Great Yarmouth Third River Crossing

Application for Development Consent Order

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Great Yarmouth Third River Crossing — Benthic Survey

WSP

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2.0	28/03/2019	3.1.4	5	Opening paragraph added to detail consultations on survey design	CA
2.0	28/03/2019	3.1.6	5	Changes made to clarify how constraints were mitigated	CA
2.0	28/03/2019	3.1.10	9	Changes made to explain that the delay to sample sieving is unlikely to have any effect on the sample integrity	CA
2.0	08/04/2019	3.1.3	3	Potential for R02 to fall within the impact area discussed.	CA
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2.0	08/04/2019	All	All	Review of all changes made under v2.0	DH

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1. Executive Summary

The biology of a section of the Yare estuary, downstream of Great Yarmouth was characterized by an environmental survey, completed in January 2019, as part of an environmental impact assessment for a proposed crossing (the Scheme). The survey included *in situ* records, grab samples, wall scrapes, quadrats and trawls.

The habitats in the footprint of the Scheme comprised a narrow marine inlet bounded by artificial walls, with shallow clay and mixed sediment in the bed of the inlet. The mid intertidal region of the walls was colonised by fucoid barnacle mosaics typical of moderate exposure shores. The subtidal sediments included oligochaete and cirratulid communities of varying richness, grading into mixed substratum habitats with barnacles and other epibiota.

Trawl samples recorded mainly brown shrimp, with lower numbers of gobies, shore crabs and mysids and occasional commercially important flatfish. No rare or declining species were found.

Several non-native species were recorded, including large numbers of the barnacle *Austrominius modestus* and a northward range extension for the Manila clam (*Ruditapes philippinarum*).

It is recommended that the Scheme ensures that there is no restriction of passage for migratory fish and that care is taken to avoid transport of sediment and other materials, which may assist the spread of non-native species, from the site to areas outside the estuary.

2. Introduction

2.1 Background

APEM Ltd. was commissioned to undertake a series of marine ecology site characterisation surveys to provide a robust dataset to inform an Environmental Impact Assessment for proposed infrastructure developments at Great Yarmouth. This report presents intertidal and subtidal environmental data obtained from the survey conducted in January 2019.

2.2 Survey objectives

The primary objective of the survey was to provide a robust biological baseline data set and to characterise the subtidal and intertidal benthic communities in the region of the River Yare that may be impacted by the developments. Data on certain physicochemical parameters were also collected in order to help interpret the biological communities but contaminant data were not acquired as these were collected under a different element of the overall scope of works associated with the Scheme. Surveys were conducted using industry standard, repeatable methodologies to ensure comparability with studies elsewhere or future studies in the region. Benthic macrobiota communities were assessed through grab sampling, whilst larger epibenthic invertebrates and fish were assessed from trawl samples. Intertidal fouling communities on the walls were examined through quadrats and wall scrape samples. Samples were analysed to provide data on the flora and fauna, sediment types and habitats within the study area.

3. Methodology

3.1 Survey methods

3.1.1 Health and Safety

Prior to mobilisation, APEM reviewed the Health & Safety (H&S) requirements of the benthic ecology surveys for the Scheme in conjunction with the vessel suppliers. Appropriate Risk Assessments were undertaken and accompanying method statements were produced prior to commencement of the surveys. All survey staff were made aware of the Risk Assessments, appropriate PPE, COSHH forms, incident handling and reporting procedures, responsibilities, contact details and staff details, including training and certification. A Dynamic Field Risk Assessment form was used to update risks as necessary throughout the survey. The purpose of the Dynamic Risk Assessment form was to cover any risks perceived on-site that were not covered by the original assessment or that had been introduced since the production of the assessment (e.g. due to changes in weather conditions). For this survey this included covering the additional risks of the snow that occurred during the survey period.

At the start of each working day, a Tool-Box Talk was held in which details of the day's survey operations were discussed and Health and Safety aspects reiterated, including any information that introduced additional H&S concerns for that day (e.g. weather conditions, passing vessels, access to wall, trawl and grab haulage). At the end of the survey day, a wrap up meeting was also held during which any issues encountered could be highlighted and discussed. All surveyors had the power to issue a 'Stop the Job' order if they deemed that continued operations may introduce a H&S risk. Surveyors were likewise encouraged to highlight any concerns to the ship's captain or other qualified person at the earliest opportunity.

3.1.2 Biosecurity

The potential for spreading non-native species was assessed in the risk assessment for this work and suggested biosecurity measures were implemented following this review.

Rigorous biosecurity measures were employed throughout the survey work. All survey equipment had been cleaned and thoroughly dried following its previous use. Prior to deployment in this survey, it was checked to ensure that it was clean. Following use in this survey, it was likewise cleaned and left to dry.

At each wall sampling site, the community was assessed prior to sampling to investigate the potential presence of non-native species. When the wall samples were taken, particular care was taken to ensure that these were taken in such a manner that they did not pose a risk of accidental spread (e.g. through fragmentation of macroalgae).

3.1.3 Survey design

To establish a comprehensive baseline, sampling was undertaken in all major habitats present within the immediate footprint of the Scheme.

In order to sample benthic communities and sediments, six benthic grab stations were established in the primary impact area for the Scheme. These impact stations were termed G01-G06. For comparative purposes, two reference grab stations were also established (RG01 and RG02), one upstream and one downstream of the Scheme, respectively.

The wall fouling communities were assessed at four stations within the primary impact area (S01-S04) and two reference sites (RS01 and RS02). The walls were assessed at upper shore level in the algal zone.

To gain an understanding of the potential use of the estuary by fish and of epifaunal invertebrates, four trawl stations were established: two parallel trawls within the primary impact area, and two reference sites, one upstream and one downstream of The Scheme.

The distribution of sampling stations is shown in Figure 1, with further detail of those in the primary impact area shown in Figure 6. All sampling positions are provided in Appendix 2 .

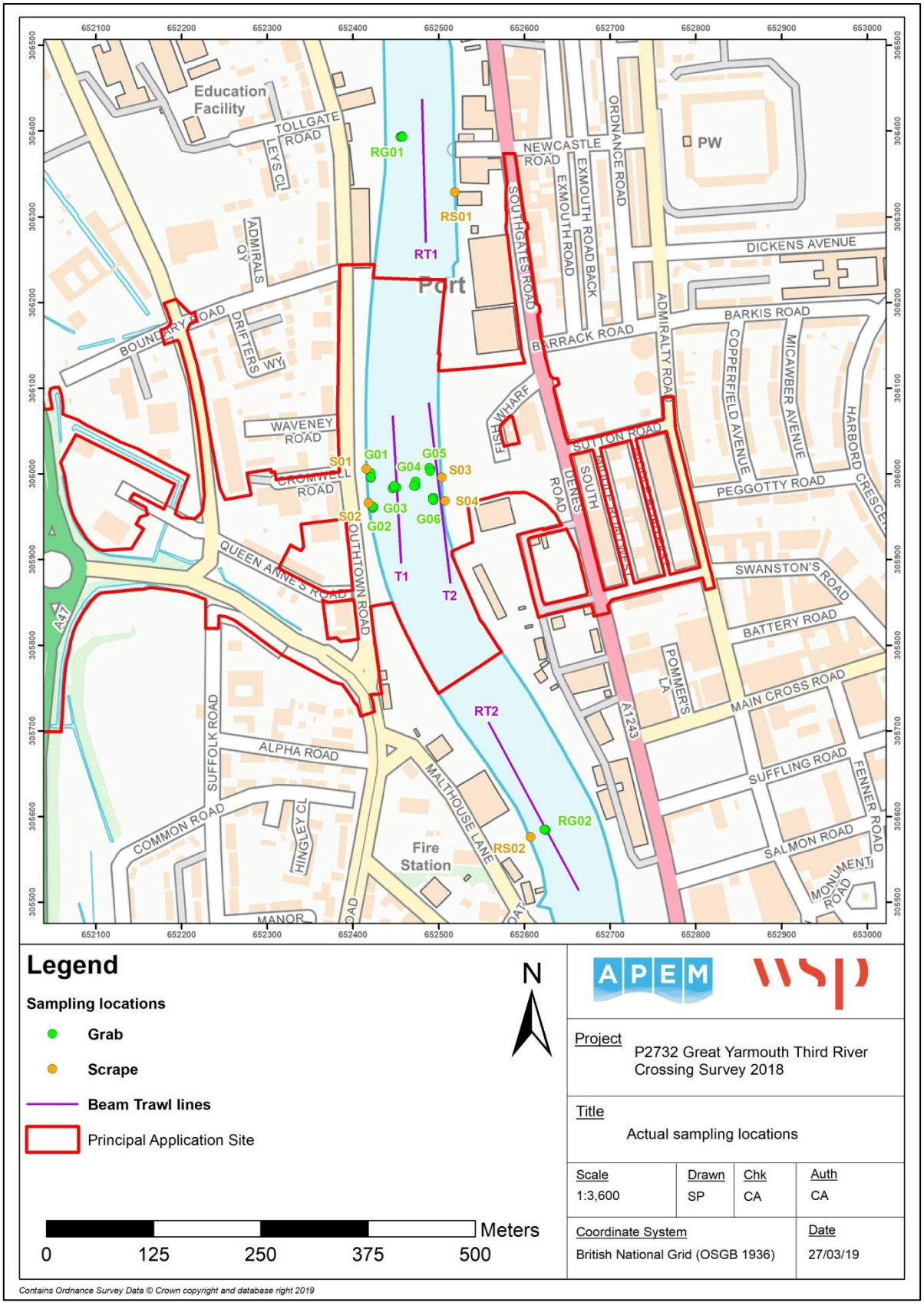

Figure 1. Distribution of all sampling stations at Great Yarmouth

3.1.4 Survey permissions and notifications

Prior to the survey the Environment Agency (EA), Natural England (NE) and the Marine Management Organisation (MMO) were consulted over the proposed survey design and sampling methodologies. Comments received by them were incorporated into the sampling design or field protocols where necessary.

A number of permissions and notifications were required before sampling occurred.

A dispensation for the use of an undersized trawl mesh (for Council Regulation 850/98 use of undersized nets) and for the retention of undersized fish was obtained from the Marine Management Organisation (MMO) and a letter of derogation was obtained from the Eastern Inshore Fisheries Commission (Eastern IFCA). As a condition of their agreement, the Eastern IFCA requested that a copy of the trawl data be made available to them. An FR2 form (application for authorisation to use fishing instruments other than rod and line in England) was also submitted to the Environment Agency (EA), although, since the trawl sampling was not intending to catch any freshwater fish this was regarded by the EA as for notification only. The benthic sampling works were exempt from a MMO Marine Licence.

Notification was made to the Statutory Harbour Authority (Peel Ports) prior to the survey; they issued and disseminated a Notice to Mariners detailing the planned survey activities.

3.1.5 Survey timings

The survey was conducted on 30th and 31st January 2019. These dates were chosen to coincide with vessel availability and suitable neap tides, providing increased duration of slack water in an effort to minimise the impact of water currents on the sampling operations (see also Section 3.1.6 – Survey constraints). The tide times for each survey day are provided in Table 1 below.

Table 1. Tide times for the survey dates

Date	Time (GMT)	Tidal Height (m)
30/01/2019	04:24	4.48
	10:57	1.04
	17:17	2.29
	23:22	1.26
31/01/2019	05:40	2.47
	12:05	1.09
	18:19	2.36
	-	-

3.1.6 Survey constraints

The main constraints of the surveys related to the tides which had the potential to affect the surveys in three main ways.

Since the river channel is highly modified and there is a large amount of freshwater flow, the water currents in the channel are very strong. This had the potential to drag the grab during deployment which could mean it wouldn't strike the riverbed squarely, leading to inadequate

samples or a misfire. To mitigate this and maximise the potential for the survey to be successful, the survey was scheduled for neap tides when the effect of the tide is minimised. However, grab sampling could only be undertaken in the period around slack water, which, in the River Yare, lasts for around 1-1.5 hours either side of the turn of the tide and lasts slightly longer on low tides than high tides due to the water flowing downstream resisting the incoming water. Once the grab started to drift during deployment, sampling was paused until the next slack water period.

Secondly, the strong currents prevent the build-up of finer sediments meaning it was necessary to use a Hamon grab for sampling, which in turn affected the ultimate choice of vessel for the work.

Finally. the tides also limited the period in which wall sampling was possible since the required mid-upper 'shore' level is not permanently accessible.

Prior to the survey, APEM confirmed with the Harbour Master that no vessels had been berthed at any of the berths that required access for wall sampling, or in positions that may have impacted the positioning of grab samples.

On two occasions it was necessary to pause survey operations for a period of approximately 10 minutes each to allow other vessels to pass. During these periods, the survey vessel pulled to the side of the river channel to allow uninterrupted passage by the other vessels.

3.1.7 Survey vessel and position fixing

All survey work was undertaken from the MV Sheerkhan (Figure 2) which is based in Great Yarmouth and owned and operated by Technical Marine Services Ltd.

MV Sheerkhan is a 17.5 m survey vessel with a 45 square meter deck and is classified by the UK Maritime Coastguard Authority to work up to 60 nautical miles offshore (MCA workboat code category 2). She is fitted with a Braden 15 tonne handling winch, a Spencer Carter 1 tonne split trawl winch and a Bonfiglioli 24t/m crane.

Figure 2. The survey vessel MV Sheerkhan used for the survey work. (Image reproduced by kind permission of Technical Marine Services Ltd. ©Technical Marine Services)

To calibrate the onboard dGPS system of the Sheerkhan, readings were compared to a known Ordnance Survey point, to ensure accuracy, and were calibrated in the harbour before leaving.

In order to record the position of the grab being deployed and not the vessel, the offset position of the grab was calculated before leaving port from the dGPS antenna on the wheelhouse bridge to the end of the crane arm when the grab was deployed. A heading output was derived from the dGPS system that provides vessel orientation and the deployment position is calculated using simple trigonometry in real-time at 10Hz using Trimble HydroPRO software. The grab target positions were entered into the dGPS system prior to mobilisation and the vessel (end of crane arm) was steered to these pre-programmed sample positions.

Although there was potential for any non-perpendicularity within the water column from the vessel to affect the actual position of the grab, if this was too great then the grab would not land square with the seabed and would not obtain a valid sample. Furthermore, within the confines of outer channel of the River Yare at Great Yarmouth the water depths are so shallow that the grab did not have the opportunity to drift much. Any deviation from the recorded sampling position was therefore regarded as minimal.

Trawls were deployed over the bow of the vessel using the crane and positions were calculated using a layback technique to work out the position of the trawl relative to the vessel. The position of the trawl was recorded as the start position once it made contact with the seabed and then an end position was recorded once the required distance had been covered and the trawl left the seabed.

3.1.8 Survey staff

Since the tidal conditions in the River Yare limit sampling windows to slack waters and neap tides, a decision was made to deploy additional survey staff than would normally be required for this work. APEM provided two experienced survey staff both of whom were able to act in a 'survey lead' capacity. Technical Marine Services supplied the skipper, a deck hand and a winch operator and CMS-Geotech provided a further deck hand and a hydrographic surveyor who was responsible for position fixing and calculating offset positions. This approach meant that the sampling could be achieved within a tighter survey window (see also Section 3.1.6 Survey Constraints and Section 3.1.10 Grab sampling methods).

3.1.9 Wall sampling methods

The term wall is used here to refer to the boundary of the river channel and refers to any hard substrata including any man-made vertical structures, such as wooden jetty pilings, sheet metal, concrete or brick walls.

At each station, the general community on the wall was photographed, visually described and large, easily identified animals and algae recorded. Three replicate quadrats were used to quantitatively record the macroalgal community and other fouling taxa present. Three wall scrape samples were collected from the algal zone, according to the layout in Figure 3. , and their location recorded using a hand-held GPS in WGS84 format.

At each wall scrape sampling station, a 0.01 m^2 sample was obtained of the biotic community at approximately mid tide level, in accordance with the methodologies described by Worsfold (1998).

Using a 0.01 m^2 sampling device (Figure 4), marine growth was scraped into a bag. Samples were not sieved on board but were transferred to an appropriate container and fixed with 4% buffered formaldehyde solution in seawater. Samples were sieved on return to the laboratory over a 0.5 mm sieve.

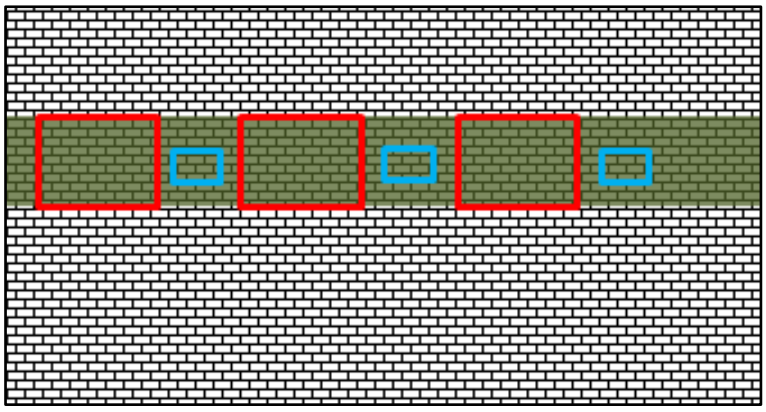

Figure 3. Example section of harbour wall indicating how the quadrat (red squares) and wall scrape samples (blue) were positioned at each station within the algal zone

Figure 4. APEM's wall scrape sampling device

3.1.10 Grab sampling methods

At each grab station, three replicate grab samples were obtained for biological analysis and an additional replicate collected for total organic carbon (TOC) and particle size analysis (PSA) (WFD UKTAG 2014).

All samples were assessed on retrieval for suitability according to standard criteria detailed in Davies *et al*. (2001) and Ware & Kenny (2011). Two grab attempts were rejected at station RG02, one due to a large cobble preventing complete closure of the jaws and the second due to insufficient volume of sediment. The third repeat attempt resulted in a successful sample. All sampling attempts at the other stations were successful.

A station log sheet was maintained providing information on all sampling attempts at each station. For each sampling attempt, the following information was recorded:

- Station number and attempt;
- Volume of the sample;
- Sample position;
- Sample description (visual assessment, with additional notes on smell etc.);
- Time of collection;
- Any obvious or notable taxa observed (e.g. Annex II species);
- Photograph of the unsieved sample.

To partially mitigate the tidal window restrictions a decision was made to not sieve the samples immediately after collection. Instead, each sample was emptied into a large, lidded crate, assessed for suitability, labelled and secured. This meant that the grab could be immediately redeployed to continue the sampling sequence and make best use of the available slack water. Samples were sieved in the periods of the tide when sampling was not possible; all were sieved on the day of collection. The Marine Monitoring Handbook (Davies *et al*., 2001) states

that sieving and preservation must be undertaken within 24 hours of sample collection. As all samples were sieved well within this time period and given the ambient temperature on the survey days (0-2°C) sample integrity was not considered compromised as a result of the delay to the sieving process. This was confirmed at analysis stage as all samples were in good condition with no evidence of degradation.

The entire retrieved grab sample was photographed prior to processing. For the PSA and TOC samples a subsample of 500-1000 ml was removed and transferred to a suitable container and the remainder of the sediment was discarded. For the macrobenthic samples field sample processing was conducted in accordance with the guidance provided in Cooper & Mason (2018), using the following steps.

1. Pour off excess water from the sample over the sieve table;
2. Photograph the sample (with identification label);
3. Measure the sample volume;
4. Wash and sieve the sample on the sieve table over a 0.5 mm mesh;
5. Transfer material to a suitable container and remove biota from the sieve mesh using forceps;
6. Preserve and label (internal and external) the sieved sample.

To facilitate sieving and to prevent damage to smaller, fragile animals, a coarse mesh sieve (5.0 mm) was used above the 0.5 mm sieve to remove any larger material.

All material retained on the sieves was fixed with 4% buffered formaldehyde solution in seawater and placed in sample containers (labelled inside and outside), following guidance in Ware & Kenny (2011) and Davies *et al.* (2001). Once the sieved sample was labelled and preserved, all apparatus and sieves were thoroughly cleaned to prevent cross-contamination before moving to the next station.

3.1.11 Trawl sampling methods

Trawl sampling was conducted at four stations, primarily to characterise larger or highly mobile epibenthos that may not be adequately sampled through grab sampling. The use of a 2m beam trawl may select against larger fish and pelagic species but for sampling epibenthos it is considered the most suitable method (Jennings *et al.*, 1999). To fully characterise fish communities, a larger trawl and regular surveys over an extended period would have been necessary, which were outside the scope of the current surveys. However, the limited fish data that were collected have also been used here.

Only start and end positions were recorded for the trawls and therefore, whilst the sampling location maps (Figure 1, Figure 6) show straight lines between these points, the actual trawl lines for samples T01 and T02 followed the curvature of the channel.

The catch of each trawl was placed into a calibrated container and the net was then checked for any remaining epibiota and fish. Sediment was rinsed away and the approximate total unsorted volume of the catch estimated. The samples were initially cleared of large debris and the total catch photographed. When there were large abundances of a particular species, subsampling was carried out for that species only. All other organisms were counted. Fish were sorted from invertebrates, divided into groups, identified to species level and counted. Fish and commercially important crustaceans were measured to the nearest millimetre using a fish board or callipers, according to the schematic below (Figure 5.).

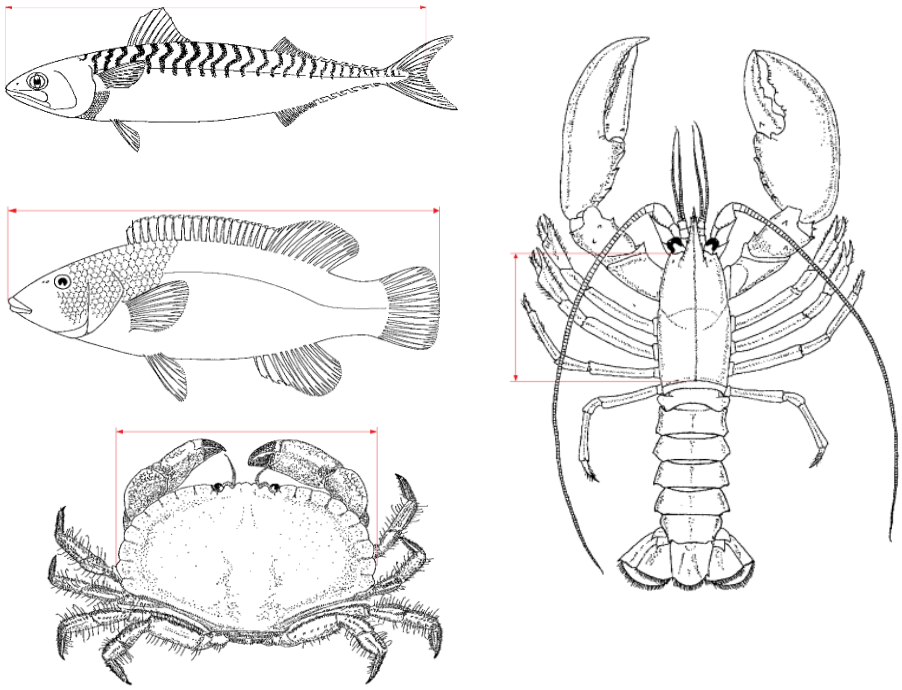

Figure 5. Schematic for points of measurement for concave tailed fish, convex tailed fish and commercially important crustacean species.

3.2 Laboratory methods

3.2.1 Biological samples

Samples were processed according to APEM's standard operating procedure for marine benthic sample analysis and in compliance with the North-east Atlantic Marine Biological Analytical Quality Control (NMBAQC) Scheme's Processing Requirement Protocol (Worsfold *et al.*, 2010).

Benthic grab and wall scrape samples were sieved in a fume cupboard over a 0.5mm mesh in accordance with WFD guidance for benthic sampling in transitional waters (WFD-UKTAG, 2014), to standardise the sizes of organisms. To improve sorting efficiency, the grab samples were also sieved through a stack of 4.0, 2.0, 1.0 and 0.5mm mesh sieves. All biota retained in the sieves were then extracted under low power microscopes, identified and enumerated, where applicable. Due to large volumes of sediment, the 0.5mm fractions were subsampled to ¼ by volume for samples G01A, G02A and G02C using a 'quarteriser' (Proudfoot *et al*., 2003).

Processing of larger species from trawl samples was conducted in the field but some specimens of taxonomically problematic taxa or those requiring microscopic identification were taken to the laboratory for confirmation or identification where required. Due to high volumes of brown shrimp (*Crangon crangon*) in trawls T01 and T02, ¼ subsamples were taken for counting and measurement of specimens. All *C. crangon* samples were returned to the laboratory to allow for accurate measurement and counting. In the laboratory, these trawl samples were also sieved through a stack of sieves with a base mesh of 1.0mm but, due to the mesh used on the trawl itself, the <4mm fractions can only be considered as qualitative.

Taxa were identified to the lowest practicable taxonomic level, using the appropriate literature (Worsfold *et al*., 2018). For certain taxonomic groups (e.g. nemerteans, nematodes, and certain oligochaetes), higher taxonomic levels were used due to the widely acknowledged lack of appropriate identification tools for these groups. Where required, specimens were also compared with material maintained within the laboratory reference collection. Fish and shrimp retained from the trawl samples were measured as described above using callipers. Nomenclature followed the World Register of Marine Species (WoRMS, 2019), except where more recent revisions were known to supersede WoRMS.

At least one lot of each taxon recorded from the surveys was set aside for inclusion in APEM's in-house reference collection. This collection acts as a permanent record of the biota recorded.

All samples were subject to internal quality assurance procedures, whereby the residues and identifications from each sample were secondarily checked by another analyst. To ensure consistency, taxonomic quality control throughout the project was conducted by the same individual. Following analysis, 10% of samples were subject to formal Analytical Quality Control (AQC) to produce pass/fail statistics.

3.2.2 Particle Size Analysis (PSA) and Total Organic Carbon (TOC)

PSA and TOC samples were analysed by Kenneth Pye Associates Limited (KPAL), in accordance with NMBAQC Guidelines for Particle Size Analysis (PSA) for Supporting Biological Analysis (Mason, 2016) to provide data over the complete particle size range allowing determination of the gravel to sand plus mud ratio. Samples were wet separated at 1.0mm to allow sieve analysis of the >1.0mm fractions; all material from the sub-1.0mm fraction was analysed via laser diffraction (size range 0.04µm to 1.0mm).

Total organic carbon (TOC) has been calculated as percentage loss on ignition (LOI). Analysis was performed on the <1 mm wet-separated fractions, which had been previously oven dried at 125 °C. Samples were then transferred to a muffle furnace and incinerated at 550°C for at least one hour, cooled in a desiccator and re-weighed. Data were converted from percentage loss on ignition to TOC using standard conversion factors (Broadbent, 1953).

3.3 Data analysis methods

3.3.1 Macrobiota

Calculation of univariate diversity indices (e.g. numbers of taxa, density, diversity, evenness) and multivariate analyses (e.g. Cluster Analysis, MDS), were carried out using PRIMER version 6.1.15 (Clarke & Warwick, 2001; Clarke & Gorley, 2006).

Before analysis, all data were checked for errors. Summary statistics were calculated and outlying values investigated to identify possible data transcription errors.

Univariate techniques

The DIVERSE component of Primer was used to calculate univariate statistics and diversity indices for each sample. In the interest of consistency, colonial taxa such as bryozoans and hydroids were included when calculating the total number of taxa, but excluded from calculating the total number of individuals and other diversity indices.

Biological diversity within a community was assessed based on taxon richness (total number of taxa present) and evenness (considers relative abundances of different taxa). The following metrics were calculated:

- **Taxon richness (*S*):** The total number of taxa in a sample.
- **Density (*N*):** The number of individuals per unit area (e.g. per square metre).
- **Shannon-Wiener Diversity Index (*H'*(log$_e$):** A widely used measure of diversity accounting for both the number of taxa present and the evenness of distribution of the taxa (Clarke & Warwick, 2001).
- **Margalef's species richness (*d*):** A measure of the number of species present for a given number of individuals.
- **Pielou's Evenness Index (*J'*):** A representation of the uniformity in distribution of individuals spread between species in a sample. The output range is from 0 to 1, with higher values indicating more evenness or more uniform distribution of individuals.
- **Simpson's Dominance Index (1-λ):** A dominance index derived from the probability of picking two individuals from a community at random that are from the same species. Simpson's dominance index ranges from 0 to 1, with higher values representing a more diverse community without dominant taxa.

Multivariate techniques

All multivariate analyses were carried out using PRIMER version 6.1.15 (Clarke & Warwick, 2001; Clarke & Gorley, 2006). Prior to calculation of Bray-Curtis similarity between macrobenthic samples, the data were square-root transformed to reduce right-skewness and down-weight the effects of a small number of numerically dominant taxa (Clarke & Warwick, 2001). The wall scrape data were predominantly composed of non-countable taxa such as algae and therefore, prior to multivariate analyses, the wall scrape abundance data were transformed to presence/absence and Jaccard similarity was used for analysis.

Cluster Analysis

Hierarchical clustering was carried out on a Bray-Curtis similarity matrix of the macrobenthic abundance data in order to visualise the biological similarity between samples. The hierarchical clustering technique compares the abundance of each taxon in each sample, with its abundance in each of the other samples. The result is a matrix of pairwise similarity indices comparing each sample with all other samples. This similarity matrix was then output diagrammatically as a dendrogram. The similarity profile (SIMPROF) test was carried out as part of the clustering routine. This permutational test distinguishes clusters of samples that cannot be statistically differentiated at the 5% significance level and identifies them on the resulting dendrogram using red lines. Black lines on the dendrogram denote samples that are statistically different from one-another at the 5% significance level.

For the wall scrape samples, the taxa were predominantly non-countable species and hierarchical cluster analysis was therefore carried out on a Jaccard similarity matrix calculated from presence/absence data.

Ordination Analyses using non-Metric Multidimensional Scaling

Non-metric multidimensional scaling (NMMDS) is an ordination method which creates a 2- or 3-dimensional 'map' or plot of the samples from the Primer resemblance matrix. The plot generated is a representation of the dissimilarity of the samples (or replicates), with distances between the replicates indicating the extent of the dissimilarity. For example, replicates that are more dissimilar are further apart on the MDS plot. No axes are present on MDS plots, as the scales and orientations of the plots are arbitrary in nature.

Each MDS plot provides a stress value which is a broad-scale indication of the usefulness of plots, with a general guide indicated below (Clarke & Warwick, 2001):

- <0.05 Almost perfect representation of rank similarities;
- 0.05 to <0.1 Good representation;
- 0.1 to <0.2 Still useful;
- 0.2 to <0.3 Should be treated with caution;
- >0.3 Little better than random points.

An MDS plot for the macrobenthic samples was created using the same Bray-Curtis similarity matrix as the hierarchical clustering process described above.

BEST Test

The BEST procedure was carried out on the macrobenthic sample data to test for any relationship between physical and biological data in the samples. This test calculates the measure of agreement between the macrobenthic Bray-Curtis similarity matrix used in the hierarchical clustering and MDS analyses and resemblance matrices generated from different variable subsets of a Euclidean distance matrix of physical variables (Clarke & Gorley, 2006). The results are presented as Spearman rank correlations (ρ).

As part of the routine, a permutational global BEST test was conducted to assess the significance of the results.

AZTI Marine Biotic Index (AMBI)

The AZTI Marine Biotic Index (AMBI) was designed to establish the ecological quality of European coasts (Borja *et al*., 2000) and has been used to assess disturbance with respect to several types of environmental impact, including dredging impacts and sand extraction (Muxika *et al*., 2005). The AMBI value is a biotic coefficient that is calculated with the following formula, based upon the relative proportions of five ecological groups (EG) to which the soft-sediment benthic species are allocated:

AMBI value = [(0 x % EGI) + (1.5 x % EGII) + (3x % EGIII) + (4.5 x % EGIV)

+ (6 x % EGV)]/100

Each species' Ecological Group is classified as below (Grall & Glémarec, 1997):

- EGI: very sensitive to organic enrichment and present under unpolluted conditions.
- EGII: indifferent to enrichment, always present in low densities with non-significant variations with time.
- EGIII: tolerant to excess organic matter enrichment; and may occur under normal

conditions; however, their populations are stimulated by organic enrichment.
- EGIV: Second-order opportunistic species, adapted to slight to pronounced unbalanced conditions.
- EGV: First-order opportunistic species, adapted to pronounced unbalanced situations.

The AMBI value can then be used to derive thresholds of site disturbance based upon the relative proportions each Ecological Groups present (Borja *et al*., 2000; Borja *et al*., 2003).

The mean AMBI value and resulting site disturbance classification calculations were made using AMBI version 5.0 (Borja *et al*., 2012) with the most up to date version of the species list (June 2017). Prior to importing the data into AMBI, some data truncation was required, including the removal of taxa considered as non-soft sediment/non-benthic, epifauna, non-invertebrate taxa and higher taxonomic levels not included in the AMBI species list, as recommended by Borja & Muxika (2005). Full data truncation details are included in Appendix 1 .

3.3.2 Particle Size Analysis

The laser and sieve data were mathematically merged to produce sediment classifications, following Folk (1954) and Blott & Pye (2012) and calculations of particle size summary parameters (percentages of mud, sand, and gravel, silt/clay ratio, sand/mud ratio, mean particle size, sorting, skewness and kurtosis, d10, d90) calculated using GRADISTAT software (Blott & Pye, 2001).

3.3.3 Biotope allocation

The data were further examined to determine the characteristic biota for each sampling station. A list of samples in each SIMPROF group identified during the hierarchical cluster analysis was compiled and the mean number of individuals of each taxon recorded in the samples assigned to each group was calculated. The resulting lists represent, in decreasing order, the numerically dominant taxa. Only the top 20 taxa are presented for each group. Separate listings were created for those taxa that were fully enumerated in the samples and those which were not countable (i.e. colonial taxa such as bryozoa and hydroids). The lists for non-countable taxa therefore represent an average of the number of samples in which each of the taxa occurred, again sorted in decreasing order. The results were then examined in tandem with the particle size data so that a biotope could be assigned following JNCC's National Marine Habitat Classification for Britain and Ireland: Version 04.05 (Connor *et al*., 2004). EUNIS codes corresponding to each biotope are also provided (JNCC 2010; Parry 2015).

4. Results

4.1 Description of site and major habitats

The benthic survey took place in the outer channel (downstream of Breydon Water) of the River Yare, Great Yarmouth, between 52.597176°N 1.7 2665°E upstream and 52.588806°N 1.728716°E downstream. The survey area was euryhaline (salinity variable but generally close to marine values) and tidal throughout. In all surveyed areas, the harbour was bound to both the east and west by artificial construction walls. In most areas, these comprised steel pilings; opposite station R1, the wall material had been recently (within the last 18 months) replaced.

At station R1, the wall comprised wooden beams mounted against a concrete wall. In most areas, the seabed was formed of clay below a sand layer, with variable mixing; at station R2, there was a higher gravel component. Along the walls of the majority of the survey area, large tyre fenders were suspended to provide protection and impact resistance during mooring.

4.2 Survey constraints, incidents, near misses and issues arising

4.2.1 Health and Safety Incidents

There were no incidents, near misses or other issues that require reporting under our Health and Safety procedures.

4.2.2 Access constraints and other issues

Access to the wall of the channel proved challenging due to size of the survey vessel and the presence of large tyre fenders along the entire length of the survey area. In an attempt to overcome this difficulty the vessel was angled perpendicular to the wall with the bow angled to allow access between the fenders. During wall sampling, surveyors were harnessed to a stable attachment point on the deck as an additional safety precaution.

Reference station RS01 was relocated from the east bank target to the opposite bank as the frontage on the East bank has been replaced within the last 18 months (Peter Woods (Skipper of the MV Sheerkahn), pers comm.) and the western bank was considered more comparable to the scrape sites within the proposed development area.

4.3 Samples obtained and processed

Grab sampling was undertaken at 8 stations, with three replicates being collected for macrobenthic analysis and one for particle size analysis at each station.

Wall sampling was completed at 6 stations, with three quadrats analysed *in situ* and three 0.01 m^2 wall scrape samples collected for subsequent laboratory analysis.

Four beam trawl samples were successfully completed: two within the primary impact zone, and two reference stations, one upstream and one downstream of the proposed development area.

As highlighted above (Section 3.1.3), there is a potential that the downstream reference station may ultimately fall within the impact area, dependent on the final placement of the small vessel waiting facility.

Samples collected at each station are listed in

Table 2 below and all sampling positions are provided in Appendix 2 .

Table 2. Samples collected at each sampling station

Sampling location	Samples collected				
	Macrobiota Grabs	PSA	Quadrats	Wall Scrape	Epibenthic / Fish Trawl
G01	✓ ✓ ✓	✓			
G02	✓ ✓ ✓	✓			
G03	✓ ✓ ✓	✓			
G04	✓ ✓ ✓	✓			
G05	✓ ✓ ✓	✓			
G06	✓ ✓ ✓	✓			
RG01	✓ ✓ ✓	✓			
RG02	✓ ✓ ✓	✓			
S01			✓ ✓ ✓	✓ ✓ ✓	
S02			✓ ✓ ✓	✓ ✓ ✓	
S03			✓ ✓ ✓	✓ ✓ ✓	
S04			✓ ✓ ✓	✓ ✓ ✓	
RS01			✓ ✓ ✓	✓ ✓ ✓	
RS02			✓ ✓ ✓	✓ ✓ ✓	
T01					✓
T02					✓
RT01					✓
RT02					✓
Total Samples	**24**	**8**	**18**	**18**	**4**

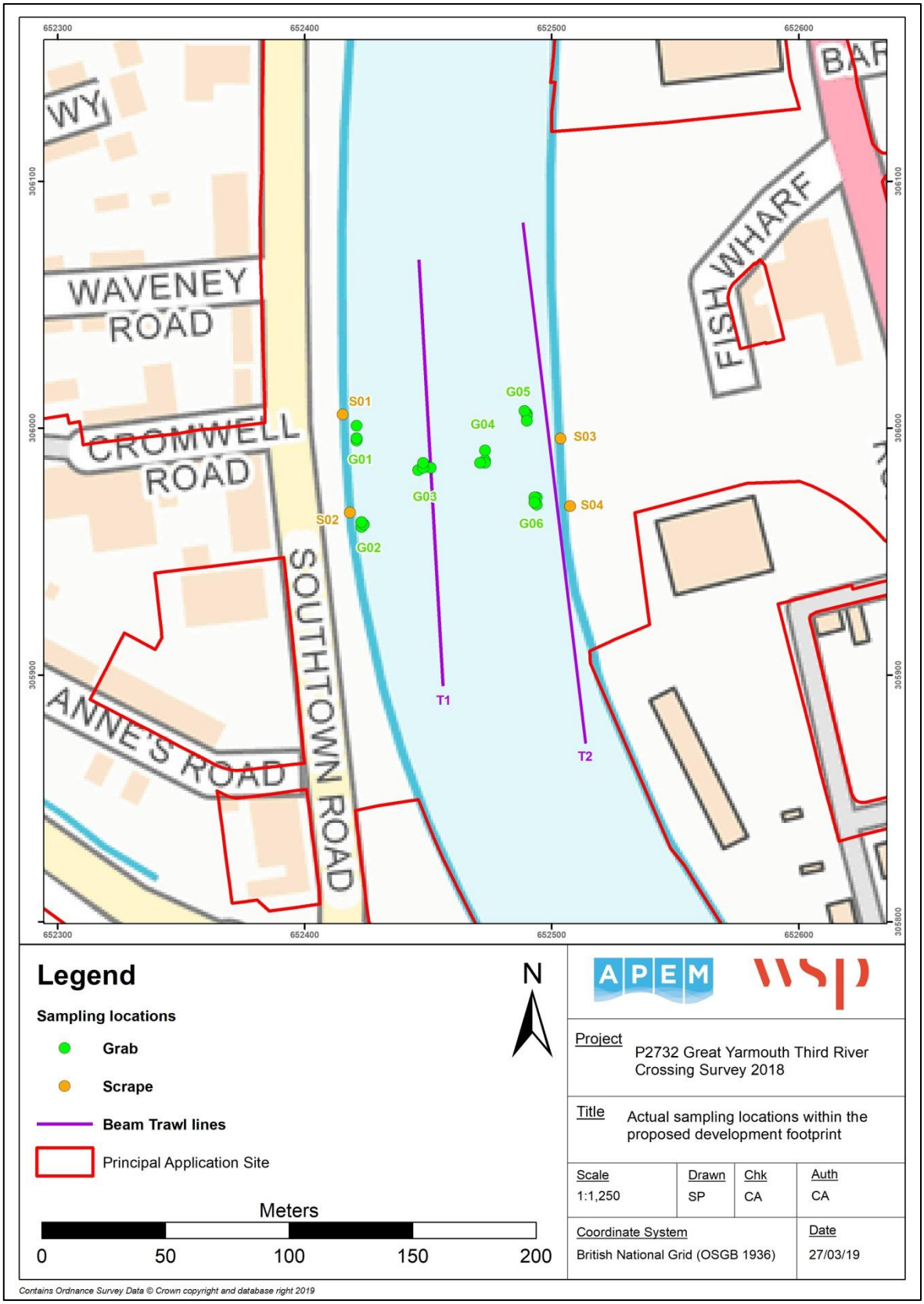

Figure 6. Wall and grab sampling stations within the impact area with positions of all replicates.

4.4 Total Organic Carbon

Percentage total organic carbon (TOC) data, expressed as percentage loss on ignition (LOI), are shown in Table 3 for each station. The values were generally very low at all stations, with five of the stations having values below 1%. The highest recorded value was 7.21% at station G02.

Table 3. Percentage TOC at each subtidal grab station

Station	Loss on ignition (%)
G01	2.10
G02	7.21
G03	0.87
G04	0.35
G05	0.31
G06	0.40
RG01	0.33
RG02	1.04

4.5 Particle Size Analysis

Full PSA data for the subtidal sediments are presented in Appendix 3 whilst summary data are given in Table 4. Proportions of mud, sand and gravel at each station are mapped in Figure 7.

The PSA data show that there was a degree of variability in sediment types across the survey area. Stations G01 and G02 had the highest proportions of finer silt and clay fractions, but differed in proportions of coarser sediments, with much higher gravel content at station G02. The more mid-channel stations G03, RG01 and RG02 had the highest proportions of coarse sediments. Stations G04, G05 and G06 were all dominated by sand fractions. Most of the samples ranged from poorly sorted to extremely poorly sorted, with the exception of G05, which had a moderate degree of sorting. Kurtosis results showed stations G02, G03, RG01 and RG02 were platykurtic, indicating a flattened distribution of size fractions, whereas the other stations were leptokurtic or very leptokurtic, indicating that most particles were distributed around the mean size.

Table 4. Summary particle size data from each subtidal grab station

Station	Mean particle diameter (µm)	Gravel (%)	Sand (%)	Mud (%)	Statistics calculated using Folk and Ward (1957) formulae			Classification	
					Sorting	Skewness	Kurtosis	Blott & Pye (2012)	Folk (1954)
G01	69.8	15.4	32.9	51.7	Extremely Poorly Sorted	Coarse Skewed	Leptokurtic	Slightly gravelly sandy mud	Gravelly Mud
G02	240.5	42.2	10.9	47.0	Extremely Poorly Sorted	Coarse Skewed	Very Platykurtic	Slightly sandy gravelly mud	Muddy Gravel
G03	3300.5	54.3	40.5	5.3	Very Poorly Sorted	Fine Skewed	Platykurtic	Slightly muddy sandy gravel	Muddy Sandy Gravel
G04	707.5	15.6	79.8	4.6	Poorly Sorted	Very Coarse Skewed	Very Leptokurtic	Very slightly muddy slightly gravelly sand	Gravelly Sand
G05	419.0	5.6	92.4	2.0	Moderately Sorted	Coarse Skewed	Very Leptokurtic	Very slightly muddy slightly gravelly sand	Gravelly Sand
G06	696.7	16.2	80.3	3.5	Poorly Sorted	Very Coarse Skewed	Very Leptokurtic	Very slightly muddy slightly gravelly sand	Gravelly Sand
RG01	1826.5	43.4	54.9	1.7	Very Poorly Sorted	Very Coarse Skewed	Platykurtic	Very slightly muddy gravelly sand	Sandy Gravel
RG02	1461.2	56.7	19.9	23.3	Extremely Poorly Sorted	Very Fine Skewed	Platykurtic	Slightly sandy muddy gravel	Muddy Gravel

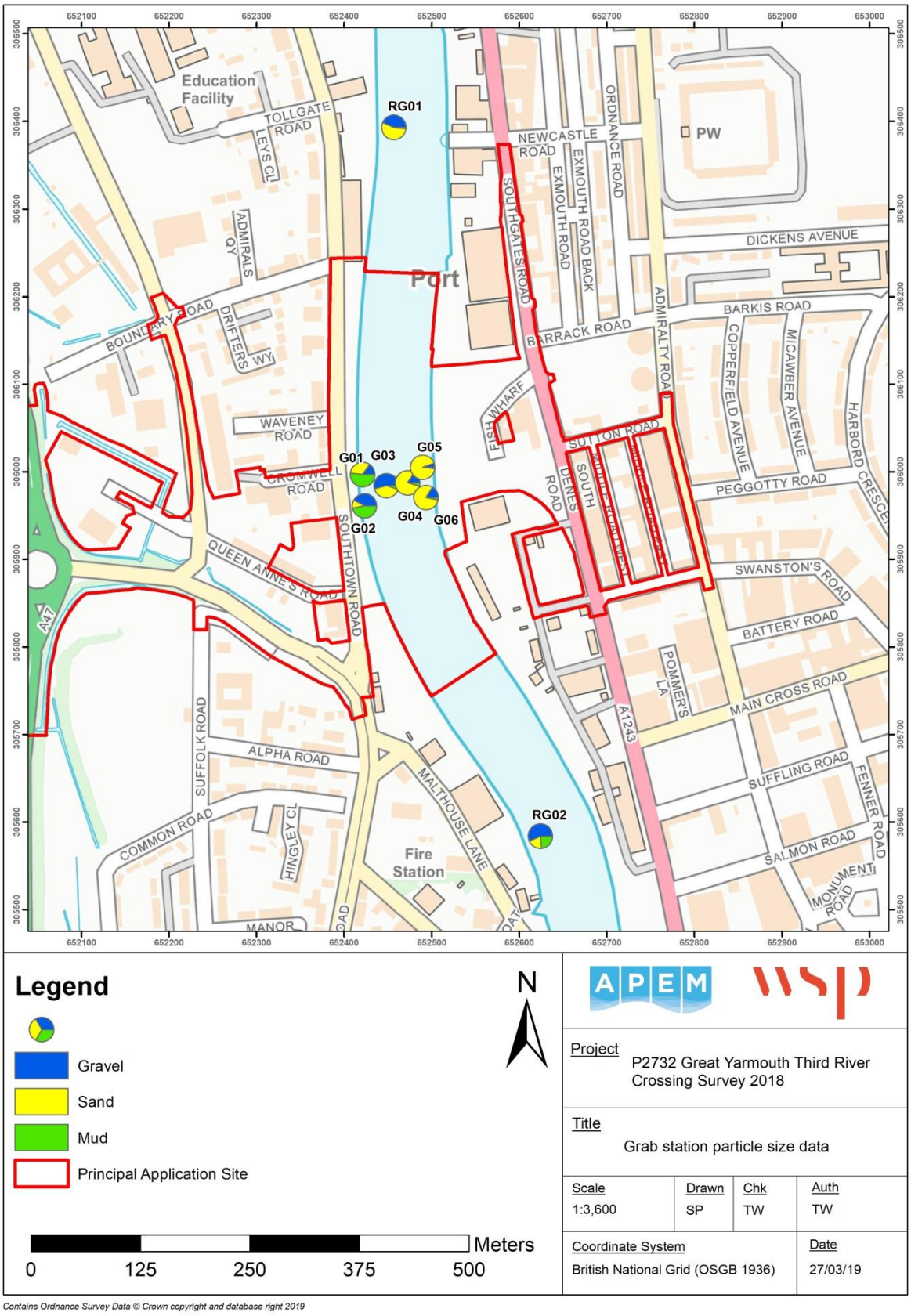

Figure 7. Map showing proportions of mud, sand and gravel at each grab location

4.6 Macrobiota

4.6.1 Benthic Grabs – Univariate Statistics

The complete benthic dataset for the subtidal grab samples is provided in Appendix 3 and photographs of the unsieved grab samples are presented in Appendix 4 . A total of 146 benthic taxa was identified from the 24 analysed subtidal benthic grab samples. Among these, nematodes and juvenile blue mussels (*Mytilus edulis*) were the most frequently recorded taxa, being present in 22 (91.7%) of the samples. Nematodes were also the most abundant taxon recorded, with a total of 580 individuals recorded across the survey, accounting for 13.9% of the total number of countable organisms from the samples. They were most abundant in sample G01A (135 individuals) and G05A (108). Numerically, annelid worms dominated the samples, accounting for 45.5% of counted individuals. Non-countable taxa (e.g. algae, bryozoans, hydroids) accounted for 40 (27.4%) of the taxa.

The univariate diversity indices are presented in

Table 5. Numbers of taxa per sample ranged from a low of 5 in sample G06B to a maximum of 75 in G01A with a mean of 28.5 across the survey. Numbers of individuals per sample ranged from 15, in samples G06C, to 997 in sample G01A, with a mean of 174.38 per 0.1m² across the survey. Margalef's species richness index (*d*) ranged from a low of 1.0, in sample G06B, to a high of 7.82 in sample G01A, with a mean value of 4.12 across the survey. Pieliou's Evenness (*J*') ranged from 0.23, in sample G05A, to 0.91 in sample RG01B, with a mean value of 0.77 across the survey. Shannon-Wiener diversity ($H'\log_e$) ranged from a low of 0.41, in sample G05A, to a high of 3.0 in sample G01A, with a mean value of 2.19. Simpson's dominance index (1- λ) ranged from a minimum of 0.16, at G05A, to a maximum of 0.93 in samples G01A-C, G02B and RG01B, with an average of 0.81 across the survey.

Table 5. Univariate statistics for the subtidal stations

Sample	Number of Taxa	Number of individuals	Density (individuals per m^2)	Margalef's species richness (*d*)	Mean Pielou's Evenness (*J'*)	Mean Shannon Wiener Diversity ($H'(\log_e)$)	Mean Simpson's Dominance (1-λ)
G01A	75	997	9,970	7.82	0.75	3.00	0.93
G01B	45	230	2,300	5.70	0.82	2.86	0.93
G01C	53	401	4,010	7.17	0.78	2.97	0.93
G02A	41	241	2,410	5.29	0.75	2.54	0.85
G02B	52	386	3,860	6.38	0.82	3.00	0.93
G02C	40	234	2,340	5.32	0.82	2.80	0.91
G03A	35	151	1,510	5.18	0.83	2.74	0.92
G03B	36	293	2,930	5.11	0.64	2.17	0.76
G03C	32	124	1,240	5.19	0.84	2.74	0.92
G04A	9	27	270	1.82	0.81	1.59	0.76
G04B	14	67	670	2.14	0.73	1.69	0.78
G04C	13	55	550	2.25	0.79	1.81	0.80
G05A	9	118	1,180	1.05	0.23	0.41	0.16
G05B	22	35	350	3.38	0.86	2.20	0.86
G05C	14	58	580	2.71	0.80	1.99	0.81
G06A	11	16	160	1.44	0.84	1.35	0.73
G06B	5	20	200	1.00	0.66	0.91	0.50
G06C	12	15	150	2.95	0.86	1.90	0.85
RG01A	13	22	220	2.59	0.86	1.89	0.85
RG01B	25	73	730	4.43	0.91	2.72	0.93
RG01C	17	29	290	4.16	0.85	2.31	0.88
RG02A	25	159	1,590	4.14	0.70	2.16	0.82
RG02B	33	189	1,890	4.77	0.71	2.31	0.84
RG01C	53	245	2,450	6.91	0.69	2.52	0.84
Min	**5**	**15**	**150**	**1.00**	**0.23**	**0.41**	**0.16**
Max	**75**	**997**	**9970**	**7.82**	**0.91**	**3.00**	**0.93**

4.6.2 Benthic Grabs – Cluster analysis

The results of SIMPROF cluster analysis on the macrobenthic data for each station are presented in Figure 8. Black lines denote significant structure within the group to that point and red lines connect samples that cannot be significantly differentiated at the 95% confidence interval. The SIMPROF test identified eight groups that can be considered statistically distinct from one-another at the 95% confidence level, four of which consisted of only single samples.

Group A comprised only sample RG02c, separating from Group B at just below 53% similarity. This sample was dominated by small lugworms (Arenicolidae) and the amphipod *Melita palmata*. The remaining two replicates from station RG02 (RG02a and RG02b) formed Group B, with many Arenicolidae, as well as mussel spat and sand mason worms (*Lanice conchilega*).

Group C comprised only sample G01a, separating from Group B at just below 53% similarity. This sample had the highest numbers of taxa and individuals of the survey and was dominated by epibiota, particularly small sea anemones (Actiniaria), barnacles (*Balanus crenatus*) and mussel (*Mytilus edulis*) spat.

Group D comprised all three replicate samples from station G03, separating from groups E-G at just below 50% similarity. This group was characterised by barnacles (*B. crenatus* and *Austrominius modestus*) as well as infaunal worms (e.g. *Pygospio elegans*) and bivalves (*Limecola balthica*).

Groups E and F both comprised single samples, G02a and G02c respectively, which separated from one-another just below 59% similarity. Group E was dominated by the cirratulid worm *Tharyx* 'species A'. Group F also included many *Tharyx* but was dominated by oligochaete worms (*Tubificoides* spp.) and had more abundant Actiniaria.

Group G included three samples: G01b, G01c and G02b and separated from Group F at just under 60% similarity. The faunal assemblages in this group were dominated by oligochaetes, *Tharyx* and *L. balthica*.

The remaining twelve samples formed a single group: H, which separated from the other groups at 22% similarity. This group was characterised by moderate numbers of Nemertea, mussel spat and infaunal worms and bivalves. Group H also had generally lower diversity than the other groups, with a mean of 14 taxa per sample, compared to means of 34-75 taxa per sample in other groups.

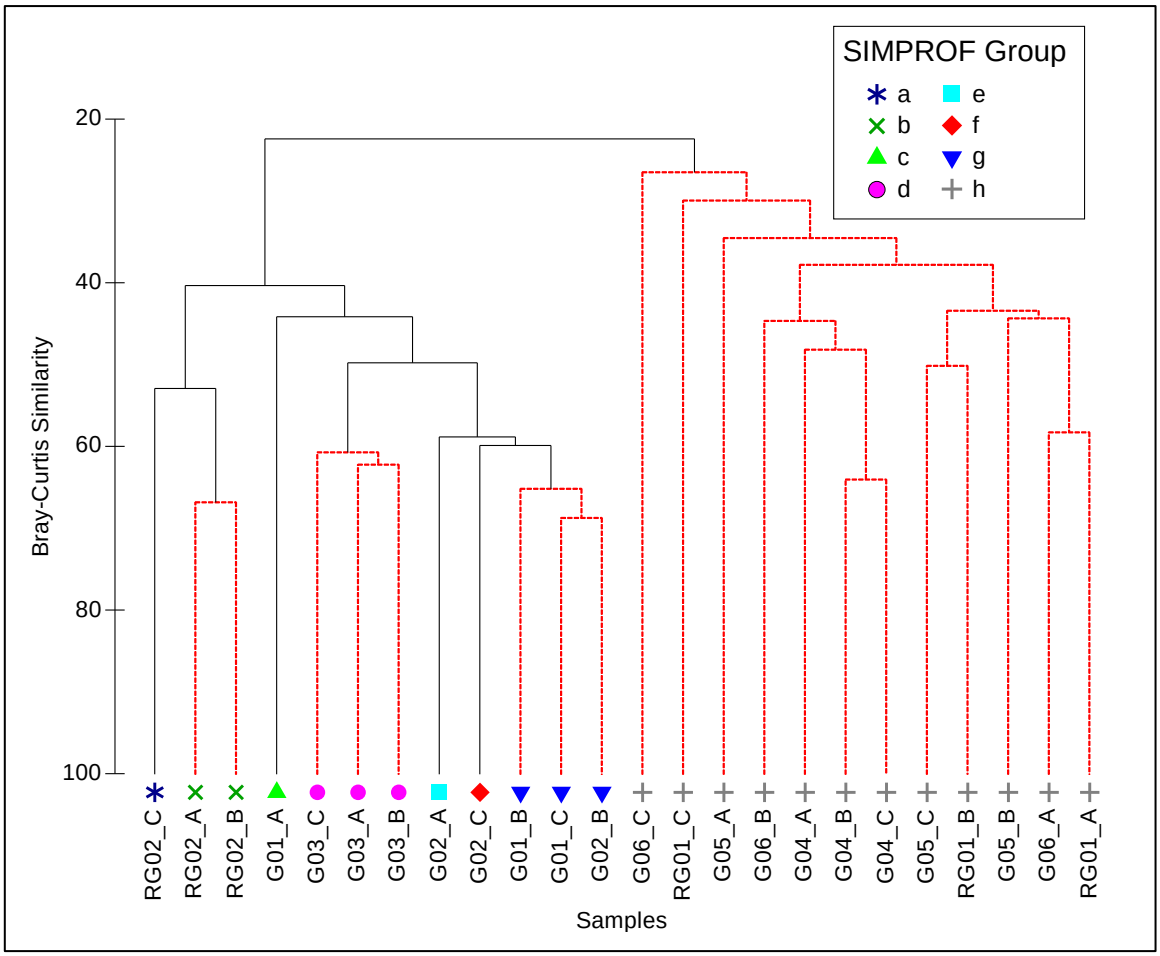

Figure 8. SIMPROF Cluster dendrogram of Bray-Curtis similarity between square-root transformed macrobenthic data for each grab sample.

4.6.3 Non-metric multi-dimensional scaling (NMMDS)

The MDS plot for the macrobenthic data is presented in Figure 9. The stress value of 0.11 is low, suggesting a good two dimensional picture of the higher dimensional relationships between samples with no real prospect of a misleading interpretation (Clarke & Warwick, 2001). The plot complements the pattern seen in the cluster dendrogram, with the samples from SIMPROF group H clearly separated from groups A-G. The samples in SIMPROF groups A-G show closer grouping of replicates from the same station, whereas those of group H show wider separation, suggesting more heterogeneity between replicates at the same station in group H.

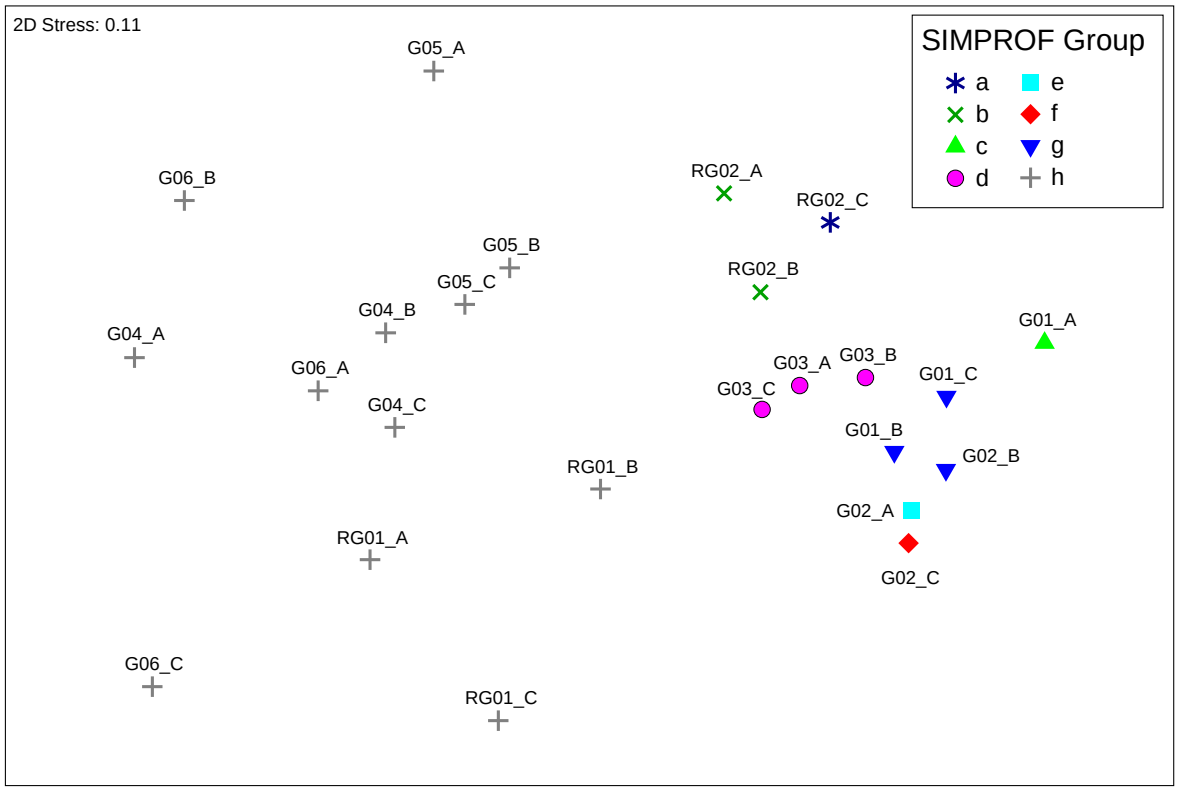

Figure 9. MDS plot of Bray-Curtis similarity between square-root transformed macrobenthic data for each grab sample

4.6.4 Correlation between PSA data and biological variables

The outputs of the BEST analysis are presented in Table 6. The results show that the highest correlation (0.873) is achieved with a single variable: % coarse sand. The highest correlation for a combination of variables is lightly lower (0.860) and includes % coarse sand along with kurtosis (phi), % silt/clay and % very coarse sand. The global test result gives a significance level of 0.4%, indicating that the correlation is significant and the null hypothesis of 'no agreement between PSA and biological multivariate patterns' can be rejected. The high correlation value indicates that the coarse sand content of the sediment is an important determining factor in the observed biological distributions.

Table 6. Results of the BEST analysis

No. Variables	Spearman Correlation (σ)	Physical Variables
1	0.873	% Coarse sand (500-1000 µm)
4	0.860	Kurtosis (phi), % Silt/clay (<63 µm), % Coarse sand (500-1000 µm), % Very coarse sand (1-2 mm)
4	0.855	Kurtosis (phi), % Very fine sand (63-125 µm), % Coarse sand (500-1000 µm), % Very coarse sand (1-2 mm)
4	0.847	Sorting (phi), Kurtosis (phi), % Coarse sand (500-1000 µm), % Very coarse sand (1-2 mm)
5	0.839	Sorting (phi), Kurtosis (phi), % Very fine sand (63-125 µm), % Coarse sand (500-1000 µm), % Very coarse sand (1-2 mm)
5	0.837	Kurtosis (phi), % Silt/clay (<63 µm), % Medium sand (250-500 µm), % Coarse sand (500-1000 µm), % Very coarse sand (1-2 mm)
5	0.835	Kurtosis (phi), % Very fine sand (63-125 µm), % Medium sand (250-500 µm), % Coarse sand (500-1000 µm), % Very coarse sand (1-2 mm)
3	0.834	Kurtosis (phi), % Coarse sand (500-1000 µm), % Very coarse sand (1-2 mm)
5	0.833	Sorting (phi), Skewness (phi), Kurtosis (phi), % Coarse sand (500-1000 µm), % Very coarse sand (1-2 mm)
3	0.832	Kurtosis (phi), % Silt/clay (<63 µm), % Coarse sand (500-1000 µm)

Global Test
Sample statistic (ρ): 0.873
Significance level of sample statistic: 0.4%
Number of permutations: 999 (Random sample)
Number of permuted statistics greater than or equal to ρ: 3

4.6.5 Biotope composition

Half of the macrobenthic samples belonged to a single cluster group; other cluster groups were represented by only small numbers of samples. However, the main group represents the least rich samples and does not fit well into any described biotope. Oligochaete worms of the genus *Tubificoides* and the cirratulid polychaete *Tharyx* 'species A' were the most consistent component of most groups, which can be considered variants of the biotope SS.SMu.SMuVS.AphTubi (*Aphelochaeta marioni* and *Tubificoides* spp. in variable salinity infralittoral mud; EUNIS A5.322). The biotope description (Connor *et al.*, 2004) notes that other cirratulids may replace *A. marioni* and that the description may include inconsistent cirratulid identifications. Group G was the most typical example of this biotope. Group H was more impoverished but not enough so for it to be assigned to SS.SMu.SMuVS.MoMu (Infralittoral fluid mobile mud; EUNIS A5.324); it is best left as the biotope complex SS.SMu.SMuVS (Sublittoral mud in variable salinity (estuaries); EUNIS A5.32). The same assignment must be applied to groups A and B, which do not fit well with the biotope level classification. The remaining groups had high numbers of epifaunal taxa and are best assigned to the complex SS.SMx.SMxVS (Sublittoral mixed sediment in variable salinity (estuaries); EUNIS A5.42); they do not fit well with either of the described component biotopes, although group E could

be considered close to SS.SMx.SMxVS.CreMed (*Crepidula fornicata* and *Mediomastus fragilis* in variable salinity infralittoral mixed sediment; EUNIS A5.422).

Table 7. Biotope assignment, AMBI and IQI Scores for each subtidal grab sample

Sample	AMBI	Disturbance Classification	IQI Score	IQI Ecological Status	SIMPROF Group	Biotope	EUNIS
G01a	3.36	Moderately disturbed	0.72	Good	c	SS.SMx.SMxVS	A5.42
G01b	3.73	Moderately disturbed	0.62	Moderate	g	SS.SMu.SMuVS.AphTubi	A5.322
G01c	3.94	Moderately disturbed	0.61	Moderate	g	SS.SMu.SMuVS.AphTubi	A5.322
G02a	3.85	Moderately disturbed	0.61	Moderate	e	SS.SMx.SMxVS.CreMed	A5.422
G02b	3.78	Moderately disturbed	0.65	Good	g	SS.SMu.SMuVS.AphTubi	A5.322
G02c	4.12	Moderately disturbed	0.61	Moderate	f	SS.SMx.SMxVS	A5.42
G03a	3.16	Slightly disturbed	0.57	Moderate	d	SS.SMx.SMxVS	A5.42
G03b	3.48	Moderately disturbed	0.55	Moderate	d	SS.SMx.SMxVS	A5.42
G03c	3.49	Moderately disturbed	0.54	Moderate	d	SS.SMx.SMxVS	A5.42
G04a	3.06	Slightly disturbed	0.53	Moderate	h	SS.SMu.SMuVS	A5.32
G04b	3.34	Moderately disturbed	0.56	Moderate	h	SS.SMu.SMuVS	A5.32
G04c	2.83	Slightly disturbed	0.59	Moderate	h	SS.SMu.SMuVS	A5.32
G05a	3.09	Slightly disturbed	0.50	Moderate	h	SS.SMu.SMuVS	A5.32
G05b	3.31	Moderately disturbed	0.64	Good	h	SS.SMu.SMuVS	A5.32
G05c	3.45	Moderately disturbed	0.55	Moderate	h	SS.SMu.SMuVS	A5.32
G06a	3.00	Slightly disturbed	0.59	Moderate	h	SS.SMu.SMuVS	A5.32
G06b	2.93	Slightly disturbed	0.48	Moderate	h	SS.SMu.SMuVS	A5.32
G06c	3.12	Slightly disturbed	0.54	Moderate	h	SS.SMu.SMuVS	A5.32
RG01a	2.80	Slightly disturbed	0.54	Moderate	h	SS.SMu.SMuVS	A5.32
RG01b	3.09	Slightly disturbed	0.58	Moderate	h	SS.SMu.SMuVS	A5.32
RG01c	2.94	Slightly disturbed	0.54	Moderate	h	SS.SMu.SMuVS	A5.32
RG02a	3.11	Slightly disturbed	0.53	Moderate	b	SS.SMu.SMuVS	A5.32
RG02b	3.23	Slightly disturbed	0.55	Moderate	b	SS.SMu.SMuVS	A5.32
RG02c	2.97	Slightly disturbed	0.62	Moderate	a	SS.SMu.SMuVS	A5.32

The distributions of the identified biotopes are mapped in Figure 10, below. As biotope distribution was clearly patchy, even at a station level (as indicated by assignment of different replicate samples from a station to separate cluster groups), biotopes have been mapped as points rather than trying to assign arbitrary ranges to their distributions. For stations G01 and G02, the majority biotope or complex has been mapped (in G02, one replicate was assigned a biotope in the complex to which another replicate had been assigned).

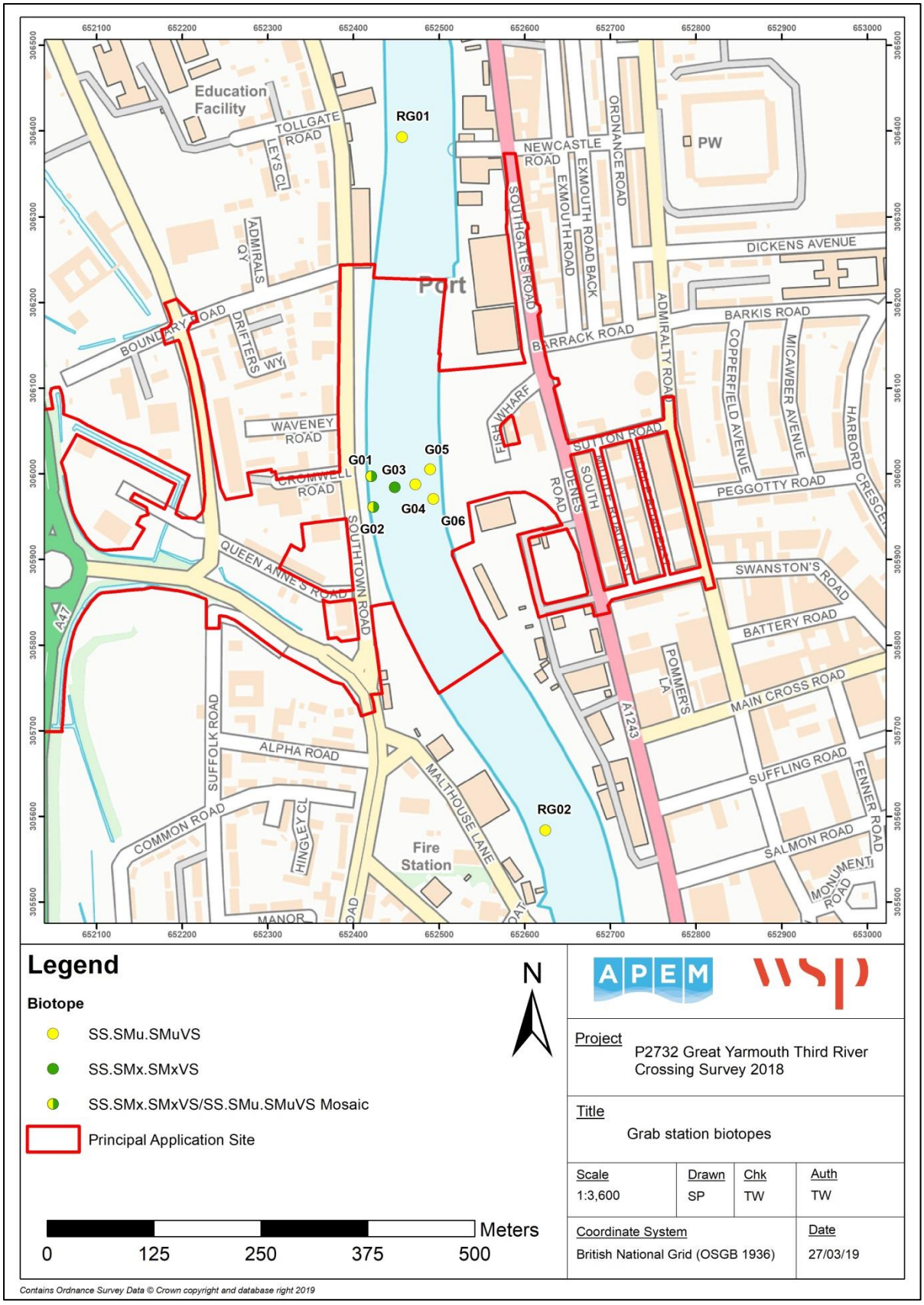

Figure 10. Biotopes present at each grab station.

4.6.6 AMBI and Infaunal Quality Index (IQI) Scores

AMBI scores for all samples (Table 7) fell within the range of 2.8 to 4.12, resulting in classifications of either moderately or slightly disturbed. Three samples had an IQI Ecological Status of 'good' (G01A, G02B and G05B), with all other samples classified as 'moderate'. These scores are likely to be highly influenced by the presence of Ecological Group III taxa that are present in the underlying structure of estuarine communities (Borja & Muxika, 2005), making it difficult to attain lower scores in estuarine conditions.

4.6.7 Wall samples

All wall stations had a covering of algae and fouling fauna. The communities were generally similar at each station, regardless of wall construction (metal or wood). Since fouling communities overgrow one another, the percentage coverage from the quadrats frequently showed more than 100% coverage, accounting for the 3-dimensional structure. The upper tidal zones of the walls showed a distinct band of green algae (mostly *Blidingia minima*). This represents a biotope with some similarity to LR.FLR.Lic.Bli (*Blidingia* spp. on vertical littoral fringe soft rock; EUNIS B3.114), although the substratum does not match. Lower down, a zone of *Fucus* was present (both *F. vesiculosus* and *F. spiralis* were noted in quadrat samples). Barnacles (*Austrominius modestus*) were abundant at most stations. Several other algal species were present, including the chlorophytes *Prasiola stipitata* and *Gayralia oxysperma*. Stations 3 and 4 had lower densities of fucoids, with correspondingly higher numbers of barnacles. Station R1 had no barnacle records. Although there was some variation between stations, the mid shore on the walls has all been assigned to the biotope LR.MLR.BF.FvesB (*Fucus vesiculosus* and barnacle mosaics on moderately exposed mid eulittoral rock; EUNIS A1.213). Photographs of all wall sampling stations are provided in Appendix 5 and the complete data for both wall scrape and quadrat samples are provided in Appendix 3 .

A SIMPROF cluster analysis was conducted on the wall scrape data for each replicate and is presented in

Figure **11**. The results show that none of the samples can be statistically differentiated at the 95% confidence interval, indicating similar species assemblages in all samples.

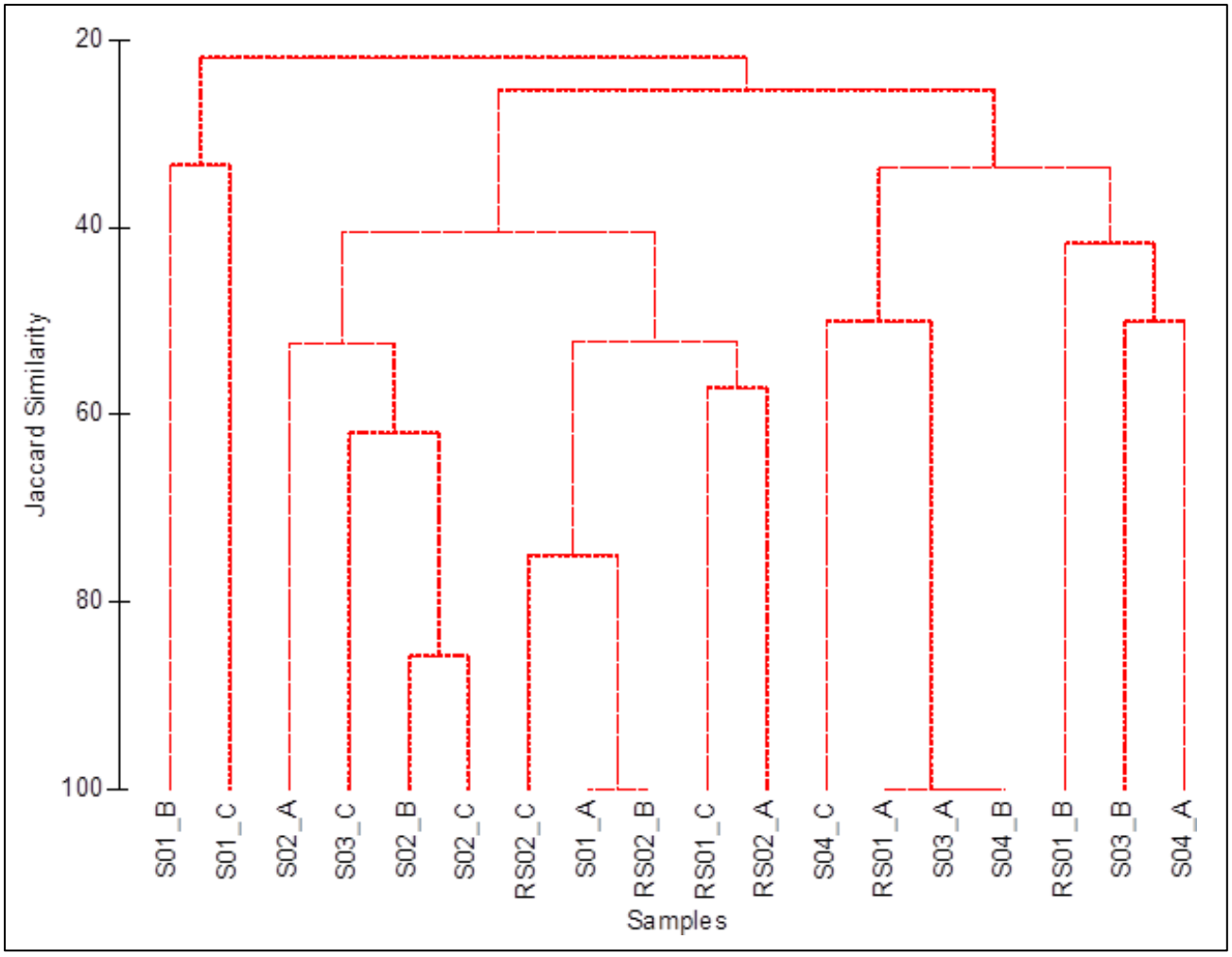

Figure 11. SIMPROF Cluster dendrogram of Jaccard similarity between wall scrape presence/absence data for each replicate.

4.6.8 Trawls

Seven invertebrate taxa and seven fish species were recorded from the beam trawl samples. The majority of taxa recorded in the trawl samples were not recorded in any of the other sample types. Data from the trawl samples are presented in Appendix 3 and photos of each trawl sample are presented in Appendix 6

The number of taxa ranged from six in RT1 and T02, to eight in RT2 and T01. The highest number of individuals (1,199) was in T02. The most abundant taxon recorded from each of the beam trawls was brown shrimp (*Crangon crangon*), with a total of 2,505 individuals recorded overall. Other invertebrates were much less common but included occasional mysids (opossum shrimps – *Neomysis integer* and *Schistomysis kervillei*) and shore crabs (*Carcinus maenas*).

Sand goby (*Pomatoschistus minutus*) was the most abundant fish species and was found in moderate numbers (8-81) in all samples. Lozano's goby (*Pomatoschistus lozanoi*) and common gobies (*P. microps*) were recorded in low numbers (totals of 2 and 1, respectively), as were the flatfish Dover sole (*Solea solea*), flounder (*Platichthys flesus*) and plaice

(*Pleuronectes platessa*) (totals of 2, 2 and 1, respectively). One three-spined stickleback (*Gasterosteus aculeatus*) was also found.

4.6.9 Notable taxa

The only benthic species of conservation interest to be recorded was the ross worm *Sabellaria spinulosa* but it is only significant if reef-forming (the reef habitat is an Annex I habitat under the EC Habitats Directive) and the numbers found in the samples were too low to constitute evidence of a biogenic reef. Commercially important species recorded in the trawl samples included brown shrimp (*Crangon crangon*) and flatfish: Dover sole (*Solea solea*), flounder (*Platichthys flesus*), plaice (*Pleuronectes platessa*); of these, Dover sole is listed as a Feature of Conservation Interest (FOCI: Reeve, 2007).

No other species considered rare (e.g. those listed by Bratton, 1991; Sanderson, 1996; Betts, 2001; Chadd & Extence, 2004) or protected under the Wildlife and Countryside Act 1981 (as amended) or the Habitats Directive were recorded. The syllid polychaete *Prosphaerosyllis chauseyensis* (Olivier *et al*., 2012) has not yet been formally published from UK waters but has been found in several surveys and is likely to have been previously overlooked.

Several non-native or cryptogenic species were recorded. The most significant may be the Manila clam (*Ruditapes philippinarum*), currently known from the south coast of England and the east coast as far north as the Orwell estuary (Ashelby, 2005); the Great Yarmouth records represent a range extension and the most northerly naturalised population in the UK, although there are farmed populations in Morecambe Bay (Humphreys *et al.*, 2015). The Australasian barnacle *Austrominius modestus* was present at most wall sampling stations and several grab samples, often in high abundance. American Slipper limpets (*Crepidula fornicata*) were found in several grab samples, especially at station G02. One specimen of the non-native ostracod crustacean *Eusarsiella zostericola* was recorded at station G01. The polychaete *Streblospio* (common at stations G01 and G02) is likely to have been the non-native *S. benedicti*, which is recently recognised to have spread widely in Britain and Europe (V. Radashevsky, Russian Aca-demy of Sciences, pers. comm.). The cryptogenic ragworms *Alitta succinea* and *A. virens* were found at stations G01-03.

5. Discussion

The River Yare is tidal for many kilometres from near Norwich to Great Yarmouth. Just upstream of Great Yarmouth, the estuary passes through a semi-enclosed broad (Breydon Water), with an extensive intertidal area, for about five km. It then passes through the town as a narrow (150m wide) marine inlet that connects to the southern bight of the North Sea at Gorleston-on-Sea. The Scheme is planned to be half way along the narrow inlet, about 2km North and upstream of the connection to the open sea. The environmental conditions at this point are tidal and euryhaline. The area is discussed within the context of Breydon Water in the JNCC Coastal Directory (Barne *et al*., 1995).

The marine environment within the footprint of the Scheme has been characterized through trawls and benthic grab samples on the sediment and by quadrats and wall scrape samples along the walls. Subtidally, the seabed comprised clay and sand, with minor mud and gravel components in some samples. Walls extended from the shallow subtidal, through the intertidal to terrestrial environments; they mostly comprised steel sheet piling, with wood over concrete in one area.

The subtidal sediment was mixed, with sand, clay and varying proportions of stone and shell, allowing the development of both infaunal and epibiota communities. Infaunal populations were characterised by varying proportions of common cirratulid, spionid and oligochaete worms in moderate to high numbers, together with typical estuarine bivalves and amphipod crustaceans. About half of the samples were of relatively low diversity and may have been affected by dredging for navigation purposes; these samples were less influenced by gravel components and belonged to the SS.SMu.SMuVS biotope complex. Other samples represented communities within this complex that were more diverse, but still difficult to assign at biotope level, as well as relatively typical examples of the widespread estuarine, shallow mud biotope (SS.SMu.SMuVS.AphTubi). There was a transition between these infaunal communities and those that had more epibiota and belonged to the complex SS.SMx.SMxVS. Of these, one community could be named at biotope level: SS.SMx.SMxVS.CreMed. In most mixed substratum samples, epibiota were dominated by barnacles and sea anemones, with encrusting Bryozoa. Although some of the benthic community compositions may suggest the need for re-evaluation of the biotope classification, it is unlikely that any would be considered of particular conservation value.

The trawl data provide a view of the larger, mobile organisms that pass over the sediment. There were large numbers of brown shrimp (*Crangon crangon*), which may be considered of commercial importance. The gobies, which dominated the trawl data, are widespread and a common component of estuaries, although the distribution of *Pomatoschistus lozanoi* in the North Sea and estuarine habitats was relatively recently recognised (Eick, 2012), relative to standard literature (Maitland & Herdson, 2009). Commercially important fish (three flatfish species) were found in low numbers.

Only the mid and upper shore biotopes were examined on the walls. The upper shore green algal zone was unusual in its dominance of *Blidingia minima* and similar to a soft rock biotope, LR.FLR.Lic.Bli, but on hard artificial substrata. The mid shore represented typical moderate exposure fucoid barnacle mozaics (LR.MLR.BF.FvesB), which are widespread nationally. The dominant barnacle was the Australasian species *Austrominius modestus*, which is now abundant in estuarine habitats, nationally (Eno *et al*., 1997).

Although the wider environment is classified as a priority habitat, estuaries, the biological communities identified within the Scheme impact zone are of limited conservation value. The construction and maintenance of the Scheme will have little impact relative to the pressures already present due to habitat modification. The main conservation interest is commercially important fish, which appear to use the area in low numbers, and brown shrimp.

There were several non-native (Eno *et al*., 1997; Minchin *et al*., 2013) and cryptogenic (species that based on distribution or other evidence may be non-native but for which there is no definitive proof) animals in the area. One of these represents a notable range extension. Manila clams (*Ruditapes philippinarum*) were found in several grab samples. It is native to the temperate northwest Pacific (Huber, 2010) and was introduced to Europe and the UK for commercial fishery. It then became naturalised in Poole Harbour and spread to other estuaries on the south coast (Humphreys et al., 2015) and as far north as the Orwell estuary, Suffolk (Ashelby, 2005). The Great Yarmouth specimens are the most northerly wild population recorded from British waters.

The non-native species are most likely to have been introduced to the area through shipping in some form and it is not possible to be certain which species have spread from within British waters or when they arrived. Care must be taken to ensure that no biological material is spread

from the area to other parts of Britain or Europe. A biosecurity risk assessment should be undertaken as part of the planning for the Scheme and a management plan put in place to avoid potentially facilitating the spread of non-native species during construction. This plan should particularly cover risks of material removed from the inlet during construction being transported beyond the harbour, without an assessment of the recipient area. It may also consider aspects of the vessels and equipment used in the process and their subsequent use in other areas. This is secured through the Outline CoCP (document reference 6.16).

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APPENDICES

Appendix 1 AMBI Truncation details

Taxon	Changes or exclusion details
Prosphaerosyllis chauseyensis	scored as per *Prosphaerosyllis* sp. (EG II)
Parougia	scored as per *Parougia caeca* (EG IV)
Dipolydora species B	scored as per *Dipolydora* sp. (EG IV)
Tharyx species A	scored as per *Tharyx* sp. (EG IV)
Notomastus	scored as per *Notomastus latericeus* (EG III)
Arenicolidae	scored as per *Arenicola marina* (EG III)
Serpulidae	scored as per *Pomatoceros lamarcki* (EG II)
Folliculinidae	Excluded: Epifauna
Animalia eggs	Excluded: Eggs
Porifera	Excluded: Epifauna
Filifera	Excluded: Epifauna
Bougainvilliidae	Excluded: Epifauna
Dynamena pumila	Excluded: Epifauna
Hydrallmania falcata	Excluded: Epifauna
Sertularia	Excluded: Epifauna
Nemertesia	Excluded: Epifauna
Campanulariidae	Excluded: Epifauna
Actiniaria	Excluded: Epifauna
Fecampia erythrocephala eggs	Excluded: Eggs
Nereididae juvenile	Excluded: Non-speciated juvenile
Pycnogonida juvenile	Excluded: Non-speciated juvenile
Acari	Excluded: Non-benthic taxon
Sessilia juvenile	Excluded: Epifauna
Austrominius modestus	Excluded: Epifauna
Balanus crenatus	Excluded: Epifauna
Copepoda	Excluded: Planktonic taxon
Coleoptera larva	Excluded: Insect
Doto	Excluded: Non-Soft sediment taxon
Cuthona	Excluded: Non-Soft sediment taxon
Crisia	Excluded: Epifauna
Alcyonidium diaphanum	Excluded: Epifauna
Alcyonidioides mytili	Excluded: Epifauna
Nolella	Excluded: Epifauna
Farrella repens	Excluded: Epifauna
Vesicularia spinosa	Excluded: Epifauna
Amathia lendigera	Excluded: Epifauna
Amathia	Excluded: Epifauna

Taxon	Changes or exclusion details
Eucratea loricata	Excluded: Epifauna
Conopeum reticulum	Excluded: Epifauna
Electra monostachys	Excluded: Epifauna
Electra pilosa	Excluded: Epifauna
Aspidelectra melolontha	Excluded: Epifauna
Flustra foliacea	Excluded: Epifauna
Bugulidae	Excluded: Epifauna
Bicellariella ciliata	Excluded: Epifauna
Scrupocellaria scruposa	Excluded: Epifauna
Ascidiacea juvenile	Excluded: Epifauna
Molgula	Excluded: Epifauna
Gloeotrichia	Excluded: Non-benthic invertebrate taxon
Rhodophyta	Excluded: Non-benthic invertebrate taxon
Plocamium cartilagineum	Excluded: Non-benthic invertebrate taxon
Heterosiphonia plumosa	Excluded: Non-benthic invertebrate taxon
Bacillariophyceae	Excluded: Non-benthic invertebrate taxon
Ectocarpaceae	Excluded: Non-benthic invertebrate taxon
Chlorophyta	Excluded: Non-benthic invertebrate taxon
Gayralia oxysperma	Excluded: Non-benthic invertebrate taxon
Blidingia minima	Excluded: Non-benthic invertebrate taxon
Chaetomorpha linum	Excluded: Non-benthic invertebrate taxon
Rhizoclonium	Excluded: Non-benthic invertebrate taxon
Bryophyta	Excluded: Non-benthic invertebrate taxon
Lemna	Excluded: Non-benthic invertebrate taxon

Appendix 2 Sampling positions

Wall sampling positions

Station / Sample	Date	Time (UTC)	OSGB36		WGS84	
			Eastings	Northings	Latitude	Longitude
S01	30/01/19	12:02	652415	306006	52.593172	1.7254051
S02	30/01/19	11:44	652418	305966	52.592812	1.7254189
S03	30/01/19	12:31	652504	305996	52.593041	1.7266938
S04	30/01/19	12:52	652507	305968	52.592797	1.7267322
RS01	30/01/19	13:24	652519	306329	52.596022	1.7271686
RS02	31/01/19	12:11	652607	305576	52.589234	1.7279064

Trawl sampling start and end positions

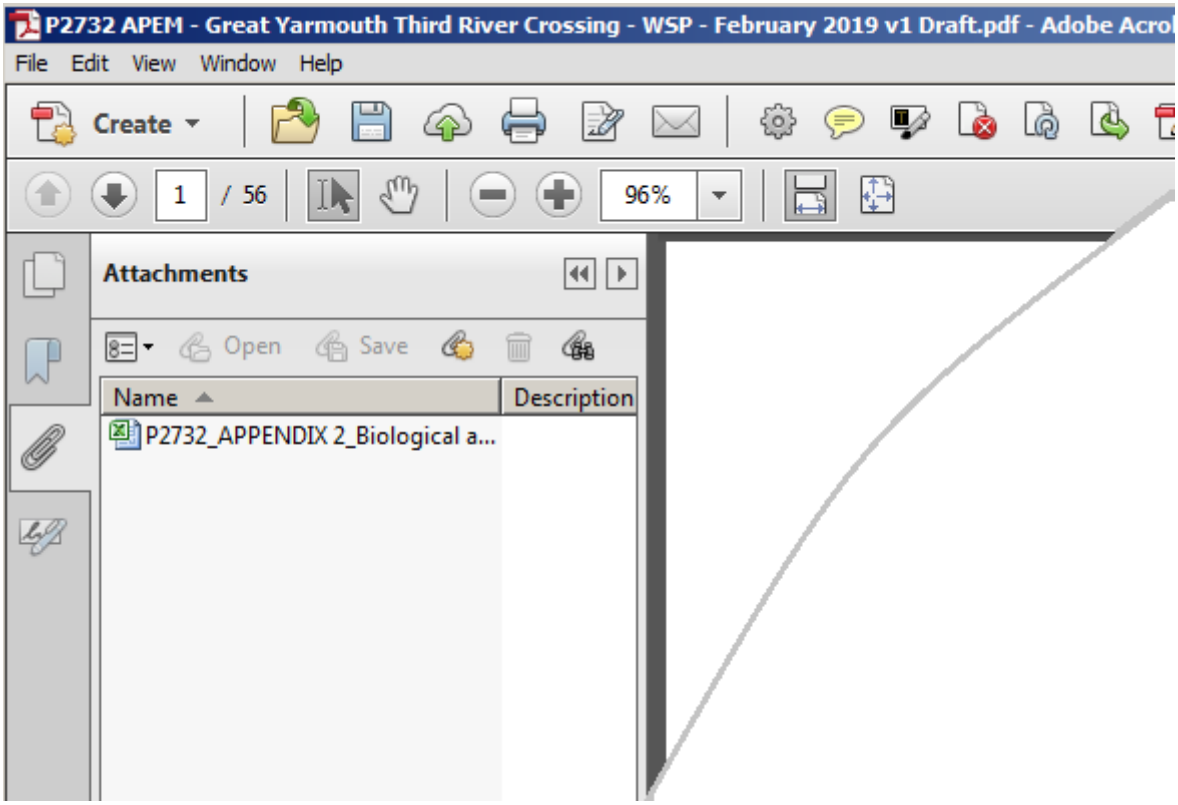
Station / Sample	Date	Time (UTC)	OSGB36		WGS84	
			Eastings	Northings	Latitude	Longitude
T01 Start	30/01/19	13:55	652456	305896	52.592167	1.7259106
T02 End	30/01/19	14:00	652446	306068	52.593723	1.7259098
T02 Start	30/01/19	14:15	652514	305872	52.591933	1.7267474
T02 End	30/01/19	14:20	652488	306083	52.593838	1.7265399
RT01 Start	31/01/19	11:21	652481	306438	52.597017	1.7266919
RT01 End	31/01/19	11:25	652485	306270	52.595517	1.7266383
RT02 Start	31/01/19	11:52	652558	305711	52.590460	1.7272721
RT02 End	31/01/19	11:57	652663	305514	52.588643	1.7286832

Grab sampling positions

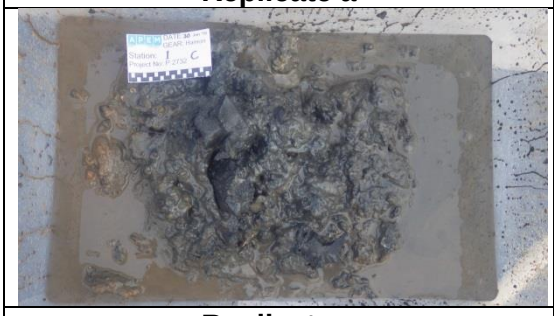
Station / Sample	Date	Time (UTC)	OSGB36		WGS84	
			Eastings	Northings	Latitude	Longitude
G01a	30/01/19	08:18	652421	306001	52.593133	1.7254905
G01b	30/01/19	08:24	652421	305996	52.593089	1.7254867
G01c	30/01/19	08:28	652421	305995	52.593080	1.7254859
G01 PSA	30/01/19	08:32	652421	305996	52.593089	1.7254867
G02a	30/01/19	08:37	652423	305960	52.592765	1.7254887
G02b	30/01/19	08:41	652424	305961	52.592773	1.7255042
G02c	30/01/19	08:44	652423	305962	52.592783	1.7254902
G02 PSA	30/01/19	08:48	652423	305962	52.592783	1.7254902
G03a	30/01/19	08:54	652451	305984	52.592967	1.7259194
G03b	30/01/19	08:58	652446	305983	52.592960	1.7258450
G03c	30/01/19	09:01	652448	305984	52.592968	1.7258753
G03 PSA	30/01/19	09:05	652448	305986	52.592986	1.7258768
G04a	30/01/19	09:11	652473	305987	52.592984	1.7262458
G04b	30/01/19	09:14	652473	305986	52.592975	1.7262450
G04c	30/01/19	09:17	652473	305991	52.593020	1.7262489
G04 PSA	30/01/19	09:20	652471	305986	52.592976	1.7262156
G05a	30/01/19	09:28	652490	306006	52.593146	1.7265107
G05b	30/01/19	09:31	652490	306005	52.593137	1.7265099
G05c	30/01/19	09:34	652489	306007	52.593156	1.7264967
G05 PSA	30/01/19	09:38	652490	306003	52.593119	1.7265084
G06a	30/01/19	09:43	652494	305969	52.592812	1.7265414
G06b	30/01/19	09:45	652494	305972	52.592839	1.7265437
G06c	30/01/19	09:49	652493	305972	52.592840	1.7265290
G06 PSA	30/01/19	09:52	652493	305970	52.592822	1.7265275
RG01a	30/01/19	10:03	652455	306393	52.596634	1.7262900
RG01b	30/01/19	10:08	652457	306394	52.596642	1.7263203
RG01c	30/01/19	10:13	652457	306393	52.596633	1.7263195
RG01 PSA	30/01/19	10:16	652458	306393	52.596633	1.7263342
RG02a	30/01/19	10:30	652625	305584	52.589298	1.7281776
RG02b	30/01/19	10:33	652623	305585	52.589308	1.7281489
RG02c	30/01/19	10:36	652624	305585	52.589307	1.7281637
RG02 PSA	30/01/19	08:18	652421	306001	52.593133	1.7254905

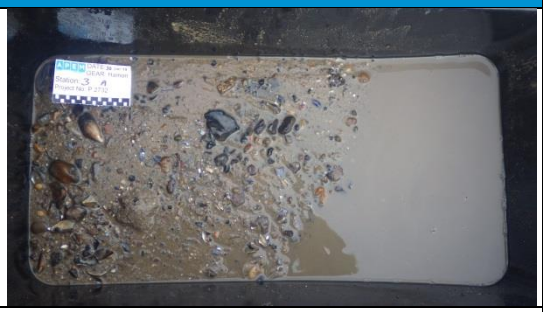
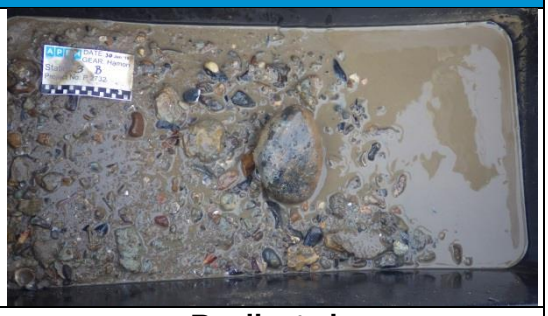
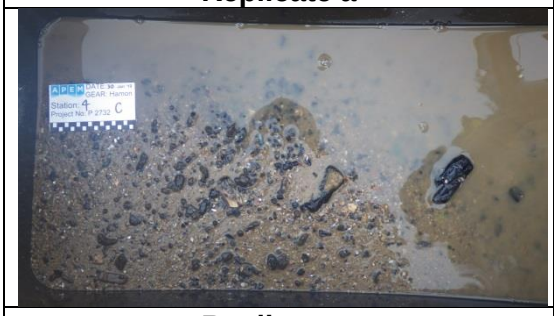
Appendix 3 Biological and sediment data

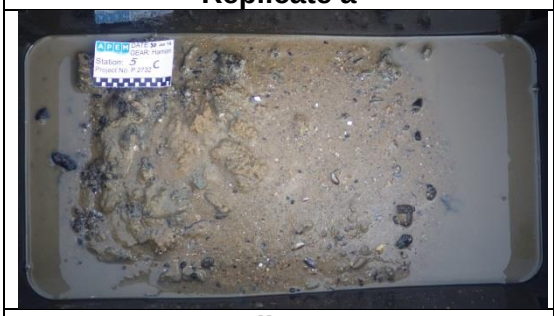
See attached file within this PDF

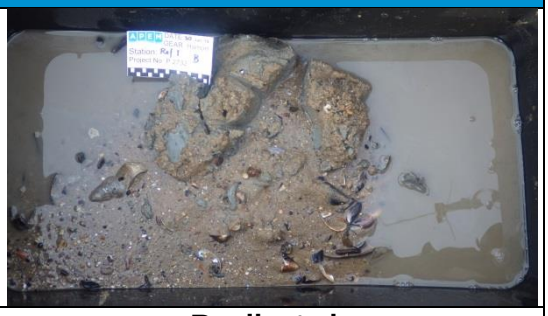
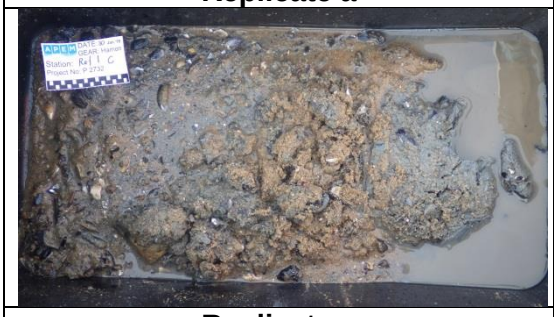
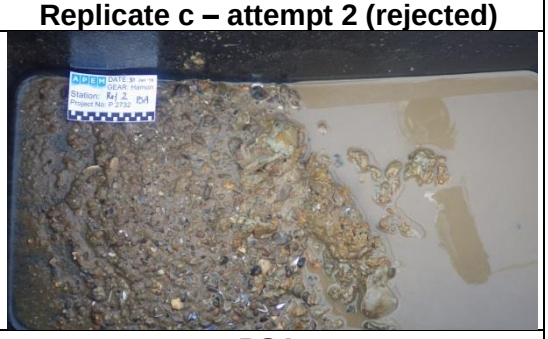


Appendix 4 Photographs of each benthic grab sample

Station		
G01		
	Replicate a	Replicate b
		
	Replicate c	PSA
G02		
	Replicate a	Replicate b
		
	Replicate c	PSA

Station		
G03		
	Replicate a	Replicate b
		
	Replicate c	PSA
G04		
	Replicate a	Replicate b
		
	Replicate c	PSA

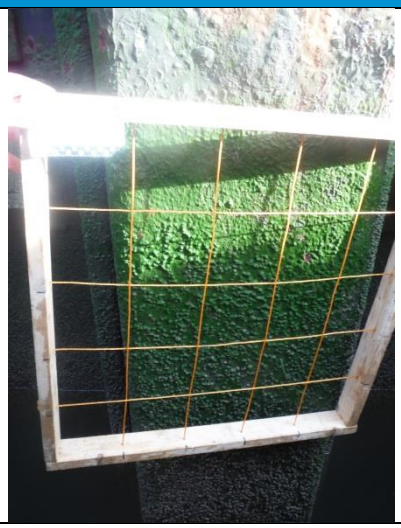
Station		
G05		
	Replicate a	Replicate b
		
	Replicate c	PSA
G06		
	Replicate a	Replicate b
		
	Replicate c	PSA

Station		
RG01		
	Replicate a	Replicate b
		
	Replicate c	PSA
RG02		
	Replicate a	Replicate b
		
	Replicate c – attempt 1 (rejected)	Replicate c – attempt 2 (rejected)
		
	Replicate c – attempt 3 (accepted)	PSA

Appendix 5 Photographs of each wall sampling station

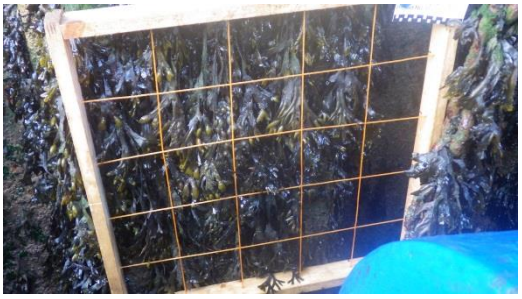
Station		
S01		
	Quadrat a	Quadrat b
		
	Quadrat c	Scrape a
		
	Scrape b	Scrape c

Station		
S02		
	Quadrat a	Quadrat b
		
	Quadrat c	Scrape a
		
	Scrape b	Scrape c

Station		
S03 (labelled as 5 in the field due to proximity to grab station G05)		
	Quadrat a	Quadrat b
		
	Quadrat c	Scrape a
		
	Scrape b	Scrape c

Station		
S04 (labelled as 6 in the field due to proximity to grab station G06)		
	Quadrat a	Quadrat b
		
	Quadrat c	Scrape a
		
	Scrape b	Scrape c

Station		
RS01		
	Quadrat a	Quadrat b
		
	Quadrat c	Scrape a
		
	Scrape b	Scrape c

Station		
RS02		
	Quadrat a	Quadrat b
		
	Quadrat c	Scrape a
		
	Scrape b	Scrape c

Appendix 6 Photographs of each trawl sample

Trawl	
T01	

T02	
Trawl	
RT01	

RT02	 APEM DATE 31 Jan '19 GEAR: Beam tr Station: REF T2 Project No: P 2732