Intertidal sediment survey in East Yorkshire, 2022

Report

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1. Background

The Yorkshire Marine Nature Partnership (YMNP), working with East Riding of Yorkshire Council (ERYC), required an intertidal sediment survey to be undertaken along the shoreline, at three selected locations (Skipsea, Mappleton and Withernsea) on the east Yorkshire coastline, within the Holderness Inshore Marine Conservation Zone (MCZ) (Figure 1).

The survey aimed at assessing the species composition / biological communities for intertidal sand and muddy sand sediments to inform coastal management. Any invasive non-native species (INNS) were also to be recorded, as well as data on the sediment composition and general topographic features to fill evidence gaps.

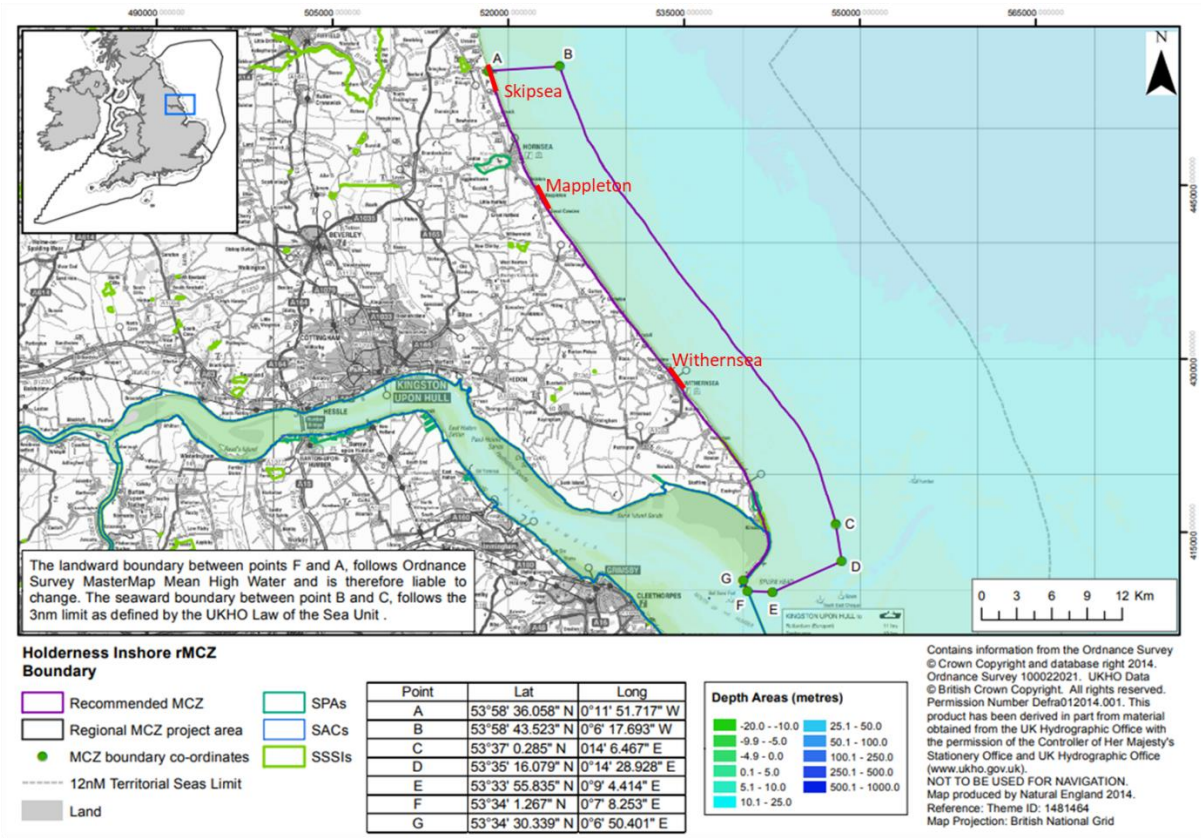

Figure 1. Holderness Inshore MCZ: 2016 designation map (source: Defra 2016). The three areas where intertidal sediment sampling was undertaken in 2022 are indicated in red.

1.1 The Holderness Inshore MCZ

The information below has been obtained from the Holderness Inshore MCZ factsheet (Defra 2016).

The Holderness Inshore MCZ is located north of the Humber Estuary on the Yorkshire coast (Figure 1). The site covers an area of approximately 309 km² and it became a Marine Conservation Zone in January 2016.

The subtidal area of the site extends out to 3 nautical miles and is composed of high and moderate energy circalittoral rock, subtidal coarse and mixed sediment, subtidal mud and subtidal sand with subtidal water depths reaching approximately 15 m. The mosaic of habitats within the site supports a diverse range of organisms including red algae, sponges and other encrusting fauna. The site also supports fish species such as European eel, dab and wrasse, as well as commercially significant crustaceans such as edible and velvet swimming crabs and lobster.

The intertidal area, of interest in this survey, is made up of a long open beach of relatively mobile sediments, backed by soft, readily eroding cliff. These sandy shores may appear devoid of marine life, but are in fact home to many species, buried in the damp sand. On all but the most barren sandy shores, there will be different kinds of worms just beneath the surface. The strandline of seaweed and other debris left behind at the top of the shore by the falling tide is also home to creatures including shrimp-like sandhoppers. Muddier sands support bivalves (with their paired, hinged shells), including the common cockle, and sea snails like the laver spire shell.

The site also protects a geological feature, Spurn Head, which is in the south of the MCZ. This is a unique example of an active spit system, extending across the mouth of the Humber Estuary.

2. Survey methods

2.1 Survey design

Three survey sites were identified along the shoreline to the north, centre and south of the Holderness coast: Skipsea, Mappleton and Withernsea, respectively (Figure 1). These areas and the sampling locations within were selected taking into account representativity of the sedimentary shores within the Holderness Inshore MCZ, site accessibility and also to avoid disturbance in sensitive areas (e.g. Withow Gap SSSI to the north, near Skipsea; The Humber Estuary SSSI and The Lagoons SSSI at Easington, to the south).

At each survey site, the sediment sampling was undertaken along two transects (North and South) perpendicular to the shoreline (Figure 2, 3 and 4). All transects were located in natural (undefended) parts of the eroding Holderness coastline, except for the southern transect at Withernsea, which was located within a defended shoreline backed by rock armour.

Three sampling stations were located along each transect to reflect different positions along the intertidal shore gradient: one station on the upper shore (near the high-water mark), one on the middle shore and one on the lower shore (immediately above low water). A total of 18 sampling stations were identified (Appendix 1; Figure 2, 3 and 4).

Four sediment core samples were collected from each station, including three replicate samples for benthic invertebrate analysis and one sample for sediment particle size analysis (PSA). The sample locations were determined randomly within a 5 m^2 area from the station point location.

The sampling was undertaken on 10-12 September 2022, during spring tides. Samples were collected within a 4-hour interval centred around low tide to ensure the lower shore levels could be accessed and adequately sampled. The timing of sampling was consistent (+/-2 hours) between transects to minimise any complications due to species behaviour (e.g. vertical migrations).

Figure 2. Locations of intertidal sampling stations at Skipsea (2022).

Figure 3. Locations of intertidal sampling stations at Mappleton (2022).

Figure 4. Locations of intertidal sampling stations at Withernsea (2022).

2.2 Field methods

The sediment samples were collected at each station using a 11.5 cm diameter corer (0.01 m^2 area). Sediment was cored to a depth of approximately 15 cm and subsequently stored in pre-labelled heavy-duty polythene bags with an internal label. The sediment samples were kept cool until analysis at the HML laboratory.

Biotopes were allocated to each sampling site, based on sample data and visual assessment of the substratum in the area surrounding the sampling locations.

2.3 Laboratory analysis

Sediment samples were analysed in the HML laboratory for particle size (PSA) and benthic invertebrate (ID and abundance).

Sediment particle size was determined using a combination of laser and dry sieve analysis to give combined data sets for each site. All samples were subject to 3 replicate analyses to determine operator, machine and measurement accuracy (with good results close or lower than 5% variation obtained).

Laboratory's standard operating procedures for the analysis of benthic invertebrate fauna followed National Marine Biological Analytical Quality Control (NMBAQC) scheme guidelines

(Worsfold and Hall 2010) and ISO16665:2014[1]. Benthic invertebrates were identified at the lowest taxonomic level possible (almost always species).

The presence of INNS in the samples was identified (if any) based on the Non-native Species Information Portal (NNSIP) of the GB Non-Native Species Secretariat[2], the body that has responsibility for helping to coordinate the approach to invasive non-native species in Great Britain.

2.4 Data analysis

Benthic communities in the samples were characterised by a set of variables accounting for primary and derived community parameters such as:

- The total number of species in the samples, giving the basic measure for species richness in the community;
- The total number of benthic organisms present in the samples, characterising the community abundance (given as number of individuals per 0.01 m^2 core sample area);
- The species diversity in the community, as calculated using the Shannon Wiener diversity index (H'), which takes into account both the total number of species (richness) and the distribution of individuals between the species (evenness):

  $$H' = -\sum p_i \log_2 p_i,$$

  where p_i is the proportion of individuals in the i^{th} species, and the sum (Σ) is undertaken across all the S species in the assemblage.

Mean values of the above variables were calculated to characterise the benthic invertebrate communities at different shore levels and survey sites.

PERMANOVA analysis of variance was applied (with 9999 permutations and with Bonferroni correction for pairwise comparison) to the benthic assemblage data (multivariate analysis on species abundance) and to the individual community variables (univariate analysis). The analysis aimed to test the statistical significance of any differences existing between the selected survey sites and shore levels (treated as fixed factors), while taking into account the spatial variability within an area (as represented by transects, treated as random factor).

A cluster analysis (group-average algorithm, with SIMPROF test) was also applied to the sample data (species abundance and particle size composition) to identify any significant ($P<0.05$) differentiation (in the taxonomic composition and structure of the benthic communities, and in the sediment composition, respectively) between shore levels, transects and survey sites.

[1] ISO16665:2014 – Water quality - Guidelines for quantitative sampling and sample processing of marine soft-bottom macrofauna.
[2] https://www.nonnativespecies.org/non-native-species/

For the multivariate analyses, species abundance in the samples were square root-transformed to reduce the influence of dominant species and a zero-adjusted Bray-Curtis similarity was calculated (i.e. with the addition of a 'dummy species' with value of 1) as suited for sparse assemblages (Clarke et al. 2006).

A multivariate analysis of variance (PERMANOVA, with 9999 permutations and with Bonferroni correction for pairwise comparison) was also applied to the sediment PSA data, based on grain size class composition. The analysis aimed to test the statistical significance of any differences existing between the selected survey sites and shore levels (treated as fixed factors), using the samples from different transects as replicates. For this analysis, the data were normalised and the Euclidean distance was calculated between sediment samples.

The data analysis was undertaken using PRIMER 6 and PERMANOVA+ (Clarke and Gorley 2006, Anderson et al. 2008).

3. Results

3.1 Sites descriptions

Descriptions of the sampling stations are provided in Table 1, with further supporting evidence from site photos taken during the survey[3].

The beach at Skipsea (both transects), Mappleton (both transects) and Withernsea (northern transect) was generally gently sloping, with sandy-gravelly sediments often presenting stones and cobbles on the surface. The upper shore was backed up by a sedimentary cliff, which in some instances (e.g. at Skipsea southern transect) showed clear signs of crumbling. In turn, a steeper gradient was present on the beach at Withernsea southern transect (particularly on the upper-middle shore), which was located within a defended stretch of coastline, with rock armour providing protection at the top of the shore. No evidence of presence of fauna was apparent from field observations in most sites.

Table 1. Site description at the intertidal stations sampled along the Holderness coast in 2022 (see Appendix 1 for station codes).

Station code	Site description (*in situ* observation)
Skip.N.U	Sloped, dry medium sand over gravel, with some stones and cobbles. Just below site larger rocks and cobbles in band along shore about 10 m wide. No evidence of animals.
Skip.N.M	Wet, smooth fine sand over gravel. Small stones on surface. No evidence of animals. Sediment liquifies when agitated.
Skip.N.L	Wet, smooth fine sand over gravel. Small stones on surface. Sediment liquifies when agitated. Bait digging (*Arenicola*) to the North of the site.
Skip.S.U	Fine, dry, smooth sand with a little gravel. Small stones on the surface. Site just in front of the crumbling mud cliff with lumps of mud and cobbles. Shallow gradient. No evidence of animals.
Skip.S.M	Wet, smooth medium sand with a little gravel. Small stones on surface. Shallow gradient. No evidence of animals.
Skip.S.L	Wet, smooth fine sand with gravel underneath. Small stones on surface. Black organic particles covering sediment just below the site. No evidence of animals.
Mapp.N.U	Sloped, dry medium sand with gravel and cobbles. Just in front of mud cliff. Above flatter water-logged area. No evidence of animals.
Mapp.N.M	Fine/medium sand. Small stones with some larger stones on the surface. Area has shallow gradient. Smooth and water-logged with no evidence of animals.
Mapp.N.L	Fine sand, coarser material about 15 cm deep. Small stones on the surface. Area has shallow gradient. Smooth and water-logged with no evidence of animals.

[3] https://universityofhull.box.com/s/x3vng4g48hv3i21o2s3ydwuuqh24qlnc

Station code	Site description (*in situ* observation)
Mapp.S.U	Thin layer of medium sand over coarser sand and gravel. Water-logged. Site just in front of mud cliff. Some stones present on surface of sand above and below site. Area has shallow gradient. No evidence of animals.
Mapp.S.M	Fine sand. Some small stones on the surface. Area has shallow gradient. Smooth and water logged with no evidence of animals.
Mapp.S.L	Fine sand, coarser material about 15 cm deep. Some small stones on the surface. Area has shallow gradient. Smooth and water-logged with no evidence of animals.
With.N.U	Medium sand with gravel, stones and cobbles. Area level but just above sloped stony area that leads onto flatter sandy area. Strand line in area. Talitridae holes above site
With.N.M	Wet, fine sand with a little gravel. Slight gradient. Water running over surface. Sediment liquifies when agitated. No evidence of animals.
With.N.L	Wet, fine sand with a little gravel. Layer of gravel about 15 cm deep. Slight gradient. Water running over surface. Sediment liquifies when agitated. No evidence of animals.
With.S.U	Dry, medium sand with lots of stones and cobbles. Beach steeply sloped. Site just in front of rock armour. Core depth 10 cm due to stones.
With.S.M	Medium sand with gravel and occasional cobbles. Start of the wet area where the water is draining from beach. Steeply sloped. Soft. No evidence of animals.
With.S.L	Fine sand with gravel. Fewer stones than further up the beach. No evidence of animals. Sediment liquifies when agitated.

3.2 Sediment characteristics

The sediments collected from the intertidal shore along the Holderness coast classified as gravelly sand, slightly gravelly sand and sandy gravel, falling within the broader categories of sand or coarse sediment as used in the EUNIS habitat classification (Table 2). Sand dominated the sediment composition (overall mean 81%, ranging between 29%-99%), with the addition of a variable gravel component (overall mean 36%, ranging between 1%-71%) (Figure 5).

The sediments were often poorly sorted, with a clear dominance of medium sand and fine sand in most of the samples (Table 2, Figure 6). Exceptions occurred for the samples collected from the upper shore at Skipsea (northern transect), Mappleton (northern transect) and Withernsea (southern transect), and from the middle shore in this latter site. Sediments at these locations showed better sorting, with a higher contribution of gravelly grain size classes in addition to sand (Table 2, Figure 6).

The multivariate analysis of variance (PERMANOVA) applied to the sediment grain size class composition did not highlight significant differences between the survey sites of Skipsea, Mappleton and Withernsea on the whole (Table 3). A difference between shore levels was detected, albeit weakly significant (P level close to 0.05). This was mainly ascribed to the

higher contribution of coarser grain size classes in the upper shore sediments (as mentioned above) compared in particular to the lower shore.

Table 2. Descriptive statistics of sediment properties in the samples collected the intertidal zone of the Holderness coast in 2022 (from PSA; see Appendix 1 for station codes).

Station	Textural group	UK SeaMap & MESH class*	Grain size (Folk and Ward method, Phi)				Sample type
			Mean	Sorting	Skewness	Kurtosis	
Skip.N.U	Sandy Gravel	Coarse Sediment	Very Fine Gravel	Poorly Sorted	Very Fine Skewed	Platykurtic	Bimodal, Poorly Sorted
Skip.N.M	Gravelly Sand	Coarse Sediment	Coarse Sand	Poorly Sorted	Very Coarse Skewed	Platykurtic	Bimodal, Poorly Sorted
Skip.N.L	Gravelly Sand	Coarse Sediment	Fine Sand	Poorly Sorted	Very Coarse Skewed	Very Leptokurtic	Unimodal, Poorly Sorted
Skip.S.U	Gravelly Sand	Coarse Sediment	Medium Sand	Poorly Sorted	Very Coarse Skewed	Very Leptokurtic	Unimodal, Poorly Sorted
Skip.S.M	Slightly Gravelly Sand	Sand	Fine Sand	Moderately Sorted	Coarse Skewed	Leptokurtic	Unimodal, Moderately Sorted
Skip.S.L	Gravelly Sand	Coarse Sediment	Fine Sand	Poorly Sorted	Very Coarse Skewed	Very Leptokurtic	Unimodal, Poorly Sorted
Mapp.N.U	Sandy Gravel	Coarse Sediment	Very Fine Gravel	Very Poorly Sorted	Coarse Skewed	Very Platykurtic	Trimodal, Very Poorly Sorted
Mapp.N.M	Slightly Gravelly Sand	Sand	Medium Sand	Moderately Sorted	Coarse Skewed	Mesokurtic	Unimodal, Moderately Sorted
Mapp.N.L	Slightly Gravelly Sand	Sand	Medium Sand	Poorly Sorted	Coarse Skewed	Leptokurtic	Unimodal, Poorly Sorted
Mapp.S.U	Gravelly Sand	Coarse Sediment	Coarse Sand	Poorly Sorted	Very Coarse Skewed	Very Leptokurtic	Unimodal, Poorly Sorted
Mapp.S.M	Slightly Gravelly Sand	Sand	Medium Sand	Moderately Well Sorted	Symmetrical	Mesokurtic	Unimodal, Moderately Well Sorted
Mapp.S.L	Slightly Gravelly Sand	Sand	Medium Sand	Moderately Sorted	Coarse Skewed	Leptokurtic	Unimodal, Moderately Sorted
With.N.U	Gravelly Sand	Coarse Sediment	Coarse Sand	Poorly Sorted	Very Coarse Skewed	Platykurtic	Bimodal, Poorly Sorted
With.N.M	Gravelly Sand	Coarse Sediment	Medium Sand	Moderately Sorted	Very Coarse Skewed	Very Leptokurtic	Unimodal, Moderately Sorted
With.N.L	Gravelly Sand	Coarse Sediment	Coarse Sand	Poorly Sorted	Very Coarse Skewed	Mesokurtic	Polymodal, Poorly Sorted
With.S.U	Sandy Gravel	Coarse Sediment	Very Fine Gravel	Very Poorly Sorted	Very Fine Skewed	Platykurtic	Trimodal, Very Poorly Sorted
With.S.M	Sandy Gravel	Coarse Sediment	Very Fine Gravel	Very Poorly Sorted	Symmetrical	Platykurtic	Polymodal, Very Poorly Sorted
With.S.L	Slightly Gravelly Sand	Sand	Medium Sand	Moderately Sorted	Coarse Skewed	Leptokurtic	Unimodal, Moderately Sorted

*Classification using the modified Folk triangle for UK SeaMap & MESH to aid designation of biotopes.

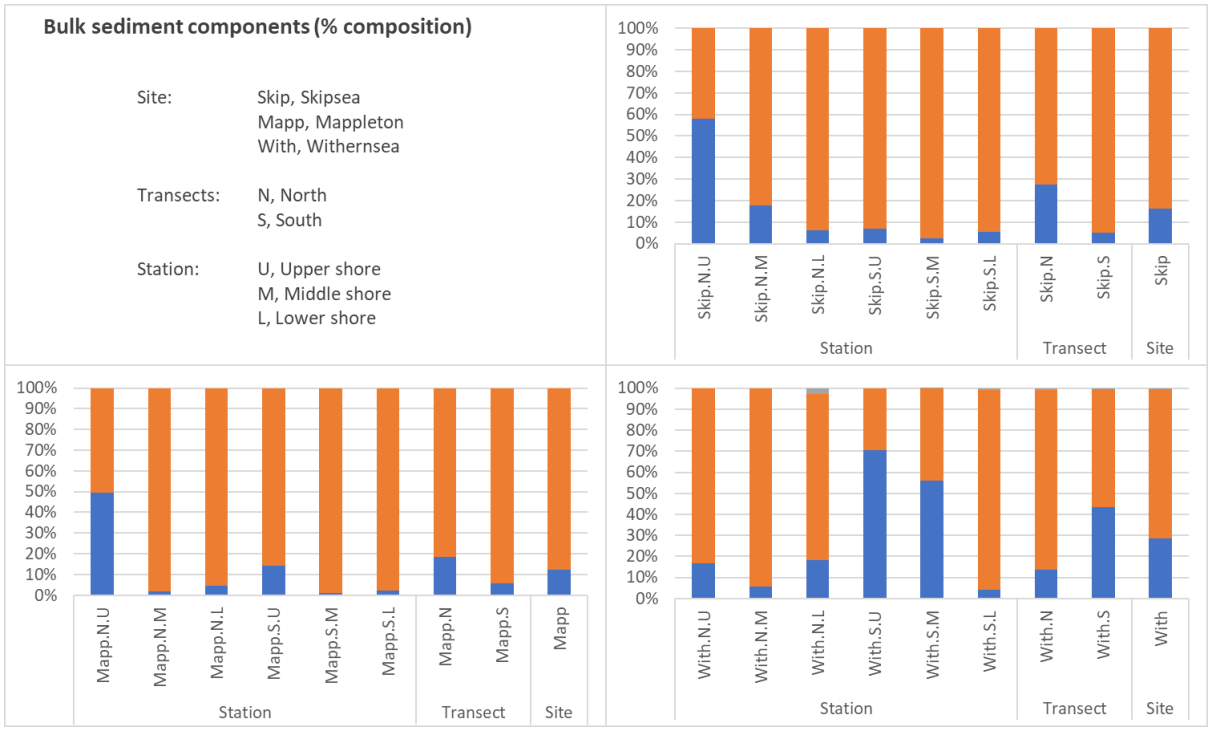

Figure 5. Bulk sediment components (% contribution): variability across survey sites, transects and stations (at different shore levels).

Figure 6. Sediment grain size distribution (% contribution by Phi classes; VC, very coarse; C, coarse; M, medium; F, fine; VF, very fine) at sampling stations.

Table 3. PERMANOVA tables of results: multivariate test on sediment grain size class composition. Significant P levels (P<0.05) are highlighted in bold.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique permutations
Survey site (Ar)	2	37.689	18.845	1.6113	0.1468	9929
Shore level (Sh)	2	56.086	28.043	2.3977	**0.0454**	9942
ArxSh	4	55.964	13.991	1.1963	0.301	9928
Residuals	9	105.26	11.696			
Total	17	255				

3.3 Benthic invertebrate fauna

The composition of the benthic faunal assemblages sampled in the intertidal sediments along the Holderness coast is shown in Table 4 (overall, by survey site and by shore level), Table 5 (by station at different shore levels within transects), and Appendix 3 (sample data).

The benthic invertebrate fauna was generally species-poor and sparsely distributed. It included 17 taxa overall, with various species of polychaete anellids (worms), crustaceans (including mysids, amphipods, isopods and cumaceans), bivalve molluscs (juvenile mussels and tellinids), and the occasional nemertean and collembola (springtails). The faunal abundance was generally low, with only 152 individuals recorded across all the 54 samples collected. No fauna was found in the samples collected from the upper shore of the northern transects at Skipsea and Withernsea, and from all shore levels of the southern transect at Withernsea. No INNS were found in the samples.

The bristleworm *Scolelepis (Scolelepis) squamata* was the most abundant species, with 82 individuals recorded overall. However, it was only present in 5 samples from the Skipsea and Mappleton sites, with the specimens collected on the upper shore of the southernmost transect at Skipsea accounting for the majority (97%) of the abundance of this species.

The burrowing amphipod *Pontocrates arenarius* was also relatively abundant, with 30 individuals recorded overall. This was the species most frequently found in the samples (in 14 out of 54), occurring most often at the middle shore level, and especially in the Mappleton area (70% of the total numbers recorded for this species).

The white catworm *Nephtys cirrosa* was recorded in 10 samples, with a total abundance of 11 individuals. It occurred mostly at mid-lower shore levels throughout the survey sites, with no dominance at a particular site.

The other species occurred only in few samples (mostly in 1 or 2 samples each) and with few numbers (between 1 and 5 individuals overall) (Table 4, Appendix 3).

Table 4. Benthic invertebrates sampled in the intertidal zone of the Holderness coast in 2022. Overall abundance and mean by survey site and shore level.

Taxon	Total count (individuals)	Mean Abundance (ind./0.01m^2)						
		Overall	By survey site			By shore level		
			Skipsea	Mappleton	Withernsea	Upper shore	Middle shore	Lower shore
Nemertea	1	0.02	0	0.06	0	0	0.06	0
Anellida, Polychaeta								
Eteone longa	1	0.02	0.06	0	0	0.06	0	0
Nephtys cirrosa	11	0.20	0.28	0.17	0.17	0	0.28	0.33
Scolelepis (Scolelepis) squamata	82	1.52	4.39	0.17	0	4.44	0.11	0
Spio martinensis	1	0.02	0	0.06	0	0	0.06	0
Arthropoda, Crustacea								
Gastrosaccus spinifer	1	0.02	0	0	0.06	0	0	0.06
Pontocrates arenarius	30	0.56	0.39	1.17	0.11	0	1.44	0.22
Urothoe brevicornis	5	0.09	0.06	0.17	0.06	0	0.17	0.11
Bathyporeia elegans	1	0.02	0.06	0	0	0	0	0.06
Bathyporeia pilosa	2	0.04	0	0.11	0	0	0.11	0
Haustorius arenarius	2	0.04	0.11	0	0	0.11	0	0
Eurydice pulchra	4	0.07	0.22	0	0	0.22	0	0
Lekanesphaera rugicauda	1	0.02	0.06	0	0	0	0	0.06
Cumopsis goodsir	4	0.07	0.22	0	0	0	0.17	0.06
Mollusca, Bivalvia								
Mytilus (Mytilus) edulis	3	0.06	0	0.17	0	0.17	0	0
Macomangulus tenuis	1	0.02	0.06	0	0	0	0	0.06
Collembola	2	0.04	0	0.11	0	0.11	0	0
Number of species	**17**	**17**	**11**	**9**	**4**	**6**	**8**	**8**
Total benthic abundance (sum)	**152**	**2.81**	**5.89**	**2.17**	**0.39**	**5.11**	**2.39**	**0.94**
Mean species abundance	**9**	**0.17**	**0.35**	**0.13**	**0.02**	**0.30**	**0.14**	**0.06**
Mean Shannon index H'(log_2)		**0.31**	**0.45**	**0.44**	**0.05**	**0.13**	**0.54**	**0.27**

Table 5. Benthic invertebrates sampled in the intertidal zone of the Holderness coast in 2022. Mean abundance by station (U, upper shore; M, middle shore; L, lower shore) and by transect (N, North; S, South) at (a) Skipsea (Skip), (b) Mappleton (Mapp) and (c) Withernsea (With).

a) Skipsea	Mean Abundance (ind./0.01m2)							
Taxon	By station						By transect	
	Skip.N.U	Skip.N.M	Skip.N.L	Skip.S.U	Skip.S.M	Skip.S.L	Skip.N	Skip.S
Nemertea	0	0	0	0	0	0	0	0
Eteone longa	0	0	0	0.33	0	0	0	0.11
Nephtys cirrosa	0	0	0	0	0.67	1.00	0	0.56
Scolelepis (Scolelepis) squamata	0	0	0	26.33	0	0	0	8.78
Spio martinensis	0	0	0	0	0	0	0	0
Gastrosaccus spinifer	0	0	0	0	0	0	0	0
Pontocrates arenarius	0	0.67	0	0	1.33	0.33	0.22	0.56
Urothoe brevicornis	0	0	0	0	0.33	0	0	0.11
Bathyporeia elegans	0	0	0	0	0	0.33	0	0.11
Bathyporeia pilosa	0	0	0	0	0	0	0	0
Haustorius arenarius	0	0	0	0.67	0	0	0	0.22
Eurydice pulchra	0	0	0	1.33	0	0	0	0.44
Lekanesphaera rugicauda	0	0	0	0	0	0.33	0	0.11
Cumopsis goodsir	0	1.00	0	0	0	0.33	0.33	0.11
Mytilus (Mytilus) edulis	0	0	0	0	0	0	0	0
Macomangulus tenuis	0	0	0.33	0	0	0	0.11	0
Collembola	0	0	0	0	0	0	0	0
Number of species	**0**	**2**	**1**	**4**	**3**	**5**	**3**	**10**
Total benthic abundance (sum)	**0**	**1.67**	**0.33**	**28.67**	**2.33**	**2.33**	**0.67**	**11.11**
Mean species abundance	**0**	**0.10**	**0.02**	**1.69**	**0.14**	**0.14**	**0.04**	**0.65**
Mean Shannon index H'(log_2)	**0**	**0.31**	**0**	**0.46**	**0.97**	**0.97**	**0.10**	**0.80**

Table 5. Continued.

b) Mappleton	Mean Abundance (ind./0.01m2)							
Taxon	By station						By transect	
	Mapp.N.U	Mapp.N.M	Mapp.N.L	Mapp.S.U	Mapp.S.M	Mapp.S.L	Mapp.N	Mapp.S
Nemertea	0	0	0	0	0.33	0	0	0.11
Eteone longa	0	0	0	0	0	0	0	0
Nephtys cirrosa	0	0	0.33	0	0.33	0.33	0.11	0.22
Scolelepis (Scolelepis) squamata	0	0.67	0	0.33	0	0	0.22	0.11
Spio martinensis	0	0	0	0	0.33	0	0	0.11
Gastrosaccus spinifer	0	0	0	0	0	0	0	0
Pontocrates arenarius	0	4.67	0.67	0	1.33	0.33	1.78	0.56
Urothoe brevicornis	0	0.33	0	0	0.33	0.33	0.11	0.22
Bathyporeia elegans	0	0	0	0	0	0	0	0
Bathyporeia pilosa	0	0.67	0	0	0	0	0.22	0
Haustorius arenarius	0	0	0	0	0	0	0	0
Eurydice pulchra	0	0	0	0	0	0	0	0
Lekanesphaera rugicauda	0	0	0	0	0	0	0	0
Cumopsis goodsir	0	0	0	0	0	0	0	0
Mytilus (Mytilus) edulis	0.33	0	0	0.67	0	0	0.11	0.22
Macomangulus tenuis	0	0	0	0	0	0	0	0
Collembola	0	0	0	0.67	0	0	0	0.22
Number of species	**1**	**4**	**2**	**3**	**5**	**3**	**6**	**8**
Total benthic abundance (sum)	**0.33**	**6.33**	**1.00**	**1.67**	**2.67**	**1.00**	**2.56**	**1.78**
Mean species abundance	**0.02**	**0.37**	**0.06**	**0.10**	**0.16**	**0.06**	**0.15**	**0.10**
Mean Shannon index H'(log_2)	**0**	**0.86**	**0.31**	**0.33**	**0.81**	**0.33**	**0.39**	**0.49**

c) Withernsea	Mean Abundance (ind./0.01m2)							
Taxon	By station						By transect	
	With.N.U	With.N.M	With.N.L	With.S.U	With.S.M	With.S.L	With.N	With.S
Nemertea	0	0	0	0	0	0	0	0
Eteone longa	0	0	0	0	0	0	0	0
Nephtys cirrosa	0	0.67	0.33	0	0	0	0.33	0
Scolelepis (Scolelepis) squamata	0	0	0	0	0	0	0	0
Spio martinensis	0	0	0	0	0	0	0	0
Gastrosaccus spinifer	0	0	0.33	0	0	0	0.11	0
Pontocrates arenarius	0	0.67	0	0	0	0	0.22	0
Urothoe brevicornis	0	0	0.33	0	0	0	0.11	0
Bathyporeia elegans	0	0	0	0	0	0	0	0
Bathyporeia pilosa	0	0	0	0	0	0	0	0
Haustorius arenarius	0	0	0	0	0	0	0	0
Eurydice pulchra	0	0	0	0	0	0	0	0
Lekanesphaera rugicauda	0	0	0	0	0	0	0	0
Cumopsis goodsir	0	0	0	0	0	0	0	0
Mytilus (Mytilus) edulis	0	0	0	0	0	0	0	0
Macomangulus tenuis	0	0	0	0	0	0	0	0
Collembola	0	0	0	0	0	0	0	0
Number of species	**0**	**2**	**3**	**0**	**0**	**0**	**4**	**0**
Total benthic abundance (sum)	**0**	**1.33**	**1.00**	**0**	**0**	**0**	**0.78**	**0**
Mean species abundance	**0**	**0.08**	**0.06**	**0**	**0**	**0**	**0.05**	**0**
Mean Shannon index H'(log_2)	**0**	**0.31**	**0**	**0**	**0**	**0**	**0.10**	**0**

The number of species recorded per sample was generally very low (mean 0.96 ± 0.13 Standard Error (SE), ranging between 0-3 taxa) (Figure 7). Mean values decreased across sites on a North-South direction, with higher number of species found at Skipsea (mean 1.39 ± 0.24; 11 taxa found overall at this site), followed by Mappleton (mean 1.17 ± 0.23; 9 taxa overall) and Withernsea (mean 0.33 ± 0.14; 4 taxa overall). Higher number of species were generally found in samples collected from the middle shore (mean 1.39 ± 0.22) compared to the lower (mean 0.83 ± 0.20) and upper shore (mean 0.67 ± 0.26) levels. However, these differences between survey sites and shore levels were not statistically significant (see PERMANOVA results in Appendix 4). In turn, a significant ($P<0.01$) variability in the number of benthic species was detected between transects within the survey sites (Appendix 4). This was most evident at Skipsea, where more species were found in the southern transect (10 taxa overall) compared to the northern one (3 taxa overall) (Figure 7). At Withernsea, the difference between transects was also apparent (Figure 7), as no fauna was found along the southern transect (within the defended area), whereas 4 taxa were recorded overall in the other transect. At Mappleton, the number of species found in the two transects was similar (6 taxa in the northern transect, 8 taxa in the southern one).

The benthic abundance recorded in the samples was also generally low, with an overall mean (±SE) of 2.81 ± 0.92 ind./0.01 m^2 and a range between 0-37 individuals per 0.01 m^2 sample (Figure 8). The pattern of variability across survey sites was similar to that observed for the number of species, with decreasing mean values of abundance from Skipsea (5.89 ± 2.55 ind./0.01 m^2), to Mappleton (2.17 ± 0.65 ind./0.01 m^2), to Withernsea (0.39 ± 0.18 ind./0.01 m^2). As for the species number, these differences in benthic abundance between survey sites were not statistically significant (Appendix 4). In turn, the analysis highlighted differences across shore levels which varied depending on transects within the survey sites (Appendix 4). In particular, the benthic abundance was significantly ($P<0.05$) higher on the upper shore of the southernmost transect at Skipsea (28.67 ± 4.26 ind./0.01 m^2) compared to the other shore levels along this transect (2.33 ± 0.33 ind./0.01 m^2) (Figure 8). The differences across shore levels at other transects within sites were not significant.

A low species diversity (as measured by the Shannon index) characterised the benthic assemblages in the samples overall (mean 0.31 ± 0.06 SE, ranging between 0-1.50 across samples) (Figure 9). The mean diversity also varied along a north-south gradient, with assemblages at Skipsea and Mappleton being on average more diverse (0.45 ± 0.11 and 0.44 ± 0.12, respectively) than those found at Withernsea (0.05 ± 0.05). However, as for species numbers and abundance, these differences were not significant (Appendix 4). In turn, the analysis highlighted a significant ($P<0.05$) differentiation between shore levels which was consistent across sites (Appendix 4). This was ascribed to the significantly higher diversity of benthic assemblages found on the middle shore (overall mean 0.54 ± 0.12) compared to those on the upper shore (0.13 ± 0.07), while assemblages on the lower shore showed intermediate values (0.27 ± 0.11) (Figure 9). The benthic diversity also significantly ($P<0.05$) varied between

transects within the survey sites (Appendix 4). This variability was most evident at Skipsea, with higher diversity on the southern transect than on the northern.

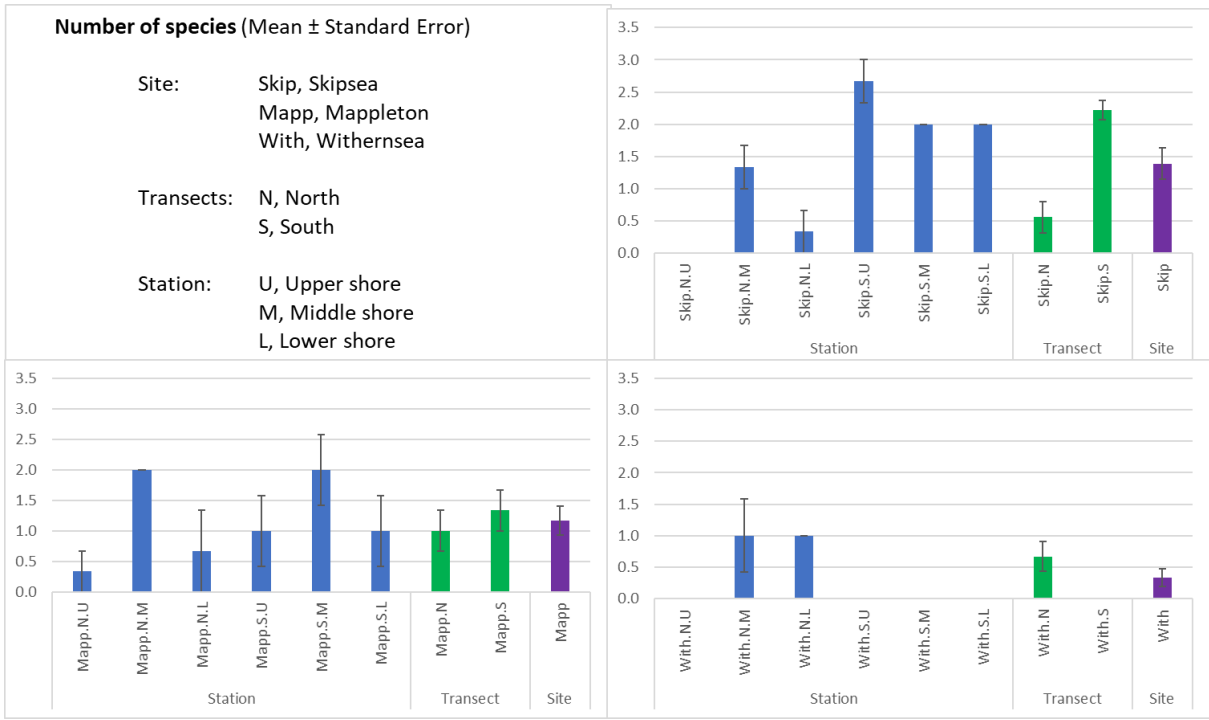

Figure 7. Number of species: variability across survey sites, transects and stations (at different shore levels) within.

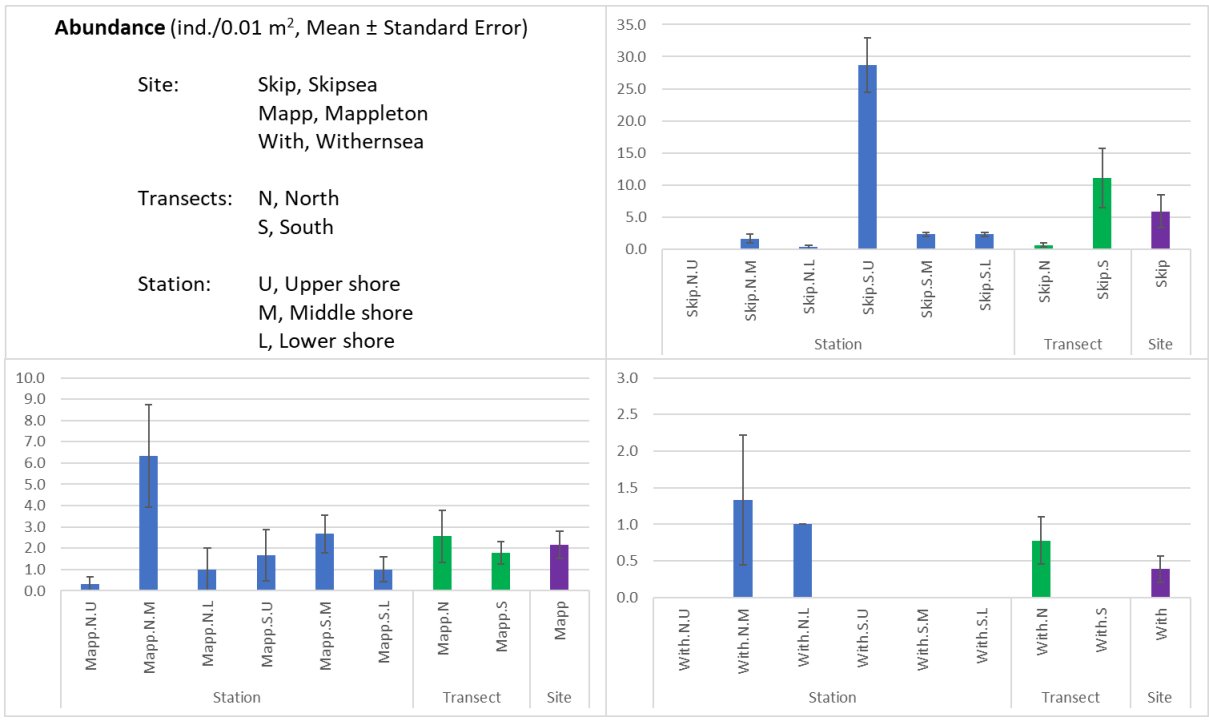

Figure 8. Total benthic abundance: variability across survey sites, transects and stations (at different shore levels) within. Note different abundance scale between sites.

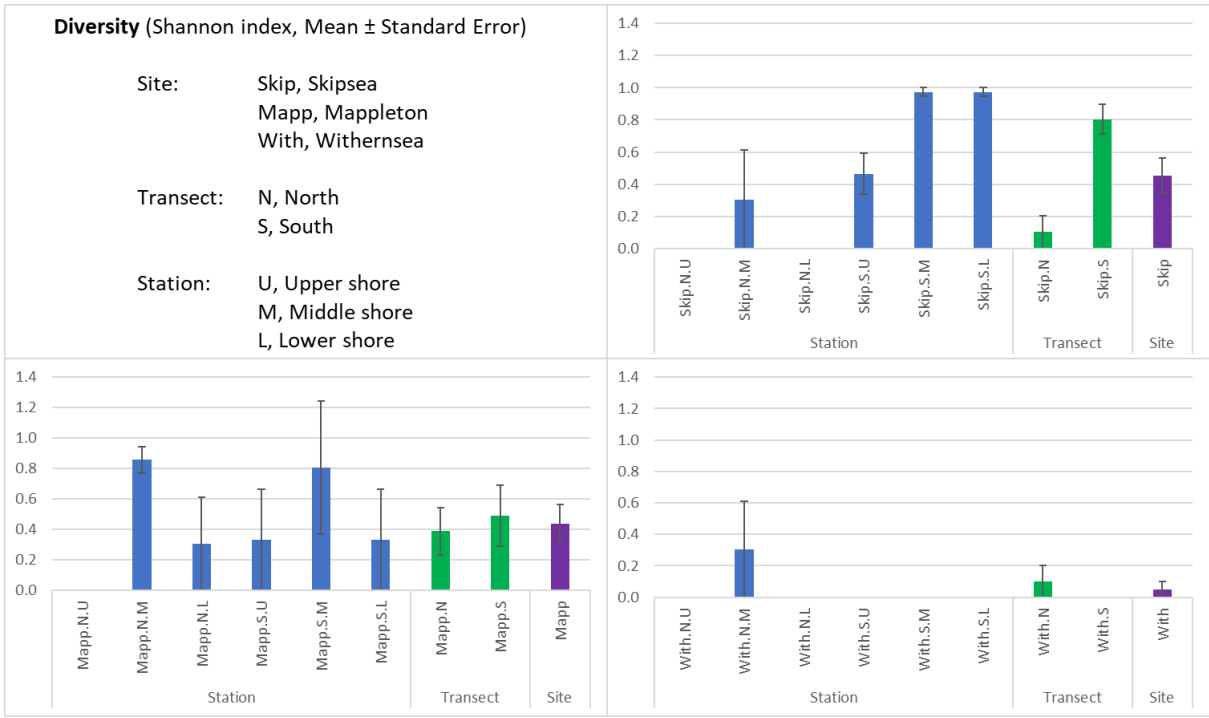

Figure 9. Species diversity (Shannon index): variability across survey sites, transects and stations (at different shore levels) within.

The analysis of the benthic assemblage structure (multivariate analysis based on the species abundance in the assemblage) did not reveal significant differentiations between survey sites as a whole (Appendix 4). In turn, differences across shore levels were detected, but these significantly ($P<0.01$) varied depending on transects within the survey sites (Appendix 4). In particular, the benthic assemblages on the upper shore were significantly ($P<0.05$) different from those on the middle and lower shore along the southern transect at Skipsea, and from those on the middle shore along the northern transect at Mappleton. The differentiation at Skipsea was mainly due to the above mentioned high benthic abundance and dominance of *Scolelepis (Scolelepis) squamata* in the assemblage of the upper shore of the southern transect, while this species was absent from the middle and lower shore, where other species such as *Nephtys cirrosa* and *Pontocrates arenarius* occurred instead (albeit in much lower numbers; Table 5a). The general higher benthic abundance and dominance of *Scolelepis (Scolelepis) squamata* in all the samples from the upper shore in the southern transect at Skipsea also denoted the significant ($P<0.05$) differentiation of the assemblage in this station from all the other samples collected in the survey, as highlighted by the cluster analysis (Group a in Figure 10). As for the shore level variability at Mappleton (northern transect), this was mainly ascribed to the fact that the assemblage on the upper shore was only composed of one juvenile individual of *Mytilus (Mytilus) edulis*, while this species was absent from the other shore levels, where *Pontocrates arenarius* (more abundant on the middle shore in particular) and few other species occurred instead (Table 5b). The abundance of *Pontocrates arenarius* was also the main reason for the differentiation of the assemblages in Group b1 identified in

the cluster analysis (Figure 10), which mostly included mid shore samples and, occasionally, lower shore assemblages. The remaining samples in Group b2 were characterised by sparser assemblages, the group also including the empty samples obtained in the survey (samples to the right of the dendrogram in Figure 10).

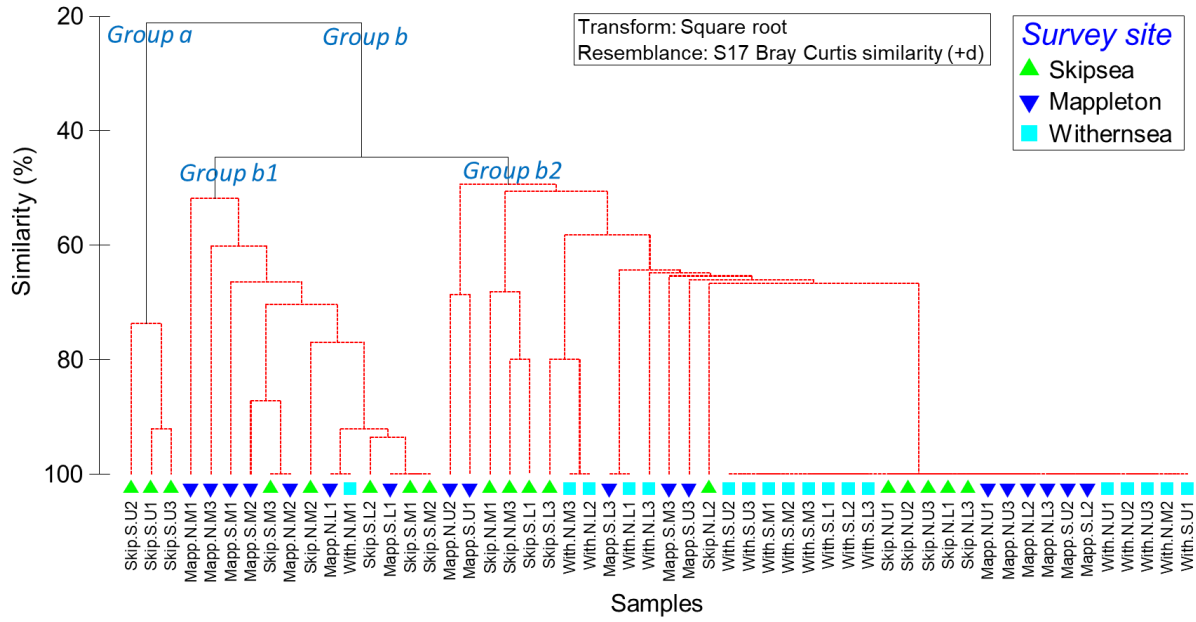

Figure 10. Cluster analysis of the sample abundance of benthic infauna species recorded in the intertidal zone of the Holderness coast (2022). Group average algorithm was applied for the cluster analysis, based on zero-adjusted Bray-Curtis similarity. Samples connected by red lines show groups (a, b, b1 and b2) of benthic communities not significantly differentiated (SIMPROF test, P>0.05).

3.4 Biotopes

The biotopes identified at each sampling station, based on the sample data and visual assessment of the substratum in the area surrounding the sampling locations, are reported in Table 6.

Table 6. Biotopes identified at the stations sampled along the Holderness coast in 2022.

Station	JNCC 2022 Biotope Code	EUNIS 2008 Biotope Code	Biotope Description
Skip.N.U	LS.LCS.Sh.BarSh	A2.111	Barren littoral shingle
Skip.N.M	LS.LSa.MoSa.AmSco	A2.223	Amphipods and *Scolelepis* spp. in littoral medium-fine sand
Skip.N.L	LS.LSa.MoSa.BarSa	A2.221	Barren littoral coarse sand

Station	JNCC 2022 Biotope Code	EUNIS 2008 Biotope Code	Biotope Description
Skip.S.U	LS.LSa.MoSa.AmSco.Sco	A2.2231	*Scolelepis* spp. in littoral mobile sand
Skip.S.M	LS.LSa.FiSa.Po.Ncir (Impoverished version)	A2.2313	*Nephtys cirrosa*-dominated littoral fine sand
Skip.S.L	LS.LSa.FiSa.Po.Ncir (Impoverished version)	A2.2313	*Nephtys cirrosa*-dominated littoral fine sand
Mapp.N.U	LS.LCS.Sh.BarSh	A2.111	Barren littoral shingle
Mapp.N.M	LS.LSa.MoSa.AmSco.Pon	A2.2233	*Pontocrates arenarius* in littoral mobile sand
Mapp.N.L	LS.LSa.FiSa.Po.Ncir (Impoverished version)	A2.2313	*Nephtys cirrosa*-dominated littoral fine sand
Mapp.S.U	LS.LSa.MoSa.AmSco	A2.223	Amphipods and *Scolelepis* spp. in littoral medium-fine sand
Mapp.S.M	LS.LSa.FiSa.Po.Ncir (Impoverished version)	A2.2313	*Nephtys cirrosa*-dominated littoral fine sand
Mapp.S.L	LS.LSa.FiSa.Po.Ncir (Impoverished version)	A2.2313	*Nephtys cirrosa*-dominated littoral fine sand
With.N.U	LS.LCS.Sh.BarSh	A2.111	Barren littoral shingle
With.N.M	LS.LSa.FiSa.Po.Ncir (Impoverished version)	A2.2313	*Nephtys cirrosa*-dominated littoral fine sand
With.N.L	LS.LSa.FiSa.Po.Ncir (Impoverished version)	A2.2313	*Nephtys cirrosa*-dominated littoral fine sand
With.S.U	LS.LCS.Sh.BarSh	A2.111	Barren littoral shingle
With.S.M	LS.LCS.Sh.BarSh	A2.111	Barren littoral shingle
With.S.L	LS.LSa.MoSa.BarSa	A2.221	Barren littoral coarse sand

4. Conclusions

The Holderness coastline is known to be one of the most rapidly retreating coastal regions in Europe (Quinn et al. 2015). The erosion rates on the undefended coast have increased since the early 1990s and further increases are anticipated over the course of the next century due to the effects of climate change (e.g. sea level rise, storminess) (Pye and Blott, 2015).

The sediment and fauna sampled in 2022 from the intertidal zone along this coastline reflected these conditions, being characteristic of littoral biotopes typically found on mobile sandy beaches, on exposed to moderately exposed shores. These result in sand and coarse sediment substrata that, due to the mobility of the sediment, are generally populated by species-poor invertebrate communities, with often sparse, if not absent, fauna, reflecting the characteristics previously reported by Defra (2016) for these shores.

The species inhabiting these sandy beaches are well adapted to such exposed and mobile conditions, with polychaetes (e.g. *Scolelepis (Scolelepis) squamata* and *Nephtys cirrosa*) and burrowing amphipods (e.g. *Pontocrates arenarius*) being common occurrences, as found in the samples.

There was a spatial differentiation in the benthic assemblages sampled along the Holderness coastline, although this was mainly due to localised variability (e.g. between shore levels within a transect, or between transects within a site) rather than broader geographical gradients. In fact, although a North-South decrease was observed in the abundance and diversity of the sampled benthic communities (from Skipsea and Mappleton to Withernsea), this was not statistically significant. The main (significant) spatial difference was ascribed to the more diverse and abundant assemblage found in the southern transect at Skipsea, particularly on the upper shore, compared to the other sites. The benthic assemblage at this site also differentiated from the others for its composition, mainly due to the particularly high abundance and dominance of *S. squamata*, leading to the identification of the biotope LS.LSa.MoSa.AmSco.Sco (*Scolelepis* spp. in littoral mobile sand) at this site.

A significant spatial differentiation was also observed between transects at Withernsea, with the sediment along the southernmost transect being barren (no fauna was found at any shore level). As a result, the biotopes LS.LCS.Sh.BarSh (Barren littoral shingle, on the upper and middle shore) and LS.LSa.MoSa.BarSa (Barren littoral coarse sand, on the lower shore) were identified for this transect. This is located in an area where sea defences are present (rock armour backing the shore) and the intertidal zone is much narrower than in other areas (as evident from the closeness of the three sampling stations along the transect, Figure 4).

Similarly barren biotopes were often found on the upper shore (LS.LCS.Sh.BarSh) at other locations (northern transects at Withernsea, Skipsea and Mappleton), and a lower species diversity generally characterised the benthic assemblages of the upper shore compared to the other shore levels across all the sampled sites. This pattern is the result of the harsher conditions experienced by the benthic fauna on the upper shore (due to more prolonged

exposure to air), which, combined with the sediment instability along the Holderness coastline, restricts the colonisation of the upper shore to few, more tolerant species (e.g. *S. squamata*).

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Appendices

Appendix 1. Sampling locations

Locations of stations sampled in 2022 (Coordinates Reference System: WGS84) and grouping factors.

Survey site	Transect	Shore level	Station code	Lat (deg N)	Long (deg E)	Sampling date
Skipsea (Skip)	North (N)	Upper (U)	Skip.N.U	53.978597	-0.19926	11/09/2022
		Middle (M)	Skip.N.M	53.978798	-0.19792	
		Lower (L)	Skip.N.L	53.979076	-0.196575	
	South (S)	Upper (U)	Skip.S.U	53.965657	-0.192131	
		Middle (M)	Skip.S.M	53.965847	-0.190874	
		Lower (L)	Skip.S.L	53.965993	-0.190003	
Mappleton (Mapp)	North (N)	Upper (U)	Mapp.N.U	53.880173	-0.13647	10/09/2022
		Middle (M)	Mapp.N.M	53.880461	-0.135608	
		Lower (L)	Mapp.N.L	53.880706	-0.134916	
	South (S)	Upper (U)	Mapp.S.U	53.873898	-0.13208	
		Middle (M)	Mapp.S.M	53.874165	-0.131261	
		Lower (L)	Mapp.S.L	53.874421	-0.130312	
Withernsea (With)	North (N)	Upper (U)	With.N.U	53.738968	0.025679	12/09/2022
		Middle (M)	With.N.M	53.739454	0.026712	
		Lower (L)	With.N.L	53.739985	0.027813	
	South (S)	Upper (U)	With.S.U	53.729223	0.037905	
		Middle (M)	With.S.M	53.72938	0.038231	
		Lower (L)	With.S.L	53.729549	0.038624	

Description of sampling stations.

Station code	Site description
Skip.N.U	Sloped, dry medium sand over gravel, with some stones and cobbles. Just below site larger rocks and cobbles in band along shore about 10 m wide. No evidence of animals.
Skip.N.M	Wet, smooth fine sand over gravel. Small stones on surface. No evidence of animals. Sediment liquifies when agitated.
Skip.N.L	Wet, smooth fine sand over gravel. Small stones on surface. Sediment liquifies when agitated. Bait digging (*Arenicola*) to the North of the site.
Skip.S.U	Fine, dry, smooth sand with a little gravel. Small stones on the surface. Site just in front of the crumbling mud cliff with lumps of mud and cobbles. Shallow gradient. No evidence of animals.
Skip.S.M	Wet, smooth medium sand with a little gravel. Small stones on surface. Shallow gradient. No evidence of animals.
Skip.S.L	Wet, smooth fine sand with gravel underneath. Small stones on surface. Black organic particles covering sediment just below the site. No evidence of animals.
Mapp.N.U	Sloped, dry medium sand with gravel and cobbles. Just in front of mud cliff. Above flatter water-logged area. No evidence of animals.
Mapp.N.M	Fine/medium sand. Small stones with some larger stones on the surface. Area has shallow gradient. Smooth and water-logged with no evidence of animals.
Mapp.N.L	Fine sand, coarser material about 15 cm deep. Small stones on the surface. Area has shallow gradient. Smooth and water-logged with no evidence of animals.
Mapp.S.U	Thin layer of medium sand over coarser sand and gravel. Water-logged. Site just in front of mud cliff. Some stones present on surface of sand above and below site. Area has shallow gradient. No evidence of animals.
Mapp.S.M	Fine sand. Some small stones on the surface. Area has shallow gradient. Smooth and water logged with no evidence of animals.
Mapp.S.L	Fine sand, coarser material about 15 cm deep. Some small stones on the surface. Area has shallow gradient. Smooth and water-logged with no evidence of animals.
With.N.U	Medium sand with gravel, stones and cobbles. Area level but just above sloped stony area that leads onto flatter sandy area. Strand line in area. Talitridae holes above site
With.N.M	Wet, fine sand with a little gravel. Slight gradient. Water running over surface. Sediment liquifies when agitated. No evidence of animals.
With.N.L	Wet, fine sand with a little gravel. Layer of gravel about 15 cm deep. Slight gradient. Water running over surface. Sediment liquifies when agitated. No evidence of animals.
With.S.U	Dry, medium sand with lots of stones and cobbles. Beach steeply sloped. Site just in front of rock armour. Core depth 10 cm due to stones.

Station code	Site description
With.S.M	Medium sand with gravel and occasional cobbles. Start of the wet area where the water is draining from beach. Steeply sloped. Soft. No evidence of animals.
With.S.L	Fine sand with gravel. Fewer stones than further up the beach. No evidence of animals. Sediment liquifies when agitated.

Appendix 2. Sediment particle size, 2022 sample data

Sediment grain size composition at sampling stations: % contribution by Phi grain size classes (VC, very coarse; C, coarse; M, medium; F, fine; VF, very fine). Mean values of three replicate analyses per sample (values =0 are in grey font). See Appendix 1 for station codes.

Grain size class (Phi)	Skip.N.U	Skip.N.M	Skip.N.L	Skip.S.U	Skip.S.M	Skip.S.L	Mapp.N.U	Mapp.N.M	Mapp.N.L	Mapp.S.U	Mapp.S.M	Mapp.S.L	With.N.U	With.N.M	With.N.L	With.S.U	With.S.M	With.S.L
VC Gravel (Phi-6)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
C Gravel (Phi-5)	1%	0%	0%	1%	0%	0%	17%	0%	0%	2%	0%	0%	0%	2%	1%	14%	11%	0%
M Gravel (Phi-4)	12%	2%	0%	2%	0%	1%	15%	0%	1%	2%	0%	0%	2%	1%	4%	23%	13%	0%
F Gravel (Phi-3)	27%	6%	2%	2%	1%	1%	9%	0%	1%	5%	0%	1%	5%	1%	7%	25%	16%	1%
VF Gravel (Phi-2)	18%	10%	4%	2%	2%	4%	9%	1%	2%	5%	1%	1%	10%	2%	7%	9%	16%	3%
VC Sand (Phi-1)	7%	11%	5%	2%	2%	5%	12%	2%	3%	6%	2%	3%	14%	2%	7%	3%	14%	4%
C Sand (Phi0)	12%	15%	4%	8%	5%	2%	18%	5%	8%	28%	7%	5%	11%	2%	6%	8%	11%	8%
M Sand (Phi1)	18%	31%	27%	46%	34%	21%	17%	43%	36%	42%	49%	41%	29%	42%	36%	15%	14%	46%
F Sand (Phi2)	5%	23%	46%	34%	47%	50%	2%	44%	40%	9%	40%	44%	27%	46%	28%	4%	5%	35%
VF Sand (Phi3)	0%	3%	12%	2%	9%	17%	0%	4%	7%	0%	2%	4%	3%	3%	1%	0%	0%	2%
VC Silt (Phi4)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%
C Silt (Phi5)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%
M Silt (Phi6)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%
F Silt (Phi7)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%
VF Silt (Phi8)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Clay (Phi9)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Total Gravel	58%	18%	6%	7%	3%	6%	50%	2%	5%	14%	1%	2%	17%	6%	18%	71%	56%	4%
Total Sand	42%	82%	94%	93%	97%	94%	50%	98%	95%	86%	99%	98%	83%	94%	79%	29%	44%	95%
Total Mud	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	0%	0%	1%

[i]Appendix 3. Benthic invertebrate, 2022 sample data

Skipsea

		Survey site	Skipsea																	
		Transect	North									South								
		Shore level	Upper			Middle			Lower			Upper			Middle			Lower		
MCS	Code	Taxon	Skip.N.U1	Skip.N.U2	Skip.N.U3	Skip.N.M1	Skip.N.M2	Skip.N.M3	Skip.N.L1	Skip.N.L2	Skip.N.L3	Skip.S.U1	Skip.S.U2	Skip.S.U3	Skip.S.M1	Skip.S.M2	Skip.S.M3	Skip.S.L1	Skip.S.L2	Skip.S.L3
G	1	Nemertea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P	118	*Eteone longa*	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
P	498	*Nephtys cirrosa*	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	2	1
P	783	*Scolelepis (Scolelepis) squamata*	0	0	0	0	0	0	0	0	0	20	25	34	0	0	0	0	0	0
P	791	*Spio martinensis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	44	*Gastrosaccus spinifer*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	135	*Pontocrates arenarius*	0	0	0	1	1	0	0	0	0	0	0	0	1	1	2	0	1	0
S	247	*Urothoe brevicornis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
S	452	*Bathyporeia elegans*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
S	457	*Bathyporeia pilosa*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	462	*Haustorius arenarius*	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0
S	854	*Eurydice pulchra*	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0
S	871	*Lekanesphaera rugicauda*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
S	1188	*Cumopsis goodsir*	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	1	0	0
W	1695	*Mytilus (Mytilus) edulis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W	2012	*Macomangulus tenuis*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
-	-	Collembola	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total number of species			**0**	**0**	**0**	**2**	**1**	**1**	**0**	**1**	**0**	**3**	**2**	**3**	**2**	**2**	**2**	**2**	**2**	**2**
Total abundance (ind. per 0.01m2)			**0**	**0**	**0**	**3**	**1**	**1**	**0**	**1**	**0**	**23**	**26**	**37**	**2**	**2**	**3**	**2**	**3**	**2**
Shannon index H'(log_2)			**0**	**0**	**0**	**0.9**	**0**	**0**	**0**	**0**	**0**	**0.7**	**0.2**	**0.5**	**1.0**	**1.0**	**0.9**	**1.0**	**0.9**	**1.0**

Mappleton

Survey site			Mappleton																	
Transect			North									South								
Shore level			Upper			Middle			Lower			Upper			Middle			Lower		
MCS	Code	Taxon	Mapp.N.U1	Mapp.N.U2	Mapp.N.U3	Mapp.N.M1	Mapp.N.M2	Mapp.N.M3	Mapp.N.L1	Mapp.N.L2	Mapp.N.L3	Mapp.S.U1	Mapp.S.U2	Mapp.S.U3	Mapp.S.M1	Mapp.S.M2	Mapp.S.M3	Mapp.S.L1	Mapp.S.L2	Mapp.S.L3
G	1	Nemertea	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
P	118	*Eteone longa*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P	498	*Nephtys cirrosa*	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	0
P	783	*Scolelepis (Scolelepis) squamata*	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0
P	791	*Spio martinensis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
S	44	*Gastrosaccus spinifer*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	135	*Pontocrates arenarius*	0	0	0	9	2	3	2	0	0	0	0	0	2	2	0	1	0	0
S	247	*Urothoe brevicornis*	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	1
S	452	*Bathyporeia elegans*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	457	*Bathyporeia pilosa*	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
S	462	*Haustorius arenarius*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	854	*Eurydice pulchra*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	871	*Lekanesphaera rugicauda*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	1188	*Cumopsis goodsir*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W	1695	*Mytilus (Mytilus) edulis*	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
W	2012	*Macomangulus tenuis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-	-	Collembola	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Total number of species			**0**	**1**	**0**	**2**	**2**	**2**	**2**	**0**	**0**	**2**	**0**	**1**	**2**	**3**	**1**	**2**	**0**	**1**
Total abundance (ind. per 0.01m2)			**0**	**1**	**0**	**11**	**3**	**5**	**3**	**0**	**0**	**4**	**0**	**1**	**3**	**4**	**1**	**2**	**0**	**1**
Shannon index H'(log_2)			**0**	**0**	**0**	**0.7**	**0.9**	**1.0**	**0.9**	**0**	**0**	**1.0**	**0**	**0**	**0.9**	**1.5**	**0**	**1.0**	**0**	**0**

Withernsea

		Survey site	Withernsea																	
		Transect	North									South								
		Shore level	Upper			Middle			Lower			Upper			Middle			Lower		
MCS	Code	Taxon	With.N.U1	With.N.U2	With.N.U3	With.N.M1	With.N.M2	With.N.M3	With.N.L1	With.N.L2	With.N.L3	With.S.U1	With.S.U2	With.S.U3	With.S.M1	With.S.M2	With.S.M3	With.S.L1	With.S.L2	With.S.L3
G	1	Nemertea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P	118	*Eteone longa*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P	498	*Nephtys cirrosa*	0	0	0	1	0	1	0	P	0	0	0	0	0	0	0	0	0	0
P	783	*Scolelepis (Scolelepis) squamata*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P	791	*Spio martinensis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	44	*Gastrosaccus spinifer*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
S	135	*Pontocrates arenarius*	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	247	*Urothoe brevicornis*	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
S	452	*Bathyporeia elegans*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	457	*Bathyporeia pilosa*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	462	*Haustorius arenarius*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	854	*Eurydice pulchra*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	871	*Lekanesphaera rugicauda*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	1188	*Cumopsis goodsir*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W	1695	*Mytilus (Mytilus) edulis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W	2012	*Macomangulus tenuis*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-	-	Collembola	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total number of species			**0**	**0**	**0**	**2**	**0**	**1**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Total abundance (ind. per 0.01m2)			**0**	**0**	**0**	**3**	**0**	**1**	**1**	**P**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Shannon index H'(log_2)			**0**	**0**	**0**	**0.9**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

P indicates presence of the species (as fragments).

Appendix 4. PERMANOVA tables of results (benthic invertebrates)

PERMANOVA analysis on benthic invertebrate assemblages (2022).

PERMANOVA design:

Factor	Abbrev.	Type	Levels
Area (Survey site)	Ar	Fixed	3
Transect	Tr	Random (nested in Area)	2
Shore level	Sh	Fixed	3

PERMANOVA tables of results (significant P levels are highlighted in bold):

a. Univariate test on number of species (S)

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Ar	2	11.148	5.5741	1.1148	0.5379	15
Sh	2	5.1481	2.5741	3.5641	0.0924	9535
Tr(Ar)	3	15	5	13.5	**0.0001**	9799
ArxSh	4	2.963	0.74074	1.0256	0.4613	9829
Tr(Ar)xSh	6	4.3333	0.72222	1.95	0.1004	9717
Res	36	13.333	0.37037			
Total	53	51.926				

b. Univariate test on total benthic abundance (ind./0.01m^2)

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Ar	2	283.59	141.8	0.85706	0.5462	15
Sh	2	161.15	80.574	0.62785	0.5704	9945
Tr(Ar)	3	496.33	165.44	34.099	**0.0001**	9957
ArxSh	4	532.41	133.1	1.0372	0.4802	9967
Tr(Ar)xSh	6	770	128.33	26.45	**0.0001**	9952
Res	36	174.67	4.8519			
Total	53	2418.1				

c. Univariate test on species diversity (Shannon index)

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Ar	2	1.8745	0.93723	1.2181	0.5381	9
Sh	2	1.558	0.77899	11.287	**0.0127**	9959
Tr(Ar)	3	2.3082	0.7694	6.4148	**0.0013**	9937
ArxSh	4	0.49981	0.12495	1.8105	0.2435	9971
Tr(Ar)xSh	6	0.41409	0.069015	0.57541	0.7511	9955
Res	36	4.3179	0.11994			
Total	53	10.972				

d. Multivariate test on species assemblage structure (based on species abundance)

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Ar	2	6237.2	3118.6	1.2845	0.4639	15
Sh	2	9847.2	4923.6	3.2207	**0.0263**	9941
Tr(Ar)	3	7283.9	2428	3.5971	**0.0002**	9926
ArxSh	4	6635.6	1658.9	1.0852	0.4268	9948
Tr(Ar)xSh	6	9172.4	1528.7	2.2649	**0.0005**	9890
Res	36	24299	674.98			
Total	53	63476				

Appendix 5. Data spreadsheets 2022

Sediment sample data from Particle Size Analysis

Holderness Sediment Data October 2022.xls

Benthic invertebrate sample data (taxa abundance)

YMNP Holderness Intertidal 2022_Benth

Field photos

https://universityofhull.box.com/s/x3vng4g48hv3i21o2s3ydwuuqh24qlnc