habitat and there is a clear and unobstructed drainage channel all the way to the main creek. This drainage channel has evolved considerably since 2013 (Colclough, S. pers.obs.). The fish community recorded in 2017 was that expected from other creek or marsh like habitats elsewhere in the

Thames and in Essex (Colclough *et al*, 2005). Juvenile bass formed an important component of the catch.

At River Road, the 2017 photographs in the site report in Appendix 1 appear to show that the *Phragmites* establishment is as dense as in 2013. On closer examination on foot through the marsh itself, it transpired that there are two small open areas within the dense growth and there is clear evidence of drainage channels evolving. The two fykes were set out in these more open areas, among a lot of woody debris, plant fragments and litter. Further investigation showed that the brushwood bundles were still tending to block the mouth of the habitat feature, but the drainage channels are now undercutting this, permitting relatively free water (and fish) movement. The scale of the fish capture during the 2017 survey, particularly of bass was not expected in view of the past sampling results. This habitat is now providing very significant nursery provisioning for young of the year bass.

This complex story may now form part of a scientific paper involving all the authors to date. The work provides a unique perspective on the value of long term data in this field and how sites can evolve, sometimes unexpectedly.

The work completed on the outside of the Thames Barrier on the sloping rock revetment is equally interesting. Such rock revetments are a common part of the sea defences in the lower estuary. Most of these revetments date from the 1970's as a common element in the improved defences associated with the development of the Thames Barrier. They are sited at the base of the vertical sea wall. As a practising fish scientist and enforcement officer on the Thames for 22yrs, the author noted the development of plant growth breaking through the rock armour at a range of sites below Woolwich from about 1995 onwards. This development appeared to be progressive. One of the photographs in Appendix 1 for this site shows what this "greening" effect looks like from the river at this point. From his experience of working on saltmarshes and intertidal habitats across the UK, the author realised that this gradual process was probably turning a sterile hard physical structure into a very useful new feeding ground for juvenile fish, acting like a very long thin salt marsh. The opportunity to study this site came in 2013 in the work supervising the Yates study referred to above. 21 fish from five species, including bass were captured in one small mesh winged fyke set perpendicular to the shore. Photographs of this site at the time of the 2013 fish sampling appear in Appendix 1. Repeating that work in October, 2017 with two small winged fyke nets demonstrated that bass (14), flounder and common goby are still utilising this habitat. Numbers of fish may have been higher earlier in the year when vegetation cover was more extensive. Partial die-back had already taken place by late October (Colclough, S. pers.obs.). This can be seen by comparing the 2013 (July) photographs with those from 2017.

This extensive new habitat, common now below Woolwich, has never been mapped or recognised. It is highly vulnerable to coastal squeeze given its proximity to the sea wall. Loss of functionality could take place before we even understand the inherent ecological value. An ecosystem services or Natural Capital approach to this subject should see inclusion of this characteristic into compensatory measures being factored into the Thames 2100 Flood Risk Programme studies. Furthermore, if this natural greening process can be more fully described, then it is entirely possible that where future hard defence options must be adopted then some provision for such greening can be built in, either at construction, or encouraged naturally later on.

Deptford Creek - Deptford Creek is one of the few larger creeks in the Thames estuary where the original habitat form has not been severely altered by the creation of a tidal barrage (e.g. Barking Creek). The derelict creek walls were sensitively restored by the Environment Agency in the last decade as a part of modern flood defence strategy, incorporating both vertical timber facings to encourage habitat creation as well as a number of terrace treatments.

The fish community described in this survey from the seine netting is similar to that reported here and elsewhere in Depford Creek through a range of informal surveys and public environmental awareness days. Tidal creeks provide a vital refuge for adult and juvenile fish in the estuary (Colclough *et al*, 2000).

Attempts were made on the survey day to assess fish movements up the timber wall treatments visually from the EA vessel provided, but poor visibility prevented this. Proving that small fish do associate with vertical structure in a tidal environment is very difficult. Visual observation remains the best option, but conditions must be near perfect. The author can confirm that in clear visibility, and in protected calm waters in both Deptford Creek and elsewhere in the estuary, he has witnessed on many past occasions unidentified round fish fry moving up vertical walls as the tide rises, appearing to feed on the surfaces as they move (Colclough, S. pers. obs.) It is likely that the small fish captured in the seine net in this survey do move up the tidal walls to feed as the tide rises.

The bass captured at Saxon Wharf were unexpected, given the nature of this site. There is no vegetation cover at all on this very flat exposed surface to the terrace. With no protective cover, it is probable that fish will only move onto the bare terrace when water depth exceeds 1m. This probably leaves only a small tidal window for fish access, given the height of the terrace. There is some risk of fish stranding on the terrace given the lack of any gradient and no drainage channels, particularly close to the front lip of the terrace, where some erosion has taken place and temporary ponding occurs behind the lip.

The poor photograph to the lower right for this site in Appendix 1 has been included because in the distance to the right can be seen Thanet Wharf terrace which faces south and is heavily vegetated. An overlong H & S induction process on the construction site here precluded sampling on this site on the survey day. In the author's experience this vegetated terrace could have supported significant numbers of fish and made a worthwhile comparison with Saxon Wharf.

West India Dock Phragmites bed - After the experience at Royal Wharf, there was some concern as to whether sufficient water would cover this terrace, also set high in the tidal range, on the tide chosen. In practice this proved to be false, as shown by one of the photographs in Appendix 1. At the centre of the shot, floats from one of the fykes set near the top of the terrace can be seen. There is a good gradient across the site and drainage channels are developing, particularly at the edges, but these are probably causing the erosion seen that is undermining the *Phragmites* beds in at least two places. Only one fish, a European eel was captured in the 2017 survey at this site. The height of the terrace will dissuade benthic species such as flounder and gobies from accessing the site, since these appear to follow gradient and do not like "steps" (Colclough, *et al*, 2004). There is no reason why pelagic species such as bass or dace would not use this site.

General Comments

Bass was the most dominant species captured during the survey (39%), taken at all the sites where fishing was possible, except for West India Dock Phragmites bed. All the fish taken were juveniles. Many sources reference bass achieving 90-110mm (total length) at the end of the first summer of life. The length frequency distributions from this survey shown in Appendix 3, indicate a few fish exceeding that limit. No scale samples were taken, and so no definitive information is available. The very largest of the fish captured in this survey may have been second year fish. However, the high average size does show very good growth of the 2017 0+ year class, now at the end of their first summer of growth. The extended size range for a single year class is consistent with bass ecology reported from the Thames and elsewhere (Colclough *et al*, 2002; Sabriye *et al*, 1988). Multiple waves of the very early life stages appear in the same estuary at different times from different spawning aggregations separated in both space and time. This is manifest as multiple modal groups in the same year class strength, at least until the end of the first summer of life. Work in the Blackwater estuary in Essex (Green *et al,* 2012) has demonstrated that young of the year bass fry arriving in an area of saltmarsh in June at 20-30mm may well stay in the same general vicinity and use the same marsh as a preferred feeding ground throughout their first summer. Whether that site affinity also applies more generally in the confines of a large estuary such as the Thames is not yet known, but the current results do help demonstrate that these habitats under study provide important nurseries for one of our most important commercial and recreational fish species.

The original intention to attempt to sample the foreshore in front of the terraces as well as the terraces themselves at each site, could not be followed for the range of operational reasons described in the main text and in Appendix 1. However, some observations can be drawn from Table 2 where the results have been separated for the two habitats per site. The best two sites for any direct comparison were at the Greenwich Millennium Terraces NE and Deptford Creek. In both cases, bass were found on both the foreshore and the terraces. They appear to be quite willing to exploit the terrace structures as the tide rises. At Deptford, the contrast with the common goby is stark. This species seems entirely unwilling to move onto the terrace. Both behaviours are consistent with previous findings (Amoo-Gottfried, 1998; Colclough et al, 2004). Pelagic species with swim bladders are able to exploit the rising tide with ease. Benthic species such as flounder and common goby appear to find vertical faces difficult to negotiate. However, at Greenwich, the common goby was equally distributed across both habitats. This might be explained by the lesser gradient and developing drainage channels now appearing on the particular terraces sampled. Indeed, the common goby is one of the dominant species found in saltmarshes and managed realignment treatments (Lafaille et al, 2000; Colclough et al, 2005). The European eel appears to be quite willing to enter onto terraces, whether confronted by a vertical face or not, as evidenced at Battersea and Greenwich. Of course, some caution should be taken with all these observations since these are only single samples and involve few fish.

A simple overview of the results would suggest that of the terrace treatments studied, the Greenwich Millennium NE terraces support the most diverse fish community, with access to the terrace structure for most of the species encountered at the site. This quality of provision is probably related to the diverse series of micro-habitats created on this section of these terraces, together with the extent of vegetation cover, low gradients involved and the evolution of drainage channels. The two creek habitats now appear to be acting as significant bass nurseries.

In the developing science base around managed realignment, flood risk management and new habitat creation, we are just beginning to take a more holistic view, after 20yrs of experimentation. Good design for fish is also probably good design for invertebrates and birds too. If we take a more ecosystem services approach we begin to include all the other services provided as well, such as carbon sequestration, air quality remediation and micro-pollutant processing. By adopting all of this through a Natural Capital approach, we begin to identify significant opportunities for multiple contributory funding streams to construct holistic sites in the future. A wholly similar argument exists with these much smaller but equally important habitat creation schemes in estuaries such as the Thames.

8. Conclusions and Recommendations

Fish are utilising these habitats successfully, although capture rates varied considerably between sites. Site design and subsequent evolution were considered to be critical elements in the degree of fish utilisation. Elevation, gradient, drainage channel evolution and vegetation cover are all important considerations. A complex of micro-habitats, with low gradients (but not flat), drainage channels and adequate vegetative cover will optimise multiple species fish utilisation of terrace structures. Setting of the base of the terrace high in the tidal range will tend to reduce fish utilisation, as will vertical faces and barrier structures. Woody base structures do appear to facilitate sedimentation and vegetation establishment in new creek treatments, but this can frustrate fish utilisation if set transversely across the channel form, at least over the short term.

Ecological studies should take place on those sites not covered in this survey, in particular the Point Wharf and Thanet Wharf in Deptford Creek, to advance our understanding further. Further studies should take place at Wandsworth Riverside Quarter and in Wandle Creek adjacent, as site conditions improve, to more fully assess the value of these terraces. This work could form part of a wider long-term potential study, to see how the whole creek habitat re-establishes itself after removal of the half-tide weir in early 2017. The weir was originally installed in 1989. In prospect then is a 25yr "before and after" case study on the problems associated with such structures, in the confines of a tidal creek with a significant urban freshwater input.

The current level of science and understanding of fish utilisation of these sites should be brought to bear on site design for new sites. It may also be possible to adopt subtle design modifications to existing sites to improve fish utilisation. Post project appraisal, including ecological studies, should become a standard element in future site implementation. Each site is unique and continues to improve our understanding.

Several sites have been studied previously. Long term studies of key sites should be undertaken to understand more clearly how these sites evolve over time.

A more holistic ecosystem services or even Natural Capital approach should be adopted, to maximise the benefits from future site creation and realise important contributory funding streams.

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Appendix 1 Site Reports for Fish Surveys conducted in October 2017

All site photographs by SC[2] and ZSL unless otherwise stated

Wandle Riverside Quarter 2/10/17 TQ 25462 75297

Operations - 4 fyke nets were set across the terraces towards the top of the shingle slopes, immediately below the vegetation. Seine netting was conducted on the lower common section of the terraces. No seine netting was conducted on the foreshore below the terraces due to lack of time (access site H & S induction).

Results - Only 4 fish were taken in total, 3 bass and 1 common goby. All but one bass came from the fykes.

Notes -The terraces drain very well, and fish can make easy access given the gentle gradients. The vegetation provides a significant level of cover for fish life. Recent physical and chemical disturbance with removal of the half-tide weir may be impacting on fish associating with site at the time of the survey.

Other site photographs

Battersea Terraces 3/10/17 TQ 26237 75599

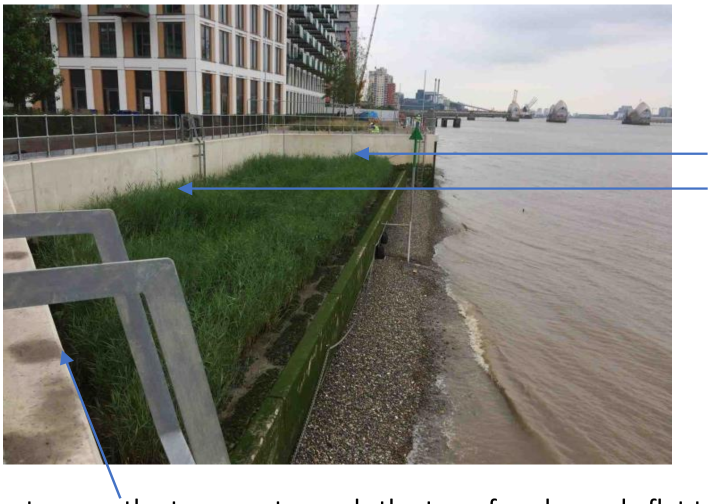
Operations - Seine netting was attempted 3 times on the foreshore below the terrace, with a fast current and considerable debris present. 3 fykes were set on the terrace near the rubber base wall, with the fyke wings extending half way up the terrace in one case.

Results - In total 3 roach, 1 bass and 1 common goby were taken in the seine sweeps. Total catches in the fykes were 1 bass and 3 eels.

Notes - All of the eels were taken in the fyke with the wings well up the terrace. The fish must have been actively foraging at the high watermark to have been able to enter the fyke. The upper sections of the terrace are bare with the base material having been washed out from the gabion basket. The rubber base wall must impede fish movements both on and off the site and must cause some strandings. There is no standing water at the base of the terrace.

Other site photographs

Royal Wharf 4/10/17 TQ 40801 79693



Operations - 3 fykes were set across the terraces towards the top of each nearly flat terrace to the rear edges where *Phragmites* growth was absent or less dense.

No seine netting was attempted on the foreshore below the terraces given H & S considerations.

The water never penetrated onto the terraces at high water, topping out just below the terrace surface, rendering fyke netting ineffective. The PLA later advised that high water had been at least 30cm lower than predicted and further advised that a barrier closure was probably required for the following day given current weather/tidal conditions.

Other site photographs

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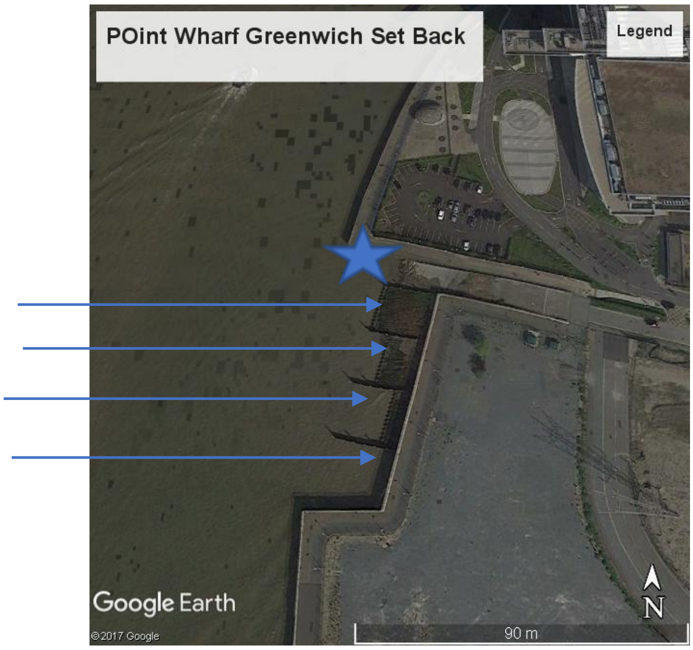
Point Wharf, Greenwich 5/10/17 TQ 38790 79999



Operations - 4 fykes were set across the terraces towards the bottom/middle of each graded terrace. The PLA had advised about a closure, and in the event, no water came across the terraces. Three seine sweeps were made in the area immediately in front of the adjacent slipway on a rising tide.

Results – A total of 26 bass were taken, together with 9 common gobies, 2 eels, 2 thin lipped grey mullet and 2 juvenile bream. A seahorse was taken in the first seine, when the majority of fish were captured. Brown shrimp & estuarine prawn were present.

Notes - The terraces have established stands of vegetation and would provide good cover for fish life. The vertical campshed face to the terraces will dissuade some species such as flounder from penetrating onto the terraces. Water drains out through holes in the campsheds, leaving significant ponded areas behind temporarily. Some fish stranding is likely.

Other site photographs

Greenwich Millennium Terraces NE   6/10/17   TQ 39764 79628

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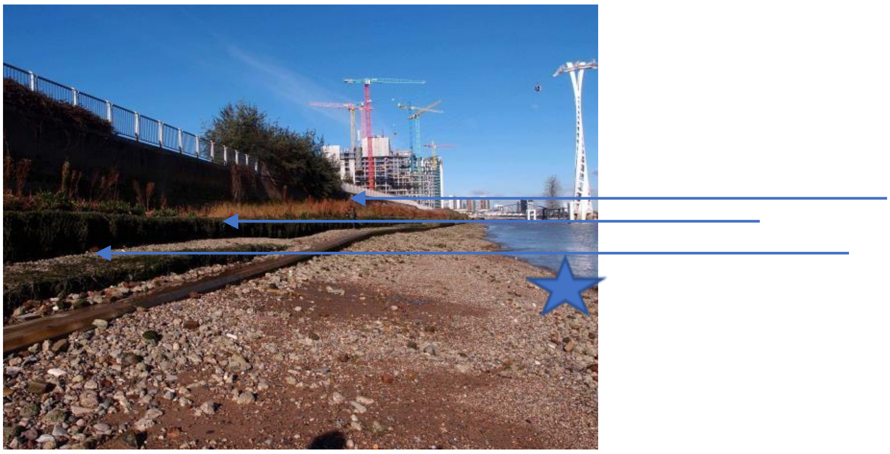


Operations – 3 fykes were set in the terraces, all towards the downstream end of the main terrace. 3 seine sweeps were conducted immediately in front of the terrace on a rising tide. Two snagged badly and ripped the net. A third sweep was made with the undamaged half of the net.

Results – 11 bass were taken in the seine, together with single sand smelt, 1 flounder and thin lipped grey mullet. The fykes produced 10 more bass, together with 1 more flounder, 9 common goby and 18 sand gobies. Brown shrimp were present.

Notes – The site is developing limited new drainage channel features of a true salt marsh which improve fish access.

Other site photographs

Historic Information on the Greenwich Millennium Terraces North East

Photographs from July 1998, 3 months after the terraces had been created





Note *Phragmites* planting and pioneer establishment of *Aster tripolium*.

Barking Creek Habitat Adjacent to TWUL Becton 17/10/17 TQ 45213 82488

Operations – No seine netting was possible in the main creek adjacent. 3 fykes were set from the head of the new creek downstream as shown. Fyke 3 was set just below the foot access point on the right-hand bank near the new creek mouth. The seine was set as a stop net at high tide at the foot access point. Fyke 2 was set just upstream of the access point. The seine was emptied after the 3rd fyke.

Results – 28 bass were taken together with 84 common gobies and 1 eel 11 bass penetrated right up the creek to fyke 1.

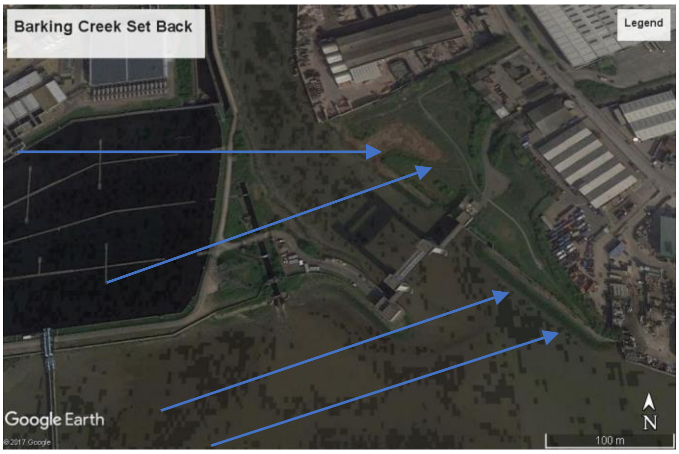
Notes - An open water channel has been maintained in the centre, with drainage channels beginning to form. These will aid fish access.

Other site photographs

Historic Information on the Barking Creek new creek habitat adjacent to Becton STW

Photographs from July fish sampling exercise in August 2013, 12 months after site creation.

Barking Creek River Road New Habitat at Barking Barrier 18/10/17 TQ 45564 81819



Operations – no seine netting was possible in the main creek adjacent. 2 fykes were set in the middle of the new creek habitat in small clear patches among the dense *Phragmites* stands. Fyke 1 was set in shallow water, fyke 2 deeper. Both were set on the line of evolving small drainage channels. Two more fykes were set among the vegetation now growing through the rip rap defence on the lhb downstream of the Barking Barrier. Fyke 3 was set 50m upstream of the access steps onto the habitat. Fyke 4 was set 100m further upstream, some 100m below the Barrier.

Results – 178 bass were taken in fyke 2 in the habitat. Total catches in this habitat were 180 bass, 2 flounder and 1 common goby. In the habitat below the Barrier, 14 bass were taken together with 4 flounder and 1 common goby. Brown shrimp were present.

Notes - Neither of the open patches or drainage channels had been present in previous sampling in the new creek habitat in 2013, where almost no fish were captured on site . At that time, the site had been covered by dense *Phragmites* throughout.

Other site photographs

Historic Information on Barking Creek River Road new creek habitat site

Photographs taken during site construction in 2005 & during fish sampling in July, 2007

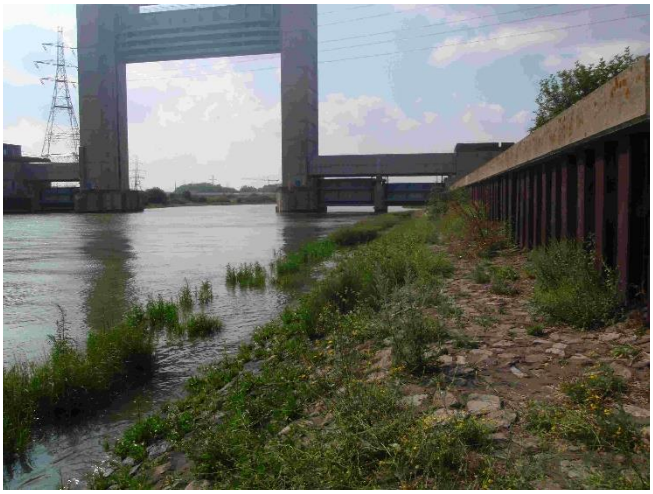
First five photographs, Environment Agency, 2006

Historic Information on Barking Creek River Road new creek habitat site

Photographs taken during fish survey in August, 2013

Historic Information on rock revetment river wall site downstream of Barking Barrier

Photographs taken during fish survey in August, 2013



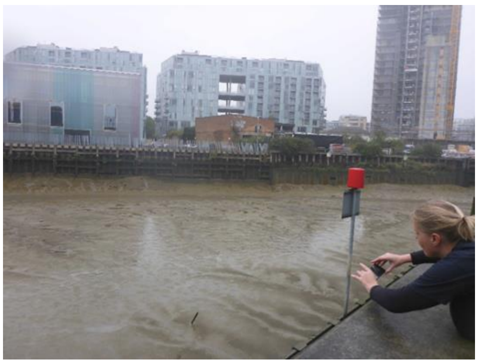
Deptford Creek 19/10/17 TQ 37627 77301 & TQ 37714 77463

Operations – 3 seine net sweeps were made in the area adjacent to Creekside Education Centre slipway on a rising tide. 2 fykes were set on an unvegetated terrace at Saxon Wharf (North facing). H & S induction delays prevented setting 2 more fykes on vegetated terraces at Thanet Wharf (South facing)

Results – 6 bass, 425 common gobies and a bream were taken in the seine sweeps. The fykes produced 16 bass and single common and sand gobies.

Notes - The bass captures at Saxon Wharf were unexpected. There is no vegetation cover at all on this very flat exposed surface to the terrace. Fish must only move across the terrace when the water depth exceeds approx. 0.5m, therefore for only a short part of the tidal cycle, given the height of the terrace.

Other site photographs



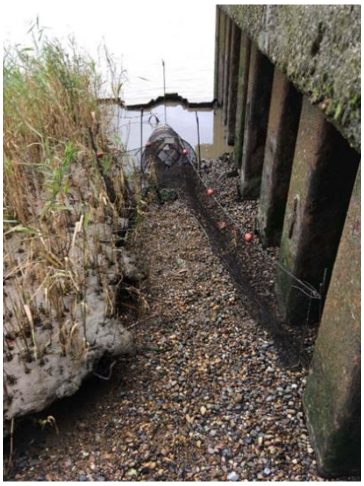
West India Dock 20/10/17   TQ 38387 79820

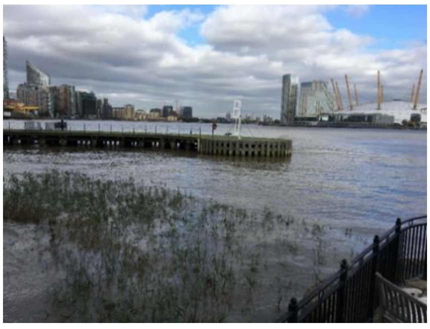
Operations – No seine netting was possible in front of the terraces due to H & S considerations. 4 fykes were set in the two lateral margins and at the rear where vegetation was absent or sparser.

Results – A single eel at 160mm was captured in fyke net 4 closed to the campshed on the downstream side of the habitat. A single brown shrimp was taken in the same fyke.

Notes – The height of the campshed will deter some species such as flounder. There may be fish strandings behind the campshed where some erosion is occurring. There is significant erosion of the *Phragmites* bed on the upstream side of the terrace.

Other site photographs





Appendix 2   Fish Species Captured During the Survey

Sea horse *Hippocampus hippocampus* at Point Wharf

Common goby, and sand smelt at Greenwich 02 terraces

Eel and estuarine prawn at West India Dock terrace and bass at Barking, in new creek habitat

All photographs by ZSL

Appendix 3 Bass Length Frequency Distributions