THE UNIVERSITY OF HULL

Colonisation of a managed realignment site by fishes.

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By

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Acknowledgements

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Abstract

Increasing pressures for coastal land reclamation intended for the purpose of settlement, flood defence and industrial development have resulted in a loss of intertidal habitats on a global scale. The result of this can be seen in the south-east of England on the Thames estuary where intertidal habitats such as mudflats and salt marshes are in decline. These environments are important for many fish species from varying life stages for protection from predators and strong currents, and also for foraging and spawning. Intertidal habitats also act as natural coastal buffers by absorbing kinetic wave energy and reducing coastal erosion. Mitigation measures such as managed realignment schemes have started to be put into practice to compensate for any loss of habitat, and as an alternative to traditional hard defences such as sea walls. Implementing a managed realignment involves breaching sea walls to allow the sea to reclaim land, usually agricultural.

The aim of this study was to assess fish utilisation of a new managed realignment site breached in 2010 in the Thames estuary, south-east England, intended to compensate for the loss of an adjacent intertidal mudflat habitat through the construction of an international port. Seine nets, fyke nets and trawling were used to gather data over an 18-month period from October 2010 to April 2012. By comparing fish species composition, density/catch-per-unit-effort, size structure and diet composition in the realignment and adjacent estuary, community structure was analysed, allowing an assessment of the success of the realignment.

Comparisons between a natural mudflat found on the Thames estuary site and the realignment site demonstrated that species composition was similar in both sites but density was higher in the realignment 50% of the time. Species richness was also similar between the two sites, with the realignment having a slightly higher richness compared to the estuary as a result of habitat heterogeneity. A wide diversity of species inhabited both sites site on both the flood and ebb tides, including bass (*Dicentrarchus labrax*), common goby (*Pomatoschistus microps*), smelt (*Osmerus eperlanus*), thick-lipped grey mullet (*Chelon labrosus*), three-spined stickleback (*Gasterosteus aculeatus*), thin-lipped grey mullet (*Liza ramada*), flounder (*Platichthys flesus*), plaice (*Pleuronectes platessa*) and eel (*Anguilla Anguilla*). Specific to the realignment site were herring (*Clupea harengus*), sprat *(Sprattus sprattus*), sand smelt (*Atherina presbyter*) and sand goby (*Pomatoschistus minutus*), and specific to the Thames estuary were sole (*Solea* solea) and whiting (*Merlangius* merlangus).Bass was the dominant species in both the Thames estuary and the realignment with one exception when common goby dominated; common goby is a species that is well documented to be present in abundance in estuaries. Densities of fish caught by seine nets were higher in the realignment compared with the estuary during October and November 2010 and August 2011, whereas in June 2011 and April 2012, the Thames estuary had greater fish densities, showing seasonal differences in fish utilization. April 2011 had under ten fish caught by seine in both sites therefore density was minute. Over half of the fyke surveys found the realignment to have a higher catch-per-unit-effort than the Thames estuary. Although common goby and bass were the only species where data allowed a comparison between the sites, diet analysis revealed similar taxonomic richness in these species at both sites.

The similarities found in this study suggest that the realignment is operating in a similar manner to the adjacent estuary, and that managed realignments can compensate for habitat loss to some extent. Future management plans should include a detailed study over a longer time period, and take in to account the wider dynamics of the estuary, including invertebrate samples, sediment samples and also the impact managed realignments could have on bird communities.

1. Introduction

The loss of intertidal habitat (coastal and estuarine) is a world-wide issue, and is particularly seen on the south-east coast of the UK (Colclough *et al.*, 2005; Shih and Nicholls, 2007; Luisetti *et al.*, 2008, Mazik *et al.*, 2010), although in the UK most estuaries have been heavily degraded by a legacy of industrial and urban development. Coastal environments have always been a prime location for settlement due to accessibility and food availability; however urban settlement along the UK's coast lines has become detrimental to the adjoining coastal environment (Shih and Nicholls, 2007). Increasing pressures for land claim of surrounding coastal areas have resulted in a rise in the number of flood defence barriers, port extensions, industrial development and to ease coastal squeeze. Consequently, this causes a loss of natural coastal buffers and habitats such as mudflats and salt marshes, vital to many fish species from varying life stages (Boyes and Allen, 2007). There are certain measures in place that aim to mitigate any loss of habitat such as managed realignment schemes and man-made coastal buffers, e.g. sea walls (Colclough *et al.*, 2005; Turner *et al.*, 2007).

1.1 Importance of intertidal areas

Estuaries are considered one of the most important coastal features globally, formed when fresh water flows into and mixes with salt water (Pritchard, 1967; Dyer, 1997). They are a mixture of complex habitat types with delicate links between them in the form of hydrology, nutrient and sediment transfer as well as animal movement. Regarded as one of the most productive ecosystems, they entrap and circulate nutrients that are retained and recycled by benthic organisms, creating a self-enriching environment (Attrill, 1998). The dominant sediments present in intertidal mudflats are silt and organically rich clay, resulting in high biological productivity, however often a low species diversity (Dyer, 1997). Mudflats are found in estuaries and coastal regions globally as a result of sediment and mud displacement when tidal energy is high, in doing so generating a natural buffer of wave energy (McHugh, 1966; Attrill, 1998; O'Brien *et al.*, 2000; Boyes and Allen, 2007). Estuaries are considered semi-enclosed water bodies that form a dynamic natural link between seas and rivers by providing an environment that suits some freshwater, as well as marine species (Attrill, 1998; Chapman and Wang, 2001).

There is a continuous immigration and emigration of fish to and from estuarine habitats (Stevenson, 2002). An extensive review of estuarine studies was conducted by Elliott and Hemingway (2008) to collate findings of numerous studies of estuaries and fish utilisation and dynamics. It was stressed that estuaries provide key migration routes and important nursery areas, as a result of high food availability and shelter, in the form of rocky habitats, vegetation and sediment. Many fish, including marine-estuarine dependent and catadromous species, use estuaries for feeding and migration, but it is mainly true estuarine species that exploit estuaries for spawning.

In addition to their importance to fishes, the intertidal areas of estuaries are often important for birds as a result of food availability in the form of fish and dense populations of invertebrates. Indeed, the Thames estuary is designated as a Special Protection Area (SPA) by the European Union Birds Directive; the importance of SPA sites is with reference to the conservation of rare and vulnerable wild bird species, their eggs and nests (Council Directive 79/409/EEC). Wildfowl, waders and other birds feed on macro-invertebrates in the intertidal area of the estuary stimulating a process to begin where the surrounding environment is supplied with organic matter through the nitrogen cycle providing nutrients (Attrill, 1998).

1.2 Impacts of intertidal loss

Habitat loss in estuaries affects many aspects of the ecosystem because of the links between biological processes (Shih and Nicholls, 2007; Mazik *et al.,* 2010). Estuaries provide a natural coastal buffer against volatile wave action by reducing tidal energy, forming mudflats in doing so by the deposition of sediment that provides protection for salt marshes and reduces the effects of erosion. The removal of mudflats can therefore cause an increase in wave energy, exacerbating flood risk due to the erosion of natural flood banks, which may cause significant problems to any neighbouring settlements. As well as habitat loss being caused by urban development, it also raises concerns for the remaining ecosystem. A loss of intertidal mudflats may result in a decline in spawning habitats, feeding areas and nursery habitats for larval and juvenile fish, which may result in a reduction in numbers, for example species such as bass (*Dicentrarchus labrax* (L.). Bass spawn offshore and the larvae and juveniles arrive in estuaries between May and June, feeding on invertebrates found in mudflats, particularly crustaceans and polychaetes (Kelley, 1988; Laffaille *et al*., 2001). Species such as European plaice (*Pleuronectes platessa* L.), sole (*Solea solea* (L.)), common goby (*Pomatoschistus microps* (Krøyer, 1838)), sand goby (*Pomatoschistus minutus* (Pallas, 1770)) and flounder (*Platichthys flesus* (L.)) use mudflats as their primary source of food- feeding on polychaetes and crustaceans- so any loss of intertidal areas could result in a reduction in the numbers of these species in the area (Defra/Environment Agency, 2002; Stevenson, 2002; Gray, 2007; Kostecki *et al.,* 2010; TEEBcase, 2011).

Ecologically, estuaries provide nursery habitat during the larval and juvenile periods of fishes' development, and shelter for juvenile and adult fishes from predators and dynamic wave action, subsequently supplying food for other levels of the food chain, e.g. birds (Boehlert, 1988; Halpin, 2000; Chapman and Wang, 2001). Phytoplankton and zooplankton numbers remain high throughout the summer in well-mixed estuaries, resulting in them being particularly valuable systems for juvenile fish due to the high food accessibility, availability, favoured water temperatures and shelter from predators (Chapman and Wang, 2001; Vasconcelos *et al*., 2010).

1.3 Restoration

Managed realignment was first established by a need to replace habitat lost through coastal squeeze and provide feeding and breeding areas for birds and fish (Dixon *et al*., 1998). The first managed realignment scheme in Europe was implemented in France in 1981 (Esteves, 2014). Alternative benefits of managed realignments including coastal management and for use as an alternative strategy for flood defence were not considered more of a priority until later on (Turner *et al*., 2007). It was developed as a component of Flood and Coastal Defence in the Ministry of Agriculture, Fisheries and Food (MAFF); now the Department for Environment, Food and Rural Affairs (Defra), who estimates that around 100 ha of intertidal habitat needs to be claimed per year in order to compensate loss due to coastal squeeze. Managed realignment is a form of flood defence, combined with habitat creation, protection and enhancement, which aims to minimise future defence maintenance costs through being an alternative to hard defences. The aim is to provide a long-term solution for the loss of intertidal areas the effects of intertidal habitat loss may be mitigated, although the long-term effects are still under study (Shih and Nicholls, 2007; Turner *et al*., 2007). The process involves the flooding of land to increase intertidal areas by the relocation of the coast line (DEFRA/Environment Agency, 2002; Leggett *et al*., 2004; Shih and Nicholls, 2007; Mazik *et al.,* 2010). After the flood defences have been breached, sedimentation is encouraged as a result of tidal deposits, providing an environment for benthic fish and other fauna. Hard sea defences such as sea walls may be adequate in the short term, but require costly maintenance and also contribute to the demise of mudflats and salt marshes (Luisetti *et al*., 2008; Roca and Villares, 2012). Currently there are approximately 54 realignment schemes in the UK that have been implemented since the early 1990's, more than 20 of which are located along the east coast (Esteves, 2014). In the last 20 years, around 1,300 ha of coastal habitat have been created due to the initial success of managed realignment schemes and regulated tidal exchange (Scott *et al.,* 2011).

Gray (2007), working in collaboration with the Environment Agency (EA), studied restored intertidal habitat in the Thames estuary and concluded that restored intertidal habitat can successfully function as a nursery area for juvenile bass in particular, which actively prefer intertidal habitat in their first summer. This was due to high foraging success, whilst also providing shelter from predators (Stevenson, 2002; Gray, 2007). The study also demonstrated that both marine estuarine-dependent and freshwater species made use of this intertidal resource (Gray, 2007).

1.4 Aims and objectives

The aim of this study was to analyse fish utilisation of a managed realignment site on the Thames estuary, UK by comparing: 1) fish species composition, and density/catch-per-unit-effort (CPUE) in the realignment and adjoining estuary, 2) fish size structure in the realignment and adjoining estuary and 3) the diet composition of fishes in the realignment and adjoining estuary. These three objectives were chosen as they provide comparable data on the status of the sites with regards to population dynamics, species composition, and diet structure, by comparing the realignment with the adjoining Thames estuary. High similarities between the realignment and estuary would suggest that the managed realignment is functioning in a manner similar to the adjacent estuary and therefore compensating for the loss of intertidal mudflat associated with the coastal development.

The outcomes of this project will improve current understanding of how the managed realignment is beginning to establish itself in terms of fish species composition, density/CPUE, size structure and diet composition when using comparisons to the Thames estuary over a period of 18 months.

Ideally, the main outcome would be for the realignment to recreate the adjoining mudflat in terms of the above parameters, showing that the use of managed realignments to compensate for losses of intertidal areas is a feasible and worthwhile method of mitigation.

1.5 Structure of content

Chapter 1 introduces the background of the study, giving a detailed description of intertidal areas and their importance with regard to fish communities. This chapter also goes on to explain currently used habitat restoration methods, including the history and function of the managed realignment.

Chapter 2 explains the sites used for the study and provides background information on why these sites were chosen. Field methods are described for data collection done on-site at the Thames estuary and realignment, I addition to statistical data analysis done in the laboratory.

Chapter 3 breaks down the results from the study into species composition, catch-per-unit-effort and diet composition, providing a detailed comparison with reference to sample site and type of gear used. Water quality information is also provided in this chapter detailing comparisons between the Thames estuary and realignment site.

Chapter 4 puts the results of the study into context with reference to the original hypothesis, explaining any similarities/differences found between the Thames estuary and realignment. A summary of the study, results and restrictions is also provided along with recommendations for future work to expand upon this study.

2. Materials and methods

2.1 Site Description

The Thames estuary is located on the south-east coast of the UK and extends 110 km east from Teddington Weir (Araújo *et al.*, 1999; Gray, 2007). Since the 1960s, when plans to reduce river pollution were implemented, the Thames estuary has developed into a commercial fishery. It is a key nursery area for many fish species by means of providing protection from strong currents and predation, as well as offering an affluent food source (Attrill, 1998; Colclough *et al.*, 2002). The largest expanse of salt marsh and mudflat within the Thames estuary occurs along the coast of Essex (4440 ha: 10% of the total scope of British salt marsh) (Attrill, 1998). The sheltered waters along the east coast and high concentrations of river sediments are ideal conditions to allow the formation of mudflats and salt marsh, providing highly productive and valuable nursery areas for estuarine fish (Peterson and Turner, 1994), as well as a means to support an abundance of wading birds and wildfowl (Attrill, 1998; O'Brien, 2000). The study site is located on the north bank of the Thames, 40 km east of London (Figure 1). The realignment was implemented in response to disputes with local marine fishermen regarding loss of fishery caused by the London Gateway port development, which would be utilizing intertidal areas for port expansion in the South East (Colclough pers. obs). In addition, it is anticipated the realignment site would provide mitigation to the loss of intertidal areas utilized by migratory fishes and as nursery grounds for sole, bass and flounder (Colclough pers. obs). The realignment site was 90*ha* of former public land adjacent to the estuary that had the flood banks breached in 2010 to allow flooding to create new mudflat and saltmarsh (Figure 2) (Colclough pers. obs., English Nature, 2001). The realignment site had greater habitat heterogeneity as a result of a wider variety of shelter and substratum, when compared to the Thames estuary. Grass verges were in the breaches around the edges of the realignment site, which extend into the water line on the flood tide, rocky shallows and vegetation patches were also found within the site. Substratum consisted of rocks, ranging in size from large to small, sand and also muddier areas. The natural estuary site does have habitat variability, however not as much as the realignment site. There are grass verges along one side of the site; however the majority of the site was mudflat with limited shelter and rocks.

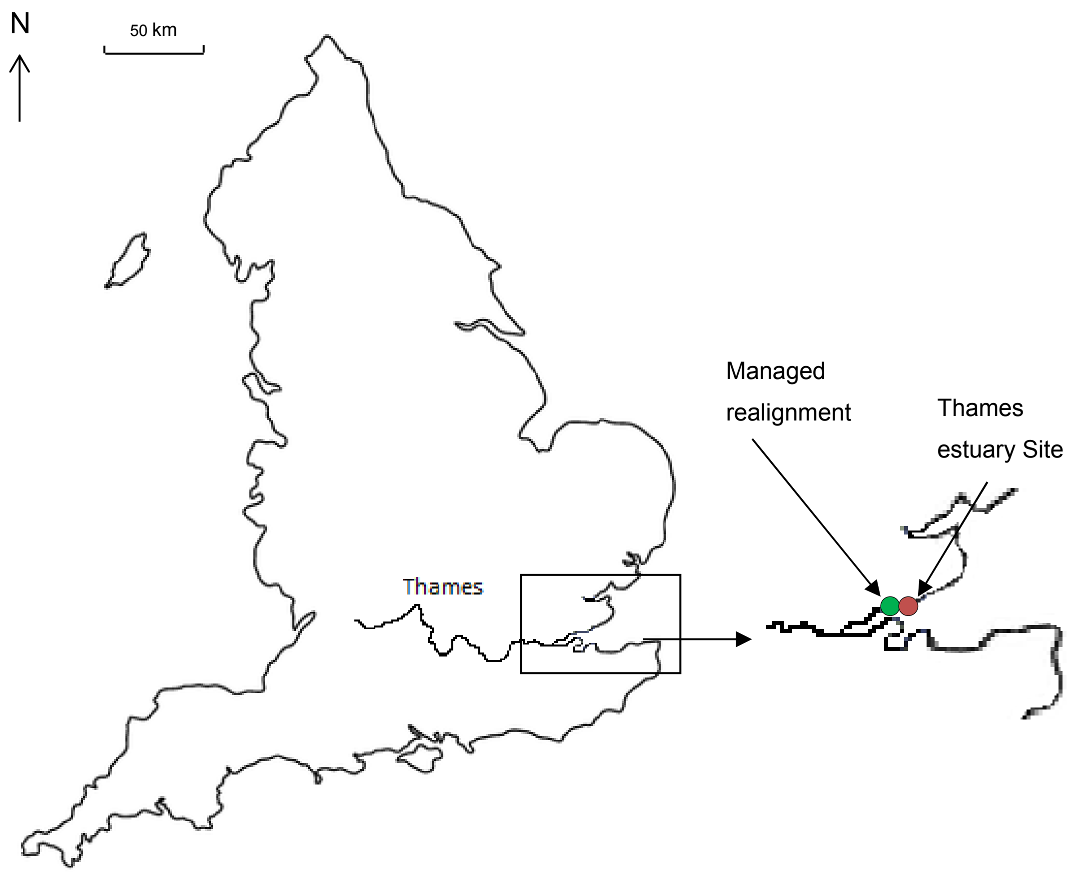


Figure 1. Location of the Thames estuary, showing the two study sites: the realignment (●), and the Thames estuary site (●).

Figure 2. The managed realignment at high water (left) and low water (right), October 2010.

2.2 Fieldwork sampling

In order to account for higher habitat heterogeneity in the managed realignment, including breaches around the site and grass boundaries (Figure 2), a larger number of samples were collected, including using trawling, that was not used in the estuary.

Two fyke nets were set in the estuary and four nets in the realignment at low water adjacent to the creeks. The fyke nets were a double-fyke assembly consisting of two nets (53 cm entrance, 10 m central panel and 14 mm mesh) connected at both entrances by their leader panels. They were secured with canes and ties, left for 12 hours (one tidal cycle) and retrieved at the next low water. Fish were counted, identified to species level and measured (total length) to the nearest mm, and then returned to the water. Catches from each fyke net were recorded as species, length and abundance per ‘fyke-hour’, i.e. the abundance of fish divided by number of hours the net was submerged (CPUE). Once all fish had been processed and returned to the water, the fyke nets were reset in the same locations until the next low water when the process was repeated. Fyke nets target larger fish, >250 mm, during the flood and ebb tides (one full tidal cycle) from the realignment site and the intertidal zone in the estuary. Mean CPUEs were compared between the realignment and the estuary using independent *t*-tests.

Trawling was carried out along the marginal shelf in the realignment at high water, and in isolated pools at low tide. The trawling targeted demersal fish species and individuals that were too small to be captured by the fyke nets. The trawl consisted of a 1-m wide epibenthic sledge with a 5-mm cod-end (Nitex cloth), supported by wide skids with a firm steel rod 2-4 cm above the skids for support. This set-up prevented the net from being filled with sediment whilst allowing the effective capture of fish that had been disturbed by the tickle chain. The trawl was pulled by hand by two people using a 20-m rope (20-m transect) at a constant speed of 1 m^3s^{-1}. Data were recorded separately for each trawl in the field and the catches were retained for further analysis. Abundance per square metre was recorded with the total area of the trawl being calculated as width of the trawl x the length of the transect. Trawls were replicated three times at each of three stations in the realignment (nine trawls in total). Control trawls in the estuary were not conducted due to the risk involved with the amount of time that would be spent wading into the estuary during spring tides; however two seine nets were able to be deployed in the estuary close to shore.

During the higher part of the tidal cycle, fish were surveyed using a micromesh seine net (25 m long by 3 m deep with 3-mm hexagonal mesh). The seine net was set in a rectangle, parallel to the bank. This micromesh net is efficient at capturing fish as small as 5 mm due to the small mesh size and is therefore a useful tool in determining abundance of small-bodied fishes. Seine nets were set at ten sites in total; eight in the realignment and two in the estuary. The area sampled was calculated from direct *in situ* measurements, i.e. length x width of the sampling area. Data were recorded as the abundance of each species per square metre and mean densities were compared between the realignment and the estuary using independent samples *t*-tests.

The catch from each trawl and seine was preserved in 4% formaldehyde solution and taken to the laboratory for analysis of species composition, size structure and diet composition. Samples were not taken from fyke net catches due to the fish being large enough to identify in the field. Seine and trawl nets were deployed and retrieved at times that would allow analysis of fish utilisation of flood and ebb tides. Sampling during ebb tides captured fishes exiting the realignment site indicating that they had been utilising the realignment site around high water, whereas sampling during flood tides captures fish entering the realignment site. The sampling sites were chosen to reflect the variety of different habitats (e.g. sheltered and open water habitat), which may show differences in the species present and their diets (Figure 3).

Aqua TROLL 200 devices were used to obtain water temperature (°C), depth (m) and salinity measurements. These devices were attached to the fyke nets, one in the estuary and one in the realignment, using cable ties and left to record data for the duration of the sampling period (two tidal cycles).

2.3 Laboratory analysis

Fish were identified using Hayward *et al.* (2001) and Maitland (2004), total length (tip of the head to the tip of the caudal fin) was measured to the nearest mm (Figure 4). Life cycle categories were used from Claridge *et al*. (1986) to classify the species caught. The life cycle categories were: catadromous (freshwater fish that migrate to sea to breed), estuarine (species dependent on estuaries throughout their life), marine with stragglers in estuaries, and marine-estuarine dependent species.

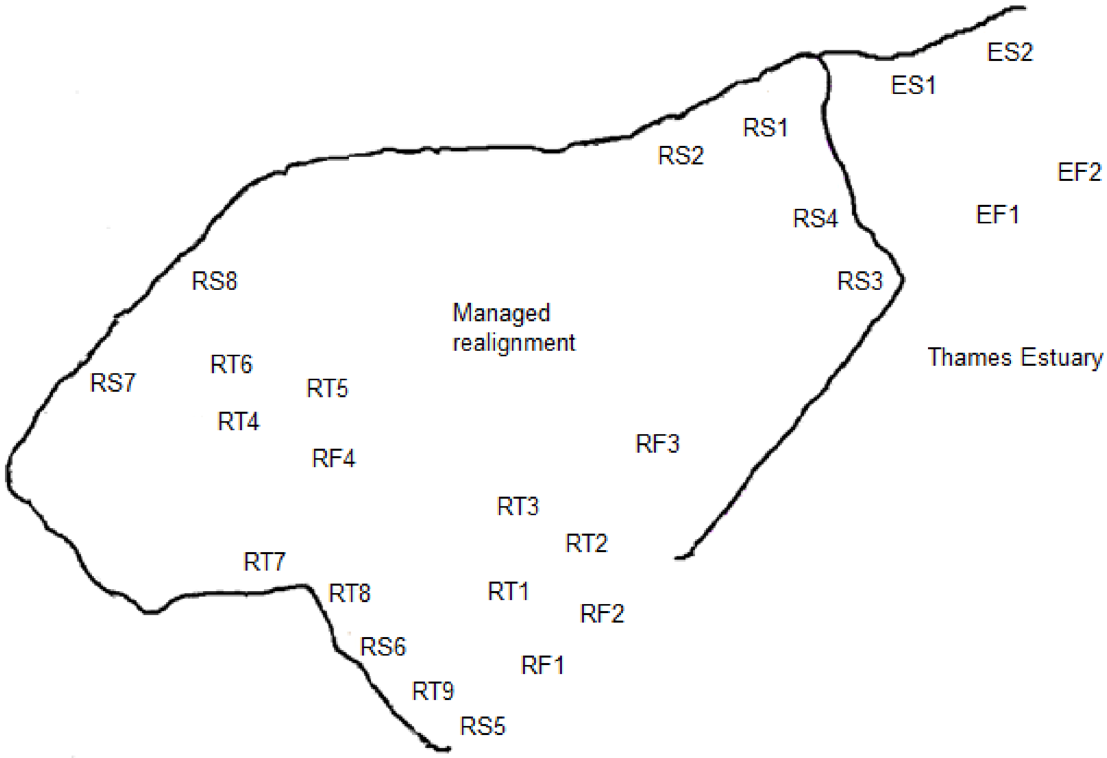


Figure 3. Locations of the sampling sites within the managed realignment and the Thames estuary. See Appendix 1 for key to codes.

Figure 4. Common sole captured in a Thames estuary fyke net, being measured to total length.

For each survey, ten fish of each species with sufficient numbers from the realignment and estuary were prepared for diet analysis for each month sampled. Each fish was measured to the nearest mm and fresh body weight (BW) was recorded to the nearest 0.001 g. Four species were examined for diet analysis as they were the only species with sufficient numbers. The entire gastrointestinal tract was removed using a scalpel then stained for 24 hours using Rose Bengal to enable observation of any small transparent organisms present. The diet analysis methodology was adapted from the points method used by Frost (1943) and described by Hyslop (1980 and Laffaille *et al*. (2001).

The points method (Hyslop, 1980; Laffaille *et al.,* 2001) avoids the time consuming process of handling large amounts of material in favour of awarding each food item points in relation to its percentage contribution to gut volume, thereby analysing gut fullness as a mark out of 10, with 0 being empty and 10 being distended. Each prey item was then identified to the lowest possible taxonomic level and enumerated. Aufwuchs (the periphyton and associated microfauna that grow on underwater surfaces) was the exception and was recorded as a percentage volume of gut contents, and later converted into a number, by using the relationship between the volume (%) of aufwuchs and the volume (%) of 'non-aufwuchs', where *N* is the number and *V* is the volume (%) of aufwuchs or non-aufwuchs (Nunn *et al.,* 2007):

$N_{aufwuchs}=N_{non\text{-}aufwuchs}\ V_{non\text{-}aufwuchs}{}^{-1}V_{aufwuchs}$

Abundance (%N), the percentage a given prey comprises from a total of all prey items, was calculated for each fish, and as a mean for each survey using the formula below, where N*i* is the number of individuals of a particular prey species, and N*t* is the total number of individual prey items found in the fish:

$\%N = (N_i / N_t) \times 100$

In addition, gut fullness of each individual fish was recorded to enable a comparison of feeding activity between the realignment and estuary. Frequency of occurrence (%O) was calculated to show the percentage of fish that had eaten certain prey species using the formula below, where FO*i* is the number of fish that had eaten the species and FO*t* is the total number of fish analysed:

$\%O = (FO_i / FO_t) \times 100$

Bray-Curtis similarity matrices (Bray and Curtis, 1957) were calculated using PRIMER 6 for each sample month to further assess and compare species and diet composition in the realignment and the estuary and also to show any temporal trends (Clarke and Gorley, 2006). The Bray-Curtis similarity index (C_z) takes the abundance of each species into consideration and calculates the overall similarity between samples (Nunn *et al.,* 2007) and is calculated as:

$C_z = 2W\,(a + b)^{-1}$

where W is the sum of the smaller percent frequency of occurrence of each prey species that is common to the catch of both sites (including tied values), and a and b are the sums of the per-cent frequency of occurrence in sites a and b, respectively. The index ranges from 0, when there are no species in common, to 1, when there are identical species.

Fish species composition in fyke, seine and trawl catches in the realignment and estuary, and diet composition in the realignment and estuary were plotted as stacked histograms. Non-metric multidimensional scaling (MDS) ordination plots, based on Bray-Curtis similarity statistic, were then used to provide a visual representation of the similarities in fish species and diet composition of common goby and bass in the realignment and estuary across the study period. The stress level indicates the significance of each MDS plot, the lower the stress, the more significant the result; however a stress level of 0 can indicate that some of the distances on the plot are to a certain extent distortions of the input data, therefore caution should be taken when analysing plots where the stress level is 0 (Kruskal, 1964). Two sets of MDS plots were implemented, the first using fish species composition and the second diet composition, with 25 restarts, and a minimum stress of 0.01. Average values were then compared using a two-way Analysis of Similarity test (ANOSIM) to test for any statistical differences in species composition between the Thames estuary and the realignment, and also any statistical differences in species composition between each gear type. A one-way ANOSIM was also used to statistically test for any similarities or differences between diet of common goby and bass for months where sufficient data was available.

3 Results

3.1 Temporal variations in water depth, water temperature and salinity

Data from the Sondes placed in the estuary and realignment in October 2010 showed that both sites were flooded for 12 hours during the 24 hour sample with a maximum depth of 2.7 m in the realignment and 2.3 m in the estuary (Figure 5) showing uniformity between sites. The salinity measurements fluctuated between 12 and 14 in the realignment (Figure 5). Salinity data from the estuary showed to be remarkably high, likely a result of a discrepancy and therefore cannot be used as a comparison. Temperature ranged between 13-16 °C in the estuary and between 10-13 °C in the realignment (Figure 5). As a result of unpredicted westerly winds in November 2010 neither the realignment nor estuary flooded in accordance with usual tidal cycles, only a small area of the site flooded (Figure 6). The recorded Sonde data showed the estuary had a maximum depth of 1.2 m over the 24 hour period, but the realignment had a maximum depth of 0.9 m. Salinity increased to 24 and temperature reached highs of 12°C during high tide in both sites.

Tides during April 2011 reached a maximum of 2.6 m with a salinity of 27 in the estuary, while depth reached 2.4 m in the realignment with a salinity measurement of 26 (Figure 7) showing consistency between sites. These were the highest tides experienced during the study period. Temperatures fluctuated between 12 and 18°C in the estuary and 12 and 15°C in the realignment, again showing similar fluctuations.

Tidal depth data during June 2011 showed a higher maximum depth in the estuary (2.0 m) compared with the realignment (1.8 m) over the 10 hours the site was flooded during the 24 hour sampling period (Figure 8). Both salinity and temperature followed a similar profile in both the realignment and the estuary; both sites had a maximum of 27 and a consistent water temperature of 17°C during high tide.

Salinity and temperature during August 2011 followed a parallel pattern during the 13 hours the site was flooded (Figure 9). Water temperature reached a maximum of 19°C in both the realignment and the estuary. A maximum depth of 2.2 m was reached in the estuary, and 1.9 m in the realignment.

Both sites were flooded for 11.5 hours during the 24 hour sample period in April 2012 (Figure 10). The tide in the estuary reached a maximum depth of 2.2 m, and the realignment maximum depth was 1.9 m. salinity reached a maximum of 27 in the realignment and 26 in the estuary. Salinity was consistently higher in the realignment than in the estuary. Temperature followed a near identical profile in both sites, with a maximum of 12°C in the estuary and 11°C in the realignment.

Overall, it seems variations between the sites are small (Figure 11). Variations in temperture appear to follow a consistant pattern between sites with highs and lows appearing around the same time. Seasonal temperatures fluctuations were visable, with lowest temperatures in winter and early spring (November 2010 and April 2011) and highest temperatures in summer of 2011 (June and August 2011). Salinity also follows similar fluctuations between the estuary and realignment although in each sample, it appears the estuary fluctuations occur before the realignment in all months except October 2010. With reference to depth at each site, this can be explained by the estuary flooding quicker than the realignment. Depth in the estuary increases slightly before that in the realignment in all months other than October 2010. This is most likely due to the size of breaches into the realignment allowing water onto the site slower than it is the estuary site.

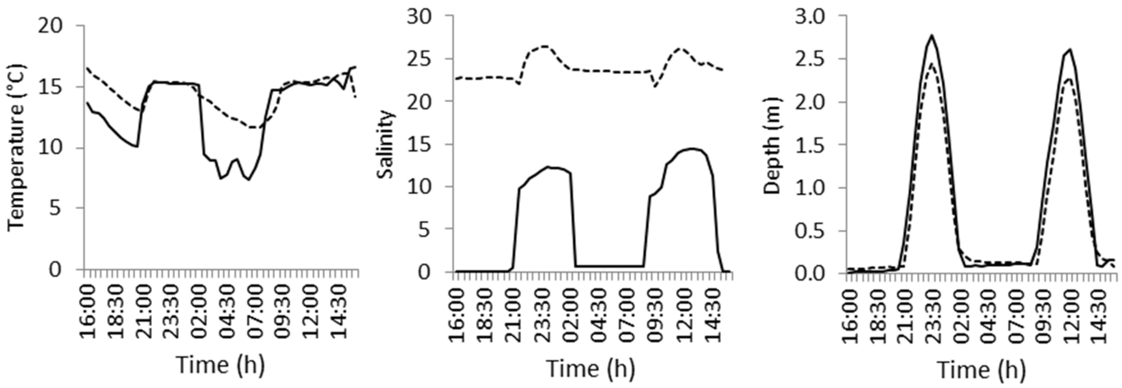


Figure 5. Water depth (m), salinity and water temperature (°C) shown from October 2010 for the realignment (——) and Thames estuary (- - - -).

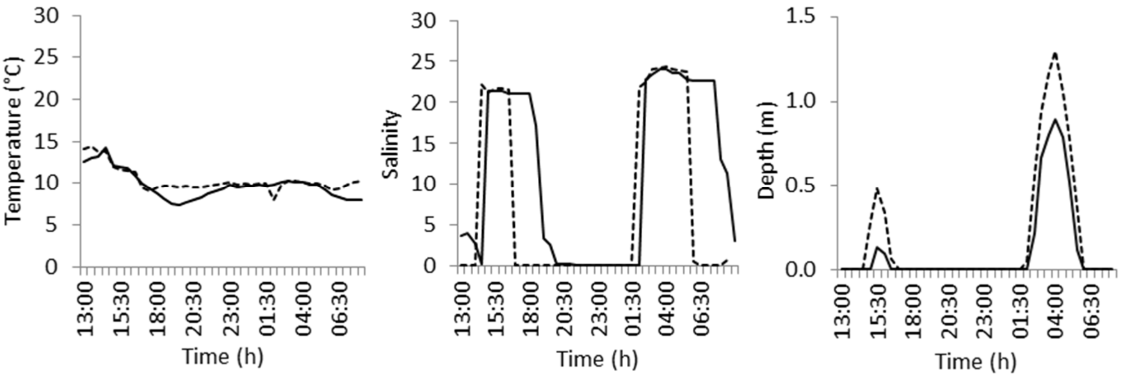


Figure 6. Water depth (m), salinity and water temperature (°C) shown from November 2010 for the realignment (—) and Thames estuary (- - - -).

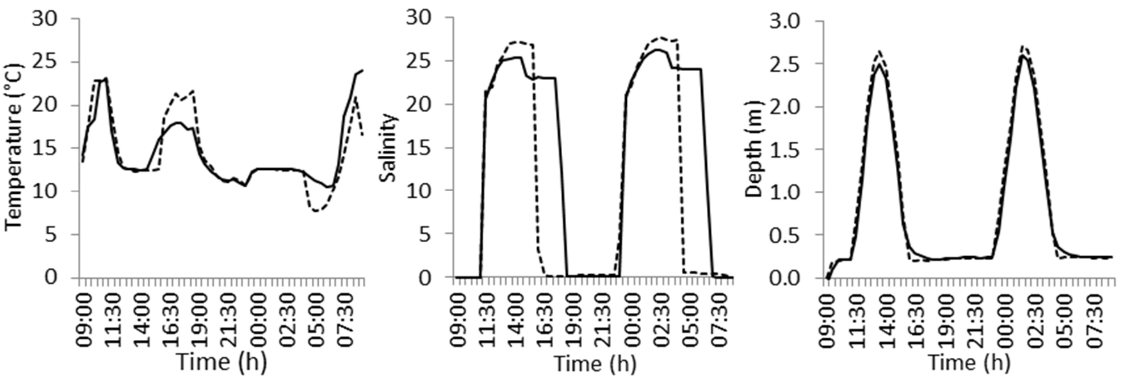


Figure 7. Water depth (m), salinity and water temperature (°C) shown from April 2011 for the realignment (—) and Thames estuary (- - - -).

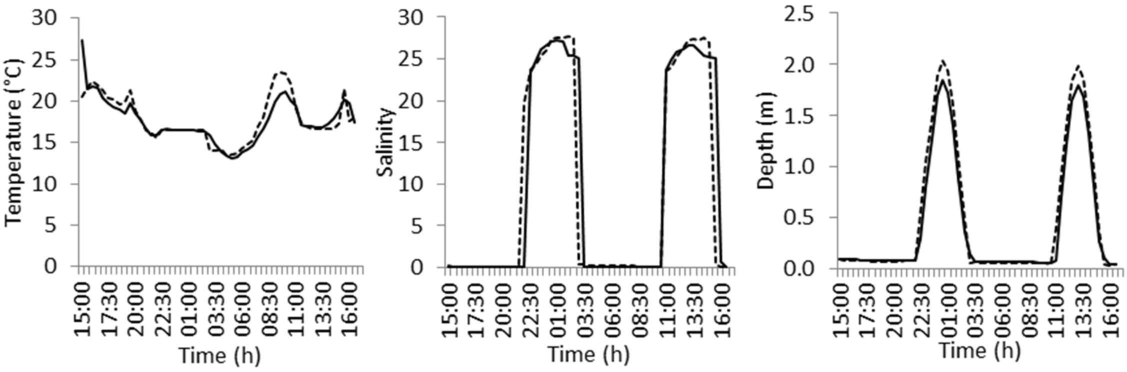


Figure 8. Water depth (m), salinity and water temperature (°C) shown from June 2011 for the realignment (—) and Thames estuary (- - - -).

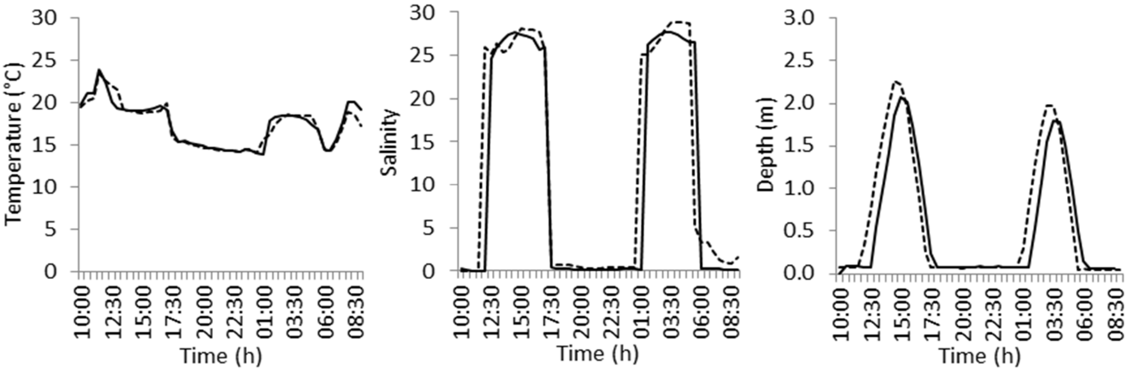


Figure 9. Water depth (m), salinity and water temperature (°C) shown from August 2011 for the realignment (—) and Thames estuary (- - - -).

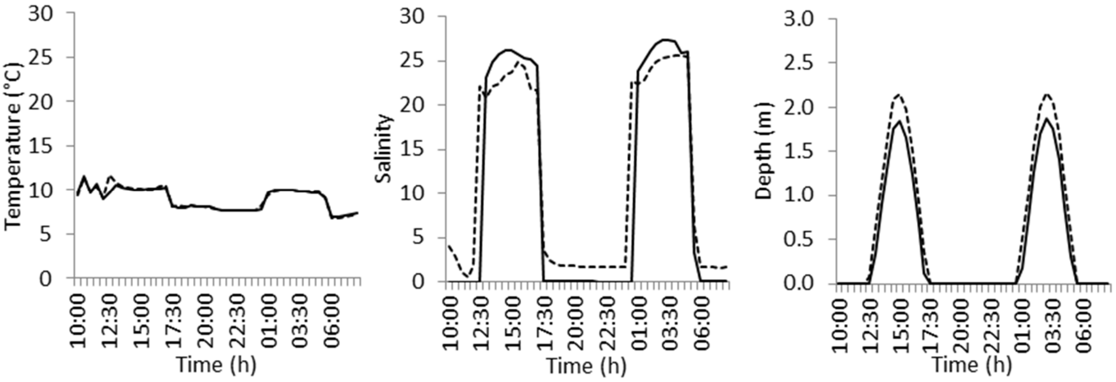


Figure 10. Water depth (m), salinity and water temperature (°C) shown from April 2012 for the realignment (—) and Thames estuary (- - - -).

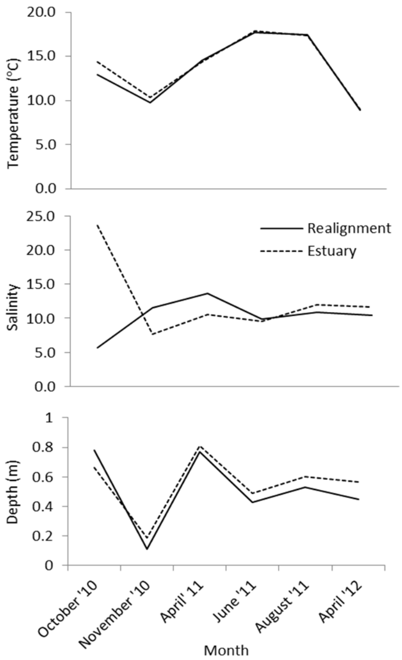


Figure 11. Mean temperature (°C), salinity and depth (m) recorded for each sampled month for the realignment (—) and the Thames estuary (----).

3.2 Species composition

Over the sampling period of October 2010-April 2012, fish of 15 species belonging to 11 families was caught (Table 1). Life cycle categories have been used from Claridge *et al*. (1986), by adjusting them in accordance with the species found in this study (Table 1). There were four life cycle categories found in this study: catadromous (freshwater fish that migrate to sea to breed), estuarine (species dependent on estuaries throughout their life), marine with stragglers in estuaries, and marine-estuarine dependent species (the latter two of which were sub-divisions of the "marine" category). All of these life cycles were found at both sites, however there were a number of species found in the realignment site and not in the Thames estuary (Herring, Sand smelt, Sprat and Sand goby), and similarly a number of species not found in the realignment but caught in the estuary (Sole and Whiting). Habitat heterogeneity was reflected in the catch from the realignment. Although only one was found, sand goby was documented in the realignment, along with eight herring and five sand smelt observed in the realignment whereas they were not found in the estuary. Since the sand goby resides on muddy and sandy intertidal areas, the fact that one was recorded shows that the realignment is progressing in terms of substratum development, habitat variance and food availability.

Table 1. Summary of number of fishes caught (n) from the realignment and Thames estuary, October 2010-April 2012, also showing the numerical composition of each species (%*n*). Life cycle (LC) categories: C, catadromous; E, estuarine; MS, marine with stragglers in estuary; MED, marine estuarine-dependent species (Claridge *et al*., 1986).

Family	**Species**	**Common name**	***n* Total**	***n* Thames estuary**	**%*n* Thames estuary**	***n* realignment**	**%n realignment**	**LC**
Gobiidae	*Pomatoschistus microps*	Common goby	20,696	212	42.32	20,484	91.10	E
Moronidae	*Dicentrarchus labrax*	Sea-bass	988	74	14.77	914	4.17	MED
Mugilidae	*Liza ramada*	Thin-lipped grey mullet	797	59	11.78	738	3.28	MED
Pleuronectidae	*Platichthys flesus*	Flounder	280	90	17.96	190	0.85	MED
Anguillidae	*Anguilla anguilla*	European eel	51	16	3.19	35	0.16	C
Pleuronectidae	*Pleuronectes platessa*	European plaice	42	2	0.40	40	0.18	MED
Osmeridae	*Osmerus eperlanus*	Smelt	58	31	6.19	27	0.12	E
Mugilidae	*Chelon labrosus*	Thick-lipped grey mullet	29	3	0.60	26	0.12	MS
Gasterosteidae	*Gasterosteus aculeatus*	Three spined stickleback	9	1	0.20	8	0.04	E
Clupeidae	*Clupea harengus*	Herring	8	0	0.00	8	0.04	MED
Atherinidae	*Atherina presbyter*	Sand smelt	5	0	0.00	5	0.02	E
Soleidae	*Solea solea*	Sole	2	2	0.40	0	0.00	MED
Clupeidae	*Sprattus sprattus*	Sprat	3	0	0.00	3	0.01	MED
Gadidae	*Merlangius merlangus*	Whiting	2	2	0.40	0	0.00	MED
Gobiidae	*Pomatoschistus minutus*	Sand goby	1	0	0.00	1	0.00	MED

Referring to Table 1, it is worth noting that ‘%n Thames estuary’ and ‘%n realignment’ are not comparable due to differences in sampling effort, the figures are to be used as a reference point when studying the abundance found in each site sampled. In addition, when examining species composition, the numbers reflect that of total fish caught across all gears unless otherwise stated. It should also be remembered that trawling was used and more samples were taken in the realignment (four fykes, eight seines, and nine trawls in the realignment compared to two fykes and two seines in the estuary). The different gear types target different species, e.g. trawling targets benthic species whereas seine netting targets pelagic species as well and fyke netting targets larger fish due to the larger size of the mesh.

In the realignment site, estuarine species accounted for >90% of abundance, with a clear dominance of common goby (Table 1) (common goby, 91%), smelt (*Osmerus eperlanus* (L.), <1%), sand smelt (*Atherina presbyter*, Cuvier, <1%) and three-spined stickleback (*Gasterosteus aculeatus* L. <1%). Compared to marine-estuarine dependent species comprising <10% of the total percentage abundance (bass, >4%), thin-lipped grey mullet (*Liza ramada* (Risso), >3%), flounder, <1%), plaice, <1%), herring (*Clupea harengus* L. <1%), sole, <1%), sprat (*Sprattus sprattus* (L.), <1%) and whiting (*Merlangius merlangus* (L.), <1%). The remaining 0.3% consisted of the catadromous eel (*Anguilla anguilla* (L.), <1%) and the marine straggler thick-lipped grey mullet (*Chelon labrosus* (Risso), <1%).

In the Thames estuary there was not such a large variation in percentage abundance between the marine-estuarine species and the estuarine species (Table 1). Marine-estuarine species comprised 47% of total catches (flounder, 18%; bass, 15%; thin-lipped grey mullet, 12%; whiting, <1%; plaice, <1%; Sole, <1%), whereas estuarine species contributed 50% (common goby, 43%; smelt, >6%; three-spined stickleback, <1%). The remaining 3% consisted of the catadromous eel (2%) and the marine straggler thick-lipped grey mullet (<1%).

October and November 2010 contributed the most towards the total catch with 3252 and 15,988 fish caught, respectively in the managed realignment. April 2011 and 2012 produced the lowest catches of the study with 246 and 163 fish caught, respectively, and June 2011 also produced a comparatively low total catch of 579 fishes. August 2011 produced a total catch of 2743 fishes. The shifts in abundance show seasonal changes of fish utilisation of the managed realignment showing lowest abundance in the spring and early summer months and highest abundance of fish in late summer and winter months. Common goby was the most abundant species found in all months from both sites (Figure 12). During October 2010, 3252 fishes representing ten species were caught. A total of 137 fish from eight species was caught in the Thames estuary, where thin-lipped grey mullet (41%) and common goby (37%) dominated. The realignment catch totalled 3115 fishes from nine species, where common goby (88%) and thin-lipped grey mullet (8%) dominated.

3.3 Temporal variations in species composition

Contrary to the tidal predictions, during November 2010 only a small area of the managed realignment flooded due to strong westerly winds. Consequently, only three out of the eight seine sites flooded which were located around the north-east of the realignment catching five species, predominantly common goby and thin-lipped grey mullet. Six out of nine of the trawl sites flooded, catching common goby alone. The fyke net in the north-west corner did not flood adequately thereby catching only one fish (sand smelt). Notwithstanding, fishes were caught in all the fykes and trawls on the managed realignment, where the fyke nets caught five species, predominantly flounder and bass. Eight fishes of five species were caught in the Thames estuary, where smelt (38%) and bass (25%) were dominant (Figure 12). There were 15,980 individuals from eight species in the realignment. November 2010 accounted for the highest abundance of common goby caught in a single month (15,514 fishes; 97%), which were found only in the realignment and thin-lipped grey mullet contributed <3% (451 fishes).

A total of 246 fish from nine species was caught in April 2011 (Figure 12); flounder (70%) dominated the estuarine catch. Flounder also dominated the realignment catch (33%) alongside common goby (32%). Common goby, plaice and thick-lipped grey mullet were found only in the realignment site and not in the estuary on this occasion.

April to June 2011 showed a shift in dominance from flounder to common goby. June 2011 provided the highest species richness with a total of 579 fish from 11 species. In the Thames estuary, 168 fish from six species were caught and common goby (90%) dominated the catch (Figure 12). Common goby (64%) and bass (17%) dominated the catch in the realignment where 411 fishes from 11 species were caught (Figure 12). Plaice (1%), three-spined stickleback (<1%), herring (<1%), thick-lipped grey mullet (<1%) and sprat (<1%) were found only in the realignment.

August 2011 showed a shift in dominance from common goby to bass in the estuary; however common goby stayed dominant in the realignment. In August 2011, 3043 fishes of nine species were caught (Figure 12). In the Thames estuary, there were a total of 57 fishes of six species; bass (54%) and common goby (16%) dominated the catch. The realignment had a considerably higher abundance with 2686 fishes being caught of eight species where common goby (71%) and bass (27%) dominated the catch.

April 2012 produced the smallest abundance of fish, 163 representing nine species were caught. In the Thames estuary 62 fishes from three species were caught; bass (47%) and flounder (37%) dominated. The realignment had a total of 101 fish from eight species caught. Bass (44%) and flounder (38%) dominated the total catch (Figure 12).

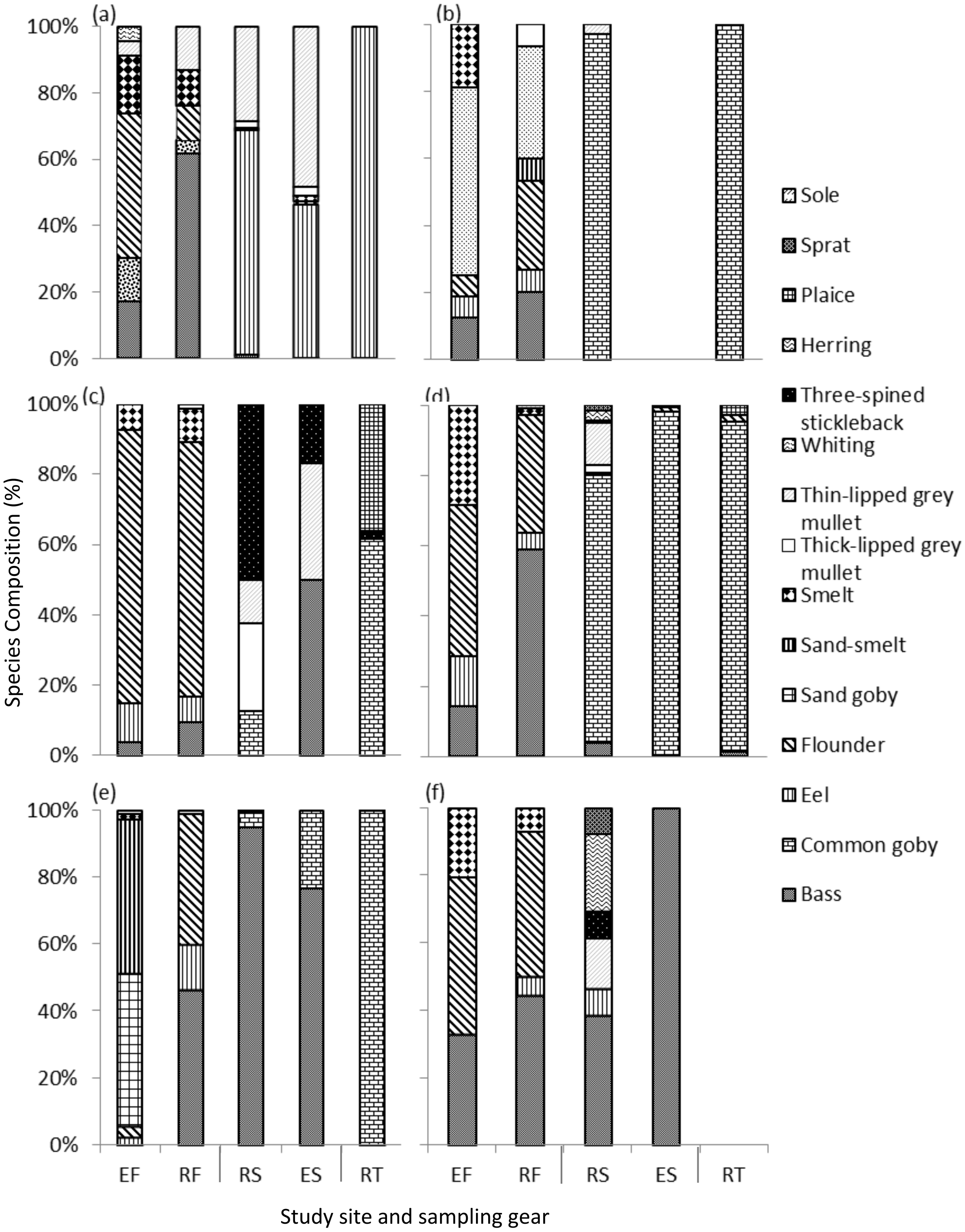


Figure 12. Species composition of fishes captured from the realignment and the Thames estuary in: (a) October 2010, (b) November 2010, (c) April 2011, (d) June 2011, (e) August 2011 and (f) April 2012. See Appendix 1 for study site key.

3.4 Temporal variations in species composition between sites and between gears using non-metric multidimensional scaling

There was a non-significant slight negative correlation shown between sites in October 2010 (Figure 13a), indicating no significant differences between species composition between the Thames estuary and the realignment. Sites did not segregate into distinct clusters. By contrast, species composition caught by different gear types showed no overlap of gears. Distinct clusters are visible and ANOSIM returned a highly significant positive correlation (*P*<0.01) between species caught in the different gear types (Figure 13b).

a.

b

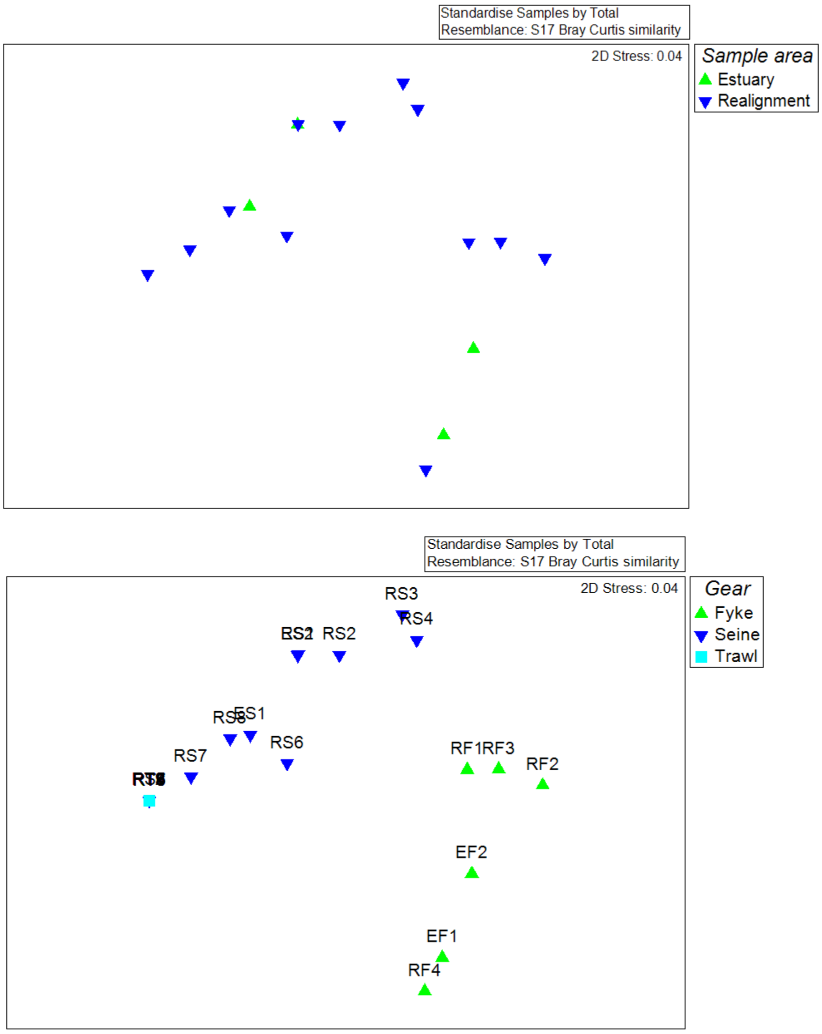
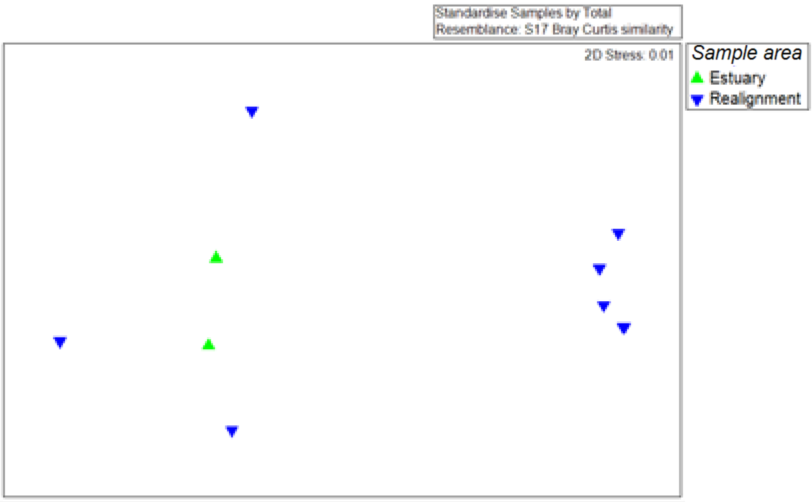


Figure 13. Non-metric multidimensional scaling plot comparing species composition between (a) the Thames estuary and realignment and (b) the different gear types used, October 2010.

A moderate non-significant negative correlation showing no significant differences in species composition between sites was found in November 2010. There were slight overlap of clusters with the definate segregation of seven sites in the realignment (points have overlapped) (Figure 14a). This could be accountable for by the unusual flooding that occurred during this sampling period, resulting in exceptionally high fish count in the breaches where the trawl and seine samples were collected. A comparison of gear types shows a clear segregation of fyke catch, from both the estuary and realignment, clustered together. Common goby was the dominant species caught in the seine and trawl, accounting for those gears being grouped together. A high positive correlation showing significant differences between gear types was found (P<0.01).



b.

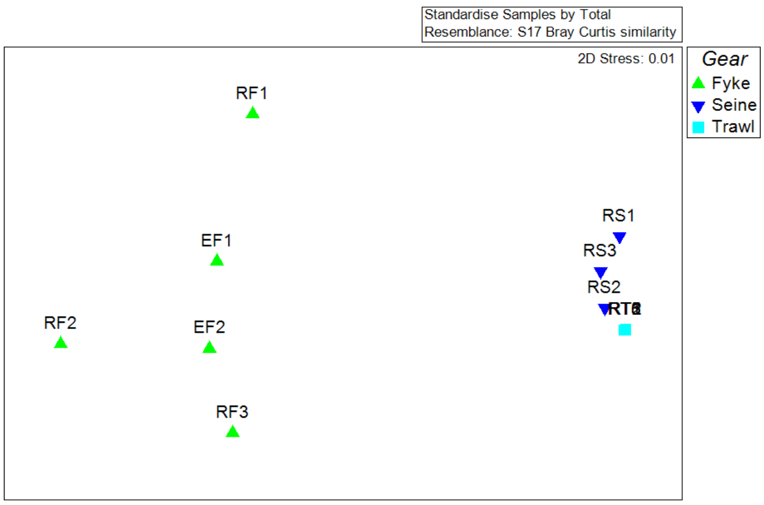


Figure 14. Non-metric multidimensional scaling plot comparing species composition between (a) the Thames estuary and realignment and (b) the different gear types used, November 2010.

A non-significant weak positive correlation was found when comparing species composition between sites in April 2011 (Figure 15a), showing no significant differences between sites. Overlap shown in the MDS plot indicates similarities between catch between the Thames estuary and realignment. By contract, distinct clusters are seen when comparing gear types (Figure 15b), indicating catch from each gear type was significantly different (*P*<0.01), with the exception of two trawl sites and two seine sites both in the realignment that overlap showing very similar species composition.

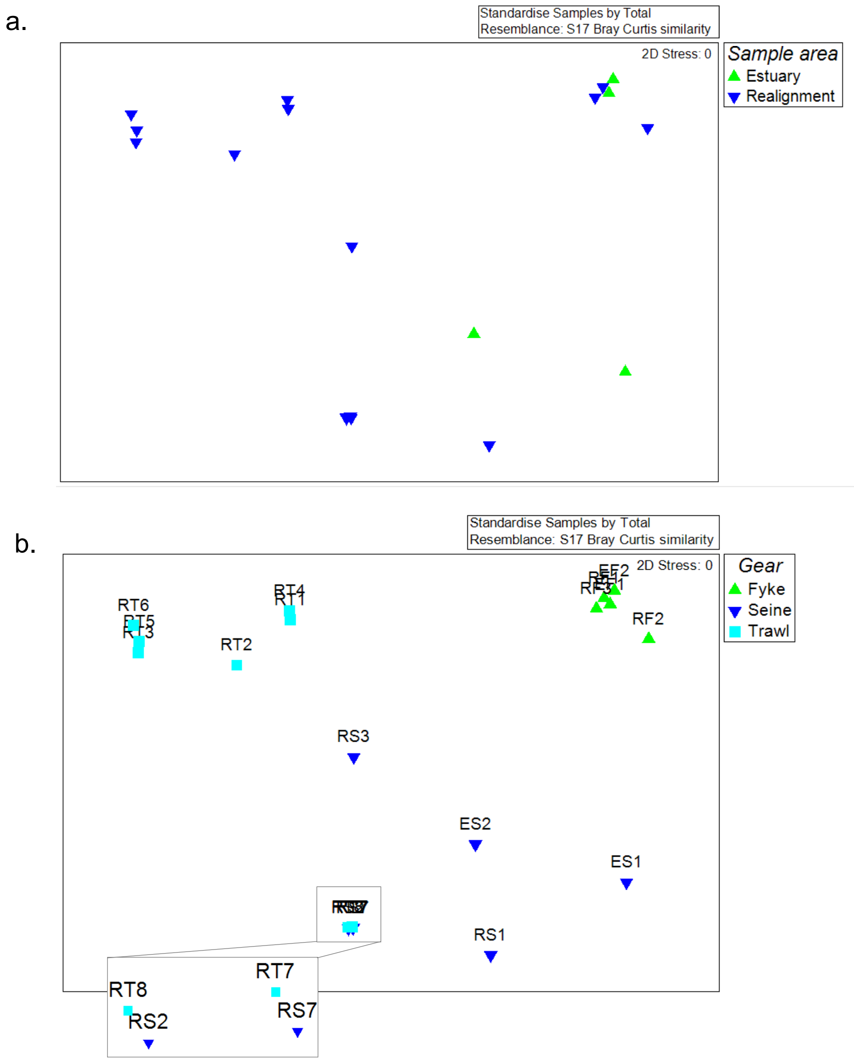


Figure 15. Non-metric multidimensional scaling plot showing similarities (%) in species composition between (a) the Thames estuary and realignment and (b) the different gear types used, April 2011.

No significant differences were found between sites in terms of species composition in June 2011. There was overlap between sites displaying similarities (Figure 16a). Overall, there was a negative correlation found and no significant differences between the sites. A comparison of gear types in June 2011 gives a highly significant positive correlation (*P*<0.01) showing strong differences between species composition. Distinct clusters are seen (Figure 16b), along with some overlap between seine and trawl between sites showing some similarities between catches. Common goby was the dominant species in June 2011 caught in the realignment and estuary seine and the realignment trawl nets, explaining the overlap seen in the MDS plot.

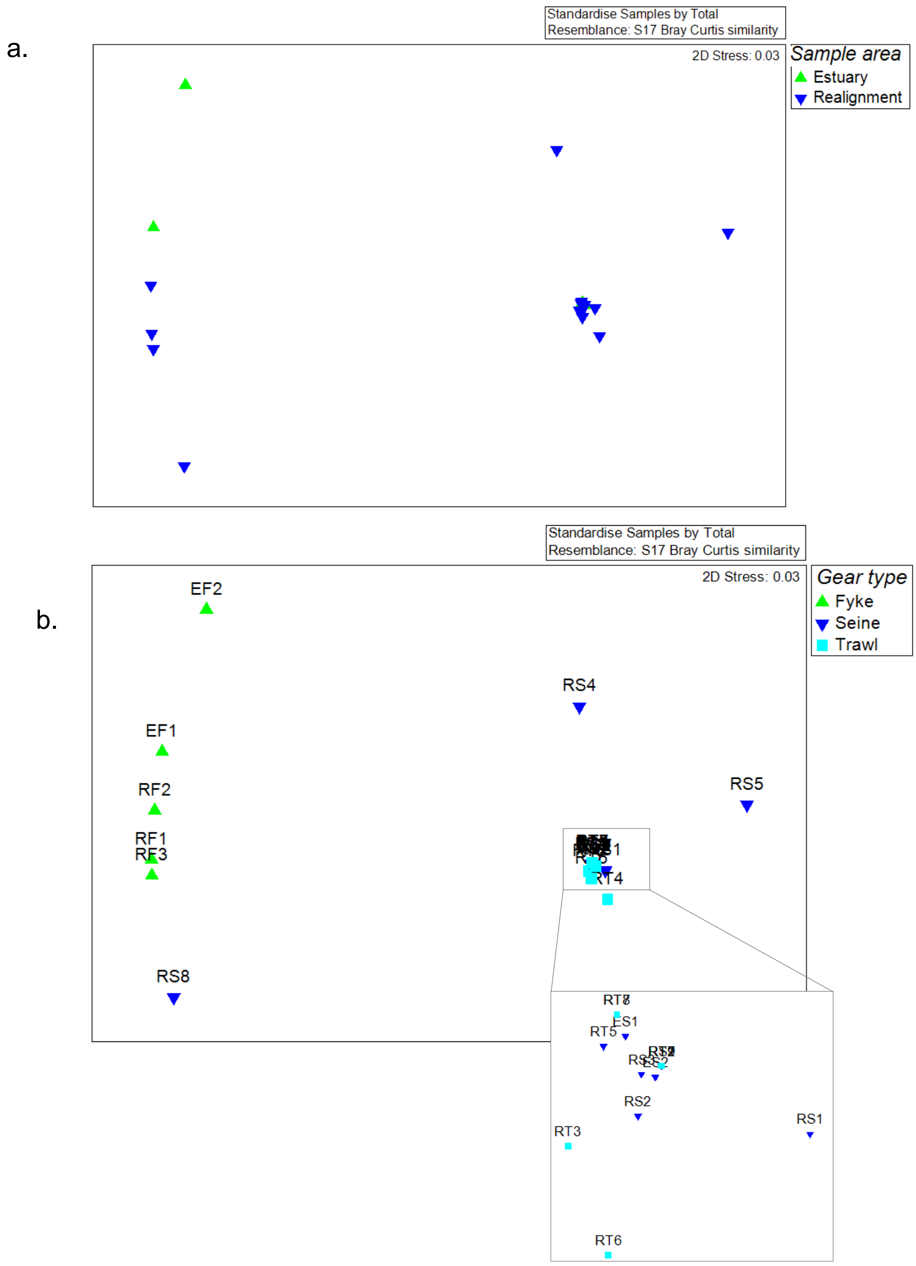


Figure 16. Non-metric multidimensional scaling plot showing similarities (%) in species composition between (a) the Thames estuary and realignment and (b) between the different gear types used, June 2011.

In August 2011, there was little variation between sites in terms of species composition, although no significant differences were seen between sites, similar species were found at both locations (Figure 17a). Overlap of two seine sites indicates high similarities at both sites. In contract, comparisons of gear types show highly significant differences (P<0.01), and no overlap of gear types, each gear is separated into clusters (Figure 17b). Bass and flounder proved to be dominant in fyke catch from both sites, bass was dominant in seine catches from both sites and common goby was dominant from trawl sites.

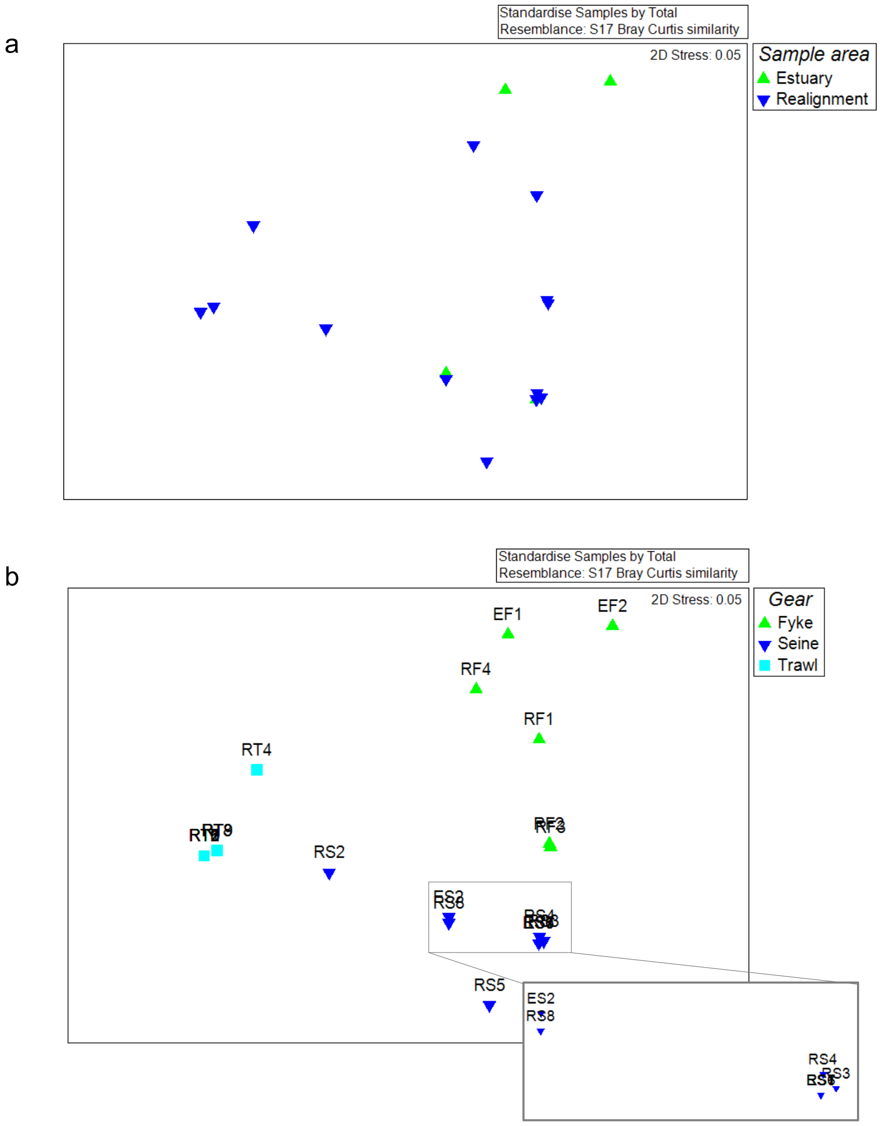


Figure 17. Non-metric multidimensional scaling plot showing similarities (%) in species composition between (a) the Thames estuary and realignment, and (b) between the different gear types used, August 2011.

For April 2012 RS8 and RS3 were removed from the statistical analysis to allow a clearer picture of what was occurring during sampling, one three-spined stickleback was caught in RS8 and three herring, one eel and one thin-lipped grey mullet were caught in RS3. These points varied largely in the MDS plot and gave a stress level of 0, preventing a clear view of the other points in the graph. April 2012 showed a non-significant moderate negative correlation between sites, and no clear separation of locations (Figure 18a). Although there is separation into two major distinct groups, there is overlap between sites indicating similarities in species composition. There is also a third site which is a realignment seine site (RS8), which was the only site where a three-spined stickleback was found, resulting in this site being further from the other groups. In contrast, there is a significant separation of seine and fyke species composition (P<0.01), where bass was dominant in seine catches and flounder dominant in fyke catches.

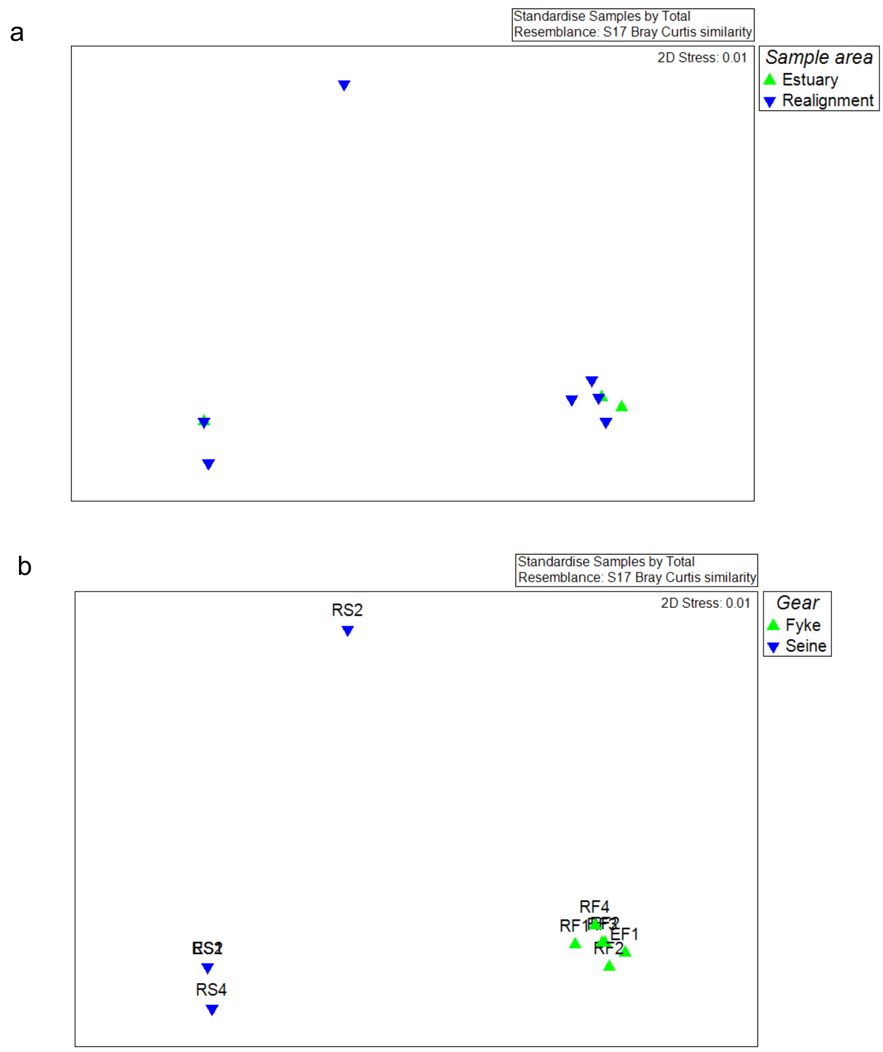


Figure 18. Non-metric multidimensional scaling plot showing similarities (%) in species composition between (a) the Thames estuary and realignment and (b) between the different gear types used, April 2012.

Overall, species composition has been shown to be similar in the Thames estuary and managed realignment using ANOSIM where in each month sampled, there were no significant differences found. In contrast, as expected there were significant differences in the catch between the different gear types across each month sampled. In each month sampled, RS1-4 appears to be separate from the main groups on the gear comparison plots; this is evidence of habitat heterogeneity within the realignment site. These sample sites are located to the far right of the realignment site, separate from the rest of the samples taken (Figure 3). Grassy verges and sandy substratum were common in this area of the realignment site, accounting for the separation in plots.

3.5 Catch-per-unit-effort/density

3.5.1 Temporal comparison of fyke CPUE between the Thames estuary and realignment.

Variations in mean CPUE (no. fish h^{-1}) from the fyke net surveys showed a higher number of fish being caught in the realignment when compared to the Thames estuary, however not significantly higher. The large standard deviation error bars indicate that there was high variability between each month and each site. In more than 50% of the monthly fyke surveys, the realignment had a considerably higher CPUE than the Thames estuary (Figure 19). During November 2010 (2.9 fish h^{-1}) and April 2012 (2.8 fish h^{-1}), mean CPUE was higher in the Thames estuary than in the realignment. June 2011 produced the highest CPUE in fyke net catches in the realignment (4.0 fish h^{-1}), along with the largest mean CPUE difference (3.1 fish h^{-1}) between the realignment and Thames estuary (Figure 19), although not statistically significant this showed a large variation between fyke samples.

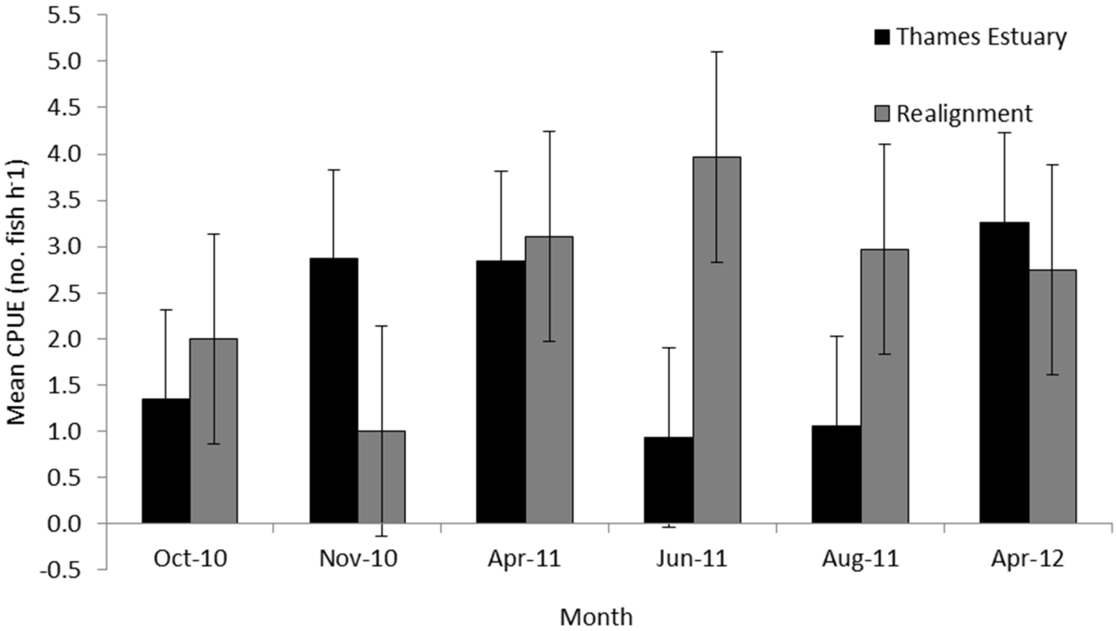


Figure 19. Variations in catch-per-unit-effort (no. fish h^{-1}) in fyke net surveys in the Thames estuary and the realignment, October 2010-April 2012.

3.5.2 Fyke day and night CPUE comparison.

A comparison of day and night fyke surveys from April 2011-April 2012 (Figure 20) showed that, although not significant, shown by the large variability, there was a consistently lower CPUE in both sites of fish caught overnight compared to during the day as a result of lower fish activity. However, there was an exception in August 2011 in the realignment where there were 0.5 fish h^{-1} more fish caught overnight than during the day (Figure 20). April 2011 was the only survey that had a higher CPUE of fish in the Thames estuary than the realignment during both the day (estuary, 4.3 fish h^{-1}; realignment, 3.8 fish h^{-1}) and night (estuary, 1.5 fish h^{-1}; realignment, 1.2 fish h^{-1}), although not significant, this indicated a large variation between samples. June 2011 produced the highest CPUE in the realignment during the day (5.6 fish h^{-1}), and also the largest difference between the two sites (4.2 fish h^{-1}). There was a CPUE of 1.4 fish h^{-1} in the Thames estuary during the day, and a CPUE of 0.5 fish h^{-1} overnight, the lowest CPUE in the Thames estuary. The only significant difference was found from a comparison between the realignment and estuary of fyke catches in August 2011 during the day (p = 0.05), but a comparison of the overnight catch did not show any significant difference.

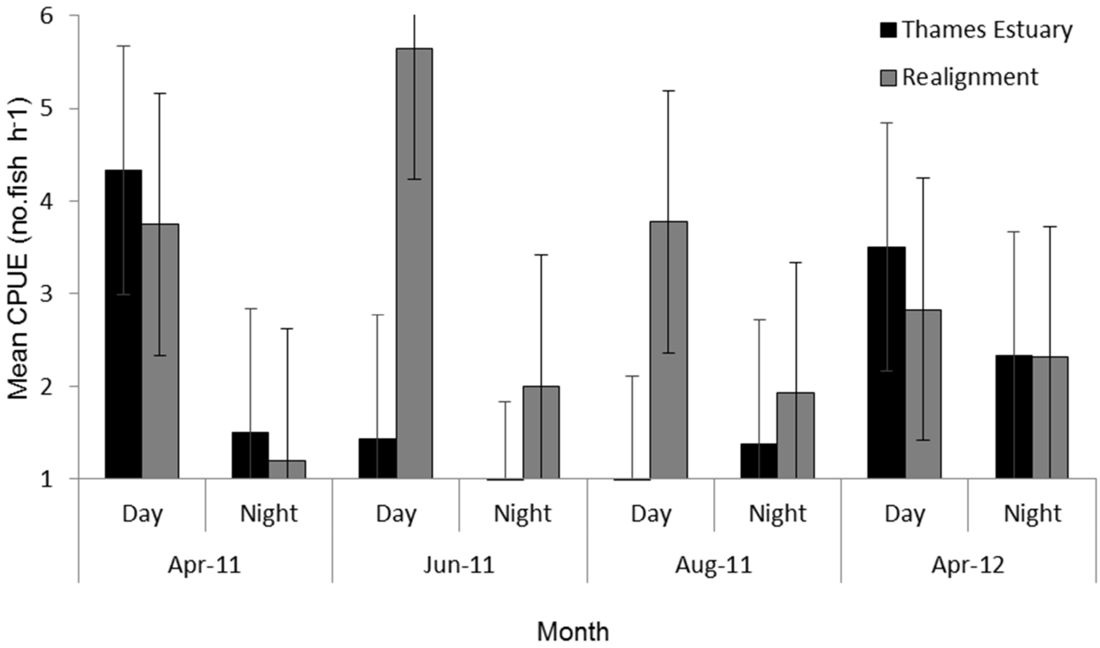


Figure 20. Mean CPUE (no. fish h^{-1}) between day and night fyke surveys, April-August 2011.

3.5.3 Variations in seine density between the Thames estuary and realignment

Comparison of fish density from the Thames estuary and the realignment using data from seine catches found no significant relationships (Figure 21). Although the average values from each site were different, the high variability indicates there were no significant differences between sites. Standard deviation was exceptionally high for realignment values as a result of the unusually high catch experienced in November 2010 (Figure 21). Density was higher, although not significant, in the realignment than the Thames estuary in October, November 2010 and August 2011. November 2010 (22.1 fish m^{-2}) produced the highest density from the realignment, resulting in such a high standard deviation, whereas the highest density in the Thames estuary occurred in June 2011 (0.6 fish m^{-2}) (Figure 21). Density was considerably higher in November than other months as a result of the fish being confined to the ditches surrounding the realignment, therefore it cannot be guaranteed that November would have had such a high density had the tides flooded as predicted. A comparison of density between sites was not possible for November as a result of no seines being deployed in the estuary. April 2011 produced an average density of <1 fish m^{-2} at both sites, as there was a total of only eight fish caught in the realignment and six caught in the Thames estuary. There were 0.5 fish m^{-2} more fish caught in the Thames estuary than in the realignment in June 2011. However, this was reversed in August 2011 when there was 0.6 fish m^{-2} more fish caught in the realignment than in the Thames estuary. In April 2012 the

Thames estuary (0.42 fish m^{-2}) supported a higher density of fish than the realignment (0.10 fish m^{-2}) (Figure 21).

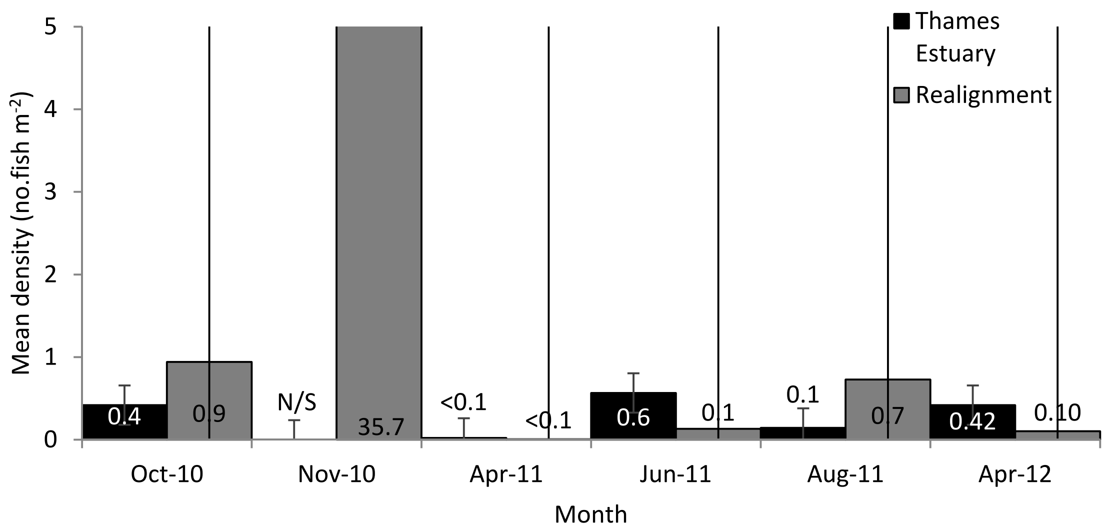


Figure 21. Variations in the mean density (no. m^{-2}) of fishes in the Thames estuary and the realignment using seine, October 2010 to April 2012.

3.5.4 Variations in trawl density between the Thames estuary and realignment

High variability was shown in the trawl catch from realignment site, however a temporal pattern was also shown, low density throughout spring and early summer, and high density through autumn and winter, indicating fish are utilizing the realignment site seasonally. October 2010 produced the highest density (11.9 fish m^{-2}) of fish caught by trawling in the realignment (Figure 22). With the exception of April 2012, when <1 fish m^{-2} were caught using the trawling method, the remaining four sample months caught between 0.9-10.4 fish m^{-2}, decreasing in density from winter through to autumn where density increases again by 9.5 fish m^{-2}. Trawling was not performed in the Thames estuary site therefore a comparison was not possible at this time.

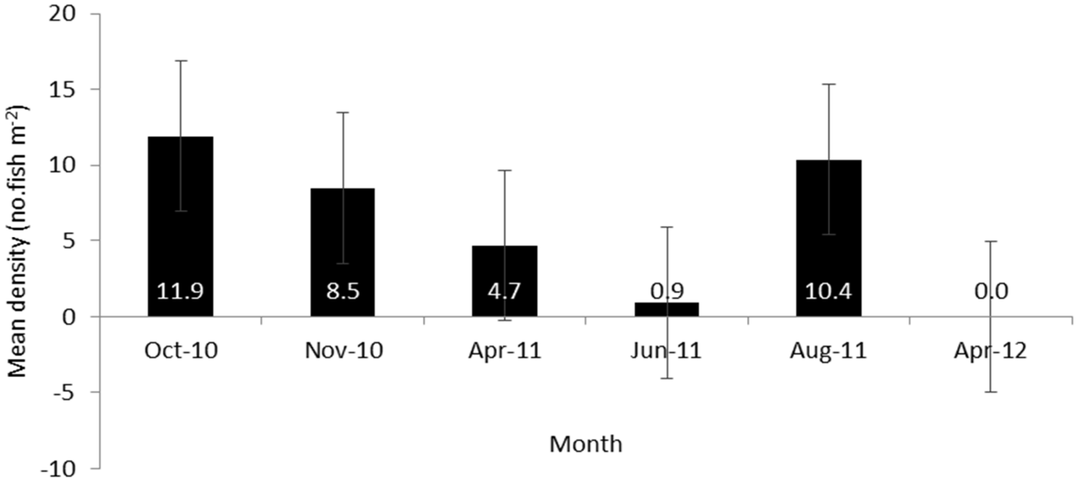


Figure 22. Variations in the mean density (no. fish m^{-2}) of fishes in the realignment using trawl, October 2010 to April 2012.

3.6 Length-frequency of fishes

Length-frequency histograms were produced for fish from October 2010-April 2012 to compare the size structure of the populations in the Thames estuary and managed realignment. This was performed by comparing length range from each gear type in both sites for a comparable analysis (Figure 23-Figure 28).

The size range of bass in October 2010 caught in the realignment by seine ranged from 30-90 mm (Figure 23a), and from 150-330 mm when caught by fyke (Figure 23b). The differences in length distributions using seine and fyke nets were a result of the fyke net targeting larger fish due to the 14 mm mesh size of compared with that of the seine (3 mm). There were only four bass caught in the Thames estuary (by fyke) which had a smaller length distribution ranging from 163-295 mm. Length distribution of common goby was between 12 mm and 50 mm at both sites (Figure 23d-e) and a comparison of mean length showed an independent samples *t*-test of $p = 0.02$, showing recruitment and significant differences between the Thames estuary and realignment. Mean lengths of common goby showed statistical significance between sites with the Thames estuary samples having a mean of 23 (± 9) mm ($n = 43$) and the realignment samples having a mean of 24 (± 7) mm ($n = 139$), a result of a higher presence of larger fish in the realignment.

Thick-lipped grey mullet showed some recruitment in the realignment (Figure 23f), with a length distribution ranging from 42-62 mm; there were three thick-lipped grey mullet caught in the estuary which ranged from 46-50 mm. Comparison of thin-lipped grey mullet caught by seine from the Thames estuary and the realignment (Figure 23g-h) found recruitment at both sites (Figure 23g-h) and a similar size structure with a mean length of 22 (± 9 SD) mm in the realignment (*n* = 202) and 19 (± 4) mm in the Thames estuary (*n* = 45). It is worth noting that the golden grey mullet (*Liza aurata*) also spawns around late summer, therefore it is possible that some of the thin-lipped grey mullet sample may have contained some golden grey mullet. The thin-lipped grey mullet caught in the realignment by fyke were of an older age group than those caught by seine, reaching lengths of 158 mm.

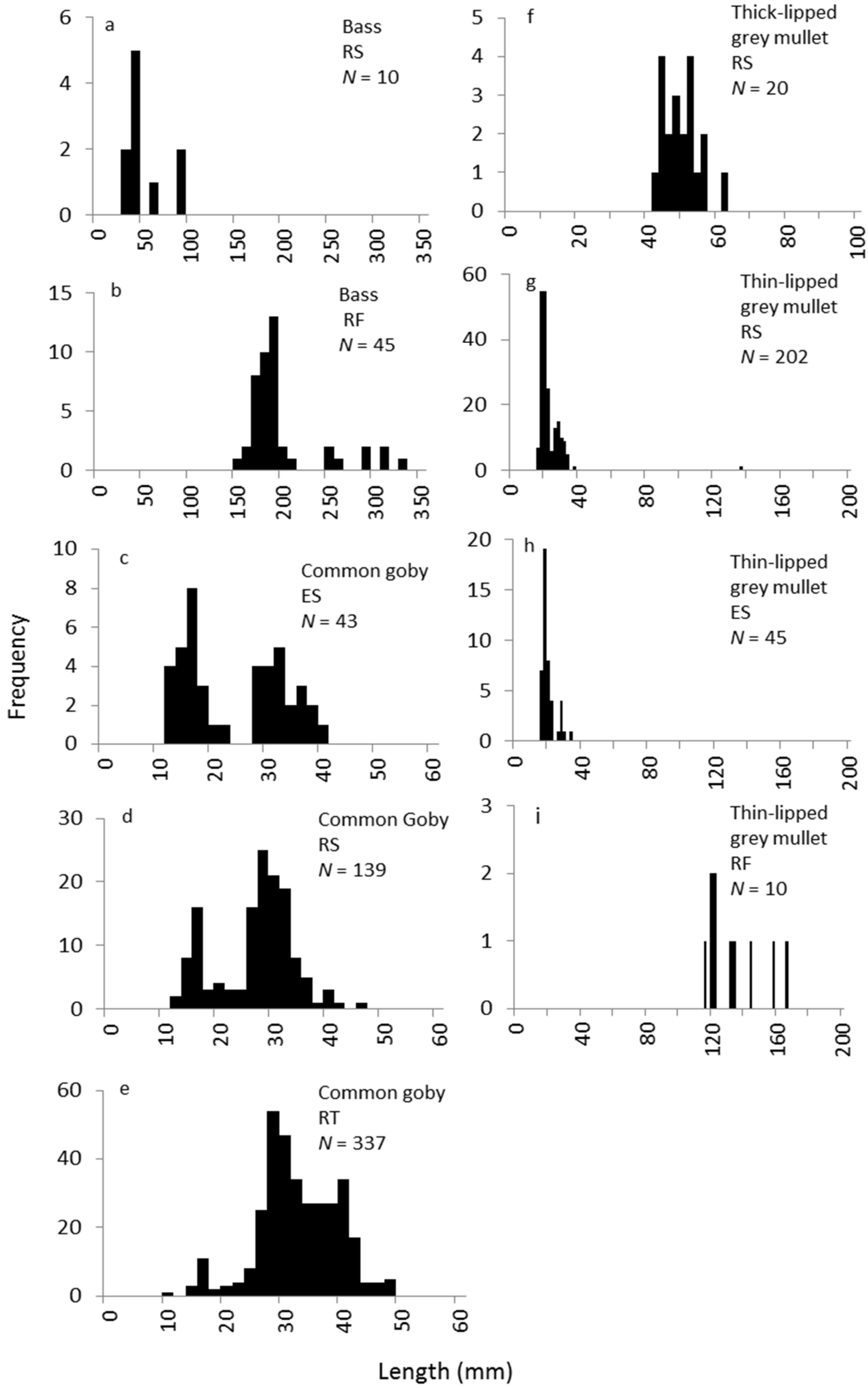


Figure 23. Length distributions bass, common goby, thick-lipped grey mullet and thin-lipped grey mullet caught from the realignment (R) and the Thames estuary (E), October 2010. Bass caught in the realignment by (a) seine net and (b) fyke net. Common goby caught in (c) Thames estuary by seine, (d) the realignment by seine and (e) the realignment by trawl. Thick-lipped grey mullet caught in the realignment by seine (f). Thin-lipped grey mullet caught in (g) the realignment by seine, (h) Thames estuary by seine and (i) the realignment by fyke. See Appendix 1 for site codes.

There was a wide length range of common goby in November 2010, suggesting recruitment in the realignment. Common goby showed a length distribution of between 13 and 54 mm in the realignment (Figure 24a-b). The length distribution of thin-lipped grey mullet caught by seine in the realignment was between 18-34 mm (Figure 24c).

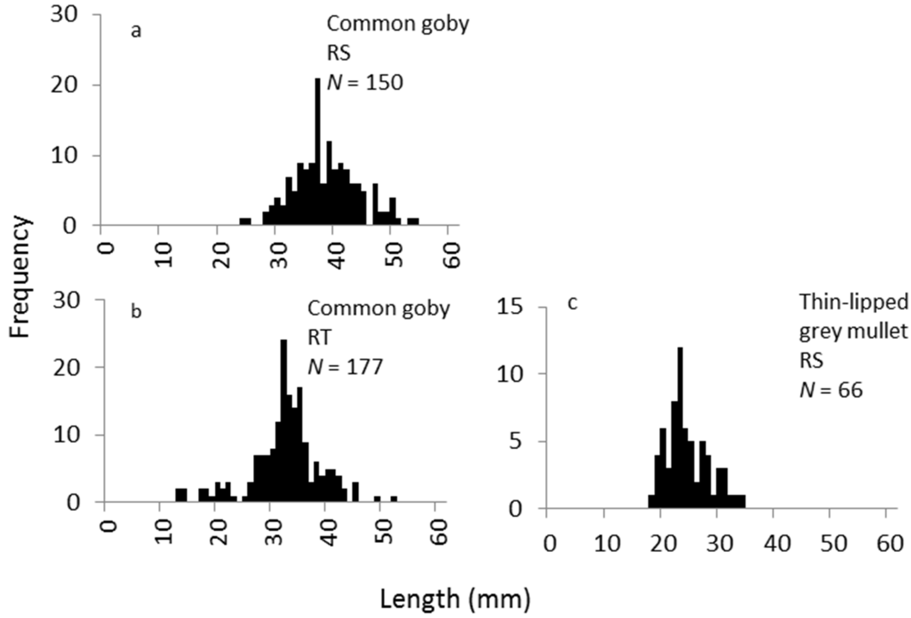


Figure 24. Length distribution of common goby and thin-lipped grey mullet caught in the realignment (R), November 2010. Common goby caught by (a) seine and (b) trawl. Thin-lipped grey mullet caught by seine (c). See Appendix 1 for site codes.

In April 2011, mean lengths of flounder caught in the Thames estuary (Figure 25a) and the realignment (Figure 25b) by fyke net were statistically significant (independent samples *t*-test, $P < 0.05$), with the Thames estuary having a mean of 222 (± 74) mm (n = 37), compared with a mean of 186 (± 56) mm (n = 66) in the realignment. This was caused by a higher presence of smaller fish in the realignment and a higher presence of larger fish in the estuary. Plaice had a length range from 25-48 mm in the realignment when caught by trawl, suggesting recruitment had occurred (Figure 25c). No plaice or common goby were caught in the Thames estuary so comparisons were not possible. There were 59 common goby caught during April 2011 by trawl in the realignment, which had a length range from 28-46 mm (Figure 25d). Seine nets in April 2011 caught 14 fish in total, including bass, common goby, thick-lipped grey mullet, thin-lipped grey mullet, and three-spined stickleback.

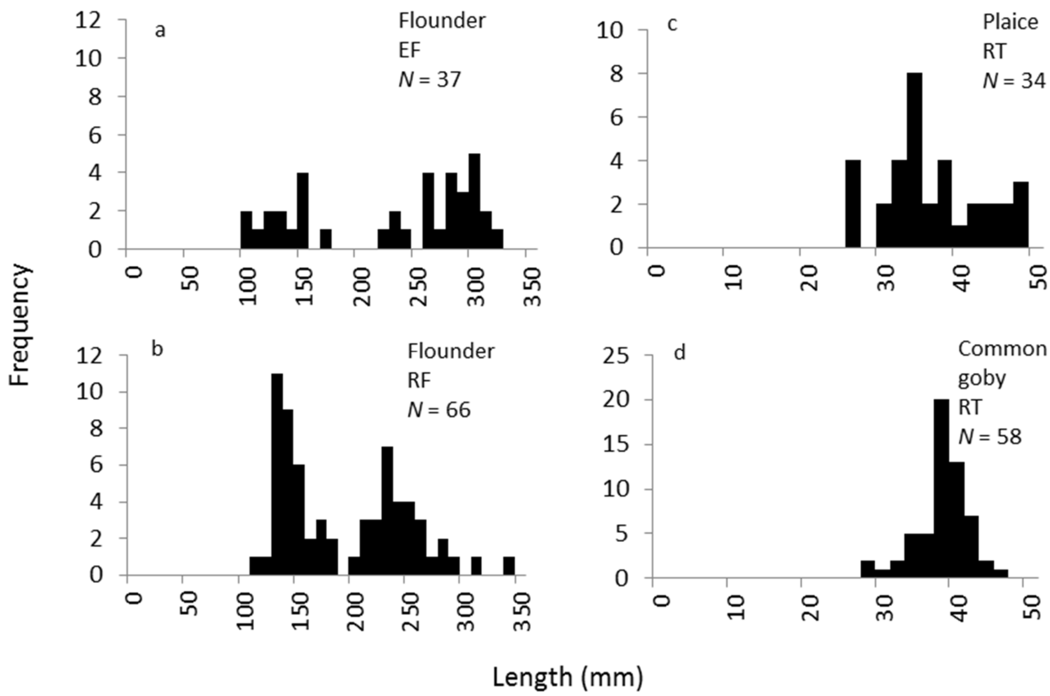


Figure 25. Length distribution of flounder, plaice and common goby caught from the realignment (R) and the Thames estuary (E), April 2011. Flounder caught by fyke in (a) Thames estuary (b) the realignment. Plaice caught in the realignment by trawl (c). Common goby caught in the realignment by trawl (d). See Appendix 1 for site codes.

Comparison of common goby caught in June 2011 by seine from the Thames estuary (Figure 26a) and the realignment (Figure 26b) found similar length distributions, ranging from 11-17 mm in the Thames estuary and 9-18 mm in the realignment. Mean length of common goby caught by seine net were significantly similar from the Thames estuary where the mean was 13 (± 1) mm (n = 151) and the realignment where the mean was 14 (± 2) mm (n = 86) (independent samples t-test, $P < 0.05$). Length distribution of common goby caught by trawl (8-46 mm) in the realignment was similar to that of common goby caught by seine in the realignment (9-18 mm), with the exception of four fish caught by trawl which were larger than 20 mm (Figure 26c). A comparable reduction in mean length of common goby caught by trawl in the realignment was seen in June 2011 when compared to April 2011 showing recruitment has occurred around the time of sampling. April 2011 gave an average of 37 mm (Figure 25), whereas June 2011 gave an average of 14 mm (Figure 26).

Thin-lipped grey mullet caught by seine in the realignment showed a length distribution of between 28-47 mm (Figure 26d), but no thin-lipped grey mullet were caught in the Thames estuary. Length distribution of bass caught by fyke ranged from 100-400 mm in the realignment (Figure 26e), but only two bass were caught in the Thames estuary, both of which were 168 mm. Flounder caught in the realignment by fyke had a length distribution of 160-300 mm and a mean of 213 (± 41) mm, but there were only six flounder, with a length range of 157-263 mm and a mean of 180 (± 41) mm caught in the Thames estuary. There was no indication of flounder recruitment in June 2011, indicating that the site has so far not recreated the necessary nursery habitat needed for flounder. There were no statistical differences in mean length.

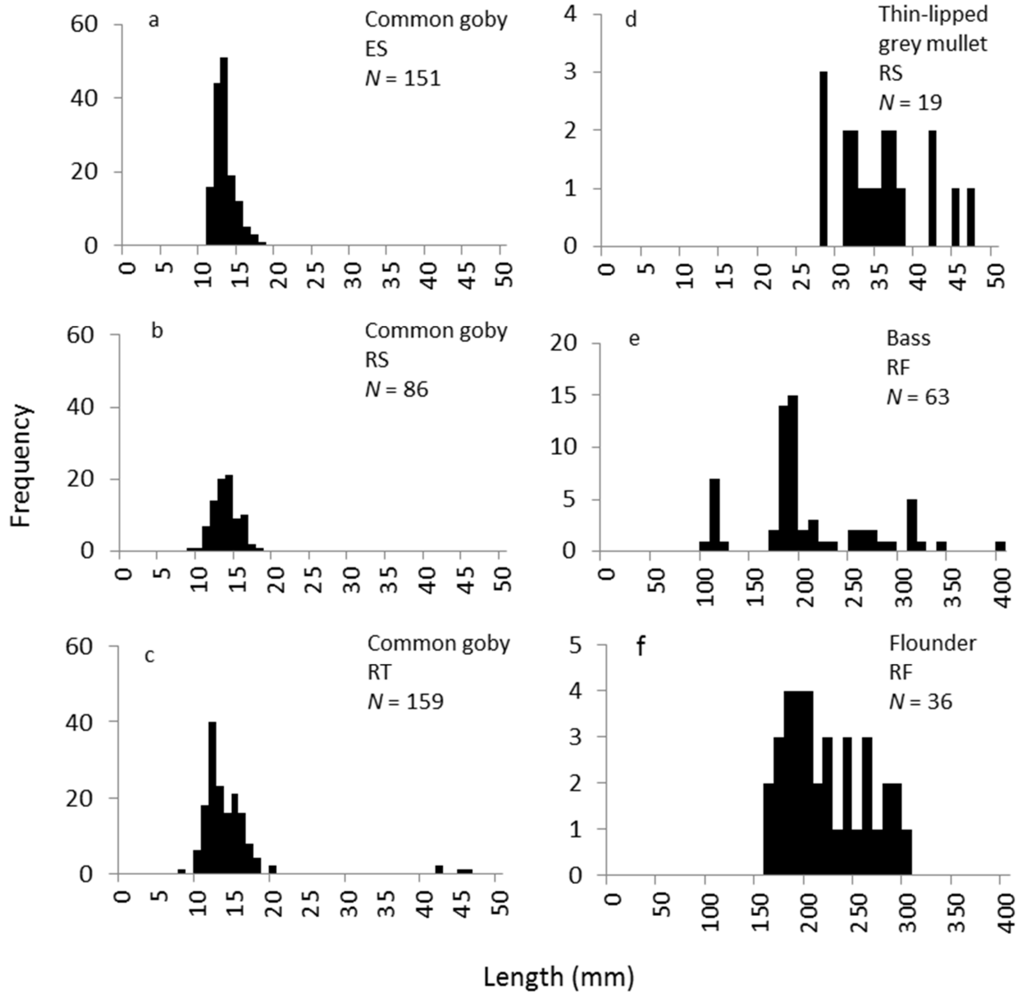


Figure 26. Length distribution of common goby, thin-lipped grey mullet, bass and flounder caught from the realignment (R) and the Thames estuary (E), June 2011. Common goby caught by seine in (a) the Thames estuary, (b) the realignment, and (c) by trawl in the realignment. Thin-lipped grey mullet caught by seine in the realignment (d). Bass in the realignment caught by fyke (e). Flounder caught in the realignment caught by fyke (f).

Bass caught in seine catches in the realignment in August 2011 had a length range of 10-140 mm (Figure 27b) (although only one fish was larger than 55 mm) and a mean length of 29 (± 8) mm (n = 684), whereas those in the Thames estuary had a length range of 20-65 mm and a mean length of 34 (± 11) mm (n = 30), showing a significant significance in mean length between the sites (independent samples t-test, $P < 0.05$). Bass caught by fyke in the realignment had a length range of 155-305 mm, showing a range of cohorts (Figure 27c). Flounder caught by fyke nets in the realignment had a mean length of 230 (± 28) mm and showed no signs of recruitment and no fish smaller than 180 mm in length due to the fyke net mesh size (Figure 27d). Only six flounder were caught in the Thames estuary, ranging from 166-267 mm in length. Common goby ranged from 8-40 mm in length with a mean of 20 (± 4) mm when caught by trawl in the realignment (Figure 27e), and 10-24 mm, with a mean of 16 (± 4) mm when caught by seine in the realignment (Figure 27f). Only nine common goby were caught in the Thames estuary by seine, which ranged from 12-31 mm in length. Recruitment was seen as were a small number of adult fish. Lengths of eel ranged from 290-505 mm with a mean length of 374 (± 81) mm in the realignment using the fyke, whereas only four were caught in the Thames estuary, which had a length range of 390-570 mm and a mean of 502 (± 79) mm, showing statistical significance between the two sites (independent samples *t*-test, $P < 0.02$).

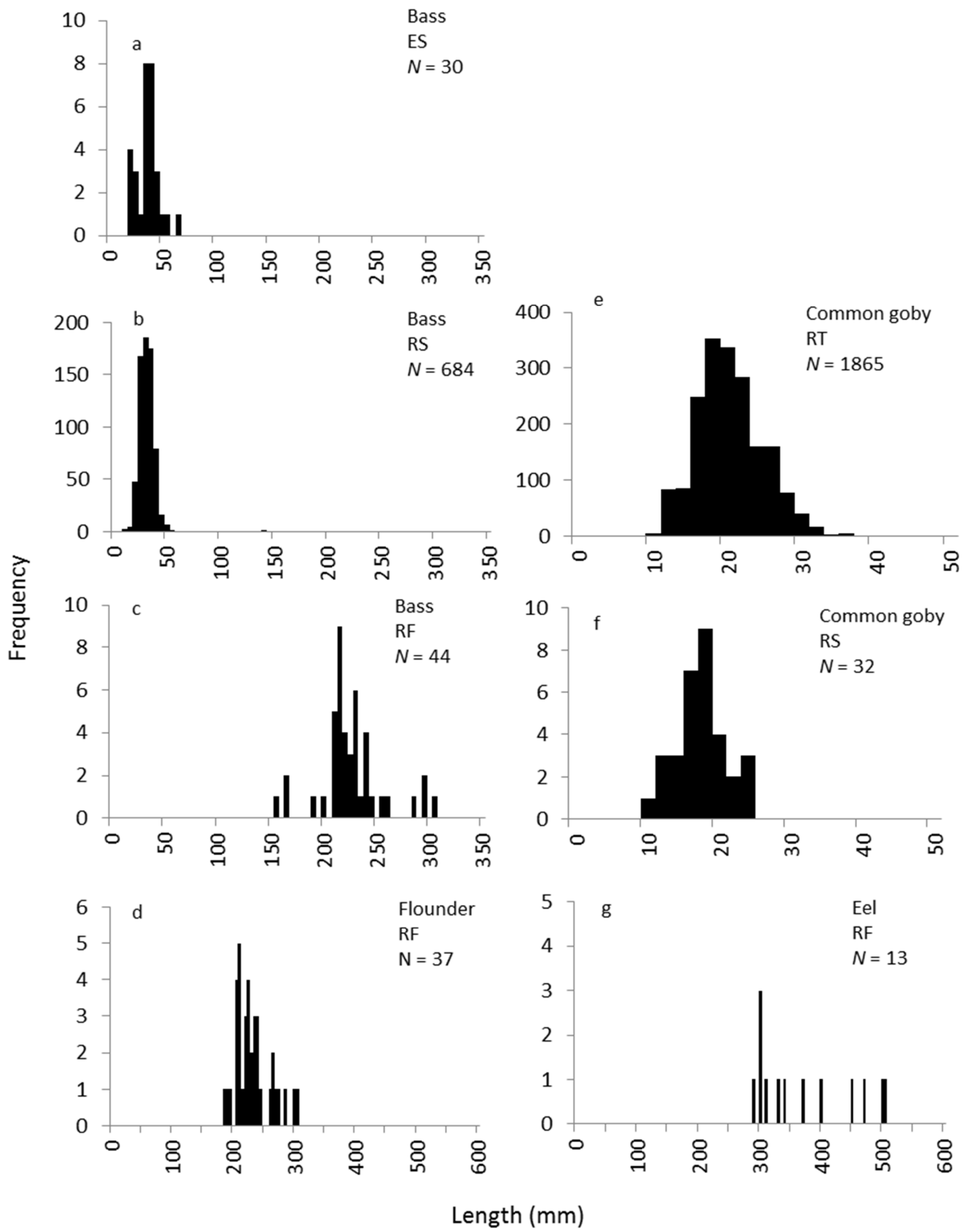


Figure 27. Length distribution of bass, common goby, eel and flounder caught from the realignment (R) and the Thames estuary (E), August 2011. Bass caught by seine in (a) the Thames estuary (b) the realignment and (c) caught by fyke in the realignment. Flounder caught in the realignment by (d) fyke. Common goby caught in the realignment by (e) trawl and (f) seine. Eel caught in the realignment by fyke (g).

In April 2012, a greater mean length of bass was observed in the realignment (112 (± 62)) mm (*n* = 39) than the estuary (90 (± 5)) mm (*n* = 16) although this was not significantly different. Length range was also wider in the realignment (70-287 mm) than the estuary (90-110 mm) (Figure 28a-b).

Flounder caught by fyke in the Thames estuary had a mean length of 211.7 (± 74) mm (n = 22) (Figure 28b) and 244.4 (±40) mm in the realignment (n = 38) (Figure 28c-d), which showed a statistically significant difference in April 2012 (independent samples t-test, $p < 0.05$). The length range in the realignment was 130-310 mm whereas the range in the estuary was 110-360 mm, showing that fish in the Thames estuary had a wider range of lengths compared with the realignment.

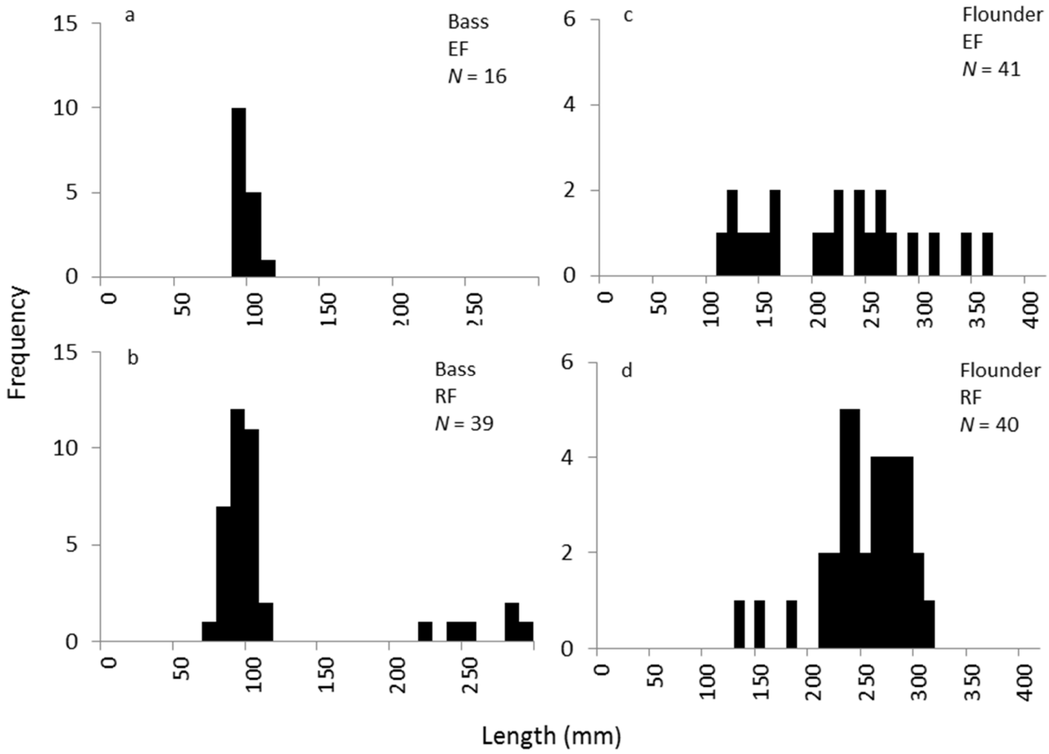


Figure 28. Length distribution of bass and flounder caught from the realignment (R) and the Thames estuary (E), April 2012. Bass caught by fyke in (a) the Thames estuary and (b) the realignment. Flounder caught by fyke in (c) the Thames estuary and (d) the realignment.

3.7 Diet analysis

A total of ten prey taxa were found from both sites in the gut contents of the four fish species examined (April 2011 to August 2011). Eight taxa were found in fish from the realignment, and six taxa were found in fish from the Thames estuary. Significant similarity was seen in diets of bass between sites, and similar, but not significant similarities were seen in common goby.

In April 2011 (Figure 29), two prey taxa were found in the gut of common goby caught in the realignment (n = 10, mean gut fullness = 44%), in addition to unidentified material. *Corophium* sp. dominated the diet in terms of both abundance (%A; 73% of prey eaten) and occurrence (%O; 90% of fish examined) (Figure 29). Although not significantly similar, gut contents of common goby from April 2011 to August 2011 showed not much separation in diet between fish from the realignment and estuary (Figure 30). Plaice (*n* = 10, mean gut fullness = 76%) had a similar diet to that of common goby, *Corophium* sp. was dominant in terms of abundance (%A; 91%) and occurrence (%O; 100%), but Harpacticoida was eaten by 60% of fish albeit only in small amounts (%A; 6%) (Figure 29). Insufficient fishes were captured from the estuary for diet analysis in April 2011 (Figure 29). There was a large amount of overlap seen in the diets of common goby between the Thames estuary and the realignment, indicating similar prey availability between sites. There were some individuals that had slightly different diets compared with the main cluster (Figure 30).

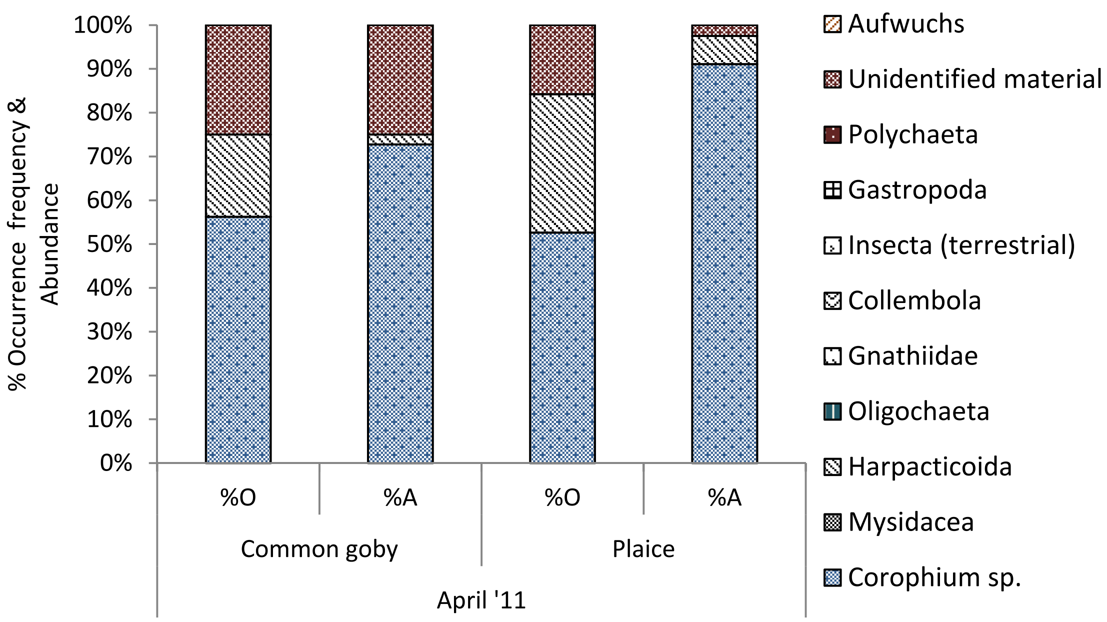


Figure 29. Frequency of occurrence (%O) and relative abundance (%A) of prey taxa found in common goby and plaice caught from the realignment (R), April 2011.

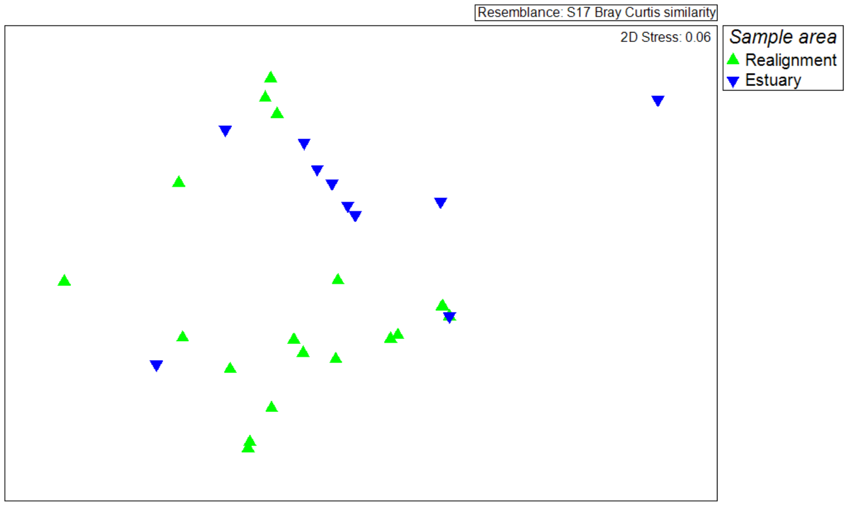


Figure 30. Non-metric multidimensional scaling plot showing similarities between diets of common goby caught in the realignment and the Thames estuary, April, June and August 2011.

The gut contents of common goby (*n* = 10, mean gut fullness = 54%) caught in the realignment in June 2011 consisted of three prey taxa (Figure 31), however, the Thames estuary showed a higher species richness of five prey taxa found in the gut contents (*n* = 10, mean gut fullness = 45%). A shift in prey dominance is seen in gut contents of common goby from *Corophium* sp. in April 2011 to Harpacticoida in June 2011.

In both sites, gut contents consisted primarily of Harpacticoida (managed realignment: %O; 90%, %A; 77%. Thames estuary: % O; 70%, %A; 34%). *Corophium* sp. (%O; 70%, %A; 38%) was most abundant in the Thames Estuary and also showed the same occurrence as Harpacticoida. *Corophium* sp. also had a high occurrence of common goby in the realignment (%O; 60%, %A: 13%) demonstrating that Harpacticoida and *Corophium* sp. were the dominant food source. Oligochaetes were found in small abundance in common gobies in both the realignment (%A = 7%) and the Thames estuary (%A = 5%), whereas gastropods and polychaetes were only consumed in the Thames estuary. Overall, the dominant taxa of Harpacticoida and *Corophium* sp. were the same at both sites for the common goby; however species richness was higher in the Thames estuary.

The primary food intake of thin-lipped grey mullet (*n* = 10, mean gut fullness = 72%) caught in the realignment in June 2011 was aufwuchs (%O; 90%, %A; 93%), although *Corophium* sp. (%O; 20%, %A; <1%), Harpacticoida (%O; 10%, %A; 6%), Collembola (%O; 10%, %A; 0%), and Insecta (terrestrial) (%O; 10%, %A; <1%) were also eaten in small amounts. Unfortunately there were insufficient thin-lipped grey mullet caught in the Thames estuary to perform diet analysis.

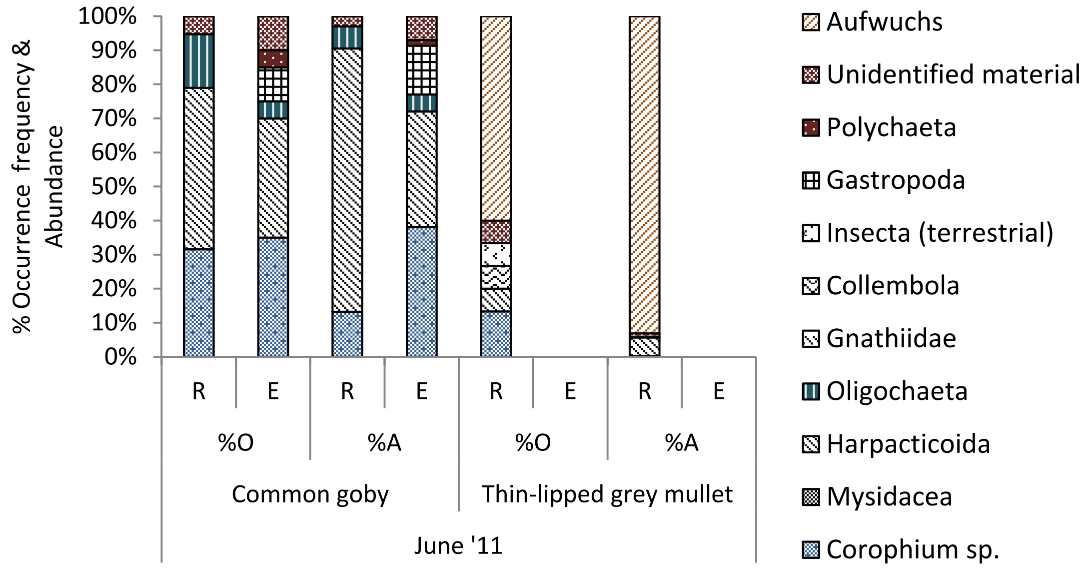


Figure 31. Frequency of occurrence (%O) and relative abundance (%A) of prey taxa found in common goby and thin-lipped grey mullet caught from the realignment (R) and the Thames estuary (E), June 2011.

In August 2011, three prey taxa were found in common goby from the realignment (*n* = 10, mean gut fullness = 56%), in addition to unidentified material. Oligochaeta (O%; 80%, %A; 39%) and Harpacticoida (O%; 80%, %A; 23%) were the main food sources of common goby, in addition to a low abundance of *Corophium* sp. (O%; 40%, %A; 4%) (Figure 32).A further shift in prey dominance was seen from Harpacticoida in June 2011 to Oligochaeta in August 2011. Insufficient common goby were captured from the Thames estuary for a comparison of diet composition.

Higher species richness was found in bass from the realignment where six prey taxa were found in gut contents (*n* = 10, mean gut fullness = 36%) (Figure 32), compared to three taxa found in bass from the Thames estuary (*n* = 10, average gut fullness = 54%). Mysidacea dominated the diet of bass caught from the realignment site in terms of occurrence in fish sampled (%O; 70%, %A; 26%), but Oligochaeta was dominant in terms of abundance (%O; 30%, %A: 30%*).* The remaining three taxa found in bass in the realignment consisted of *Corophium* sp. (O%; 60%, %A; 18%), Harpacticoida (O%; 10%, %A; 3.3%) and Gnathiidae (O%; 10%, %A; 10%) (Figure 32). Overall bass had the same primary food source at both sites, with small numbers of additional taxa for in the diets of bass in the realignment indicating higher species richness.

The primary food source of bass caught from the Thames estuary was Mysidacea (%O; 80%, %A; 57%), though *Corophium* sp. also occurred frequently (%O; 60%, %A; 35%). Significant similarity was seen in diets of bass between the Thames estuary and the realignment (P<0.05) shown by considerable overlap of samples (Figure 33).

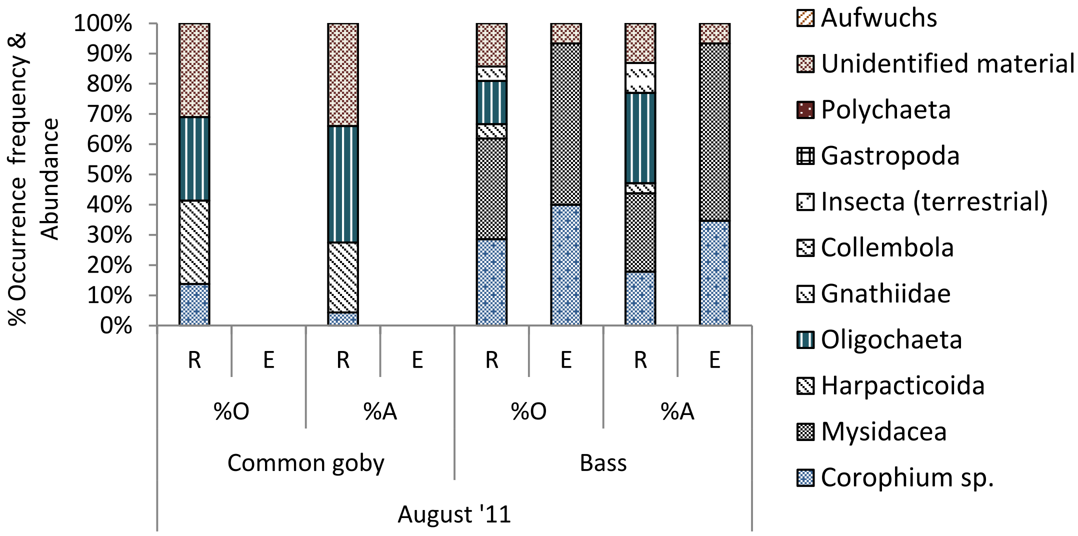


Figure 32. Frequency of occurrence (%O) and relative abundance (%A) of prey taxa found in common goby and bass caught from the realignment (R) and the Thames estuary (E), August 2011.

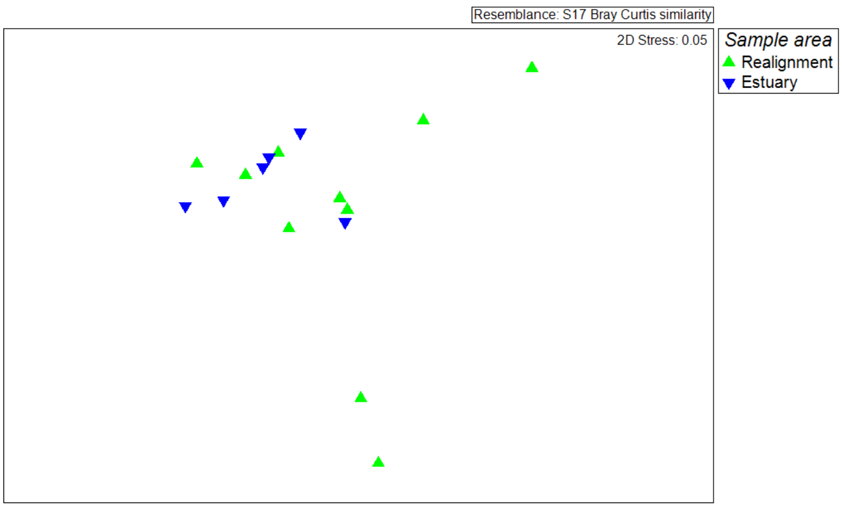


Figure 33. Non-metric multidimensional scaling plot showing similarities between diets of bass caught from the realignment and the Thames estuary, August 2011.

It was not possible to produce MDS plots for thin-lipped grey mullet and plaice as diet data were only gathered from the realignment due to a lack of sufficient samples in the estuary.

4 Discussion

Throughout the study there was a dominance of common goby, bass, flounder and thin-lipped grey mullet in the realignment and the Thames estuary, with common goby the most abundant species in both sites accounting for 91% of the total abundance in the realignment and 42% of the total abundance in the estuary. Common goby is considered an inshore benthic species that has a preference for sandy or muddy shallows in estuaries and salt marshes (Miller, 1986; Magnhagen, 1992; Leitão *et al*., 2005). As an estuarine resident species, common goby complete their life cycle within the estuary and are therefore heavily reliant on the habitats these ecosystems provide. Estuaries function as spawning habitat and also provide nursery habitats for common gobies. Consequently, the species is sensitive to the loss of intertidal mudflats and marshes (Cattrijsse and Hampel, 2000). Common goby is able to tolerate a wide range of salinities, although preferring lower levels, living on or in the substratum where it can tolerate low water levels and also avoid predation (Araújo *et al*., 1999; Colclough *et al*. 2005; Thacker, 2011). This species was found in both sites in abundance indicating that the realignment has successfully recreated suitable common goby habitat.

Dominance of a small number of fish species is a key feature of intertidal areas due to the limitations that the fluctuating physical and chemical elements impose; species inhabiting estuarine environments must be able to tolerate fluctuations in salinity, turbidity and temperature through the seasons (Haedrich, 1983). Conversely, the richness of nutrients and organic matter provided in estuaries provides support for large number of individuals (Gray, 2007). A large percentage of species recorded were marine-estuarine dependent and able to tolerate the pressures associated with inhabiting an estuarine environment (bass, thin-lipped grey mullet, flounder and plaice). The dominance of marine-estuarine species is likely related to the location of the sampling site <30 km to the mouth of the estuary where salinity ranged to a maximum average of 23 during the flood tides. These species do not spend their entire life in estuaries, but spend at least one stage of their life cycle utilising estuarine habitats, for example for spawning grounds, nursery grounds for juveniles or as a feeding ground for adult fish (Claridge *et al*., 1986). Colclough *et al*. (2002) assessed spatial and temporal trends in the distribution and community structure of the fish species present from Richmond to West Thurrock on the Thames estuary. Results showed that thin-lipped grey mullet and flounder dominated the lower estuary downstream of West Thurrock (15 km upstream of the realignment site), and bass and gobies dominated upstream during the late summer months, mirroring the dominating species of this study. Colclough *et al*. (2002) also observed that common goby and bass fry appeared from June, approximately the same time juveniles were observed in this study.

Species composition in the realignment reflected that of the Thames estuary. Out of the 15 species recorded overall, 13 were found in the realignment and 11 in the estuary suggesting the realignment site is recreating habitat similar to the estuary to support a variety of species. The observation of higher species richness in the realignment can be accounted for by the wider habitat heterogeneity present in the realignment site. Colclough, *et al*. (2005) found a positive relationship between fish utilization and habitat heterogeneity when studying the Thames estuary and the Blackwater estuary. Gray *et al*. (2002) revealed a significant ecological response to a managed realignment in the Salmon River estuary, Oregon, within the first two to three years when studying fish and invertebrates. However, Tupper and Able (2000) suggested that it takes between 12 and 21 years for full ecosystem functioning to be achieved in terms of habitat use, tidal circulation and diet composition. A total of 13 species were found to be utilising the realignment site, flounder and bass were found in abundance and evidence of common goby spawning and recruitment was documented on the site, reflecting the results of this study. Unfortunately no evidence of flatfish recruitment was seen in the realignment, indicating prime nursery functioning may have been lost for sole and flounder. Colclough *et al*. (2005) demonstrated a positive relationship between a realignment and fish utilisation at Abbots Hall on the Thames estuary, which showed the sites were well utilised particularly by juvenile fishes three years after the realignment was breached. However other studies have shown that successful progression is not always the case. A study by Mazik (2010) noted that a managed realignment in the Humber estuary, UK did not progress as hoped and abundance and diversity was still significantly lower in the realignment site 36 months after site construction, even though species composition and community biomass were similar. In another study by Evans *et al*, (1998) on the Tees estuary, UK, it was found that after three years, the managed realignment site was still was not considered to be developed in terms of abundance and significant establishment did not occur.

The peak of the common goby breeding season ranges from May to August in the UK, with both sexes spawning repeatedly throughout the season (Jones and Miller, 1966; Fouda and Miller, 1981; Magnhagen, 1992). Results from this study showed that recruitment occurred primarily before June 2011, when average length reduced to 7-13 mm in both sites from April-June 2011 caused by the appearance of a 0+ cohort. This demonstrates the importance of the realignment site as a nursery area for common goby. However, this is not to suggest that recruitment did not also occur earlier, as it can start earlier on a small scale in the UK (Fouda and Miller, 1981; Leitão *et al*., 2006). Small numbers of common goby were caught in April 2011, zero were caught by seine net in the estuary and only one in the realignment in April 2011, which was 35 mm and just reaching sexual maturity. Consequently it cannot be guaranteed that recruitment did not start earlier due to a low abundance of common goby inhabiting the sample area.

The largest abundance of common goby, one of the most abundant fish found along estuarine coasts in Europe (Gysels *et al*., 2004; Leitão *et al*., 2006) was recorded in November 2010. 15,514 common goby were logged in the realignment, of which the majority were between 30-40 mm in length. Contrary to the tidal predictions, only a small section of the site actually flooded due to strong westerly winds, eliminating the usual seine sites in the realignment and estuary, therefore samples were taken from a drainage ditch in the realignment. As a result, densities were substantially higher than normal and large numbers of fish were aggregated and caught. Probable reasoning for this are gobies, along with other small fish, swim up the ditches surrounding the realignment with the flood tide, and then diffusing across the realignment when the ditches over-flow. However, in November 2010 the ditches did not over-flow which left the fish concentrated in the ditch, resulting in the larger than usual catches. Semi-permanent bodies of water, such as the ditches surrounding the realignment have been shown to support greater species richness by offering food and refuge at low tide over each tidal cycle (Colclough *et al*., 2005). They also provide an additional habitat formation of deeper water, encouraging larger fish into the area without such extensive risk of predation. It would be beneficial to perform seine and fyke net sampling in the realignment ditches on a monthly basis, in addition to existing sample sites to assess the fish utilisation of the ditches comprehensively and better understand the advantages associated with semi-permanent water bodies. Unfortunately, an embryonic creek system was never implemented into the design of the realignment site, and the ditches do not connect to the wider estuary. As a result, fish strandings have been observed (Colclough pers. obs), over time a creek system will develop in the realignment site at which point the drainage ditches would become part of the migratory creek system. At this point, it would be valuable to perform further studies to look into which fish species are utilizing the migratory route.

Bass were also caught in abundance in both the Thames estuary and the realignment site, particularly in August 2011 when an abundance of juveniles were documented. They are known to be heavily dependent on estuaries in their early years for growth, prey availability and shallow creeks (Kelley, 1988). Kelley (1988) documented the potential impacts of removing bass habitat from estuarine waters as a result of human-related interaction and recognized the importance of bass in estuaries on an ecological and commercial scale. Effects included, among others, impeding bass recruitment and growth retardation. By introducing a managed realignment into the Thames estuary, it is anticipated that the effects of estuarine habitat removal will be mitigated, on condition that that the managed realignment continues to provide suitable habitat. During this study bass utilized the shallower habitats in seine catches, as well as the deeper waters in fyke catches in the realignment site and estuary.

Although not significant, there was a consistently higher abundance of bass caught by seine and fyke in the realignment than in the estuary site. Possible reasons for a higher abundance in the realignment are predator avoidance from larger piscivorous fish, in addition to higher food availability (Colclough *et al*., 2005), including an abundance of common goby providing a food resource. Colclough *et al*. (2005) also noted that bass was one of the most abundant species captured in a realignment site on the Thames estuary, supporting the results of this study.

A wider variety of shelter was available in the realignment, particularly in the ditches around the edge of the site which consisted of rocks, shallows and vegetation patches. It is possible that, like common goby, bass utilises the ditches surrounding the realignment as a means of entering the site on the flood tide, dispersing onto the realignment plain when they overflow. Since the fyke nets were situated relatively close to the ditches in the realignment, when the water over-flows, the fish have a higher probability of being captured in the nets. Comparatively, there are no ditches in the estuary for this behaviour to occur. The higher abundance in the realignment may suggest that bass are utilising the ditches in preference to the habitat in the Thames estuary as there were consistently more bass caught in the realignment site.

The phenomenon of piscivorous fish avoiding shallower areas has been shown to change at night, when reduced visibility reduces predation risk and fish utilisation increases (Morrison *et al*., 2002; Colclough *et al*., 2005; Copp and Jurajda, 2005; Grey, 2007). Colclough *et al*. (2005) reported a significantly higher presence of large bass at night compared with during the day, when water depth allowed. This was explained by saltmarsh habitats being too shallow for large piscivorous fish to enter during the day to feed because of the risk of stranding or predation by birds. By contrast, fyke results found reduced utilisation of the in-shore habitats overnight, particularly by the piscivorous bass and flounder, with the exception of August 2011 when there was a higher fyke catch in the estuary overnight compared with during the day. A possible explanation for the overnight reduction in larger fish is prey abundance may have reduced overnight in the locations sampled (Grecay and Targett, 1996). It is important to highlight that no seine or trawl samples were taken overnight, therefore it is not possible to determine utilisation of smaller fish or prey availability to larger piscivorous fish. Nocturnal seine samples would provide further information regarding overnight prey availability, and give some additional insight into the overnight reduction in large fish abundance. Gaelzer (2008) observed diel differences in species richness and diversity in Cabo Frio, Brazil can be caused by species moving to other areas during darkness to feed as a protection measure. Other possible reasoning for apparent reduced fish utilisation overnight could be due to gear avoidance (Gaelzer, 2008); although to what degree this may have contributed is unknown and further data would be required to investigate this further. Observations of eels in both the Thames estuary and realignment site were encouraging as they are listed as 'critically endangered' on the IUCN red list of threatened species, therefore it is positive to document this species inhabiting a realignment site, indicating that the habitat is recreating that of the estuary.

Temperature can have strong influences on fish survival, with warm waters during spring and summer months of the first year of life generally resulting in a strong year-class. This is because growth rates generally increase alongside increasing temperature, especially when fish are young (Gliwicz, 1994; Nunn *et al*., 2007; Handeland *et al*., 2008). Larger individuals have increased chances of surviving predation, fish survival is positively correlated with growth and fish size, as foraging efficiency improves and predation risk decreases (Kelley, 1988; Gliwicz, 1994; Russell *et al*., 1996). Optimal temperatures may change as the fish ages and increases in size, with adults preferring cooler temperatures than juveniles. However, it is usually the case that optimal temperature is higher than the individuals' habitat offers, therefore to maximise survival and fitness, food utilization is a more important trait (Handeland *et al*., 2008). High abundance of >0-group common goby (15-25 mm) and >0-group bass (30-60 mm) were found in the Thames estuary and the realignment in August 2011, indicating that 2010 may have provided the conditions needed to support a strong year-class determining recruitment into British coastal waters (Russell *et al*., 1996; Gray, 2007). Monthly seine samples alongside environmental surveys of temperature would allow a thorough analysis of the effects of temperature on growth and abundance of juvenile bass and common goby.

The realignment had a range of substrata, including rocks and mud, providing protection against flow (McHugh, 1966) and refuge from predation (Attrill, 1998; O'Brien *et al*., 2000), perhaps partly explaining why there was a higher density of fish in the realignment site than the estuary. Despite the differences in habitat, few differences were noted in diet composition between the Thames estuary and the realignment over the course of the study, suggesting that the realignment site is recreating the estuary in terms of prey taxa range. Estuaries provide an important and diverse range of food availability (Russell *et al*., 1996) and bass are known as opportunistic feeders (Laffaille *et al*., 2001). Those of <30 mm generally had a narrow diet of two or fewer prey taxa on average in both the Thames estuary and the realignment (samples used for gut analysis ranged from 17-54 mm). In total, five prey taxa were found during the gut analysis of all bass sampled (*Corophium* sp., Mysidacea, Oligochaeta, Gnathiidae and Harpacticoida). This is supported by Fonseca *et al*. (2011) who compared managed realignment sites to established saltmarsh sites in terms of the feeding habits of 0-group bass in the Blackwater Estuary, S.E. England. Fonseca *et al*. (2011) found that diet consisted predominantly of Harpacticoida, also that bass of <30 mm and >60 mm had a narrower diet than of those of between 30-60 mm. The results of the current study support Fonseca *et al*. (2011), as >30 mm bass had a larger range of prey in the gut on average than those <30 mm in the estuary. For this study it was not possible to analyse the diet of bass >60 mm, as none were caught in the seine nets in the realignment or the Thames estuary. Fish caught by fyke were not used for conducting diet analysis as they could have been in the net, not eating but digesting any food already in the gut for numerous hours before analysis could have taken place, therefore leading to misrepresentation of the diets of >60 mm bass.

There was a shift in dietary prey dominance for common goby from April-August 2011 for fish from the realignment. *Corophium* sp*.* was the dominant prey in April 2011, which shifted to a dominance of Harpacticoida and *Corophium* sp. in June and then Oligochaeta in August. Zloch *et al*. (2005) noted the feeding intensity of common goby was higher in April, June and August between 2001 and 2003, explained by warmer temperatures and less metabolic cost. There was a higher abundance of juvenile common goby in June in the realignment when length ranged from 9-16 mm (n = 86), compared with April (28-46 mm (n = 58)) and August (10-24 mm (n = 32)). Gee (1987) documented the significance of Harpacticoida for common goby found in mudflats and found that they were particularly important in the juvenile stages due to their high energy content.

Diet can depend on a range of factors usually dictated by prey availability. Observed changes in diet composition may be a result of seasonal changes in prey availability and ontogenetic shifts in preferred prey. Seasonal changes in diet is common place for common goby as documented by Salgado *et al*. (2004), who found that amphipods, copepods, isopods and polychaetes were preferred prey in the upper Tagus estuary, Portugal. Amphipods and polychaetes were found to be favoured in spring and oligochaetes and isopods being important in summer months, mirroring the results of this study where amphipods were dominant in April and oligochaetes dominant in August.

High densities of Harpacticoida and *Corophium* sp. have generally been found to occur through the summer months (Schizas and Shirley, 1996), potentially explaining the high numbers found in diets of common goby, plaice and bass in June and August 2011. *Corophium* sp. generally begin to reproduce at the start of the summer, increasing their abundance dramatically. The diet change witnessed in common goby from *Corophium* sp. in April 2011 to Harpacticoida in June 2011 to a combination of Harpacticoida and Oligochaeta in August 2011 could be explained by the optimal foraging theory which predicts that predators select their prey to exploit the maximum potential energetic gain (Brown, 1988; Gill and Hart, 1994). This theory is based on the assumption that there is density dependant competition for food. Also, that the individuals behaviour while foraging may determine its contribution to the next generation, through a hereditary component of foraging a particular way (Pyke, 1984). These assumptions attempt to predict the behaviour of an animal while it is foraging, but this method is often more risky due to predation risk that increases with the amount of time the individual spends foraging, therefore the individual must decide whether it is beneficial to aim for the prey with the highest certainty of capture (Pyke, 1984; Brown, 1988; Gill and Hart, 1994). Magnhagen and Wiederholm (1982) observed that common goby consumed *Corophium* sp. more than any other prey species, even when it was not the most abundant species in the vicinity. However when offered either *Corophium* sp. or chironomid larvae under laboratory conditions, common goby chose to ingest the closest mobile prey, providing a possible explanation for the dietary change witnessed in the Thames estuary and realignment. Prey profitability can be increased by eating high energy prey, reducing the time taken to obtain the prey and reduce the costs associated with obtaining the prey item. Therefore it is possible that the change in diet for common goby was a result of the individuals maximising on prey profitability.

The mean length of common goby was 37 mm in the realignment in April 2011, which dropped to 14 mm in the realignment and 13 mm in the estuary in June, suggesting that diet variance may be linked to fish size. However, Salgado *et al*. (2004) showed there was no correlation between diet composition and fish size for common goby, but they noted a positive correlation was in the diets of sand goby. The study conducted by Saldago *et al*. (2004) was conducted in Portugal; therefore differences in latitude may be an implicating factor in the differences between this study and that of Saldago *et al*. (2004). As a result, further investigation into the relationship between diet composition and fish length is required through monthly seine samples and an increase in the number of fish used for diet analysis.

June 2011 was the only month when a dietary comparison was possible for common goby between the Thames estuary and the realignment. Fish from the realignment had a prey dominance of Harpacticoida and a higher taxonomic richness than the Thames estuary where *Corophium* sp. dominated the gut contents, closely followed by Harpacticoida. This could indicate that there was a wider variety of prey available to common goby in the Thames estuary, which was not yet as readily available in the realignment. *Corophium* sp. is generally found in shallow water with a muddy substratum and frequently between tidemarks and is increasingly abundant in summer months (Crawford, 1937); it is possible the substratum in the realignment may not yet be as preferable as that of the well-established estuary. Alternatively, it may suggest that Harpacticoida, that reaches peak numbers through the summer months, was potentially more abundant in the realignment than the estuary. If preferred prey was not as abundant in the estuary, then common goby would utilize the optimal foraging theory and seek out alternative prey that provides the highest net intake of energy, resulting in an increase in prey diversity (Magnhagen and Wiederholm, 1982; Brown, 1988)

Existing realignment schemes have received positive results. Along with supporting results by Colclough *et al*. (2005), a site in the Humber Estuary was breached in 2003 and invertebrate colonisation was monitored by Mazik *et al.* (2007). Comparisons were made between the newly breached realignment site and the existing Humber mudflats. Findings showed that although there were some similarities between sites in terms of species composition and community biomass, abundance and diversity still remain significantly lower in the realignment site compared to the Humber estuary 36 months after initial site construction (Mazik *et al.,* 2010). As of April 2012 when the last samples were taken for this study, it was two years since initial site construction; therefore it is still too early to say whether the site has been a complete success. Initially it appears that fish utilization is occurring on the realignment site despite the lack of an embryonic creek system that will hopefully develop over time.

4.1 Conclusions

Comparisons between the Thames estuary and the managed realignment sites found many similarities between the two sites in terms of fish species composition, density/CPUE, size structure and diet composition. Common goby and bass consistently dominated in both sites. With the exception of thin-lipped grey mullet that had a dominance of aufwuchs in the diet, Harpacticoida was the dominant prey type for common goby, bass and plaice in both sites, closely followed by *Corophium* sp. and Mysidacea. Species richness and density were similar in both sites, although CPUE was similar, it was higher in the realignment in >50% of the sample months. **The results therefore mostly support the hypothesis that 'fish species composition,**

density/CPUE, size structure and diet composition in the managed realignment site would reflect that in the Thames estuary', with the exception of CPUE. Further investigation into fish utilisation of the realignment with regards to CPUE would be beneficial to further assess the relationship between the realignment and the Thames estuary.

4.2 Recommendations

Although diet composition was similar in the realignment and estuary, the data were not extensive. There was only two occasions where a sufficient number of individuals were caught in both sites to allow a comparison of diet between sites. **It is recommended that zooplankton and benthic invertebrate studies be carried out concurrently with the fish surveys to understand better the influence of potential differences in food availability between sites on the foraging ecology of fishes**. Although diet composition was largely similar in both locations, energy intake may differ greatly. Therefore **it would be beneficial to analyse abundance and size of prey eaten by fishes in the two habitats and relate it to the amount of energy provided by each food item**.

To assess thoroughly the long-term dynamics involved in the development of the managed realignment, **sediment testing should be implemented to analyse particle size and sediment composition (%)**. In addition, **macroinvertebrate and bird surveys would be beneficial to understand better the wider environmental effects of creating a managed realignment in the Thames estuary** by providing understanding of the ecological capacity of the re-created site, and additional assessment into whether the realignment is developing into a habitat reflecting that of the estuary. In this study there were gaps in the data set throughout winter that prevented some comparisons. For example October and November data were only taken in 2010, in addition, a larger sampling effort was experienced in the realignment compared to the Thames estuary**. Consistent data collection in both sites over a longer timescale would be beneficial in producing a larger data set to analysis species composition, size structure, density/CPUE and diet analysis**. Since this study was completed, there have been further capital dredges implemented on the realignment site, resulting in site disturbance. Ongoing studies on this site would allow review of what effect the dredges have had on the site and allow analysis of how the site is progressing as a nursery function once dredging is complete. With the addition of these recommendations this study could be improved and expanded to further our understanding of managed realignment sites.

Appendix 1

Code	Description
ES	Thames estuary seine net (25 m long by 3 m deep with 3 mm hexagonal mesh).
EF	Thames estuary fyke net (double-fyke assembly consisting of two fyke nets (53 cm entrance, 10 m central panel and 14 mm mesh) connected at both entrances by their leader panels).
RS	Managed realignment seine net (25 m long by 3 m deep with 3 mm hexagonal mesh).
RF	Managed realignment fyke net (double-fyke assembly consisting of two fyke nets (53 cm entrance, 10 m central panel and 14 mm mesh) connected at both entrances by their leader panels).
RT	Managed realignment trawl net (1 m wide epibenthic sledge with a 0.5 mm cod-end (Nitex cloth), supported by wide skids with a firm steel rod 2-4 cm above the skids).

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