Littoral sediment survey of the Duddon Estuary SSSI

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Foreword

ABPmer was commissioned by Natural England to undertake an intertidal benthic monitoring survey of the Duddon Estuary SSSI. The aim of the study was to undertake a comprehensive Phase I and Phase II intertidal survey of the SSSI to inform the ecological condition of the SSSI feature 'Littoral sediment' and the SAC feature 'Mudflats and Sandflats not covered by seawater at low tide'.

There has not previously been a full littoral sediment survey of the Duddon Estuary. With the only known example to be a survey of the Morecambe Bay SAC, which covered partial areas of the Duddon Estuary SSSI (Royal Haskoning, 2006). Therefore, the aim of the survey was to provide an initial baseline description of the estuary along with details of the extent and condition of the 'Mudflats and Sandflats not covered by seawater at low tide' feature. Ultimately, the data will form a part of the ongoing condition assessment for the site and to contribute to long term site monitoring.

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England. Natural England comments on the limitations of the survey and recommendations for future studies are summarised in Appendix G.

Executive summary

The Duddon Estuary was designated as a Site of Special Scientific Interest (SSSI) in 1991. It was subsumed by the Morecambe Bay and Duddon Estuary Special Protection Area (SPA) in 2005, contributing to the UK's suite of Natura 2000 sites and overall Marine Protected Area (MPA) network. It is also recognised as a Wetland of International Importance under the Convention on Wetlands (Ramsar) (Ramsar, 1999).

ABPmer was commissioned by Natural England to undertake an intertidal benthic monitoring survey of the Duddon Estuary SSSI. There has not previously been a full littoral sediment survey of the Duddon Estuary. Therefore, the aim of the study was to undertake a comprehensive Phase I and Phase II intertidal survey of the SSSI to provide an initial baseline description of the estuary along with details of the extent and condition of the 'Mudflats and Sandflats not covered by seawater at low tide' feature.

A comprehensive intertidal survey of the Duddon Estuary SSSI was completed between 5 and 7 June 2023. The survey identified and mapped the distribution and extent of sedimentary intertidal habitats across the area. The results of this survey also provide a baseline description of the Duddon Estuary which will be used to inform future temporal comparisons and subsequent condition assessments by Natural England. Ultimately, the data will form a part of the ongoing condition assessment for the site and to contribute to long term site monitoring.

The majority of the intertidal area across the Duddon Estuary comprised of firm, well drained sediments ranging from clean fine sands to muddy sand forming extensive areas of intertidal soft sediment. The mudflats and sandflats across the area typically supported an invertebrate community characteristic of moderately exposed inner to middle estuary, variable salinity conditions.

All stations sampled within the Duddon Estuary SSSI were assessed to have either good or high Infaunal Quality Index (IQI) status, meaning the species composition observed within the samples were typical of expected faunal communities within the 'Mudflats and sandflats not covered by seawater at low tide' feature. Characteristic fauna included burrowing amphipods, the mudsnail *Peringia ulvae*, polychaetes and Nematoda. Additional species of note included the Baltic tellin *Macoma balthica* and the thin tellin *Macomangulus tenuis*, the common cockle *Cerastoderma edule* and the lugworm *Arenicola marina.*

Eight biotopes were recorded across Duddon Estuary SSSI. The biotopes recorded were:

- Saltmarsh (LS.LMp.Sm);
- Littoral sand (LS.LSa);
- Polychaetes in littoral fine sand (Ls.Lsa.FiSa.Po);
- Amphipods and *Scolelepis spp*. in littoral medium-fine sand (LS.LSa.MoSa.AmSco);
- Polychaete/bivalve dominated muddy sand shores (LS.LSa.MuSa);

- *Mytilus edulis* beds on littoral mud (LS.LBR.LMus.Myt);
- *Bathyporeia pilosa* and *Corophium arenarium* in littoral muddy sand (LS.LSa.MuSa.BatCare); and
- *Hediste diversicolor, Macoma balthica* and *Eteone longa* in littoral muddy sand (LS.LSa.MuSa.HedMacEte).

Total organic carbon content within the Duddon Estuary SSSI ranged from 0.16 % to 0.20 %, within the range recorded during a condition assessment of north-west intertidal sand and mud. No contaminants recorded within sediments at any of the stations within Duddon Estuary SSSI were above their respective Action Level (AL) 1, where levels are provided, indicating that contaminant levels were typically low.

Across Duddon Estuary there were multiple records of anthropogenic activities recorded during the survey including vehicular access to intertidal areas, evidence of fishing and bait digging, abandoned vehicles and vessels and litter. However, there was limited evidence of disturbance to habitat features as a result of the activities observed.

As no previous baseline sampling has been undertaken within Duddon Estuary SSSI a quantitative assessment of temporal change was not possible, however a qualitative assessment has been undertaken using the only known historic report (Royal Haskoning, 2006).

Overall, across the estuary there appears to have been a marginal shift in sediment composition from occasional finer muddier sand sediments to medium sand from 2004-2005 to 2023. Infauna appear to be slightly impoverished in some areas due to the presence of more mobile sand sediments with a potential reduction in *A. marina, M. balthica* and *C. edule* for more polychaete dominated sediments, resulting in a shift in some biotope classifications.

However, whilst there is some variation in biotopes present (composition and coverage), there does appear to be a broad level of comparability in the biotopes present between 2004-2005 and 2023.

Overall, the Mudflats and sandflats not covered by seawater at low tide feature within the Duddon Estuary SSSI is considered to broadly meet the key attributes for the feature. This conclusion will be reviewed by Natural England when they undertake a formal condition assessment of the site.

Contents

Figures

Tables

1 Introduction

The Duddon Estuary is located to the north of Morecambe Bay, formed by the River Duddon which drains into the north of the estuary and the smaller Kirkby Pool. It is a wide tidal inlet with a high tidal range. Tidal flows into and out of the estuary are strong and wave action can be significant at high water due to the wide estuary mouth and south westerly exposure (Cumbria County Council, 2018). Due to this, sediments in the estuary can be highly mobile. The freshwater drainage is small in comparison to the tidal influence.

The Duddon Estuary was designated as a Site of Special Scientific Interest (SSSI) in 1991. It was included as a component of the Morecambe Bay and Duddon Estuary Special Protection Area (SPA) and Morecambe Bay Special Area of Conservation (SAC) in 2005, contributing to the UK's suite of Natura 2000 sites and overall Marine Protected Area (MPA) network. It is also recognised as a Wetland of International Importance under the Convention on Wetlands (Ramsar) (Ramsar, 1999).

The Morecambe Bay SAC designation (a total area of 61,506.22 ha), of which Duddon Estuary forms a component part, is based on the qualifying habitats described in the citation. These include mudflats and sandflats not covered by seawater at low tide.

The Duddon Estuary SSSI features of interest are grouped into 26 Monitored Features, listed on Designated Sites View[1]. These features include 'Littoral sediment' which covers all sedimentary habitats located between high and low tide.

ABPmer was commissioned by Natural England to undertake an intertidal benthic monitoring survey of the Duddon Estuary SSSI. The aim of the study was to undertake a comprehensive Phase I and Phase II intertidal survey of the SSSI to inform the ecological condition of the SSSI feature 'Littoral sediment' and the SAC feature 'Mudflats and Sandflats not covered by seawater at low tide'.

There has not previously been a full littoral sediment survey of the Duddon Estuary. With the only known example to be a survey of the Morecambe Bay SAC, which covered partial areas of the Duddon Estuary SSSI (Royal Haskoning, 2006). Therefore, the aim of the survey was to provide an initial baseline description of the estuary along with details of the extent and condition of the 'Mudflats and Sandflats not covered by seawater at low tide' feature. Ultimately, the data will form a part of the ongoing condition assessment for the site and to contribute to long term site monitoring.

[1] Designated Site View. Duddon Estuary SSSI - https://designatedsites.naturalengland.org.uk/SiteDetail.aspx?SiteCode=S1000104&SiteName=Duddon%20Estuary&countyCode=&responsiblePerson=&SeaArea=&IFCAArea=

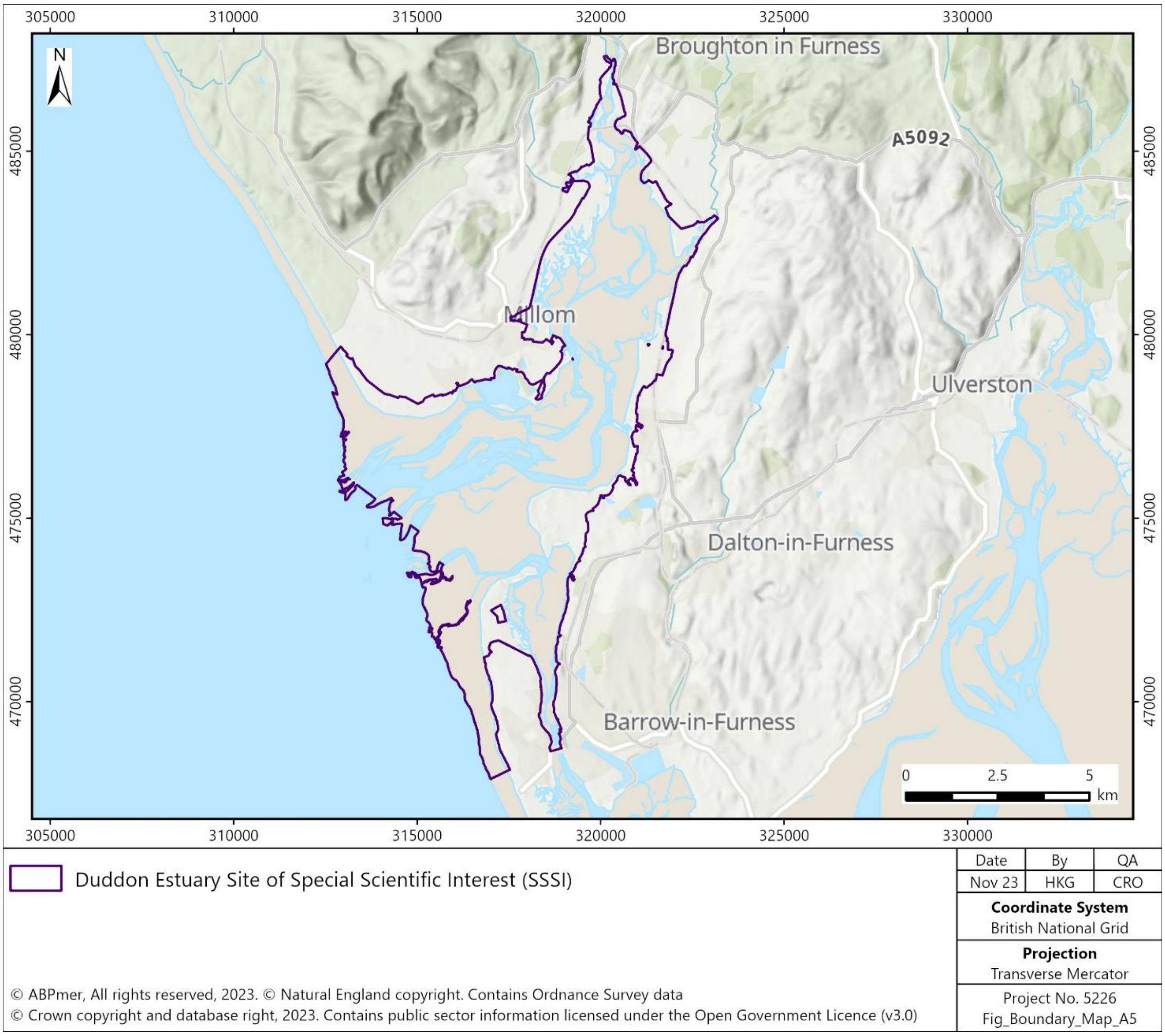

Figure 1. Map of South Cumbria showing the location of the Duddon Estuary

1.1 Objectives

The key aims and objectives of the survey were to:

- Undertake Phase I and Phase II surveys of the Duddon Estuary SSSI to gather robust evidence on the distribution and extent of sedimentary intertidal habitats and features;
- Identify and map the extent and distribution of intertidal sedimentary habitats and biotopes of the Duddon Estuary SSSI according to the European Nature Information System (EUNIS) habitat classifications; and
- Provide a preliminary assessment of the condition of the features from the Phase I and Phase II survey data.

The evidence collected will be used by Natural England to enhance the understanding of the extent and feature condition of the littoral sediment feature within Duddon Estuary SSSI and the SAC qualifying habitat 'Mudflats and Sandflats not covered by seawater at low tide' within the Duddon Estuary SSSI against the key attributes:

- Distribution: presence and spatial distribution of biological communities
- Structure and function: presence and abundance of key structural and influential species
- Structure: non-native species
- Structure: sediment composition and distribution
- Structure: sediment total organic carbon content
- Structure: species composition of component communities
- Supporting processes: sediment contaminants

The survey methodology and analysis were designed to be compatible with the previous monitoring undertaken within Morecambe Bay SAC (Royal Haskoning, 2006). This was to allow a temporal comparison of the extent and distribution of intertidal habitats, where possible. This report presents the results of the monitoring undertaken in June 2023, to summarise the distribution and extent of intertidal sedimentary habitats throughout the Duddon Estuary SSSI.

2 Methods

2.1 Phase I habitat mapping

A Phase I intertidal ecological survey was conducted between 5 and 7 June 2023 to characterise the intertidal mudflat and sandflat habitats present within Duddon Estuary SSSI.

The survey was undertaken by hovercraft, operated by Intertidal Ltd., at low water and coincided with a spring tidal phase to maximise the accessibility of the site and the quality of the data (Figure 2). The survey approach was based on the standardised Phase 1 mapping methodology as detailed in the Marine Monitoring Handbook, Procedural Guidance No 3-1 (Wyn and Brazier, 2001) and Countryside Council for Wales (CCW) Handbook for Marine Intertidal Phase 1 Survey and Mapping (Wyn *et al.,* 2000). Habitats in the area were mapped using the Marine Habitat Classification for Britain & Ireland (MHCBI) v22.04) to biotope class levels 4 or 5 (JNCC, 2022).

Figure 2. Hovercraft use to undertake Phase I habitat mapping of the Duddon Estuary SSSI at low water, June 2023

Mapping of habitats was undertaken along defined line transects to allow interpolation of results across non surveyed areas, to maximise survey coverage. A Garmin hand-held Global Positioning System (GPS) (accurate to ±5 m) was used to track the movements of the hovercraft with waypoints marked where notable changes in the substratum occurred (e.g., sediment type or surface features such as standing water, ripples etc., and/or where there was a notable change in biological surface features which may indicate a change in species composition e.g., tubes, casts, feeding pits, faecal mounds). Digital photographs were taken of the substratum where each waypoint was marked to aid in post-survey habitat assessment and mapping.

Where observed species of conservation interest and any characterising, nationally rare or scarce species were also recorded within the study area. In addition, the density of conspicuous organisms (e.g., *Arenicola marina*) were estimated by counting the number of surface features in a 50 cm^2 quadrat (casts, surface siphon holes etc).

Detailed field notes were made during the course of the survey with the information recorded relating to the time and date of survey, the habitats and sediments encountered, the presence of any obvious or interesting fauna or habitats, evidence of bird feeding and/or evidence of anthropogenic disturbance. Digital photographs of the sediment surface, and the wider area in general were taken at each sampling site and geo-referenced, together with the target notes, to aid in biotope identification.

2.2 Phase II sampling

Phase II core sampling was undertaken concurrently with the Phase I mapping. Core sampling was undertaken in line with the North East Atlantic Marine Biological Analytical Quality Scheme (NMBAQC) and Water Environment (Water Framework Directive) Regulation protocols for sampling of benthic core samples and Particle Size Analysis (PSA). Sampling was undertaken at 20 stations using a 0.01 m^2 hand-held corer (Figure 3).

Figure 3. Faunal core sampling using a 0.01 m^2 hand-held corer

At Stations 1 to 20, one core sample (to a depth of approximately 15 cm) was collected for macrofaunal analysis (invertebrate abundance and biomass) and an additional core collected for PSA. Triplicate samples were also taken and stored separately at a subset of five stations. At the same five stations a further core was also collected for contaminants analysis. A summary of the samples collected at each station was as follows and a list of samples provided in Appendix **A**:

- 30 macrofaunal cores, 15 cm deep – 5 triplicate cores; 15 single cores;
- 20 sediment/ PSA cores, 15 cm deep; and
- 5 contaminant samples.

Interstitial salinity measurements were taken at all core sample locations using a salinity refractometer.

Samples were collected from a combination of historic stations and new stations, at locations shown in Figure 4. The use of historic stations, building on previous partial monitoring of Duddon Estuary SSSI by Royal Haskoning (2006), provided a temporal comparison of habitat extent between years and also allowed some comparison of the condition of the SSSI through time.

At each station a waypoint was taken with the hand-held GPS to log the sample location. Detailed field notes were recorded to capture the nature of the habitat at each location. Information recorded included:

- Date and time;
- GPS waypoint;
- Sediment type (Folk2 classification);
- Biotope (high-level classification);
- Salinity;
- Anoxic layer depth;
- Notable habitat features (e.g., tubes, casts, feeding pits, faecal mounds);
- Evidence of bird feeding (e.g., footprints); and
- Evidence of anthropogenic disturbance (e.g., bait digging).

Digital photographs of the sediment surface, characteristic species and features, and the wider area in general were taken at each sampling site and geo-referenced, together with the target notes. Station photos are provided in Appendix B.

[2] Folk, R.L. (1954) The distinction between grain size and mineral composition in sedimentary rock nomenclature. J. Geology 1954,62, 344–359.

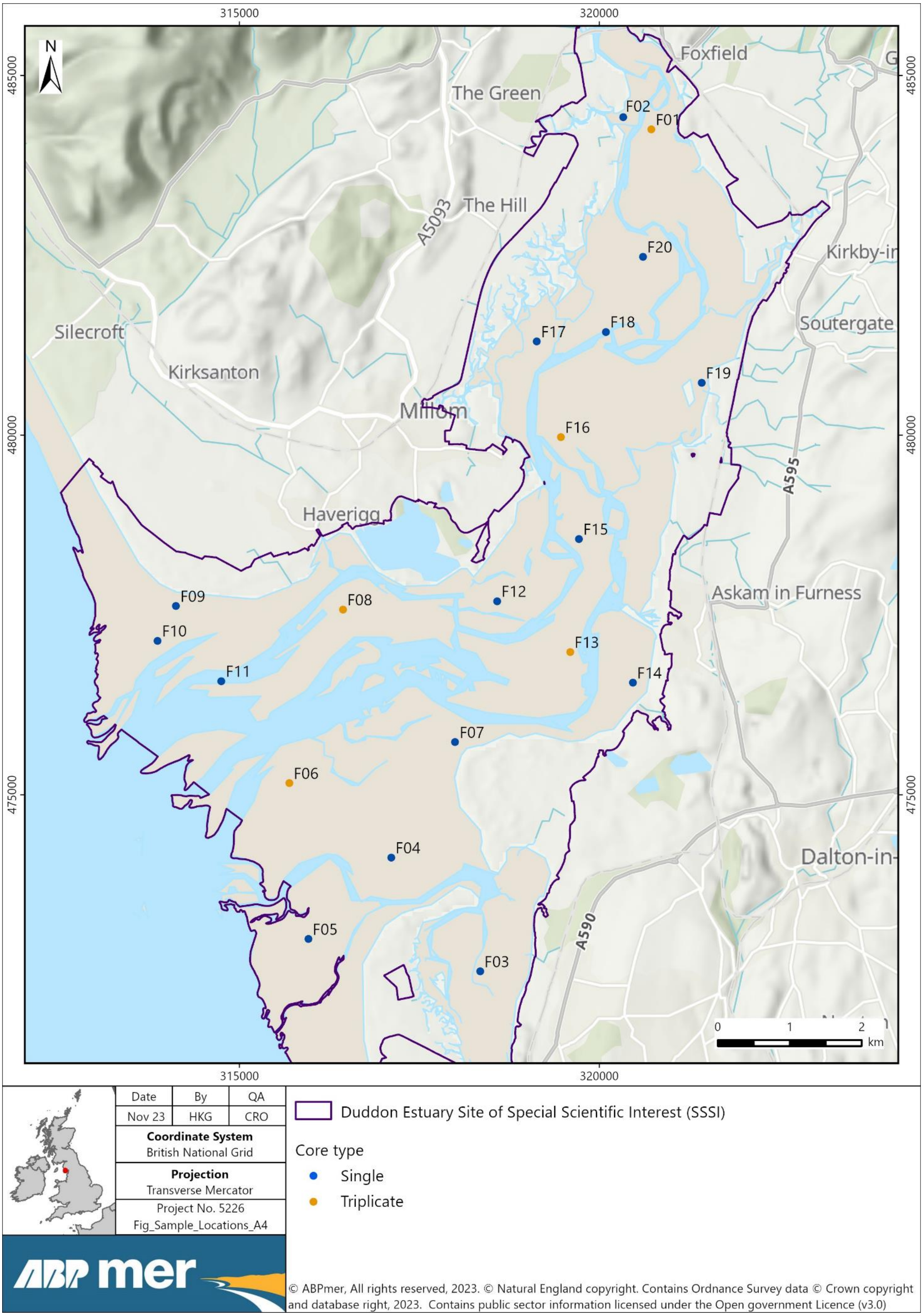

Figure 4. Survey stations within Duddon Estuary SSSI

2.3 Sample analysis

Following collection, samples were processed ready for transport to respective laboratories for analysis. Faunal samples were discharged onto a sieving table and gently washed over a 0.5 mm sieve to remove excess substrate. The residue was photographed before being transferred to a labelled (internal and external), plastic bucket and preserved using 4 % buffered formaldehyde solution (Figure 5). The lids were sealed with tape and buckets placed within ridged plastic boxes for shipping.

Figure 5. Sieving and preparation of faunal cores

The faunal samples were analysed by Hull Marine Laboratory, an accredited Marine Biological Analytical Quality Control Scheme (NMBAQC) laboratory. All work was undertaken in conformance with ISO 16665 standards and the NMBAQC Scheme Guidelines (Worsfold and Hall, 2010).

On arrival at the laboratory, fauna were sorted from the sieve residue using low power binocular microscopes. Macrofaunal specimens were identified to species level (where practicable) and enumerated. Biomass was recorded at the major Phyla.

A minimum of 10% of all core samples were re-analysed by an external laboratory for quality assurance for sample processing; this was carried out for both the extraction of fauna and for identification.

The full results of the faunal analysis are provided in Appendix C.

The sediment samples were analysed by SOCOTEC Ltd for PSA and contaminant analysis. The PSA was carried out following the NMBAQC standardised methodology, using a Mastersizer laser diffractor which produces detailed sedimentary profiles for fine sediments (clay, sand and silts). Total Organic Carbon (TOC) content was calculated through Loss on Ignition, whereby samples were dried for 24 hours at 105˚C before being burned to a constant weight at 450˚C for 12 hours.

Contaminant analysis included metals, polycyclic aromatic hydrocarbons (PAHs), organotins, polychlorinated biphenyls (PCBs) and Brominated Flame Retardants (PBDEs). Table 1 provides a summary of the analysis undertaken.

The full results of the PSA and contaminant analysis are provided in Appendix E and F respectively.

Table 1. Parameters measured for the PSA and sediment contaminant analysis

Determinant	LoD	Method/Instrument
Metals suite: As, Cd, Cr, Cu, Pb, Mn, Hg, Ni, Zn	0.01-2 mg/kg	Microwave HF/Boric acid extraction followed by ICP analysis.
Metals suite: Al, Fe, Li, N	0.5-36 mg/kg	Aqua Regia extraction and ICPOES
PCBs (ICES 7)	0.08 µg/kg	Solvent extraction and GC-MS-MS
PAH (16)	1 µg/kg	Solvent extraction & GC-MS
PBDEs	0.05 µg/kg	Solvent extraction & GC-MS-MS
Organotins (TBT)	1 µg/kg	Acid digest and solvent extraction GC-MS
Organochlorine Pesticides (OCPs)	0.1 µg/kg	Solvent extraction & GC-MS-MS
PSA	%	Distribution by wet and dry sieving and laser diffraction
TOC	% LOI	Carbonate removal and sulphurous acid/combustion at 1600°C/NDIR.

2.4 Post survey analysis

Following completion of the Phase I habitat survey, raw data were transferred from field notes to electronic spreadsheets. GPS waypoints and track logs were downloaded and were subsequently used to create maps showing the spatial distribution of habitats and species as mapped during the survey (accurate to within 5 m).

Biotopes were assigned according to MHCBI v22.04 (JNCC, 2022) and mapped as polygons to show, as far as possible, the distribution and extent of biotopes within Duddon Estuary SSSI. The Joint Nature Conservation Committee (JNCC) correlation table was used to assign EUNIS codes to each habitat type (JNCC, 2018).

All Geographical Information System (GIS) outputs were generated in ArcGIS version 10.7.1 and metadata were produced in accordance with MEDIN standards in the MESH data exchange format.

A range of statistical analyses were used to describe the benthic faunal assemblages recorded within the Duddon Estuary SSSI.

Univariate statistical descriptors of the invertebrate assemblages were calculated using Microsoft Excel software. The data were analysed in a number of ways in order to extract information describing the abundance of fauna, the number of taxa present (diversity) and the total major group biomass at each station.

The AZTI Marine Biotic Index (AMBI) (Borja *et al.,* 2000) was also used to define the Infaunal Quality Index (IQI) for each station, to assess the ecological status of macrobenthic infaunal samples. The IQI is based on a weighted average of the taxa richness, the AMBI Ecological Group (EG) score (a weighted average sensitivity score of all individuals within a sample) and Simpsons diversity. The AMBI describes the sensitivity of a macrobenthic community to anthropogenic and natural disturbance.

3 Survey Results

This section presents the results from the Duddon Estuary SSSI benthic survey undertaken in June 2023. The section is structured as follows:

- Section 3.1: Provides an overview of the Site;
- Section 3.2: Describes the extent of mudflat and sandflat biotopes across the Duddon Estuary;
- Section 3.3: Provides data on the sediment classification;
- Section 3.4: Describes the structure of the invertebrate assemblages in terms of composition and relative abundance;
- Section 3.5: Outlines the results of the contaminant analysis; and
- Section 3.6: Provides an overview of the potential effects arising from anthropogenic activities within the Site.

Field notes including records of the sediment and biotopes identified at each station, are presented in Appendix A.

3.1 Site overview

The Duddon Estuary is characterised by extensive mobile sandflats in the channel and lower estuary. To the eastern side at the mouth of the estuary is a large area of sand dunes. Sediments become progressively muddier in the upper estuary, where they become backed by saltmarsh and marshland in the upper reaches, notably on the western side.

Two main intertidal soft sediment habitats were identified within the area:

- Saltmarsh (Figure 6A); and
- Extensive low shore firm rippled medium to fine sandflats.

The low shore sandflats consisted of firm, well drained, rippled sand which supported several biotopes (Figure 6B). The presence of *Arenicola* sp. casts as well as other polychaetes and amphipod crustaceans was variable across the site.

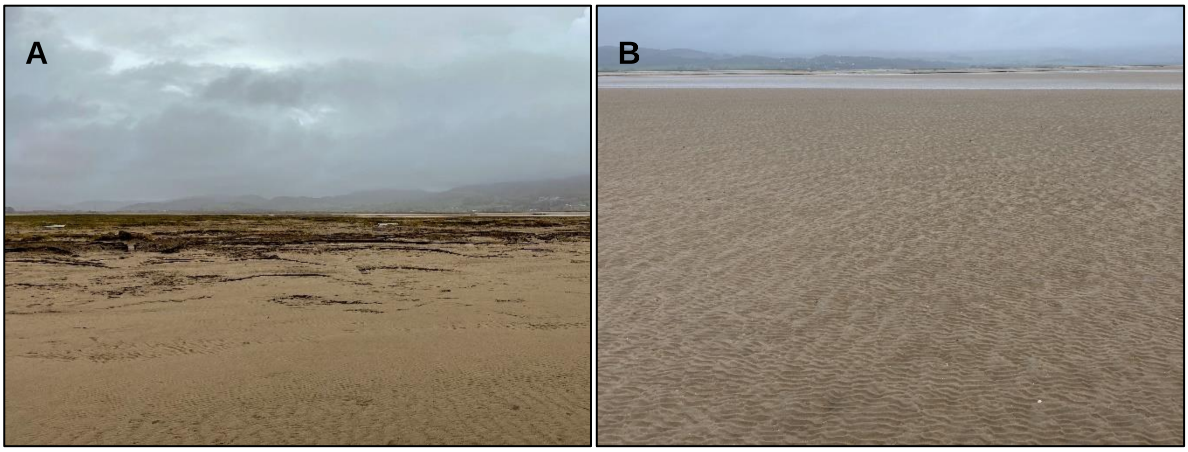

Figure 6. Predominant habitats recorded within the Duddon Estuary. A) saltmarsh, B) extensive low shore sandflats

3.2 Biotope description

Biotopes were assigned following Phase I mapping and were ground truthed following the Phase II faunal analysis. Figure 7 shows the distribution and extent of the biotopes identified within the Duddon Estuary SSSI. The area of each identified biotope is provided in Table 2. The total extent of the littoral sediment feature observed during the Phase I habitat mapping of the Duddon Estuary was 3,680 ha.

Extensive areas of saltmarsh, predominantly Atlantic salt meadow, were observed along the eastern and western banks of the inner estuary. Muddier sediments were present adjacent to the saltmarsh and within the saltmarsh creeks on either side of the estuary. Faunal communities within the muddier sediments were characterised by oligochaetes, polychaetes and the mudsnail *Peringia ulvae.* This biotope was classified as Polychaete / bivalve dominated muddy sand shores (LS.LSa.MuSa).

Within the central area of the inner estuary an area of well drained, slightly muddy sand was observed with a notable presence of amphipods, including *Corophium* sp. and *Bathyporeia* sp.. As a result the habitat was identified as '*Bathyporeia pilosa* and *Corophium arenarium* in littoral muddy sand' (LS.LSa.MuSa.BatCare) (Figure 7).

Within the middle estuary, to the eastern side of the channel the area transitioned to fine rippled slightly more muddy sand with oligochaetes, polychaetes *P. elegans and E. longa* and mudsnail *P. ulvae* common. The habitat was identified as '*Hediste diversicolor, Macoma balthica* and *Eteone longa* in littoral muddy sand' (LS.LSa.MuSa.HedMacEte; Figure 7).

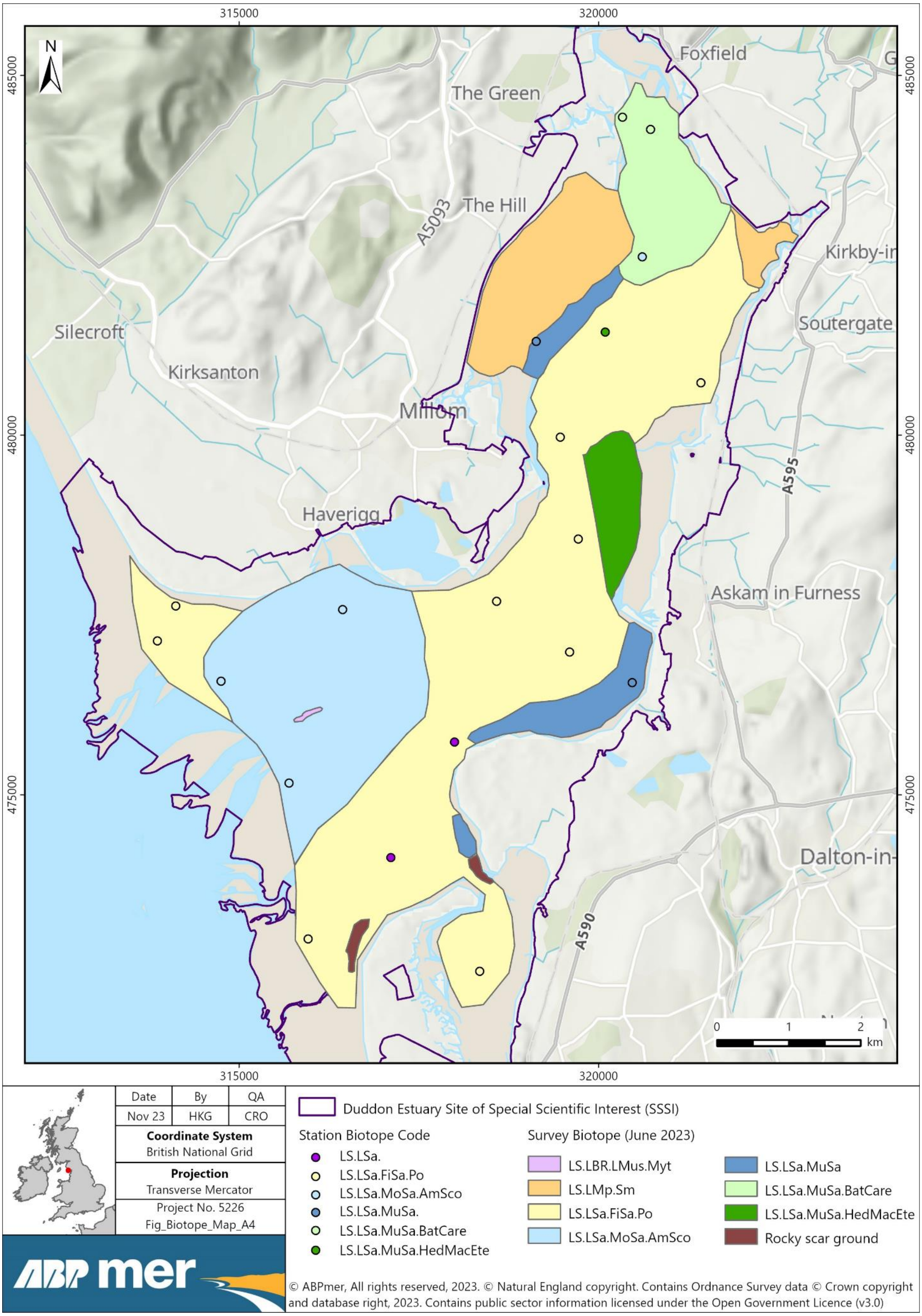

Figure 7. Distribution of biotopes observed during Phase I habitat mapping of the Duddon Estuary, in June 2023.

Across much of the rest of the Duddon Estuary the sediments become better drained rippled sand forming extensive sandflats composed of mobile, clean medium and fine sand. This habitat extended from the middle estuary to the mouth of the estuary. All stations had a low species richness and the infaunal communities were characterised by polychaetes and crustaceans. The dominant biotope was identified as ‘Polychaetes in littoral fine sand’ (LS.LSa.FiSa.Po). Fauna observed within the area included *Eteone longa, Macoma balthica, Pygospio elegans, Bathyporeia* sp. and *Nephtys hombergii*, *Cerastoderma edule* were also observed (Figure 8).

Figure 8. Well drained, rippled sand forming extensive sandflats across Duddon Estuary SSSI. Biotope: Polychaetes in littoral fine sand (LS.LSa.FiSa.Po)

To the northern side of the mouth of the Duddon Estuary SSSI the sediment profile changed from low lying ripples to larger sand waves (Figure 9).

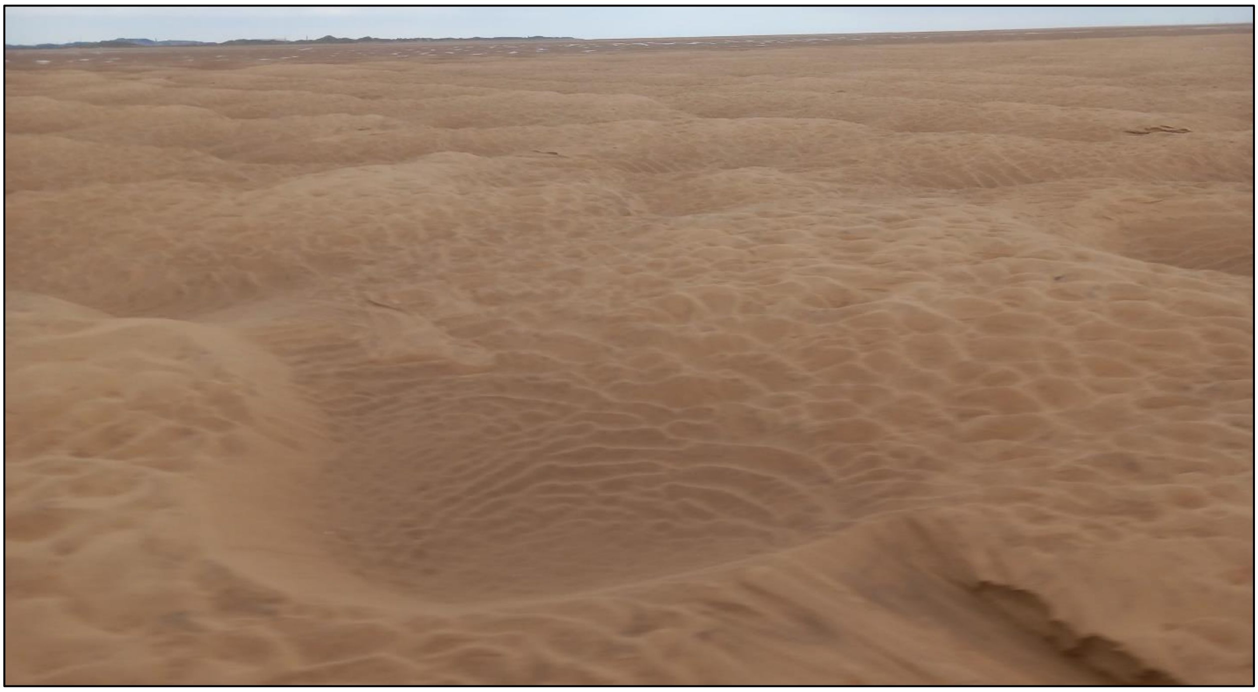

Figure 9. Larger sand waves present to the northern side of Duddon Estuary entrance. Biotope ‘Amphipods and *Scolelepis spp*. in littoral medium-fine sand’ (Ls.LSa.MoSa.MaSco)

Sediment remained as medium to fine sand, however, a fraction of coarser sediment was present. The sediment contained little or no organic matter, had no anoxic layer and was well drained. Within this area the community was relatively species poor but was dominated by burrowing amphipods *Bathyporeia spp*. and *Haustorius arenarius* alongside polychaetes and isopods. This biotope was identified as 'Amphipods and *Scolelepis spp*. in littoral medium-fine sand' (Ls.LSa.MoSa.AmSco).

Within a small area to the centre of the 'Amphipods and *Scolelepis spp*. in littoral medium-fine sand' biotope a patch of dense mussel *Mytilus edulis* bed on sheltered mud was identified. Beneath the mussels there was a build-up of pseudofaeces that resulted in a layer of very soft sediment which was anoxic at the surface with few other fauna present (Figure 10). This patch was classified as '*Mytilus edulis* beds on littoral mud' (LS.LBR.LMus.Myt).

Figure 10. *Mytilus edulis* beds on littoral mud (LS.LBR.LMus.Myt)

To the east of the estuary, sediments were finer than central and western areas, with a larger mud fraction present. Large areas of sediment had aggregations of the lugworm *Arenicola marina* casts (Figure 11), but not in sufficient density to suggest a change to the biotope '*Macoma balthica* and *Arenicola marina* in littoral muddy sand' (LS.LSa.MuSa.MacAre). In addition, no anoxic layer was observed at any of the sites within the Duddon Estuary, with the exception of the very small area of '*Mytilus edulis* beds on littoral mud' (Figure 7). As such the area was classified as 'Polychaete/bivalve dominated muddy sand shores' (LS.LSa.MuSa).

Figure 11. *Arenicola marina* casts observed at the mid and outer extent of the Duddon Estuary.

Shingle scars were recorded in the Duddon Estuary at the entrance to Walney Channel (Figure 12). These scars were composed of pebbles with some small cobbles and gravel. Marine communities present were animal dominated with occasional clumps of algae *Ulva sp*.. Rock surfaces were dominated by barnacles, mainly *Austrominius modestus* with *Semibalanus balanoides* also present and Littorinids.

Figure 12. Rocky scar ground at the entrance of Walney Channel

Table 2. Extent of each biotope identified during the June 2023 survey of the Duddon Estuary SSSI

Biotope description	Biotope code	Area (ha)
***Mytilus edulis* beds on littoral mud**	LS.LBR.LMus.Myt	2.64
Saltmarsh	LS.LMp.Sm	371.83
Polychaetes in littoral fine sand	LS.LSa.FiSa.Po	1958.58
Amphipods and *Scolelepis spp*. in littoral medium-fine sand	LS.LSa.MoSa.AmSco	758.18
Polychaete/bivalve dominated muddy sand shores	LS.LSa.MuSa	194.63
***Bathyporeia pilosa* and *Corophium arenarium* in littoral muddy sand**	LS.LSa.MuSa.BatCare	271.42
***Hediste diversicolor, Macoma balthica* and *Eteone longa* in littoral muddy sand**	LS.LSa.MuSa.HedMacEte	122.68
Rocky scar ground	-	15.25

In total eight biotopes were recorded throughout the area surveyed, these were:

- Saltmarsh (LS.LMp.Sm);
- Littoral sand (LS.LSa);
- Polychaetes in littoral fine sand (Ls.Lsa.FiSa.Po);
- Amphipods and *Scolelepis spp*. in littoral medium-fine sand (LS.LSa.MoSa.AmSco);
- Polychaete/bivalve dominated muddy sand shores (LS.LSa.MuSa);
- *Mytilus edulis* beds on littoral mud (LS.LBR.LMus.Myt);
- *Bathyporeia pilosa* and *Corophium arenarium* in littoral muddy sand (LS.LSa.MuSa.BatCare); and
- *Hediste diversicolor, Macoma balthica* and *Eteone longa* in littoral muddy sand (LS.LSa.MuSa.HedMacEte).

3.3 Sediment classification

The sediment classifications based upon PSA data for each station collected during the June 2023 survey are presented in Table 3. Stations were classified as very fine to medium sand. The distribution of sediments sampled throughout the estuary are presented in Figure 13.

Finer muddier sediments were generally distributed towards the inner estuary and towards the edges of the channel, medium and coarser sediments, classified as sand and slightly gravelly sand were predominantly distributed to the central channel and towards the mouth of the estuary.

Total organic carbon content was sampled at six stations within the Duddon Estuary SSSI, the TOC recorded at each station sampled is presented in Table 4. TOC varied only marginally across the Duddon Estuary SSSI, ranging from 0.16 to 0.20 with the average TOC 0.17 (% volume LOI).

Table 3. Sediment classification based on particle size data for each station in Duddon Estuary in June 2023

Station	Sediment Description	Major Sediment Fractions		
		% Gravel	% Sand	% Mud
F01	Slightly Gravelly Sand	0.02%	93.04%	6.93%
F02	Muddy Sand	0.00%	78.81%	21.19%
F03	Sand	0.00%	97.70%	2.30%
F04	Sand	0.00%	100.00%	0.00%
F05	Slightly Gravelly Sand	0.14%	98.68%	1.18%
F06	Slightly Gravelly Sand	0.04%	99.96%	0.00%
F07	Slightly Gravelly Sand	0.27%	98.09%	1.64%
F08	Slightly Gravelly Sand	1.79%	98.21%	0.00%
F09	Slightly Gravelly Sand	0.74%	99.26%	0.00%
F10	Sand	0.00%	100.00%	0.00%
F11	Sand	0.00%	100.00%	0.00%
F12	Sand	0.00%	100.00%	0.00%
F13	Sand	0.00%	98.32%	1.68%
F14	Slightly Gravelly Sand	0.03%	96.68%	3.29%
F15	Sand	0.00%	98.09%	1.91%
F16	Sand	0.00%	98.58%	1.42%
F17	Muddy Sand	0.00%	80.69%	19.31%
F18	Slightly Gravelly Sand	0.02%	93.97%	6.01%
F19	Sand	0.00%	91.33%	8.67%
F20	Muddy Sand	0.00%	89.11%	10.89%

Table 4. Total Organic Carbon content for stations within Duddon Estuary in June 2023

Station	TOC (% Volume LOI)
F01	0.20
F06	0.16
F08	0.18
F13	0.16
F16	0.17

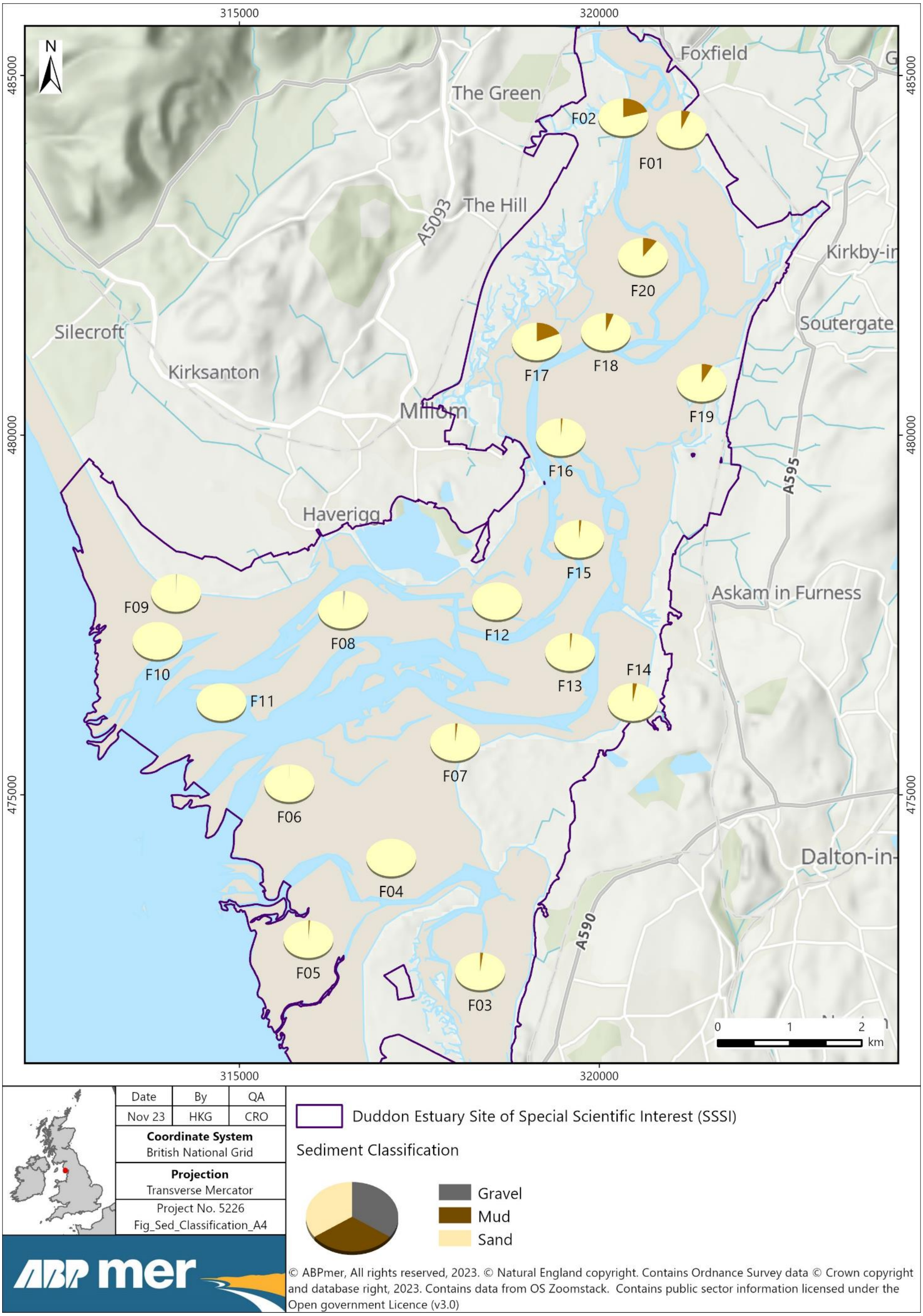

Figure 13. Distribution of sediments sampled within the Duddon Estuary in June 2023.

3.4 Characterisation of benthic fauna

Analysis of the June 2023 faunal data was undertaken to investigate the structure and composition of faunal communities present within the mudflats and sandflats at the Duddon Estuary SSSI at this snapshot in time.

3.4.1 Community composition

The average abundance, diversity and biomass of taxa recorded at each station are presented in Table 5.

Table 5. Abundance, biomass and diversity (Simpsons index (1- ʎ) at stations within the Duddon Estuary in June 2023

Station	No. of taxa	No. of Individuals	Diversity (1-ʎ)	Biomass (g)
F01A	7	236	0.61	0.3886
F01B	4	215	0.37	0.2911
F01C	5	322	0.65	0.3075
F02	3	8	0.46	0.0091
F03	3	5	0.80	0.2534
F04	2	4	0.50	0.0024
F05	1	1	0.00	0.0072
F06A	2	3	0.67	0.0406
F06B	3	9	0.56	0.0596
F06C	5	17	0.66	0.0732
F07	2	2	1.00	0.0003
F08A	1	49	0.00	0.0652
F08B	2	70	0.03	0.0755
F08C	2	50	0.04	0.0541
F09	2	3	0.67	0.001
F10	2	2	1.00	0.0002
F11	2	3	0.67	0.0172
F12	2	77	0.03	0.8803
F13A	4	5	0.90	0.0071
F13B	2	3	0.67	0.0177
F13C	4	26	0.48	0.1876
F14	6	251	0.73	0.1212
F15	2	3	0.67	0.0169
F16A	2	2	1.00	0.0045
F16B	3	4	0.83	0.0131
F16C	4	4	1.00	0.0299
F17	8	281	0.71	1.045

Station	No. of taxa	No. of Individuals	Diversity (1-ʎ)	Biomass (g)
F18	10	78	0.76	0.67
F19	2	145	0.12	0.4557
F20	2	3	0.67	0.0002

The mean number of taxa at each station was 3 and the average number of individuals was 36. Average diversity was 1-ʎ = 0.575 and average biomass was 0.17 g. This suggests that the area is dominated by larger numbers of small individuals.

The taxa contributing most to overall abundance were the amphipod *Corophium volutator,* the polychaete *P. elegans,* Nematoda and the mudsnail *P. ulvae*. Abundances were highest at Stations F01 (A-C), F14, F17 and F18. With the exception of F14 all of these stations were located in the inner estuary and all were largely associated the muddier, less mobile sediments.

Biomass was also relatively high at Station F01 (A-C), attributed predominantly to crustacean biomass, in particular *C. volutator.* Biomass was also high at Stations F12 and F17. At both stations predominant biomass was comprised of molluscs, with the thin tellin *Macomangulus tenuis* the main contributor at F12 and the Baltic tellin *Macoma balthica* the main contributor at F17.

Figure 14 shows the relative proportions of abundance and biomass for each major taxonomic group. As can be seen from the figure molluscs were responsible for the high biomass observed across the site whereas crustacea were responsible for the majority of species abundance, followed by annelids. Miscellaneous taxa was formed of Nematoda, Nemertea and Platyhelminthes.

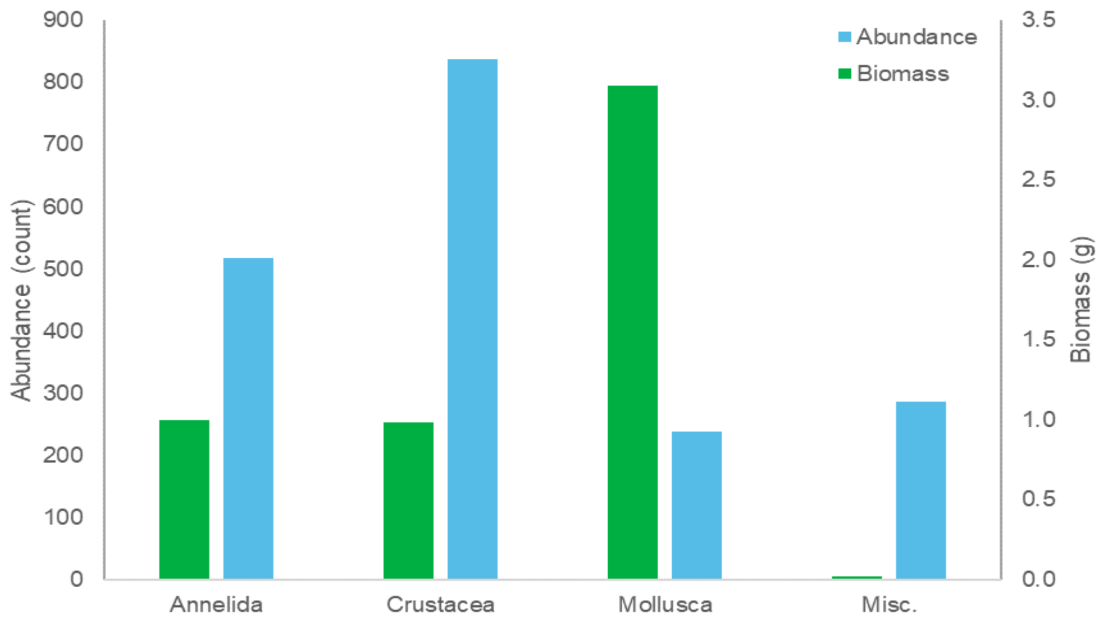

Figure 14. Total abundance (no. of individuals per sample) and biomass (g) of characterising faunal groups in samples from the Duddon Estuary SSSI.

3.4.2 Macrobenthic assemblage

Intertidal ‘mudflats and sandflats not covered by seawater at low tide’ can be divided into three broad sediment categories; clean sands, muddy sands and muds. Within the Duddon Estuary SSSI sediments consisted of muddy sandflats and as such are expected to support a rich and diverse range of infaunal species. Characteristic muddy sandflat species include the common cockle *Cerastoderma edule,* along with other bivalves, amphipods, polychaete worms and the mudsnail *P. ulvae*.

Species, characteristic of intertidal sand and muddy sand communities, and of note recorded within core samples from the Duddon Estuary SSSI include the Baltic tellin (*M. balthica*) and the thin tellin (*M. tenuis*), which were present in five and three of the samples, respectively. The common cockle *C. edule* was not recorded in any faunal core samples collected within the Duddon Estuary, however, its presence was observed by surveyors throughout the survey area. These species can be an important prey resource for birds, which may be important to support populations within the Morecambe Bay and Duddon Estuary SPA.

Similarly, the lugworm *A. marina* was not recorded within any faunal core samples, but evidence of its presence was observed regularly across the site. Due to its large size *A. marina* is often missed during core sampling. As a result, quadrat counts of lugworm casts were undertaken at numerous locations to assess potential densities of *A. marina* within the Duddon Estuary SSSI. Densities of casts were variable across the site ranging from zero up to 64 m^{-2}, recorded at two locations within the ‘Polychaete/bivalve dominated muddy sand shores’ biotope to the east of the site. Where present, more common abundances of *A. marina* casts recorded across the area were 8 to 12 m^{-2}.

Other taxa identified within faunal core samples characteristic of muddy sandflats included amphipods *Corophium volutator, Bathyporeia pelagica, B. pilosa,* polychaetes *P. elegans* and *Nephtys cirrosa,* and *P. ulvae*.

No non-native species were recorded within any of the samples. The only non-native species identified within the Duddon Estuary SSSI was the Modest barnacle *A. modestus* recorded on the shingle scars to the entrance of Walney Channel (Section 3.2).

3.4.3 Ecological status

To assess the ecological status of macrobenthic communities at stations within the Duddon Estuary SSSI AMBI was used to define the IQI for each station. The IQI is based on a weighted average of the taxa richness, the EG score (a weighted average sensitivity score of all individuals within a sample) and Simpsons diversity. ‘EG I’ describes the most sensitive taxa to natural or anthropogenic disturbance, and ‘EG V’ represent the most opportunistic taxa (i.e., those able to best colonise disturbed environments).

Results of the AMBI identified the species having the most significant contribution to faunal composition within Duddon Estuary SSSI. Table 6 shows the EG scores for each of the key species identified, full results from the AMBI assessment are provided in Appendix D.

Benthic communities were dominated by the burrowing amphipods *B. pelagica, B. pilosa* and the mudshrimp *C. volutator,* the mudsnail *P. ulvae*, polychaetes *N. cirrosa* and *P. elegans* and Nematoda (Table 6). The majority of the species identified are disturbance sensitive, disturbance indifferent, or disturbance tolerant. Only one opportunistic species was identified (*Enchytraeidae*) recorded at Stations F14, F17 and F18, located in the inner estuary, with the exception of F14, and all associated with muddier sediments.

All stations sampled within the Duddon Estuary SSSI were determined to have either good or high IQI status.

Table 6. The dominant taxa contributing most to the faunal composition at each station. Note: some cells are left blank.

Station No.	Most abundant taxa (EG score)	2nd Most abundant taxa (EG score)	3rd Most abundant taxa (EG score)	4th Most abundant taxa (EG score)	5th Most abundant taxa (EG score)	IQI Status
F01a	*Corophium volutator* (III)	*Bathyporeia pilosa* (I)	*Pygospio elegans* (III)	NEMATODA (III)	MOLLUSCA	**High**
F01b	*Corophium volutator* (III)	*Bathyporeia pilosa* (I)	NEMATODA (III)	*Pygospio elegans* (III)	-	**High**
F01c	*Corophium volutator* (III)	*Pygospio elegans* (III)	*Bathyporeia pilosa* (I)	NEMATODA (III)	*Macoma balthica* (III)	**High**
F02	*Corophium volutator* (III)	*Peringia ulvae* (III)	*Bathyporeia pilosa* (I)	-	-	**High**
F03	*Nephtys cirrosa* (II)	*Angulus tenuis* (I)	*Peringia ulvae* (III)	-	-	**High**
F04	*Bathyporeia sarsi* (I)	NEMATODA (III)	-	-	-	**High**
F05	*Angulus tenuis* (I)	-	-	-	-	**High**
F06a	*Bathyporeia pelagica* (I)	*Haustorius arenarius* (I)	-	-	-	**High**
F06b	*Bathyporeia pelagica* (I)	*Haustorius arenarius* (I)	*Pontocrates arenarius* (II)	-	-	**High**
F06c	*Bathyporeia pelagica* (I)	*Haustorius arenarius* (I)	*Pontocrates arenarius* (II)	NEMATODA (III)	*Mytilus edulis* (III)	**High**
F07	*Pygospio elegans* (III)	*Peringia ulvae* (III)	-	-	-	**Good**
F08a	*Bathyporeia pelagica* (I)	-	-	-	-	**High**
F08b	*Bathyporeia pelagica* (I)	*Eurydice pulchra* (I)	-	-	-	**High**
F08c	*Bathyporeia pelagica* (I)	*Eurydice pulchra* (I)	-	-	-	**High**
F09	Paraonis fulgens	*Corophium volutator* (III)	-	-	-	**Good**
F10	*Nephtys* (II)	*Cumopsis goodsir* (II)	-	-	-	**High**
F11	*Bathyporeia pilosa* (I)	*Nephtys* (II)	-	-	-	**High**

Station No.	Most abundant taxa (EG score)	2nd Most abundant taxa (EG score)	3rd Most abundant taxa (EG score)	4th Most abundant taxa (EG score)	5th Most abundant taxa (EG score)	IQI Status
F12	NEMATODA (III)	*Angulus tenuis* (I)	-	-	-	**Good**
F13a	*Bathyporeia pelagica* (I)	*Nephtys cirrosa* (II)	*Peringia ulvae* (III)	*Bathyporeia pilosa* (I)	-	**High**
F13b	*Nephtys cirrosa* (II)	NEMATODA (III)	-	-	-	**High**
F13c	NEMATODA (III)	*Bathyporeia pelagica* (I)	*Nephtys cirrosa* (II)	*Macoma balthica* (III)	-	**High**
F14	NEMATODA (III)	*Peringia ulvae* (III)	*Pygospio elegans* (III)	*Enchytraeidae* (V)	*Eteone longa* (III)	**Good**
F15	*Nephtys cirrosa* (II)	*Bathyporeia pelagica* (I)	-	-	-	**High**
F16a	NEMERTEA (III)	*Corophium volutator* (III)	-	-	-	**High**
F16b	*Bathyporeia pelagica* (I)	*Nephtys cirrose* (II)	NEMATODA (III)	-	-	**High**
F16c	*Nephtys* (II)	NEMATODA (III)	*Glycera tridactyla* (II)	*Bathyporeia sarsi* (I)	-	**High**
F17	*Peringia ulvae* (III)	NEMATODA (III)	*Enchytraeidae* (V)	*Manayunkia aestuarina* (III)	*Pygospio elegans* (III)	**High**
F18	*Peringia ulvae* (III)	NEMATODA (III)	*Bathyporeia pilosa* (I)	*Macoma balthica* (III)	*Enchytraeidae* (V)	**High**
F19	*Pygospio elegans* (III)	NEMATODA (III)	-	-	-	**Good**
F20	*Bathyporeia pilosa* (I)	NEMATODA (III)	-	-	-	**High**

*** Associated AMBI EG scores listed for each taxon: I = disturbance sensitive, II = disturbance indifferent, III = disturbance tolerant, IV = 2nd order opportunistic and V = 1st order opportunistic**

3.5 Contaminant analysis

There are no formal quantitative environmental quality standards for sediment contaminants, however, when characterising baseline sediment quality, it is common practice to compare against the Centre for Environment, Fisheries and Aquaculture Science (Cefas) Guideline Action Levels for the disposal of dredge material. Therefore, to assess sediment quality within the Duddon Estuary SSSI contaminant results were compared against these Cefas Guideline Action Levels to provide context to the results. Summary results are presented in Table 7. The full list of results is provided in Appendix F.

Cefas guidance indicates that, in general, contaminant levels below Action Level 1 (AL1) are of no concern, however, material with contaminant levels above Action Level 2 (AL2) are generally considered unsuitable for disposal at sea. Sediment with contaminant levels between AL1 and AL2 requires further consideration before a decision can be made.

Metal concentrations were all below AL1. Similarly, concentrations of the organotins tributyltin (TBT), as well as PCBs (sum of ICES 7 congeners) and PAHs (sum of 16 congeners) were consistently below their respective AL1. No contaminants recorded at any of the stations within the Duddon Estuary SSSI were above their respective AL1, where levels are provided.

Table 7. Concentration of contaminants in sediment samples collected from Duddon Estuary SSSI

Contaminant	Cefas Guideline Action Level (mg/kg)		Sediment Sample Concentration (mg/kg) at each core				
	AL1	AL2	F01	F06	F08	F13	F20
Arsenic	20	100	5.57	8.37	7.07	7.87	5.27
Cadmium	0.4	5	0.08	<0.03	<0.03	0.04	<0.03
Chromium	40	400	19.9	10.1	10.7	20.2	7.6
Copper	40	400	3.7	3.0	3.3	2.6	2.1
Lead	50	500	11.5	6.9	6.6	8.8	7.4
Magnesium	-	-	206	155	133	163	94.0
Mercury	0.3	3	0.03	0.05	0.01	0.01	0.04
Nickel	20	200	6.4	5.5	4.7	5.1	3.9
Zinc	130	800	24.5	15.1	10.6	11.0	11.6
Aluminium	-	-	22900	17600	18100	16400	15100
Iron	-	-	8010	7330	6710	8100	5000
Lithium	-	-	16.1	16.3	15.0	13.1	12.3
Total Nitrogen	-	-	<0.05	<0.05	<0.05	<0.05	<0.05
Hexachlorobutadiene	-	-	<0.01	<0.01	<0.01	<0.01	<0.01
Tributyltin (TBT)	0.1	1	<0.01	<0.01	<0.01	<0.01	<0.01
Polychlorinated Biphenyls (PCBs; Sum of ICES 7 congeners)	0.01	0.14	<0.01	<0.01	<0.01	<0.01	<0.01
Polyaromatic Hydrocarbons (PAHs; Sum of 16 congeners)	3.17	12.8	<0.05	<0.02	<0.02	<0.02	<0.02
Key	Cores with contaminant levels below Cefas Guideline Action Level 1 (AL1)						
	Cores with contaminant levels above AL1 and below Cefas Guideline Action Level 2 (AL2)						
	Cores with contaminant levels above AL2						

3.6 Anthropogenic activities

Potential anthropogenic influences within the Duddon Estuary SSSI were identified and mapped during the June 2023 survey. Figure 17 shows the locations where anthropogenic influences were recorded.

The types of anthropogenic activities identified were grouped into the following categories:

- Abandoned vehicles or vessels;
- Abrasion/ trampling;
- Bait digging;
- Fishing or aquaculture;
- Litter (including dumped or discarded material, gear or nets); and
- Non-natural structures.

Evidence of bait collection was confined to the eastern side of the Duddon Estuary SSSI, to the south of Askem-in-Furness. Two bait diggers were observed digging for lugworm (*A. marina*) in the low shore having accessed the site via vehicle (Figure 15). Within the same general area, slightly to the south, additional tyre tracks were also observed indicating a potential pressure from both abrasion and bait digging activities (Figure 16A).

Despite this, no further evidence of bait collection was observed within Duddon Estuary SSSI and no evidence of long-term impacts or changes to sediment composition as a result of bait digging activities were observed.

Across the wider Duddon Estuary SSSI evidence of some fishing activity was observed, with one person seen fishing with rod and line for seabass, having accessed the site via quadbike (Figure 16B). A number of abandoned vehicles were also observed including cars (Figure 16C), a vessel boiler, and a shipwreck (Figure 16D).

Only occasional evidence of litter or abandoned gear were observed throughout the estuary, however, it is worth noting that plastic fragments were recorded within core samples collected at Stations F04, F09 and F14 (Figure 4).

Figure 15. Evidence of bait digging activity

Figure 16. (A) tyre tracks to the southeast of Duddon Estuary SSSI, (B) fisherman accessing the site via quadbike (C) abandoned vehicles and (D) vessel shipwreck

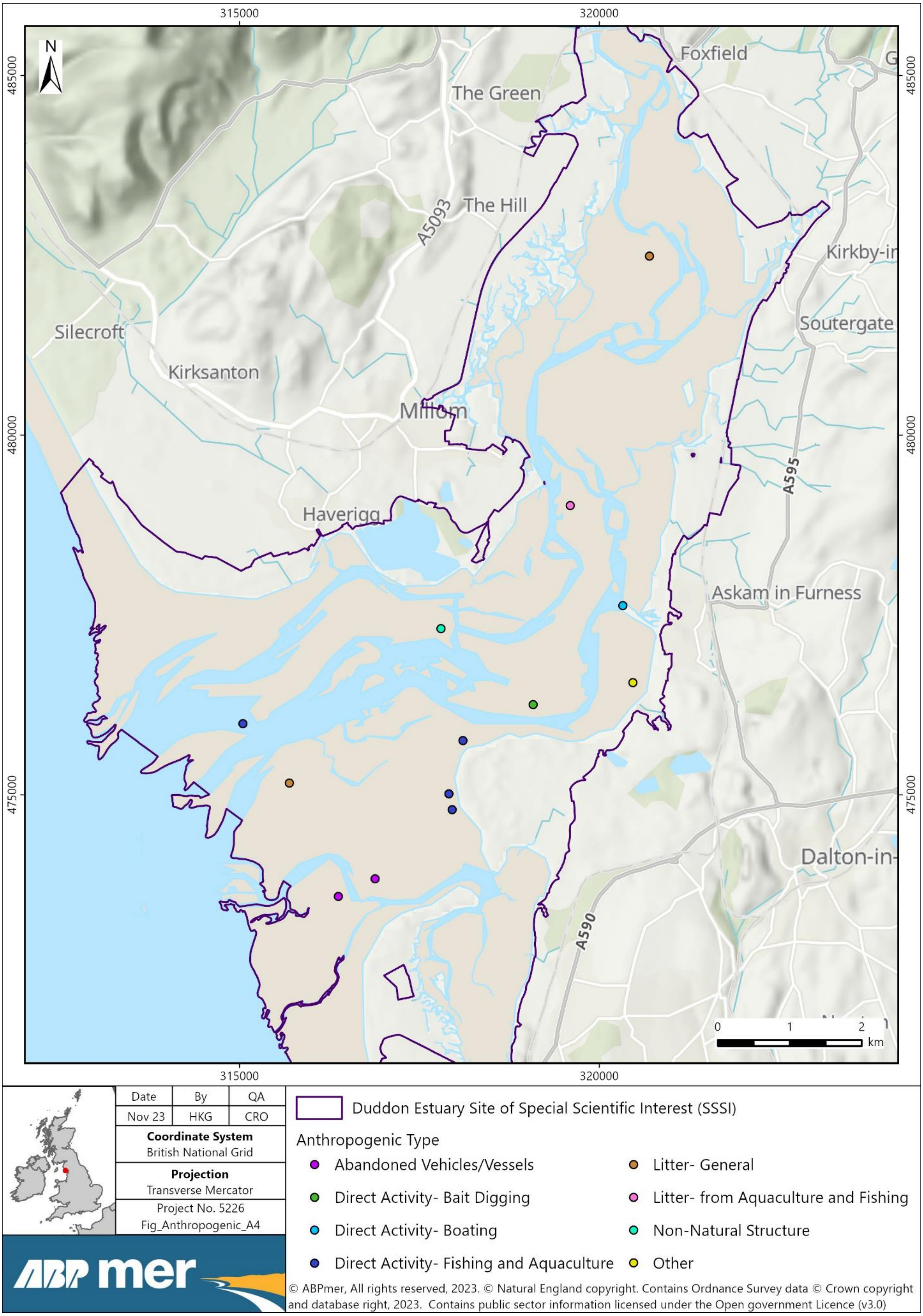

Figure 17. Locations of anthropogenic activities recorded during the June 2023 survey.

4 Temporal Comparison

Although some data on the Morecambe Bay SAC is available, there has not yet been a full littoral sediment survey undertaken on the Duddon Estuary. As no previous, baseline sampling has been undertaken at locations within Duddon Estuary SSSI it is not possible to make a quantitative comparison or statistical assessment of temporal changes to faunal communities at the sample sites or a direct comparison of changes in biotope extent. As such, as far as possible, a qualitative assessment of temporal change to faunal community composition and biotope extent has been undertaken using the only known historic report (Royal Haskoning, 2006). The report summarises the results of a survey of the Morecambe Bay SAC, which covered partial areas of the Duddon Estuary SSSI in 2004-2005 (Royal Haskoning, 2006).

The 2004-2005 survey was undertaken using a hovercraft along a series of pre-defined transects along which habitats and biotopes were identified. A total of five transects were undertaken within the Duddon Estuary (Transects A-D and F), the locations of which are shown in Figure 18. However, as a consequence of the method used the authors concluded that mapping of biotope boundaries was not an appropriate output of the study.

Temporal changes in biotope extent cannot therefore be assessed, instead, Table 8, provides a summary of the biotopes encountered along each transect during 2004-2005 and compares the results to the biotopes overlapping the transect during the June 2023 survey.

The 2004-2005 survey found that the vast majority of the intertidal area comprised fine sediments ranging from clean sand through to sand mud. Specifically, at Transect A, to the mouth of Duddon Estuary large expanses of rippled medium to coarse sand were recorded, classified predominantly as *Macoma balthica* and *Arenicola marina* in muddy sand (Royal Haskoning, 2006). During the 2023 survey sediments within this area were classified as medium to fine sand and the fauna were generally impoverished but characterised by polychaetes and crustaceans. The biotope classified as Polychaetes in littoral fine sand.

At Transect B in 2004-2005, in the inner estuary saltmarsh was observed at the channel edges. Sediments were predominantly sandy mud or muddy sand with higher mud content towards to banks, adjacent to the saltmarsh. Sediments nearer the saltmarsh edge were intensively burrowed by *C. volutator,* and the Baltic tellin *M. balthica* was also present. Three sediments biotopes were recorded, *Bathyporeia spp. and Corophium spp*. in upper shore slightly muddy fine sands, Sandy mud shores and *Hediste diversicolor* and *Macoma balthica* in sandy mud shores. During 2023, sediments similarly had a higher fine sediment content that the rest of the estuary. Saltmarsh was present at the estuary edge with muddier sediments adjacent. Amphipods dominated the faunal communities in the area. Only one biotope was identified, classified as *Bathyporeia pilosa* and *Corophium arenarium* in littoral muddy sand, comparable to that observed in 2004-2005.

Transect C, in the inner, mid estuary consisted of elevated sand banks in the central channel with muddier sediments adjacent to the saltmarsh in 2004-2005, which was comparable to the habitats observed during 2023. During the 2004-2005 survey observed fauna included *M. balthica, C. volutator* and *P. ulvae*, with biotopes *Macoma balthica* and *Arenicola marina* in muddy sand and *Bathyporeia* spp. and *Corophium* spp. in upper shore slightly muddy fine sands the two main biotopes recorded.

During 2023 faunal communities within the muddier sediments were characterised by oligochaetes, polychaetes and *P. ulvae,* with the biotope classified as Polychaete / bivalve dominated muddy sand shores. In the central channel the biotope recorded was Polychaetes in littoral fine sand. Polychaetes dominated the faunal community, in particular *P. elegans* with very few *M. balthica or C. volutator* recorded.

In 2004-2005, sediments at Transect D, in the mid-estuary, consisted of medium sands which were heavily rippled in some areas. The sediments to the western bank were generally coarser and more mobile than the rest of the transect and were likely the primary reason for the lack of conspicuous fauna noted in the area. In the mid channel medium sands were characterised by abundant *A. marina*. The eastern shore sediments were muddier in nature with *C. edule* and *H. diversicolor* present. Both *Macoma balthica* and *Arenicola marina* in muddy sand and Polychaetes and *Cerastoderma edule* in fine sand and muddy sand shores biotopes were recorded.

Sediments within the mid-estuary in 2023 were similarly recorded as medium, heavily rippled sand. Sediments to the central and western bank were coarser than those recorded on the eastern bank. Towards the eastern bank the slightly muddier sediments supported a greater abundance of *A. marina*, similar to that observed in 2004-2005. However, in the central and western areas fauna were relatively impoverished and dominated by polychaetes, including *E. longa, P. elegans* and *N. hombergii. C. edule* were observed but not in high enough abundances to define the biotope.

Situated within Walney Channel the sediments at Transect F, in 2004-2005, were described as barren to medium fine sand. Isolated muddier areas supported *C. edule* and *H. diversicolor*. Within this area during the 2023 survey the area surveyed only covered the central channel and did not capture the coarser sediments to the estuary banks, however, rocky scar ground was observed at the entrance to Walney Channel. Within the central area of Walney Channel sediments consisted of fine sand and were dominated, as with much of the rest of the estuary, by polychaetes. Few *C. edule* were observed in this area, however, occasional *M. tenuis* were recorded.

Overall, across the estuary there appears to have been a marginal shift in sediment composition from occasional finer muddier sand sediments to medium sand from 2004-2005 to 2023. Likely associated with the loss of fine sediment the fauna appear to have become slightly more impoverished with a potential reduction in *A. marina, M. balthica* and *C. edule* for more polychaete dominated sediments, resulting in a shift in some biotope classifications. However, without quantitative benthic data it is not possible to make a direct comparison or assessment of change.

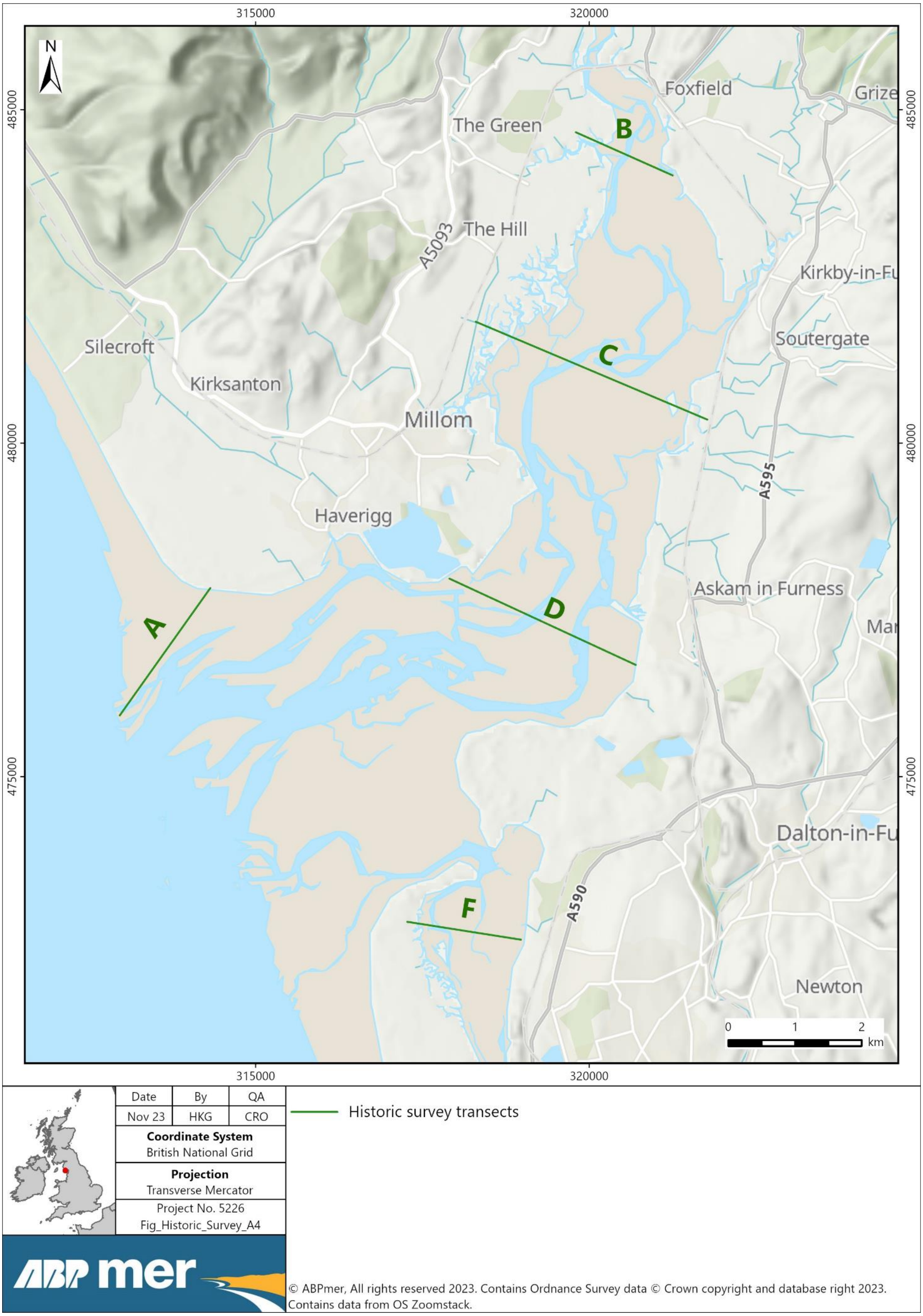

Figure 18. Transect locations during the Duddon Estuary survey in 2004-2005.

Table 8. Summary of the biotopes encountered

Transect	Biotope (as described in Royal Haskoning, 2006)	Overlapping biotopes identified during the June 2023 survey
A	LGS.BarSnd - Barren coarse sand shores LMS.MacAre – *Macoma balthica* and *Arenicola marina* in muddy sand	LS.LSa.FiSa.Po - Polychaetes in littoral fine sand
B	LMU.Sm – Saltmarsh LMS.BatCor – *Bathyporeia spp*. and *Corophium* spp. in upper shore slightly muddy fine sands LMU. SMu – Sandy mud shores LMU. HedMac – *Hediste diversicolor* and *Macoma balthica* in sandy mud shores	LS.LSa.MuSa.BatCare - *Bathyporeia pilosa* and *Corophium arenarium* in littoral muddy sand
C	LMU.Sm – Saltmarsh LMS.MacAre – *Macoma balthica* and *Arenicola marina* in muddy sand LGS.BarSnd - Barren coarse sand shores LMS.BatCor – *Bathyporeia spp*. and *Corophium* spp. in upper shore slightly muddy sine sands	LS.LMp.Sm - Saltmarsh LS.LSa.MuSa - Polychaete/bivalve dominated muddy sand shores LS.LSa.FiSa.Po - Polychaetes in littoral fine sand
D	LMU.Sm – Saltmarsh LMS.MacAre – *Macoma balthica* and *Arenicola marina* in muddy sand LMS.PCer – Polychaetes and *Cerastoderma edule* in fine sand and muddy sand shores	LS.LSa.MuSa - Polychaete/bivalve dominated muddy sand shores LS.LSa.FiSa.Po - Polychaetes in littoral fine sand
F	LMU.Sm – Saltmarsh LGS.BarSnd - Barren coarse sand shores LMS.PCer – Polychaetes and *Cerastoderma edule* in fine sand and muddy sand shores LMS – Littoral muddy sands LMX – Littoral mixed sediments	LS.LSa.FiSa.Po - Polychaetes in littoral fine sand

It should also be noted that whilst there is some variation in biotopes present (composition and coverage), some of this observed variation is likely due to the differences in survey methods rather than an indicator of condition change. Based on a broad comparability in the high-level biotopes present between 2004-2005 and 2023 there does not appear to be a measurable decrease in the extent of the mudflats and sandflats feature.

5 High Level Assessment of Ecological Condition

The results of the June 2023 have been used to provide a high-level assessment of the current condition of the ‘Mudflats and Sandflats not covered by seawater at low tide’ feature of the Duddon Estuary SSSI. This high-level assessment is set in the context of the lack of previous data for the site with which full comparisons can be made. This limits the conclusions that can be drawn from the condition assessment as many of the targets are framed in the context of “maintaining or restoring” a particular attribute.

It was therefore not possible to undertake a formal designated site level condition assessment. However, where available, a review of reports from previous surveys in nearby sites within Morecambe Bay or sections of the Duddon Estuary (Bhatia *et al*., 2013, Royal Haskoning 2006, WA Marine & Environment Ltd. 2010) has been undertaken to provide context to the results of the current survey and provide an indicative assessment. The results from this survey will be treated as a baseline to inform a Natural England led condition assessment and future temporal comparisons.

The indicative assessment of ecological condition for Duddon Estuary SSSI, in the context of wider site information, is provided in Table 9.

Table 9. Indicative assessment of ecological condition

Feature	Attribute	Target	Sub-features	Wider site/ area context information	Comments from the 2023 survey	Concluding remark
Mudflats and sandflats not covered by seawater at low tide	Distribution: presence and spatial distribution of biological communities	Maintain the presence and spatial distribution of intertidal sand and muddy sand communities.	Intertidal sand and muddy sand Intertidal mud	Within Morecambe Bay SAC (adjacent to, and incorporating, Duddon Estuary SSSI) upper shore muddy sands exist around the bay as expansive flats. These areas are characterised by amphipods such as *Bathyporeia* and *Corophium* species, the lug worm (*Arenicola marina*), the baltic tellin (*M. balthica*), and the mudsnail (*P. ulvae*), which can all occur in high densities. Habitats include EUNIS A2.241 (*Macoma balthica and Arenicola marina in muddy sand shores*), EUNIS A2.243 (*Hediste diversicolor, Macoma balthica and Eteone longa in littoral muddy sand*) and A2.244 (*Bathyporeia pilosa and Corophium in littoral muddy sand*) (Bhatia *et al.,* 2013). The mid and low shore consisted of medium to very fine sand and typically lack a diverse or abundant infaunal	Sand and muddy sand sediments exist around the bay as expansive flats. During the 2023 survey sediments within this area were generally classified as medium to fine sand and the fauna were generally impoverished but characterised by polychaetes, *N. cirrosa* and *P. elegans,* amphipods such as *Bathyporeia* sp. and *Corophium* sp., and the mudsnail *P. ulvae.* The baltic tellin (*M. balthica*), and thin tellin (*M. tenuis*) were also observed throughout the estuary. The common cockle *C. edule* and lugworm *A. marina* were not recorded in any faunal samples collected within the Duddon Estuary however their presence was noted at stations throughout the survey. The size of *A. marina* in particular often	Overall, across the estuary there appears to have been a marginal shift in sediment composition, from occasional finer muddier sand sediments to medium sand from 2004-2005 to 2023. Likely associated with the loss of fine sediment the infauna appear to have become slightly more impoverished with a potential reduction in *A. marina, M. balthica* and *C. edule* for more polychaete dominated sediments, resulting in a shift in some biotope classifications. However, whilst there is some variation in biotopes present (composition and coverage), some of this observed variation is likely due to the differences in survey methods rather than an indicator of condition change. Based on a broad comparability in the high-level biotopes present between 2004-2005 and 2023 there does not appear to be a

Feature	Attribute	Target	Sub-features	Wider site/ area context information	Comments from the 2023 survey	Concluding remark
				community. Where species are observed, these tend to include *A. marina* and the thin tellin *M. tenuis.* Habitats include A2.23 (*Polychaete/amphipod-dominated fine sand shores*) and A2.231 (*Polychaetes in littoral fine sand*) (Bhatia *et al.,* 2013). The common cockle *C. edule* can be found in the bay as part of the habitat A2.242 (*Cerastoderma edule and polychaetes in littoral muddy sand*). This habitat is important to the SAC and Morecambe Bay and Duddon Estuary SPA as a prey resource for birds, but it can be highly variable in distribution with significant variations in cockle density from year to year (Bhatia *et al.,* 2013). Within the Duddon Estuary SSSI, in 2004-2005 the vast majority of the intertidal area comprised fine sediments ranging from clean sand through to sand mud. Large	means it is missed during core sampling. Habitats were all sand or muddy sand biotopes and included: • Littoral sand (LS.LSa); • Polychaetes in littoral fine sand (Ls.Lsa.FiSa.Po); • Amphipods and *Scolelepis spp*. in littoral medium-fine sand (LS.LSa.MoSa.AmSco); • Polychaete/bivalve dominated muddy sand shores (LS.LSa.MuSa); • *Bathyporeia pilosa* and *Corophium arenarium* in littoral muddy sand (LS.LSa.MuSa.BatCare); and • *Hediste diversicolor, Macoma balthica and Eteone longa* in littoral muddy sand (LS.LSa.MuSa.HedMacEte) .	measurable decrease in the extent of the mudflats and sandflats feature.

Feature	Attribute	Target	Sub-features	Wider site/ area context information	Comments from the 2023 survey	Concluding remark
				expanses of rippled sand were also recorded, classified predominantly as *Macoma balthica* and *Arenicola marina* in muddy sand. Other key biotopes recorded across the site included *Bathyporeia spp. and Corophium spp*. in upper shore slightly muddy fine sands, Sandy mud shores and *Hediste diversicolor* and *Macoma balthica* in sandy mud shores (Royal Haskoning, 2006).		
Mudflats and sandflats not covered by seawater at low tide	Structure and function: presence and abundance of key structural and influential species	[Maintain OR Recover OR Restore] the abundance of listed species, to enable each of them to be a viable component of the habitat.	Intertidal sand and muddy sand Intertidal mud	Structural species are those that form part of the habitat structure or help to define a key biotope. Within Morecambe Bay SAC upper shore muddy sands are characterised by amphipods such as *Bathyporeia* and *Corophium* species, the lug worm (*A. marina*), the baltic tellin (*M. balthica*), and the mudsnail (*P. ulvae*), which can all occur in high densities. (Bhatia *et al.,* 2013).	Benthic communities were dominated by the burrowing amphipods *B. pelagica, B. pilosa* and the mudshrimp *C. volutator*, the mudsnail *P. ulvae,* polychaetes *N. cirrosa* and *P. elegans* and Nematoda. All characteristic of 'Polychaete/ bivalve-dominated muddy sand shores' (LS.LSa.MuSa) and 'Polychaete/ amphipod-dominated fine sand shores' (LS.LSa.FiSa) biotopes. Additional species of note included the Baltic tellin *M.*	Within the Duddon Estuary SSSI sediments consisted of muddy sandflats. As such characteristic species are expected to include *C. edule*, along with other bivalves, amphipods, polychaete worms and the mudsnail *P. ulvae*. A number of species characteristic of intertidal sand and muddy sand communities were observed within the Duddon Estuary SSSI including *M. balthica, M. tenuis* and *C. edule*. Other

Feature	Attribute	Target	Sub-features	Wider site/ area context information	Comments from the 2023 survey	Concluding remark
				The mid and low shore typically lack a diverse or abundant infaunal community. Where species are observed, these tend to include A*. marina* and *M. tenuis* (Bhatia *et al.,* 2013).	*balthica* and the thin tellin *M. tenuis*, the common cockle *C. edule* and the lugworm *A. marina.* These species can be an important prey resource for birds, which may be important to support populations within the Morecambe Bay and Duddon Estuary SPA.	taxa identified, characteristic of muddy sandflats included amphipods *C. volutator, B. pelagica, B. pilosa*, polychaetes *P. elegans, N. cirrosa*, and *A. marina*, and *P. ulvae*. Infauna appear to be slightly impoverished in some areas due to the presence of more mobile sand sediments. In comparison to 2004-2005 there has been a potential reduction in *A. marina, M. balthica* and *C. edule* for more polychaete dominated sediments. However, without qualitative benthic data it is not possible to make a direct comparison or assessment of change. Based on a high-level comparison there appears to have been relatively limited change in overall composition or extent, which does not suggest any measurable decrease in the structure and function of the mudflats and sandflats feature.

Feature	Attribute	Target	Sub-features	Wider site/ area context information	Comments from the 2023 survey	Concluding remark
Mudflats and sandflats not covered by seawater at low tide	Structure: non-native species and pathogens (habitat)	Restrict the introduction and spread of non-native species and pathogens, and their impacts.	Intertidal sand and muddy sand Intertidal mud	There have been very few records of non-native or invasive species within the Morecambe Bay SAC. Non-native species identified within Morecambe Bay include the Pacific oyster, *Magallana (=Crassostrea) gigas* reported at Foulney Island in 2010 (WA Marine & Environment Ltd., 2010), the leathery sea squirt, *Styela clava*, at Fleetwood marina in 2016 (Hurst, 2016), Japanese wireweed, *Sargassum muticum*, within the Walney Channel (Hawes *et al.,* 2015), and in rockpools at North Walney and the Foulney Island areas (WA Marine & Environment Ltd., 2010). The Pacific oyster, *Magallana (=Crassostrea) gigas* is also present through the hatchery and trestle farm to the west of the site (Herbert *et al.,* 2012), however, mitigation measures and monitoring are part of an adaptive management strategy to prevent the	The only non-native species identified during the June 2023 survey of the Duddon Estuary SSSI was the Modest barnacle *A. modestus,* recorded on the shingle scars to the entrance of Walney Channel. *A. modestus*, has been frequently recorded in the north-west of England and within the Morecambe Bay SAC. This species is unlikely to adversely impact designated features of the site.	Only one non-native species *A. modestus*, was recorded within Duddon Estuary SSSI and this species is unlikely to adversely impact designated features of the site. As such, and within the context of the limited available comparable data, it is concluded that this target has been met.

Feature	Attribute	Target	Sub-features	Wider site/ area context information	Comments from the 2023 survey	Concluding remark
				accidental escape of non-native species There have been individual records of Chinese mitten crab, *Eriocheir sinensis*, in the Duddon Estuary; the most recent of which was at Millom Pier in 2012 (North Western Inshore Fisheries and Conservation Authority, 2020). It is not clear if these are indications of persistent populations or sporadic occurrences. The barnacle, *A. modestus*, has been frequently recorded in the north-west of England and within the Morecambe Bay SAC in intertidal habitats (Hurst, 2016).		
Mudflats and sandflats not covered by seawater at low tide	Structure: sediment composition and distribution	Maintain the distribution of sediment composition across the feature	Intertidal sand and muddy sand Intertidal mud	The distribution of intertidal sediments in the Morecambe Bay SAC conforms to the common pattern found in coastal inlets. Finer sediments occur in the sheltered innermost areas of the site and at the top of the shores. Deposits become	Throughout the Duddon Estuary SSSI sediments were classified as very fine to medium sand. Finer, muddy sand sediments were predominantly located within the inner estuary and towards the saltmarsh edges, with sand and slightly gravelly	Sediments within the Duddon Estuary SSSI were dominated by fine to medium sand with small mud and gravel fractions also present. There were some small variations in the sediment composition observed

Feature	Attribute	Target	Sub-features	Wider site/ area context information	Comments from the 2023 survey	Concluding remark
				increasingly coarse towards the open sea and lower down the shore. The predominant sediment types are very fine and fine sand with considerable quantities of silt present at sites in the upper part of the SAC. The distribution of these sediments can vary significantly on a local scale with time and with tidal forces (Anderson, 1972). Within the Duddon Estuary, in 2004-2005 the vast majority of the intertidal area comprised fine sediments ranging from clean sand through to sand mud with large expanses of rippled sand recorded. In the inner estuary saltmarsh was observed at the channel edges. Sediments were predominantly sandy mud or muddy sand with higher mud content towards to banks, adjacent to the saltmarsh (Royal Haskoning, 2006).	sand sediments generally towards the mid and outer estuary.	between 2004-2005 and 2023, with a marginal shift from occasional finer muddier sand sediments to more mobile medium sand. Despite this, the broad sediment parameters have remained similar and as such, it is concluded that this sediment target has been met.

Feature	Attribute	Target	Sub-features	Wider site/ area context information	Comments from the 2023 survey	Concluding remark
Mudflats and sandflats not covered by seawater at low tide	Structure: sediment total organic carbon content	Maintain total organic carbon (TOC) content in the sediment at existing levels.	Intertidal sand and muddy sand Intertidal mud	A condition assessment of north- west intertidal sand and mud features showed that organic content of sediment was low, ranging from 0.13% to 2.3% (Bhatia *et al.,* 2013). Additionally, these values are within the range of those recorded in 1972 (Anderson, 1972), indicating that no major changes in organic input have occurred since that time. Higher values were associated with samples taken from estuarine areas (where the sediments are naturally fine with a high organic content) and upper shore muddy areas, often close to marsh boundaries.	Total organic carbon content within the Duddon Estuary SSSI ranged from 0.16 % to 0.20 % with an average TOC 0.17 %, within the range previously recorded by Bhatia *et al.* (2013). Samples were predominantly taken from mobile sand sediments within the mid and outer estuary where TOC content would be expected to be lower. The highest TOC (0.20%) was recorded from the most inner estuary sample, however, still within an area of sandy sediment. No samples were collected from upper shore muddy areas.	Total organic carbon content within the Duddon Estuary SSSI ranged from 0.16 % to 0.20 %, within the range recorded during a condition assessment of north-west intertidal sand and mud, which ranged from 0.13% to 2.3% (Bhatia *et al*., 2013). As such, it is concluded that this sediment structure target has been met.
Mudflats and sandflats not covered by seawater at low tide	Structure: species composition of component communities	Maintain the species composition of component communities.	Intertidal sand and muddy sand Intertidal mud	Within Morecambe Bay SAC upper shore areas generally have a higher species abundance and species richness in comparison to mid and lower shore sections, typically characterised by amphipods such as *Bathyporeia and Corophium*	Sand and muddy sand sediments exist around the bay as expansive flats. These areas were characterised by amphipods such as *Bathyporeia* and *Corophium* species, the mudsnail *P. ulvae* and polychaetes *N. cirrosa* and *P. elegans*.	The faunal quality of both sub-features should be maintained at Good Status (a minimum mean IQI score of ≥ 0.64), with no sustained deterioration within the status (Environment Agency Marine Monitoring Service, 2014).

Feature	Attribute	Target	Sub-features	Wider site/ area context information	Comments from the 2023 survey	Concluding remark
				species, the lugworm *A. marina*, the baltic tellin *M. balthica*, and the mudsnail *P. ulvae* (Bhatia *et al.,* 2013). Upper shore muddy sand sediments generally transition into medium to very fine sand at the mid and lower shore areas of the bay. Species richness and abundance are relatively low in comparison to upper shore areas and here species tend to include (*A. marina*) and the thin tellin (*M. tenuis*). In past surveys of the SAC *M. balthica* and *C. volutator* have dominated the infauna throughout the intertidal mud and sandflats of the SAC, with the mudsnail *P. ulvae* and the lugworm, *A. marina* also being common (Bhatia *et al.,* 2013). Muddy sediments often support a high abundance of *M. balthica*, *Corophium* species, *P. ulvae* and the ragworm, *Hediste diversicolor* (Bhatia *et al.,* 2013). The peppery furrow shell,	The baltic tellin (*M. balthica*), and thin tellin (*M. tenuis*) were also observed throughout the estuary. The lugworm *A. marina* was not recorded in any faunal samples collected within the Duddon Estuary, however, its presence was noted at stations throughout the survey. Densities of casts were variable across the site ranging from zero up to 64 m^{-2}, recorded at two locations within the 'Polychaete/bivalve dominated muddy sand shores' biotope. Where present, more common abundances of *A. marina* casts were 8 to 12 m^{-2}. All stations sampled within Duddon Estuary SSSI were assessed to have either good or high IQI status, with scores ranging from 0.68 to 1.07.	Results of the IQI showed that all stations sampled within the Duddon Estuary SSSI were assessed to have either good or high IQI status, meaning that the species composition observed within the samples were typical of expected faunal communities within intertidal sand and muddy sand sediments and suggested that the feature is in good condition within Duddon Estuary SSSI. As such, it is concluded that this species composition target has been met.

Feature	Attribute	Target	Sub-features	Wider site/ area context information	Comments from the 2023 survey	Concluding remark
				Scrobicularia plana has also been observed in muddy sediments. The species composition of sediments in the site varies significantly with location as a consequence of the dynamic nature of the sediment and physical process of Morecambe Bay (Bhatia *et al.,* 2013).		
Mudflats and sandflats not covered by seawater at low tide	Supporting processes: sediment contaminants	Restrict surface sediment contaminants (<1 cm from the surface) to below the OSPAR Environment Assessment Criteria (EAC) or Effects Range Low (ERL)	Intertidal sand and muddy sand Intertidal mud	The sediments of the eastern Irish Sea are known to have been historically contaminated with heavy metals such as cadmium, mercury, lead, zinc and arsenic (Camacho-Ibar *et al.,* 1992). Sediment samples from within Morecambe Bay SAC have been shown to contain high concentrations of aluminium and iron, thought to be a result of the erosion of landmasses and subsequent riverine export. However, sediments within the SAC did not contain metal contaminants exceeding	Metal concentrations recorded within Duddon Estuary SSSI were all below AL1. Similarly, concentrations of TBT, as well as PCBs (sum of ICES 7 congeners) and PAHs (sum of 16 congeners) were consistently below their respective AL1. No contaminants recorded at any of the stations within Duddon Estuary SSSI were above their respective AL1, where levels are provided.	All survey contaminant concentrations recorded within the Duddon Estuary SSSI were below the respective AL1 targets used to assess suitability of material for disposal at sea (where provided). On this basis it is concluded that this sediment contaminants supporting processes target has been met.

Feature	Attribute	Target	Sub-features	Wider site/ area context information	Comments from the 2023 survey	Concluding remark
				Cefas AL 1 (DONG Energy, 2013). Concentrations of PAH and PCB were significantly higher in inshore areas where there was either riverine input and/or direct industry discharges (Cefas, 2005).		

6 Conclusions

A comprehensive Phase I and Phase II intertidal survey of the Duddon Estuary SSSI was successfully completed between 5 and 7 June 2023. The survey identified and mapped the distribution and extent of sedimentary intertidal habitats across the area. It provides a snapshot in time of habitat distribution and extent and the composition of faunal communities within the SSSI feature ‘Littoral sediment’ and the SAC feature ‘Mudflats and Sandflats not covered by seawater at low tide’. . The results of this survey also provide a baseline description of the Duddon Estuary which will be used to inform future temporal comparisons and subsequent condition assessments by Natural England.

The majority of the intertidal area across the Duddon Estuary comprised firm, well drained sediments ranging from clean fine sands to muddy sand forming extensive areas of intertidal soft sediment. The mudflats and sandflats across the area typically supported an invertebrate community characteristic of moderately exposed inner to middle estuary, variable salinity conditions. All stations sampled within the Duddon Estuary SSSI were assessed to have either good or high IQI status, with scores ranging from 0.68 to 1.07. Meaning the species composition observed within the samples were typical of expected faunal communities within the ‘Mudflats and sandflats not covered by seawater at low tide’ feature. Furthermore, this suggested that the feature is in good condition within the Duddon Estuary SSSI. Eight biotopes were recorded across Duddon Estuary SSSI. The biotopes recorded were:

- Saltmarsh (LS.LMp.Sm);
- Littoral sand (LS.LSa);
- Polychaetes in littoral fine sand (Ls.Lsa.FiSa.Po);
- Amphipods and *Scolelepis spp*. in littoral medium-fine sand (LS.LSa.MoSa.AmSco);
- Polychaete/bivalve dominated muddy sand shores (LS.LSa.MuSa);
- *Mytilus edulis* beds on littoral mud (LS.LBR.LMus.Myt);
- *Bathyporeia pilosa* and *Corophium arenarium* in littoral muddy sand (LS.LSa.MuSa.BatCare); and
- *Hediste diversicolor, Macoma balthica* and *Eteone longa* in littoral muddy sand (LS.LSa.MuSa.HedMacEte).

Characteristic fauna included burrowing amphipods *B. pelagica, B. pilosa* and the mudshrimp *C. volutator,* the mudsnail *P. ulvae*, polychaetes *N. cirrosa* and *P. elegans* and Nematoda.

Additional species of note included the Baltic tellin *M. balthica* and the thin tellin M*. tenuis*, the common cockle *C. edule* and the lugworm *A. marina,* all of which can be an important prey resource for birds. This is of relevance to supporting bird populations within the Morecambe Bay and Duddon Estuary SPA and Ramsar site.

Only one non-native species was identified during the June 2023 survey, the Modest barnacle *A. modestus,* recorded on the shingle scars to the entrance of Walney Channel.

A. modestus, has been frequently recorded in the north-west of England and within the Morecambe Bay SAC and this species is unlikely to adversely impact designated features of the site Within the context of the limited available comparable data, it is concluded that this target has been met.

Metal concentrations recorded within Duddon Estuary SSSI were all below AL1. Similarly, concentrations of TBT, as well as PCBs (sum of ICES 7 congeners) and PAHs (sum of 16 congeners) were consistently below their respective AL1. No contaminants recorded at any of the stations within Duddon Estuary SSSI were above their respective AL1, where levels are provided, indicating that contaminant levels were typically low.

Total organic carbon content within the Duddon Estuary SSSI ranged from 0.16 % to 0.20 %, within the range recorded during a condition assessment of north-west intertidal sand and mud, which ranged from 0.13% to 2.3% (Bhatia *et al.,* 2013). As such, it is concluded that this sediment structure target has been met.

Across Duddon Estuary there were multiple records of anthropogenic activities recorded during the survey including vehicular access to intertidal areas, evidence of fishing and bait digging, abandoned vehicles and vessels and litter. Levels of disturbance to habitat features as a result of anthropogenic activities are a product of their nature, frequency, magnitude and spatial distribution. Understanding levels of disturbance to habitats therefore relies on an understanding of these variables for each activity type. There was limited evidence of disturbance to habitat features as a result of the activities observed during the current survey. However, due to the snapshot nature of the observed activities and the Duddon Estuary being a highly dynamic environment, whereby the impacts from historic events are often quickly masked by natural processes, it is not possible to ascertain the frequency, magnitude or extent of disturbance effects.

As no previous baseline sampling has been undertaken within Duddon Estuary SSSI it has not been possible to make a quantitative assessment of temporal changes to faunal communities or biotope extents. However, a qualitative assessment of temporal change has been undertaken using the only known historic report (Royal Haskoning, 2006).

Overall, across the estuary there appears to have been a marginal shift in sediment composition from occasional finer muddier sand sediments to medium sand from 2004-2005 to 2023. Infauna appear to be slightly impoverished in some areas due to the presence of more mobile sand sediments with a potential reduction in *A. marina, M. balthica* and *C. edule* for more polychaete dominated sediments, resulting in a shift in some biotope classifications.

However, whilst there is some variation in biotopes present (composition and coverage), there does appear to be a broad level of comparability in the biotopes present between 2004-2005 and 2023.

Overall, the Mudflats and sandflats not covered by seawater at low tide feature within the Duddon Estuary SSSI is considered to broadly meet the key attributes for the feature, namely:

- Maintain the presence and spatial distribution of intertidal sand and muddy sand communities;
- Maintain, recover or restore the presence and abundance of key structural and influential species;
- Restrict the introduction and spread of non-native species and pathogens, and their impacts;
- Maintain the distribution of sediment composition across the feature;
- Maintain the species composition of component communities.
- Restrict surface sediment contaminants to below the OSPAR EAC or ERL.

This conclusion will be reviewed by Natural England when they undertake a formal condition assessment of the site.

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Abbreviations

ABPmer	ABP Marine Environmental Research Ltd
AL	Action Level
AMBI	AZTI Marine Biotic Index
ArcGIS	Mapping Software (Esri)
AZTI	Scientific and technological centre
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CCW	Countryside Council for Wales
EAC	Environment Assessment Criteria
EG	Ecological Group
ERL	Effects Range Low
EUNIS	European University Information Systems organisation
GC-MS	Gas chromatography–Mass Spectrometry
GC-MS-MS	Gas Chromatography-Tandem Mass Spectrometry
GIS	Geographic Information System
GPS	Global Positioning System
HF	Hydrofluoric Acid
ICES	International Council for the Exploration of the Sea
ICP	Inductively coupled plasma

ICPOES	Inductively Coupled Plasma Optical Emission spectroscopy
IQI	Infaunal Quality Index
ISO	International Organization for Standardization
JNCC	Joint Nature Conservation Committee
LoD	Limit of Detection
LOI	Loss on Ignition
LS	Littoral Sediment
MEDIN	Marine Environmental Data and Information Network
MESH	Mapping European Seabed Habitats
MHCBI	Marine Habitat Classification for Britain and Ireland
MPA	Marine Protected Area
NDIR	Nondispersive infrared spectroscopy
NMBAQC	Northeast Atlantic Marine Biological Analytical Quality Scheme
OCPs	Organochlorine Pesticides
OSPAR	Convention for the Protection of the Marine Environment of the NE Atlantic
PAH	Polycyclic Aromatic Hydrocarbons
PBDE	Brominated Flame Retardants
PCB	Polychlorinated Biphenyls
PSA	Particle Size Analysis
Ramsar	Wetlands of international importance, designated under The Convention on Wetlands (Ramsar, Iran, 1971)
SAC	Special Area of Conservation
SPA	Special Protection Area
SSSI	Site of special Scientific Interest
TBT	Tributyl Tin
TOC	Total Organic Carbon
UK	United Kingdom

Appendices

A Field Notes

Field notes from core stations within the Duddon Estuary SSSI are available in the excel files:

NECR605_Appendix_A_DuddonSSSI_FieldNotes xlsx

B Station Photo Log

Table B1. Photo log from core stations within Duddon Estuary SSSI June 2023 survey (five pages)

Core no.	Station Location	Biotope Description	Biotope Code/ EUNIS Code	Wide Angle Station Photo	Close up Station Photo
F01	54.24778, -3.21814	*Bathyporeia pilosa* and *Corophium arenarium* in littoral muddy sand.	LS.LSa.MuSa.BatCare/ A2.244		
F02	54.24924, -3.22417	*Bathyporeia pilosa* and *Corophium arenarium* in littoral muddy sand.	LS.LSa.MuSa.BatCare/ A2.244		
F03	54.14223, -3.25145	Polychaetes in littoral fine sand.	LS.LSa.FiSa.Po/ A2.231		
F04	54.15625, -3.27080	Littoral sand	LS.LSa./ A2.2		

Core no.	Station Location	Biotope Description	Biotope Code/ EUNIS Code	Wide Angle Station Photo	Close up Station Photo
F05	54.14588, -3.28810	Polychaetes in littoral fine sand.	LS.LSa.FiSa.Po/ A2.231		
F06	54.16531, -3.29275	Amphipods and *Scolelepis* spp. in littoral medium-fine sand.	LS.LSa.MoSa.AmSco/ A2.223		
F07	54.17081, -3.25763	Littoral sand	LS.LSa./ A2.2		
F08	54.18710, -3.28200	Amphipods and *Scolelepis spp*. in littoral medium-fine sand.	LS.LSa.MoSa.AmSco/ A2.223		

Core no.	Station Location	Biotope Description	Biotope Code/ EUNIS Code	Wide Angle Station Photo	Close up Station Photo
F09	54.18718, -3.317567	Polychaetes in littoral fine sand.	LS.LSa.FiSa.Po/ A2.231		
F10	54.18280, -3.32135	Polychaetes in littoral fine sand.	LS.LSa.FiSa.Po/ A2.231		
F11	54.17791, -3.307617	Amphipods and *Scolelepis spp*. in littoral medium-fine sand.	LS.LSa.MoSa.AmSco/ A2.223		
F12	54.18852, -3.24923	Polychaetes in littoral fine sand.	LS.LSa.FiSa.Po/ A2.231		

Core no.	Station Location	Biotope Description	Biotope Code/ EUNIS Code	Wide Angle Station Photo	Close up Station Photo
F13	54.18231, -3.233517	Polychaetes in littoral fine sand.	LS.LSa.FiSa.Po/ A2.231		
F14	54.17861, -3.220067	Polychaete / bivalve dominated muddy sand shores.	LS.LSa.MuSa./ A2.24		
F15	54.19646, -3.232033	Polychaetes in littoral fine sand.	LS.LSa.FiSa.Po/ A2.231		
F16	54.20915, -3.23630	Polychaetes in littoral fine sand.	LS.LSa.FiSa.Po/ A2.231		

Core no.	Station Location	Biotope Description	Biotope Code/ EUNIS Code	Wide Angle Station Photo	Close up Station Photo
F17	54.22104, -3.24177	Polychaete / bivalve dominated muddy sand shores.	LS.LSa.MuSa./ A2.24		
F18	54.22239, -3.22708	*Hediste diversicolor, Macoma balthica* and *Eteone longa* in littoral muddy sand.	LS.LSa.MuSa.HedMacEte/ A2.243		
F19	54.21624, -3.20649	Polychaetes in littoral fine sand.	LS.LSa.FiSa.Po/ A2.231		
F20	54.23185, -3.21946	Amphipods and *Scolelepis spp*. in littoral medium-fine sand.	LS.LSa.MoSa.AmSco/ A2.223		

C Faunal Data

Table C1. Faunal abundance data from core samples collected from Duddon Estuary SSSI in June 2023 (three pages). Note: some cells are left blank.

	F01a	F01b	F01c	F02	F03	F04	F05	F06a	F06b	F06c	F07
Animalia_eggs											
Platyhelminthes											
Nemertea											
Nematoda	1	7	3			1				1	
Eteone longa_agg.											
Glycera tridactyla											
Hediste diversicolor	1										
Nephtys_juv											
Nephtys											
Nephtys cirrosa					2						
Paraonis fulgens											
Pygospio elegans	50	5	110								1
Manayunkia aestuarina											
Enchytraeidae											
Pontocrates arenarius									1	1	
Bathyporeia pelagica								2	6	9	
Bathyporeia pilosa	52	37	66	1							
Bathyporeia sarsi						3					
Haustorius arenarius								1	2	5	
Corophium arenarium											
Corophium volutator	130	166	142	6							
Eurydice pulchra											
Cumopsis goodsir											
Peringia ulvae				1	1						1
Mytilus edulis_juv										1	
Tellinoidea_juv	1										
Macomangulus tenuis					2		1				

Macoma balthica	1		1								

	F08a	F08b	F08c	F09	F10	F11	F12	F13a	F13b	F13c	F14
Animalia_eggs											1
Platyhelminthes											
Nemertea											
Nematoda							76		1	18	81
Eteone longa_agg.											1
Glycera tridactyla											
Hediste diversicolor											
Nephtys_juv					1						
Nephtys						1					
Nephtys cirrosa								1	2	1	
Paraonis fulgens				2							
Pygospio elegans											68
Manayunkia aestuarina											
Enchytraeidae											28
Pontocrates arenarius											
Bathyporeia pelagica	49	69	49					2		6	
Bathyporeia pilosa						2		1			
Bathyporeia sarsi											
Haustorius arenarius											
Corophium arenarium											
Corophium volutator				1							
Eurydice pulchra		1	1								
Cumopsis goodsir					1						
Peringia ulvae								1			72
Mytilus edulis_juv											
Tellinoidea_juv											
Macomangulus tenuis							1				
Macoma balthica										1	

	F15	F16a	F16b	F16c	F17	F18	F19	F20			
Animalia_eggs					1						
Platyhelminthes						1					
Nemertea		1				1					
Nematoda			1	1	58	23	9	1			
Eteone longa_agg.											
Glycera tridactyla				1							
Hediste diversicolor						1					
Nephtys_juv											
Nephtys				1							
Nephtys cirrosa	2		1								
Paraonis fulgens											
Pygospio elegans					7	1	136				
Manayunkia aestuarina					39						
Enchytraeidae					51	3					
Pontocrates arenarius											
Bathyporeia pelagica	1		2								
Bathyporeia pilosa						15		2			
Bathyporeia sarsi				1							
Haustorius arenarius											
Corophium arenarium					1						
Corophium volutator		1				3					
Eurydice pulchra											
Cumopsis goodsir											
Peringia ulvae					123	27					
Mytilus edulis_juv											
Tellinoidea_juv											
Macomangulus tenuis											
Macoma balthica					1	3					

Table C2. Faunal biomass data from core samples collected from Duddon Estuary SSSI in June 2023 (three pages). Note: some cells are left blank.

	F01a	F01b	F01c	F02	F03	F04	F05	F06a	F06b	F06c	F07
Animalia											
Platyhelminthes											
Nemertea											
Nematoda	0.0001	0.0001	0.0001			0.0001				0.0001	
Eteone longa											
Glycera tridactyla											
Hediste diversicolor	0.0232										
Nephtys											
Nephtys											
Nephtys cirrosa					0.0218						
Paraonis fulgens											
Pygospio elegans	0.0209	0.0684	0.1601								0.0002
Manayunkia aestuarina											
Enchytraeidae											
Pontocrates arenarius									0.0001	0.0001	
Bathyporeia pelagica								0.0029	0.0047	0.0127	
Bathyporeia pilosa	0.0123	0.0098	0.0162	0.0001							
Bathyporeia sarsi						0.0023					
Haustorius arenarius								0.0377	0.0548	0.0602	
Corophium arenarium											
Corophium volutator	0.1899	0.2128	0.131	0.0084							
Eurydice pulchra											
Cumopsis goodsir											
Peringia ulvae				0.0006	0.0001						0.0001
Mytilus edulis										0.0001	
Tellinoidea	0.0001										
Macomangulus tenuis					0.2315		0.0072				
Macoma balthica	0.1421		0.0001								

	F08a	F08b	F08c	F09	F10	F11	F12	F13a	F13b	F13c	F14
Animalia											-
Platyhelminthes											
Nemertea											
Nematoda							0.0001		0.0001	0.0001	0.0029
Eteone longa											0.0004
Glycera tridactyla											
Hediste diversicolor											
Nephtys					0.0001						
Nephtys						0.0171					
Nephtys cirrosa								0.0016	0.0176	0.0107	
Paraonis fulgens				0.0009							
Pygospio elegans											0.0395
Manayunkia aestuarina											
Enchytraeidae											0.0047
Pontocrates arenarius											
Bathyporeia pelagica	0.0652	0.0728	0.0505					0.0049		0.0117	
Bathyporeia pilosa						0.0001		0.0001			
Bathyporeia sarsi											
Haustorius arenarius											
Corophium arenarium											
Corophium volutator				0.0001							
Eurydice pulchra		0.0027	0.0036								
Cumopsis goodsir					0.0001						
Peringia ulvae								0.0005			0.0737
Mytilus edulis											
Tellinoidea											
Macomangulus tenuis							0.8802				
Macoma balthica										0.1651	

	F15	F16a	F16b	F16c	F17	F18	F19	F20			
Animalia					-						
Platyhelminthes						0.0001					
Nemertea		0.0044				0.0116					
Nematoda			0.0001	0.0001	0.0022	0.0002	0.0002	0.0001			
Eteone longa											
Glycera tridactyla				0.0269							
Hediste diversicolor						0.0832					
Nephtys											
Nephtys				0.0007							
Nephtys cirrosa	0.0132		0.0103								
Paraonis fulgens											
Pygospio elegans					0.0121	0.001	0.4555				
Manayunkia aestuarina					0.0024						
Enchytraeidae					0.0038	0.0001					
Pontocrates arenarius											
Bathyporeia pelagica	0.0037		0.0027								
Bathyporeia pilosa						0.0102		0.0001			
Bathyporeia sarsi				0.0022							
Haustorius arenarius											
Corophium arenarium					0.0001						
Corophium volutator		0.0001				0.0001					
Eurydice pulchra											
Cumopsis goodsir											
Peringia ulvae					0.2849	0.0165					
Mytilus edulis											
Tellinoidea											
Macomangulus tenuis											
Macoma balthica					0.7395	0.547					

D AMBI Scores

Table D1. AMBI IQI Scores for each station samples at Duddon Estuary SSSI in June 2023 (three pages). Note: some cells are left blank.

Sample code	EG I (%)	EG II (%)	EG III (%)	EG IV (%)	EG V (%)	Most abundant taxa (% of sample)	2nd Most abundant taxa (% of sample)	3rd Most abundant taxa (% of sample)	4th Most abundant taxa (% of sample)	5th Most abundant taxa (% of sample)	IQI (v4)	Ecological status (v4)
F01a	22.1	0.0	77.9	0.0	0.0	*Corophium volutator* (55.1%)	*Bathyporeia pilosa* (22%)	*Pygospio elegans* (21.2%)	NEMATODA (0.4%)	MOLLUSCA (0.4%)	**0.84**	**HIGH**
F01b	17.2	0.0	82.8	0.0	0.0	*Corophium volutator* (77.2%)	*Bathyporeia pilosa* (17.2%)	NEMATODA (3.3%)	*Pygospio elegans* (2.3%)	-	**0.76**	**HIGH**
F01c	20.5	0.0	79.5	0.0	0.0	*Corophium volutator* (44.1%)	*Pygospio elegans* (34.2%)	*Bathyporeia pilosa* (20.5%)	NEMATODA (0.9%)	Macoma balthica (0.3%)	**0.81**	**HIGH**
F02	12.5	0.0	87.5	0.0	0.0	*Corophium volutator* (75%)	*Hydrobia ulvae* (12.5%)	*Bathyporeia pilosa* (12.5%)	-	-	**0.85**	**HIGH**
F03	40.0	40.0	20.0	0.0	0.0	*Nephtys cirrosa* (40%)	*Angulus tenuis* (40%)	*Hydrobia ulvae* (20%)	-	-	**1.00**	**HIGH**
F04	75.0	0.0	25.0	0.0	0.0	*Bathyporeia sarsi* (75%)	NEMATODA (25%)	-	-	-	**1.00**	**HIGH**
F05	100.0	0.0	0.0	0.0	0.0	*Angulus tenuis* (100%)	-	-	-	-	**0.93**	**HIGH**
F06a	100.0	0.0	0.0	0.0	0.0	*Bathyporeia pelagica* (66.7%)	*Haustorius arenarius* (33.3%)	-	-	-	**1.04**	**HIGH**
F06b	88.9	11.1	0.0	0.0	0.0	*Bathyporeia pelagica* (66.7%)	*Haustorius arenarius* (22.2%)	*Pontocrates arenarius* (11.1%)	-	-	**1.03**	**HIGH**

Sample code	EG I (%)	EG II (%)	EG III (%)	EG IV (%)	EG V (%)	Most abundant taxa (% of sample)	2nd Most abundant taxa (% of sample)	3rd Most abundant taxa (% of sample)	4th Most abundant taxa (% of sample)	5th Most abundant taxa (% of sample)	IQI (v4)	Ecological status (v4)
F06c	82.4	5.9	11.8	0.0	0.0	*Bathyporeia pelagica* (52.9%)	*Haustorius arenarius* (29.4%)	*Pontocrates arenarius* (5.9%)	NEMATODA (5.9%)	*Mytilus edulis* (5.9%)	**1.04**	**HIGH**
F07	0.0	0.0	100.0	0.0	0.0	*Pygospio elegans* (50%)	Hydrobia ulvae (50%)	-	-	-	**0.72**	**GOOD**
F08a	100.0	0.0	0.0	0.0	0.0	*Bathyporeia pelagica* (100%)	-	-	-	-	**0.93**	**HIGH**
F08b	100.0	0.0	0.0	0.0	0.0	*Bathyporeia pelagica* (98.6%)	*Eurydice pulchra* (1.4%)	-	-	-	**0.98**	**HIGH**
F08c	100.0	0.0	0.0	0.0	0.0	*Bathyporeia pelagica* (98%)	*Eurydice pulchra* (2%)	-	-	-	**0.98**	**HIGH**
F09	0.0	0.0	100.0	0.0	0.0	*Paraonis fulgens* (66.7%)	*Corophium volutator* (33.3%)	-	-	-	**0.68**	**GOOD**
F10	0.0	100.0	0.0	0.0	0.0	*Nephtys* (50%)	*Cumopsis goodsiri* (50%)	-	-	-	**0.96**	**HIGH**
F11	66.7	33.3	0.0	0.0	0.0	*Bathyporeia pilosa* (66.7%)	*Nephtys* (33.3%)	-	-	-	**1.04**	**HIGH**
F12	1.3	0.0	98.7	0.0	0.0	NEMATODA (98.7%)	*Angulus tenuis* (1.3%)	-	-	-	**0.67**	**GOOD**
F13a	60.0	20.0	20.0	0.0	0.0	*Bathyporeia pelagica* (40%)	*Nephtys cirrosa* (20%)	*Hydrobia ulvae* (20%)	*Bathyporeia pilosa* (20%)	-	**1.07**	**HIGH**
F13b	0.0	66.7	33.3	0.0	0.0	*Nephtys cirrosa* (66.7%)	NEMATODA (33.3%)	-	-	-	**0.86**	**HIGH**

Sample code	EG I (%)	EG II (%)	EG III (%)	EG IV (%)	EG V (%)	Most abundant taxa (% of sample)	2nd Most abundant taxa (% of sample)	3rd Most abundant taxa (% of sample)	4th Most abundant taxa (% of sample)	5th Most abundant taxa (% of sample)	IQI (v4)	Ecological status (v4)
F13c	23.1	3.8	73.1	0.0	0.0	NEMATODA (69.2%)	*Bathyporeia pelagica* (23.1%)	*Nephtys cirrosa* (3.8%)	*Macoma balthica* (3.8%)	-	**0.86**	**HIGH**
F14	0.0	0.0	88.8	0.0	11.2	NEMATODA (32.4%)	*Hydrobia ulvae* (28.8%)	*Pygospio elegans* (27.2%)	*Enchytraeidae* (11.2%)	*Eteone longa* (0.4%)	**0.71**	**GOOD**
F15	33.3	66.7	0.0	0.0	0.0	*Nephtys cirrosa* (66.7%)	*Bathyporeia pelagica* (33.3%)	-	-	-	**0.98**	**HIGH**
F16a	0.0	0.0	100.0	0.0	0.0	NEMERTEA (50%)	*Corophium volutator* (50%)	-	-	-	**0.77**	**HIGH**
F16b	50.0	25.0	25.0	0.0	0.0	*Bathyporeia pelagica* (50%)	*Nephtys cirrosa* (25%)	NEMATODA (25%)	-	-	**1.01**	**HIGH**
F16c	25.0	50.0	25.0	0.0	0.0	*Nephtys* (25%)	NEMATODA (25%)	*Glycera tridactyla* (25%)	*Bathyporeia sarsi* (25%)	-	**1.01**	**HIGH**
F17	0.0	0.0	81.8	0.0	18.2	*Hydrobia ulvae* (43.9%)	NEMATODA (20.7%)	*Enchytraeidae* (18.2%)	*Manayunkia aestuarina* (13.9%)	*Pygospio elegans* (2.5%)	**0.80**	**HIGH**
F18	19.2	1.3	75.6	0.0	3.8	*Hydrobia ulvae* (34.6%)	NEMATODA (29.5%)	*Bathyporeia pilosa* (19.2%)	*Macoma balthica* (3.8%)	*Enchytraeidae* (3.8%)	**0.86**	**HIGH**
F19	0.0	0.0	100.0	0.0	0.0	*Pygospio elegans* (93.8%)	NEMATODA (6.2%)	-	-	-	**0.68**	**GOOD**
F20	66.7	0.0	33.3	0.0	0.0	*Bathyporeia pilosa* (66.7%)	NEMATODA (33.3%)	-	-	-	**1.07**	**HIGH**

E PSA Data

Table E1. Particle Size Analysis data for sediment collected within the Duddon Estuary SSSI (two pages)

Sieve Aperture (um)	F01	F02	F03	F04	F05	F06	F07	F08	F09	F10
63000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4000	0.02	0.00	0.00	0.00	0.05	0.01	0.08	0.82	0.38	0.00
2000	0.01	0.00	0.00	0.00	0.09	0.02	0.19	0.97	0.36	0.00
1000	0.02	0.00	0.00	0.00	0.19	0.05	0.30	0.62	0.70	0.45
500	0.00	0.00	2.16	2.53	6.32	6.39	3.30	4.80	6.99	3.83
250	0.01	0.00	27.84	26.62	49.71	67.27	35.68	46.58	47.21	30.17
125	30.25	10.41	59.95	67.24	39.86	25.97	55.38	46.10	44.23	64.63
63	62.77	68.40	7.75	3.61	2.60	0.28	3.43	0.10	0.14	0.92
31	4.04	14.72	0.56	0.00	0.27	0.00	0.37	0.00	0.00	0.00
15.6	0.58	1.75	0.27	0.00	0.12	0.00	0.20	0.00	0.00	0.00
7.8	0.47	1.43	0.28	0.00	0.08	0.00	0.14	0.00	0.00	0.00
3.9	0.33	1.14	0.21	0.00	0.05	0.00	0.10	0.00	0.00	0.00
0.06	1.51	2.17	0.97	0.00	0.65	0.00	0.83	0.00	0.00	0.00
Major Sediment Fractions										
% Gravel	0.02%	0.00%	0.00%	0.00%	0.14%	0.04%	0.27%	1.79%	0.74%	0.00%
% Sand	93.04%	78.81%	97.70%	100.00%	98.68%	99.96%	98.09%	98.21%	99.26%	100.00%
% Mud	6.93%	21.19%	2.30%	0.00%	1.18%	0.00%	1.64%	0.00%	0.00%	0.00%

Table E2. Particle Size Analysis data for sediment collected within the Duddon Estuary SSSI continued.

Sieve Aperture (um)	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20
63000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4000	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.00
2000	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00
1000	0.59	0.00	0.00	0.03	0.00	0.00	0.00	0.01	0.00	0.00
500	7.39	2.44	0.00	0.00	0.00	2.27	0.00	0.00	0.00	0.00
250	53.12	40.61	18.68	5.62	10.07	24.10	0.00	5.56	0.73	0.00
125	38.76	56.37	73.23	63.98	75.92	64.97	21.07	58.47	46.39	35.21
63	0.14	0.58	6.41	27.05	12.10	7.25	59.62	29.93	44.22	53.90
31	0.00	0.00	0.45	1.35	0.60	0.35	9.18	1.74	4.30	4.56
15.6	0.00	0.00	0.18	0.30	0.18	0.12	2.66	0.75	1.10	1.32
7.8	0.00	0.00	0.11	0.24	0.10	0.06	2.53	0.99	0.99	1.49
3.9	0.00	0.00	0.06	0.17	0.07	0.04	2.12	0.82	0.71	1.28
0.06	0.00	0.00	0.89	1.22	0.96	0.85	2.82	1.71	1.57	2.25
Major Sediment Fractions										
% Gravel	0.00%	0.00%	0.00%	0.03%	0.00%	0.00%	0.00%	0.02%	0.00%	0.00%
% Sand	100.00%	100.00%	98.32%	96.68%	98.09%	98.58%	80.69%	93.97%	91.33%	89.11%
% Mud	0.00%	0.00%	1.68%	3.29%	1.91%	1.42%	19.31%	6.01%	8.67%	10.89%

F Contaminants

Table F1. Contaminant concentrations in sediment samples at Duddon Estuary SSSI (three pages). Note: some cells are left blank.

Contaminant	Cefas Guideline Action Level (mg/kg)		Sediment Sample Concentration (mg/kg)				
	AL1	AL2	F01	F06	F08	F13	F20
Arsenic	20	100	5.57	8.37	7.07	7.87	5.27
Cadmium	0.4	5	0.08	<0.03	<0.03	0.04	<0.03
Chromium	40	400	19.9	10.1	10.7	20.2	7.6
Copper	40	400	3.7	3.0	3.3	2.6	2.1
Lead	50	500	11.5	6.9	6.6	8.8	7.4
Magnesium	-	-	206	155	133	163	94.0
Mercury	0.3	3	0.03	0.05	0.01	0.01	0.04
Nickel	20	200	6.4	5.5	4.7	5.1	3.9
Zinc	130	800	24.5	15.1	10.6	11.0	11.6
Aluminium	-	-	22900	17600	18100	16400	15100
Iron	-	-	8010	7330	6710	8100	5000
Lithium	-	-	16.1	16.3	15.0	13.1	12.3
Total Nitrogen	-	-	<0.05	<0.05	<0.05	<0.05	<0.05
Hexachlorobutadiene	-	-	<0.01	<0.01	<0.01	<0.01	<0.01
Tributyltin (TBT)	0.1	1	<0.01	<0.01	<0.01	<0.01	<0.01
Polychlorinated Biphenyls (PCBs; Sum of ICES 7 congeners)	0.01	0.14	<0.01	<0.01	<0.01	<0.01	<0.01
Polyaromatic Hydrocarbons (PAHs; Sum of 16 congeners)	3.17	12.8	<0.05	<0.02	<0.02	<0.02	<0.02
Acenaphthene	0.1	-	<0.001	<0.001	<0.001	<0.001	<0.001

Contaminant	Cefas Guideline Action Level (mg/kg)		Sediment Sample Concentration (mg/kg)				
	AL1	AL2	F01	F06	F08	F13	F20
Acenaphthylene	0.1	-	<0.001	<0.001	<0.001	<0.001	<0.001
Anthracene	0.1	-	0.001	<0.001	<0.001	<0.001	<0.001
Benzo[a]anthracene	0.1	-	0.003	<0.001	<0.001	<0.001	<0.001
Benzo[a]pyrene	0.1	-	0.003	<0.001	<0.001	<0.001	<0.001
Benzo[b]fluoranthene	0.1	-	0.003	<0.001	<0.001	<0.001	<0.001
Benzo[ghi]perylene	0.1	-	0.002	<0.001	<0.001	<0.001	<0.001
Benzo[k]fluoranthene	0.1	-	0.003	<0.001	<0.001	<0.001	<0.001
Chrysene	0.1	-	0.004	<0.001	<0.001	<0.001	<0.001
Dibenzo[a,h]anthracene	0.1	-	<0.001	<0.001	<0.001	<0.001	<0.001
Fluoranthene	0.1	-	0.007	<0.001	<0.001	<0.001	<0.001
Fluorene	0.1	-	<0.001	<0.001	<0.001	<0.001	<0.001
Indeno[123,cd]pyrene	0.1	-	0.002	<0.001	<0.001	<0.001	<0.001
Naphthalene	0.1	-	0.002	<0.001	<0.001	<0.001	<0.001
Phenanthrene	0.1	-	0.007	<0.001	<0.001	<0.001	<0.001
Pyrene	0.1	-	0.006	<0.001	<0.001	<0.001	<0.001
alpha-Hexachlorcyclohexane	-	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
beta-Hexachlorcyclohexane	-	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
gamma-Hexachlorcyclohexane	-	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Dieldrin	-	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Hexachlorobenzene	-	-	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
p,p'-Dichlorodiphenyldichloroethylene	-	-	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
p,p'-Dichlorodiphenyltrichloroethane	-	-	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005

Contaminant	Cefas Guideline Action Level (mg/kg)		Sediment Sample Concentration (mg/kg)				
	AL1	AL2	F01	F06	F08	F13	F20
p,p'-Dichlorodiphenyldichloroethane	-	-	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
PBDE 17	-	-	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
PBDE 28	-	-	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
PBDE 47	-	-	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
PBDE 66	-	-	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
PBDE 100	-	-	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
PBDE 99	-	-	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
PBDE 85	-	-	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
PBDE 154	-	-	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
PBDE 153	-	-	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
PBDE 138	-	-	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
PBDE 183	-	-	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
PBDE 209	-	-	0.0009	0.0024	0.0005	0.0010	0.0005
Key to colours			Cores with contaminant levels below Cefas Guideline Action Level 1 (AL1)				
			Cores with contaminant levels above AL1 and below Cefas Guideline Action Level 2 (AL2)				
			Cores with contaminant levels above AL2				

G Natural England comments on the limitations of the survey and recommendations for future studies

This survey's aim was to undertake a comprehensive Phase I and Phase II intertidal survey of the SSSI to provide an initial baseline description of the estuary along with details of the extent and condition of the 'Mudflats and Sandflats not covered by seawater at low tide' feature. This baseline data is intended to be used for future temporal comparisons.

The current level of replication of phase II samples is not sufficient for statistically strong temporal analysis to be conducted at the biotope level. It is recommended at least five stations are sampled per biotope (Marine monitoring handbook, 2001) to allow for statistically meaningful generalisation to be made of the entire biotope. As the phase I mapping found eight biotopes, this would require a minimum of 40 stations to be sampled. This survey sampled 20 stations.

The biotopes lacking replication are LS.LSa.MuSa.HedMacEte (0 stations), Rocky scar ground (0 stations), LsLMp.Sm (0 stations) LS.LBR.LMus.Myt (0 stations), LS.LSa.MuSa (2 stations), Ls.LSa.MuSa.BatCare (2 stations) Ls.LSa.MoSa.AmSco (4 stations).

Natural England recommend for future surveys to strategically target biotopes based on the habitat map generated after a phase I survey. This will ensure sufficient replication for multivariate analysis. Budgeting for future intertidal surveys in the Duddon Estuary should use the assumption of at least 8 biotopes present and therefore at least 40 core stations. If budget is a constraint replication in fewer biotopes should be prioritised over sampling all biotopes as per the common standard monitoring guidance (2004).

SSSI assessments are now aligning with Marine Protected Areas (MPA's) which require condition assessments to be done at the biotope level. Whilst Infaunal Quality Index (IQI) is a valuable tool in Water Framework Directive (WFD) assessments it does not align with the feature attributes at the biotope level. IQI is also not as sensitive to change as multivariate analysis and therefore using multivariate analysis allows for an earlier warning sign of community changes than a change in IQI from "good" to "bad". IQI can however be used alongside multivariate analysis in the future as a useful tool for communicating changes in ecological status.

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