REPORT NO. 3586

SAMPLING SURVEY OF PORT OF NAPIER OFFSHORE SPOIL GROUND: OCTOBER 2020

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EXECUTIVE SUMMARY

Port of Napier Ltd (PONL) holds resource consents to deepen its existing approach channel to allow for vessels of greater draft. Consent CD180012W covers the establishment and use of an offshore spoil ground to accept the dredged material. Following on from a baseline survey of the area in April 2019, this report describes the implementation and findings of a benthic monitoring survey to meet the requirements of condition 12 of the consent. The survey was conducted 2 October 2020 and sampled benthic sediments and associated macrofaunal and epifaunal communities across three designated zones relative to the spoil ground. To ensure comparability, this spatial gradient sampling design was based closely on that of the baseline.

The spoil ground received approximately 50,000 m^3 of maintenance dredge spoil in late 2019 and a further 185,000 m^3 of capital dredge spoil were deposited between June and October of 2020. At the time of the current survey, spoil deposition by barge was ongoing.

Benthic conditions were found to be effectively the same as those encountered during the baseline survey, except where what appeared to be recently deposited dredge spoil was sampled by dredge trawl/epifaunal sled within the spoil ground. There were no clear spatial gradients or patterns in either sediment grainsize distribution or trace metal concentrations that were consistent with a deposition or dispersion effect centred on the spoil ground. Benthic communities were also closely comparable to those recorded by the baseline, even within the spoil ground itself.

It was noted from the baseline survey that benthic conditions and communities reflected the dynamic nature of the seabed in the vicinity of this site, with sediments regularly disturbed and sorted by periodic swell events. It is considered that this is the principal factor contributing to the absence of discernible effects from spoil deposition.

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GLOSSARY

Item	Description	Type
µm	Micron or micrometre	Unit
ADL	Analytical Detection Limit	Acronym
ANOVA	Analysis of Variance	Acronym
ANZG	Australia and New Zealand (water quality) guidelines	Acronym
aRPD	Apparent redox potential discontinuity	Acronym
As	Arsenic	Abbreviation
Cd	Cadmium	Abbreviation
cm	Centimetre	Unit
Cr	Chromium	Abbreviation
Cu	Copper	Abbreviation
DGV	Default guideline value	Acronym
FF	Far-field (zone)	Acronym
g	Grams	Unit
H’	Shannon-Weiner diversity index	Index
ha	Hectare	Unit
Hg	Mercury	Abbreviation
ICP-MS	Inductively coupled plasma mass spectrometry	Acronym
J'	Pielou’s evenness index	Index
km	Kilometre	Unit
m	Metre or metres	Unit
mg/kg	Milligrams per kilogram (parts per million)	Unit
mm	Millimetres	Unit
MSL	Mean sea level	Acronym
MW	Molecular weight	Acronym
N	Number of individuals	Index
n	Number of individuals/replicates in a sample	Variable
Ni	Nickel	Abbreviation
nMDS	Non-metric multidimensional scaling	Acronym
Pb	Lead	Abbreviation
PONL	Port of Napier Ltd	Acronym
PVC	Polyvinyl chloride	Acronym
r	Pearson's correlation coefficient	Coefficient
R^2	Coefficient of determination	Coefficient
S	Number of species (species richness)	Index
SG	Spoil ground (zone)	Acronym
SIMPER	Similarity percentage	Abbreviation
SZ	Spreading zone	Acronym
TOC	Total organic carbon	Acronym
TSHD	Trailer suction hopper dredge	Acronym
USEPA	United States Environmental Protection Agency	Acronym
Zn	Zinc	Abbreviation

1. INTRODUCTION

1.1. Background

Port of Napier Limited (PONL) is deepening its existing approach channel to accept deeper draft vessels and establish a new berth (No.6 berth) on the northern face of the main Port reclamation. This entails widening the current dredged channel and extending it seaward by approximately 1.3 km. The swing basin at the Port entrance will also be extended approximately 120 m westwards and 220 m south and deepened to serve the new berth. Over multiple stages, the dredging project will generate approximately 3.2 million m^3 of dredge spoil and this will be deposited in a consented 346 ha disposal area located approximately 3.3 km south-east of Pania Reef and 4 km offshore in water depths of 20–23 m. The spatial footprint for the dredging work and the disposal area for the dredge spoil, in relation to the principal features of the coastline, are depicted in Figure 1.

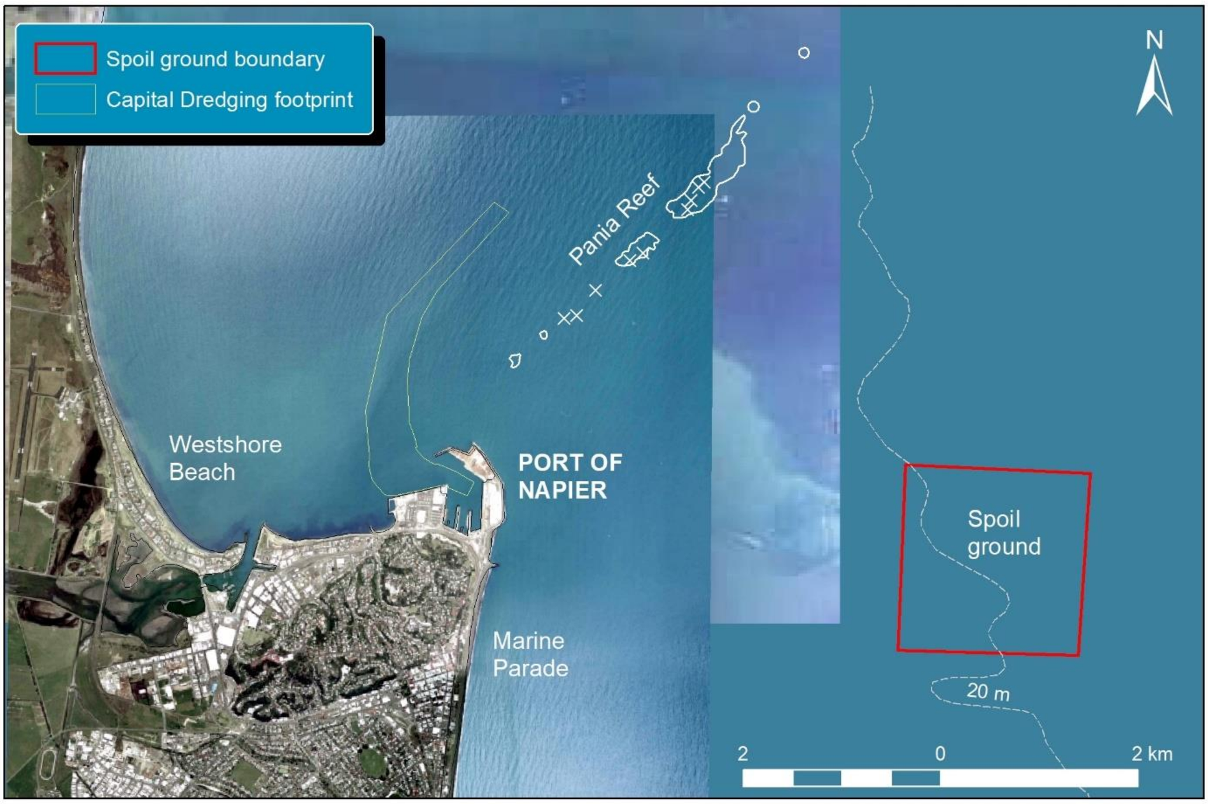

Figure 1. Composite image showing the location of the offshore spoil ground in relation to the Port of Napier, Pania Reef and the capital dredging footprint.

The resource consent covering the use of the disposal area (CD180012W) requires that effects on the seabed in its vicinity be monitored. Prior to commencement of the dredging project, a baseline survey of the area was conducted by Cawthron institute (Cawthron) in April 2019. In interpreting the results of the baseline survey, Sneddon (2019) compared the findings to an earlier 2005 survey of the area. The consent and the associated Water Quality Management Plan (WQMP) require that post-disposal monitoring shall be carried out in the vicinity of the spoil ground to assess the effects of the activity on benthic habitats.

In late 2019, a campaign of maintenance dredging at Port of Napier was undertaken by the trailer suction hopper dredge (TSHD) *Albatross.* This resulted in the deposition of approximately 50,000 m^3 of material at the offshore disposal ground.

Use of the offshore disposal area to receive capital dredge spoil from the project commenced in June 2020. By the date of the benthic survey (2 October), deposition of 185,721 m^3 of marine sediments had been recorded. The pattern of deposition of this material is shown in Figure 2.

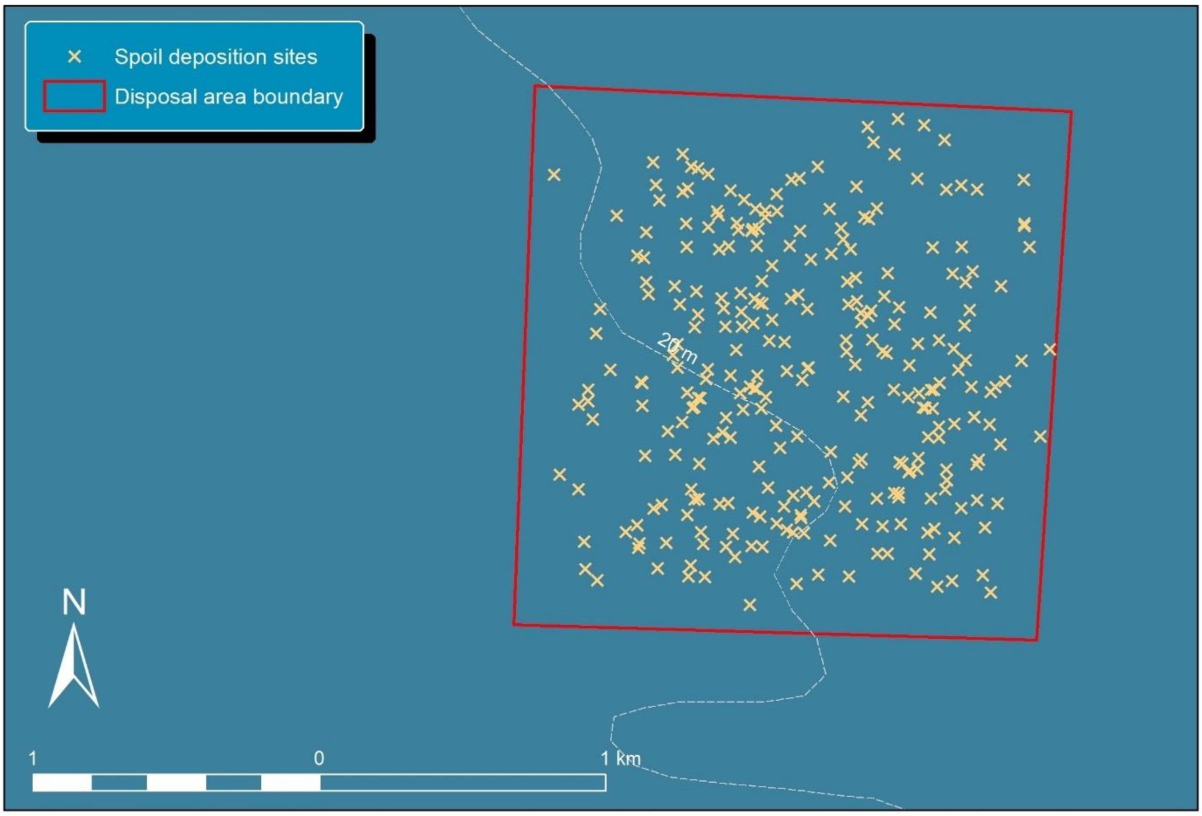

Figure 2. Pattern of spoil deposition from capital dredging in 2020 up until the benthic survey on 2 October. Source: Port of Napier Ltd.

1.2. Scope

The scope of this work is set by the requirements of conditions 11–16 of Resource Consent CD180012W. Condition 12 notes that:

The purpose of post-disposal monitoring is to:

a. Identify changes occurring in and near to the disposal area since the baseline surveys. This shall include changes to benthic communities and sediment characteristics in areas where deposition occurred during the previous capital dredging stage, and in any areas containing high value habitats or communities identified in the baseline survey.

b. Assess whether deposited material has caused effects on surrounding benthic communities and/or sediment characteristics.

Cawthron were contracted by PONL to design and conduct this first post-deposition survey. This report presents the survey data and provides a comparison to the baseline information to establish the nature and scale of any changes that may have occurred as a result of the activity.

2. METHODS

2.1. Design

The survey employed a spatial layout of sampling elements based on the pattern established by the April 2019 baseline (Sneddon 2019). On the basis that previous survey work had identified a highly uniform seabed habitat, the design sought to balance sample replication with site coverage, opting for single grab deployments at stations grouped according to area and bathymetry (Figure 3). Survey elements were structured around 22 benthic sample stations (Figure 3).

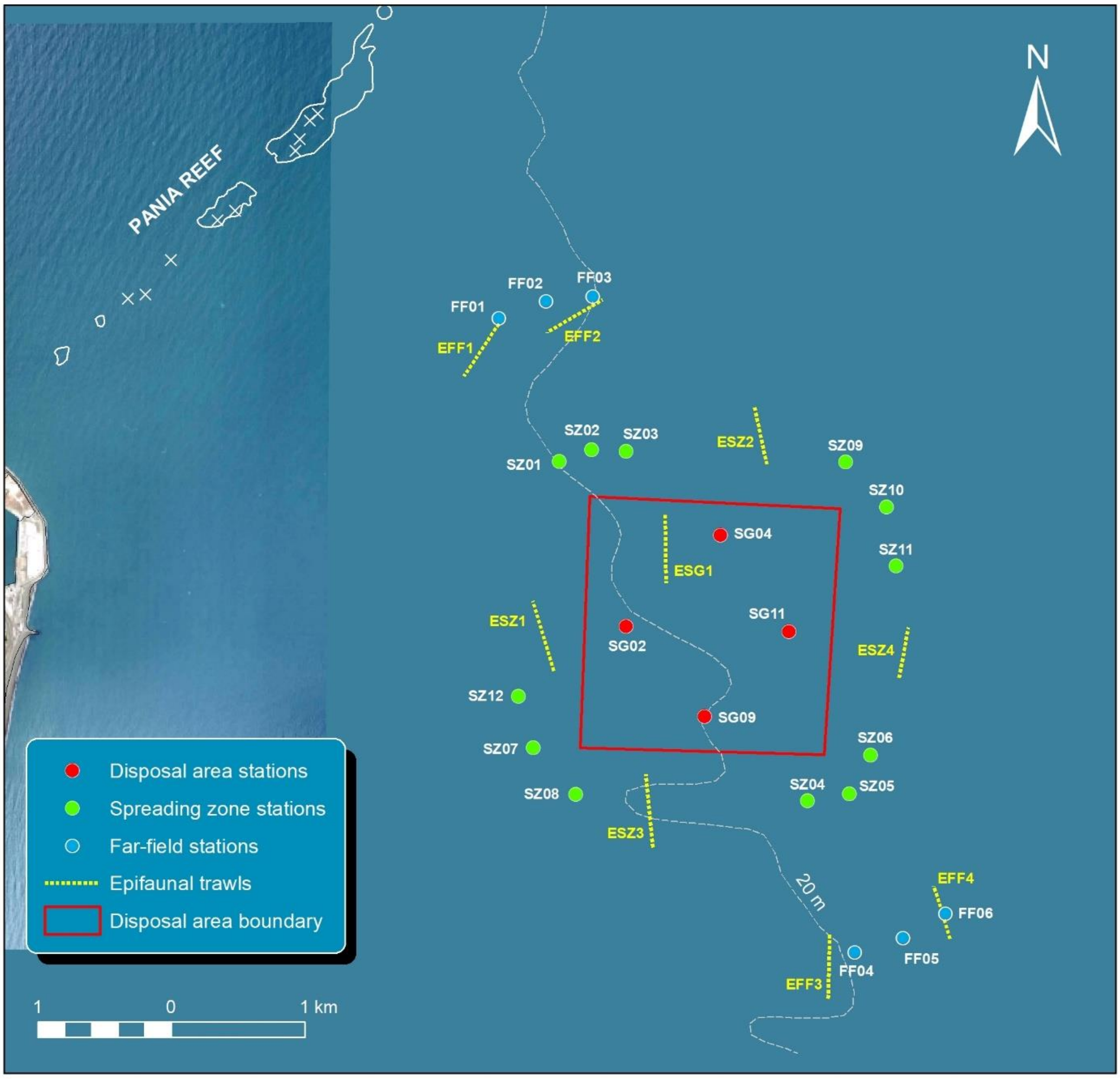

Figure 3. Spatial layout of principal sampling elements of the October 2020 survey; benthic grab stations and epifaunal dredge trawls. The 20 m depth contour from hydrographic chart NZ571 has been overlaid.

The 22 stations were arranged spatially according to three area or zone classifications:

- **Spoil ground (SG):** Four stations within the consented spoil ground boundary, chosen from the twelve originally established for the 2019 baseline survey.
- **Spreading zone (SZ):** Twelve stations at 350 m from the spoil ground boundary, including:
  - Three stations (300–400 m apart) at each end of an approximate isobath running through the spoil ground centre (SZ01–SZ06)
  - Three stations (400–500 m apart) at each of locations inshore and offshore from the NE and SW vertices of the spoil ground (four established for the 2019 baseline plus one additional at each of the inshore and offshore locations) (SZ07–SZ12).
- **Far-field (FF):** Three stations (300–400 m apart) at each end of an approximate isobath running through the spoil ground centre and located 1500 m from its closest boundary (FF01–FF06).

Benthic sampling stations retained from the baseline survey have retained the same station codes (Figure 3). Unlike the baseline survey, only direct sampling methods (grab and epibenthic trawl) were used. Sampling was conducted on 2 October 2020 from the 11-m inshore trawler *FV Chips.*

2.2. Benthic sampling

Sediments were collected using a 0.1 m^2 stainless steel van Veen grab mounted in a weighted frame to assist with penetration in dense fine sand substrates (Figure 4). This method collects a relatively undisturbed section of surficial sediment down to a depth of 10-12 cm in the profile. Upon retrieval, the grab contents can be sub-sampled using standardised corers to provide material for sediment and infauna analyses.

2.2.1. Sediment core samples

At each station, three 62-mm diameter cores were collected from the contents of the grab. These were photographed and their colour and any noticeable odour noted, along with the depth to any apparent redox potential discontinuity (aRPD) layer[1]. The top 5 cm from each of the three cores was combined to provide a single composite sample for analysis of grain size distribution, organic content and trace metals. All samples were chilled for transport to the laboratory. The sediment analyses and analytical methods are listed in Table 1.

[1] The aRPD refers to the often-distinct colour change, between surface and underlying sediments, brought about by the changing redox environment with depth in the profile. This gradient of colour change is in reality continuous but may be reduced to an average transition point (sediment depth) for descriptive purposes.

Figure 4. **Top left:** The van Veen grab sampler. **Bottom left:** The research dredge used to sample epifauna. **Right:** The grab sampler mounted in its frame.

The analysis of sediment texture (particle grain size distribution) defines the coarseness of sediments and provides an important measure of the physical characteristics of a site that can be used to investigate and interpret differences between sites in other environmental parameters. Chemical contaminants are primarily retained within fine sediments (e.g. Förstner 1995). Metals, especially, can adsorb to particulates and may accumulate over long time periods. Both sediment texture and organic content play an important role in determining the capacity for adsorption and retention of contaminants and allow the assessment of associations between substrate type and the associated sediment faunal communities.

Total recoverable concentrations of sediment trace metals/metalloids were analysed and the results compared against the applicable national sediment guideline criteria (ANZG 2018; DGV)[2] and the 2019 baseline data.

[2] The ANZG (2018) DGV and DG-High levels represent the two threshold levels under which biological effects are predicted. The lower threshold indicates a *possible* biological effect while the upper threshold (DG-High) indicates a *probable* biological effect.

Table 1. Summary of analytical methods used for sediment characterisation.

Analyte	Method Number	Description
Particle grain size distribution (sediment texture)	Hill Laboratories in-house method	Wet sieved through screen sizes: > 2 mm = Gravel < 2 mm to > 1 mm = Coarse Sand < 1 mm to > 500 µm = Medium Sand < 500 µm to > 250 µm = Medium/Fine Sand < 250 µm to > 125 µm = Fine Sand < 125 µm to > 63 µm = Very Fine Sand < 63 µm = Mud (Silt & Clay) Size classes from Udden-Wentworth scale
Trace metals (As, Cd, Cu, Pb, Hg, Ni, Cr, Zn)	USEPA 200.2	Detected by ICP-MS (inductively coupled plasma mass spectrometry) following nitric/hydrochloric acid digestion
Total organic carbon	Hill Laboratories in-house method	Acid pre-treatment to remove carbonates if present, neutralisation, [Elementar combustion analyser].

2.2.2. Benthic macrofauna

The ecological assemblage of small invertebrate animals (larger than 0.5 mm) living in the upper 100 mm of the sediment profile is generally referred to as macrofauna or infauna[3]. Infauna have been used for several decades to assess the effects of human impacts in marine environments and various studies have demonstrated that they respond relatively rapidly to anthropogenic and natural stress (Pearson & Rosenberg 1978; Dauer et al. 1993; Borja et al. 2000).

Sample collection

At each sample station, one macrofauna sediment core was extracted from the contents of the grab. The corer consisted of an elliptical section made from PVC pipe with cross-sectional area equivalent to a circular corer 130 mm in diameter (133 cm^2). Each corer was manually driven into the contents of the grab then withdrawn and the core emptied into a 0.5 mm mesh sieve where it was gently rinsed with seawater to remove the majority of the fine sediment matrix. The residue was transferred to a sample container for preservation with a solution comprising 3% glyoxal and 70% ethanol.

Sample analysis

In the Cawthron taxonomy laboratory, macrofauna within the preserved samples were identified and counted with the aid of a binocular microscope. Identifications were made to the lowest practicable taxonomic level. For some groups of macrofauna, species level identification is very difficult and, in such instances, macrofauna were

[3] While the infauna are technically the subset of macrofauna that lives within the sediment matrix, core samples invariably also include those which are principally surface-dwelling.

grouped into recognisable taxa (morphologically similar groups). In this manner, a list of taxa and their abundance was compiled for each station.

Community data analysis

The macrofauna count data were compiled and analysed to ascertain levels of abundance (individual species density), species richness and standardised indices of community diversity and evenness for each station (Table 2). These values were compared among stations and significant differences interpreted with respect to key factors such as water depth and substrate characteristics.

Table 2. Descriptions of standard community indices.

Index	Equation	Description
No. species (S)	$\sum s$	Total number of species (s) in a sample.
No. abundance (N)	$\sum n$	Total number of organisms (n). This comprised the sum of percentage cover of colonial organisms and solitary individuals.
Evenness (*J'*)	$J' = \frac{H'}{log_e S}$	Pielou's evenness. A measure of equitability, or how evenly the individuals are distributed among the different species. Values can theoretically range from 0.00 to 1.00, where a high value indicates an even distribution and a low value indicates an uneven distribution or dominance by a few taxa.
Diversity (*H'*)	$H' = -\sum P_i \, log_e \, (P_i)$ P_i is the proportion of N comprised of the *i*th species.	Shannon-Wiener diversity index describes, in a single number, the different types and amounts of taxa present in a sample. The index ranges from 0 for communities containing a single species to high values for communities containing many species each represented by a similar number of individuals.

The infaunal assemblages recorded at each site were contrasted using non-metric multidimensional scaling (nMDS; Kruskal & Wish 1978) ordination and cluster diagrams using Bray-Curtis similarities between samples. Abundances were square-root transformed to de-emphasise the influence of numerically dominant taxa. The principal taxa contributing to dissimilarities in sample groupings were identified using SIMPER (Clarke et al. 2014). All statistical analyses were conducted using PRIMER v7 (Clarke & Gorley 2015; Anderson et al. 2008).

Count data from the current survey were compiled with that of the 2019 pre-deposition baseline to enable comparison of community structure and the identification of any changes between surveys.

2.2.3. Epifaunal communities

Epifauna refers to the larger organisms living on the sediment surface. Epifaunal communities were sampled using a small research dredge or epibenthic sled. This had a 250 mm x 500 mm throat and was fitted with a 500 mm deep stainless-steel wire mesh basket of mesh size 10 mm (Figure 4). Dredge trawls were carried out at vessel idle speed (1.5–2 knots), with the track and depths logged for each one. Upon retrieval, fauna within the dredge contents were photographed, identified, and the number of individuals of each taxon counted.

Nine epifaunal dredge trawls were completed, each covering a distance between approximately 400 m and 550 m. Four trawls were conducted in the spreading zone, two each at inshore and offshore locations. Two trawls were conducted at each of the north and south far-field locations. Only one trawl was completed within the spoil ground (Figure 3).

3. RESULTS AND DISCUSSION

3.1. Field observations

Field notes from grab sampling recorded sediments as being comprised predominantly of fine mobile sands or semi-consolidated silty sands. Similar to the baseline, variability across the survey area was quite small; although, there was some patchiness apparent in the silt content of the samples.

None of the sampled sediments were characterised by significant odour (which, if present, can indicate organic enrichment). Although slightly darker underlying sediments were sometimes observed where conditions were siltier, only two samples (from the spreading zone) exhibited a measurable, if indistinct, aRPD layer.

Spreading zone – 12 grabs

Seven of the spreading zone samples were described as being noticeably siltier. Samples from SZ05 and SZ06 were the only cores from the current survey described as featuring a discernible aRPD (at ~3-8 cm depth in the profile, see Appendix 1). Similar sediment characteristics were noted for the grab from SZ06 during the baseline survey.

Far-field zone – 6 grabs

Similar to the baseline, heavier mobile sands were noted for stations at the southern far-field site (FF04-6), resulting in poorer grab penetration. Two of the three grab samples from the northern far-field were siltier and slightly more consolidated.

Spoil ground – 4 grabs

The grab samples collected from within the spoil ground exhibited a very similar range of characteristics to those from the spreading and far-field zones. Three of the four were described as grey mobile sands, with the fourth (SG11) being slightly siltier.

Although grab samples from within the disposal area were not notably different from those collected from outside its boundaries, the one epifaunal trawl (ESZ2 in Figure 1) conducted in the north of the area became quickly packed with clumps of cohesive mud. This would have affected the efficiency of the trawl and was very difficult to wash through the 10 mm mesh. Since this material had not been observed during the baseline survey, it was believed to derive from recently deposited dredge spoil, but it is likely that its distribution within the spoil ground was uneven. A trawl within the southern sector of the disposal ground was not possible due to the operation of the barge disposing of a load of dredged sediments.

3.2. Sediment physico-chemical characteristics

3.2.1. Grain size distribution and organic enrichment

Most of the sediment samples collected from the 22 benthic stations were dominated by very fine sands (average 61%) with the majority of the balance made up by the silt/clay fraction (average 34%).

There was some variability across stations but that between zones was quite small (Figure 5). The silt/clay component tended to be slightly lower at the southern far-field site (FF04-6; ranging 13-27 g/100 g) and within the spoil ground (19–35 g/100 g). The fine sand fraction was conspicuously higher in three of the four spoil ground samples, but this did not manifest as a distinctly coarser substrate to sampling personnel.

Ranging from below ADL (< 0.13%) to 0.62% (average 0.21%), the organic carbon content of the sediments was generally very low, reflecting the mobile nature of the substrate. Spatial trends in the organic carbon component were weak but tended to follow those of the silt fraction (Figure 5; $R^2 = 0.87$).

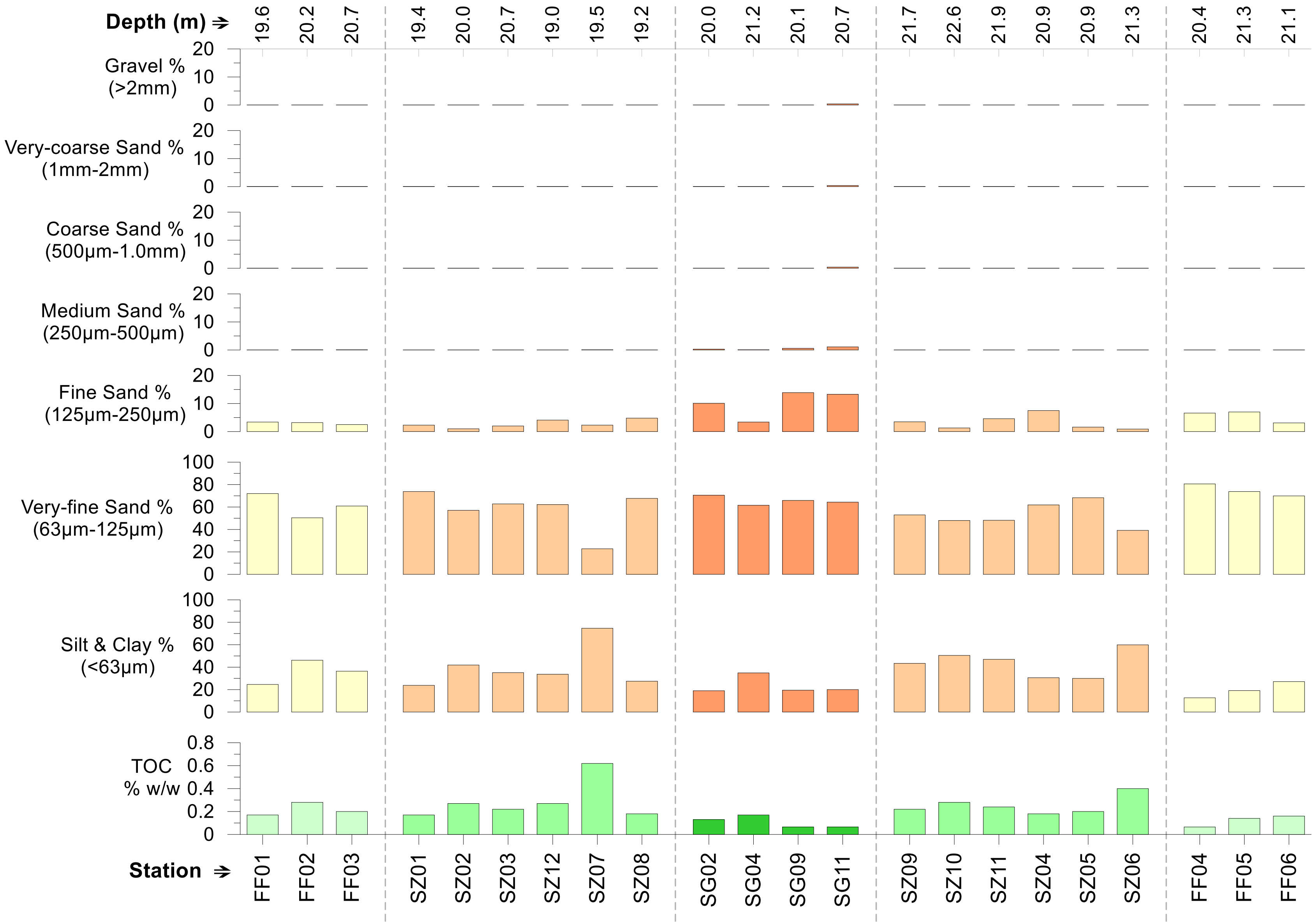

Figure 5. Grain-size distribution and organic content of sediments sampled from the vicinity of the spoil ground. Divisions and colour-shadings depict the three station zones of spoil ground (SG), spreading zone (SZ) and far-field (FF). Station order: north – south / inshore – offshore.

3.2.2. Sediment trace metals

None of the trace metals analysed in the sediment samples were elevated relative to national guideline levels (DGV; Table 3) and there was very little variation across stations (Figure 6). As noted during the baseline survey, however, some metals were moderately to strongly correlated with the sediment silt/clay and organic components, especially chromium, copper, nickel, lead and zinc (Table 4). Hence, these metals tended to exhibit slightly lower concentrations in the four spoil ground samples. Otherwise, differences between zones were minimal.

Table 3. Summary statistics for metals concentrations in sediments sampled from the 22 benthic stations with ANZG (2018) DGV values presented for comparison. Units are mg/kg.

Metal	Mean ± std dev	Maximum	DGV
Arsenic	5.2 ± 0.6	6.4	20
Cadmium	0.02 ± 0.002	0.024	1.5
Chromium	11 ± 1.2	14.5	80
Copper	3.5 ± 0.8	6.3	65
Lead	7.9 ± 1.0	10.4	50
Mercury	0.055 ± 0.007	0.07	0.15
Nickel	8.3 ± 0.8	10.4	21
Zinc	39.9 ± 5.1	55	200

Table 4. Coefficients of determination (R^2) between the silt/clay and organic carbon (TOC) components of sediments and their trace metal concentrations across all survey samples.

Metal/metalloid	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
Silt/clay	0.37	0.20	0.88	0.88	0.84	0.29	0.77	0.86
TOC	0.32	0.08	0.87	0.98	0.82	0.48	0.81	0.91

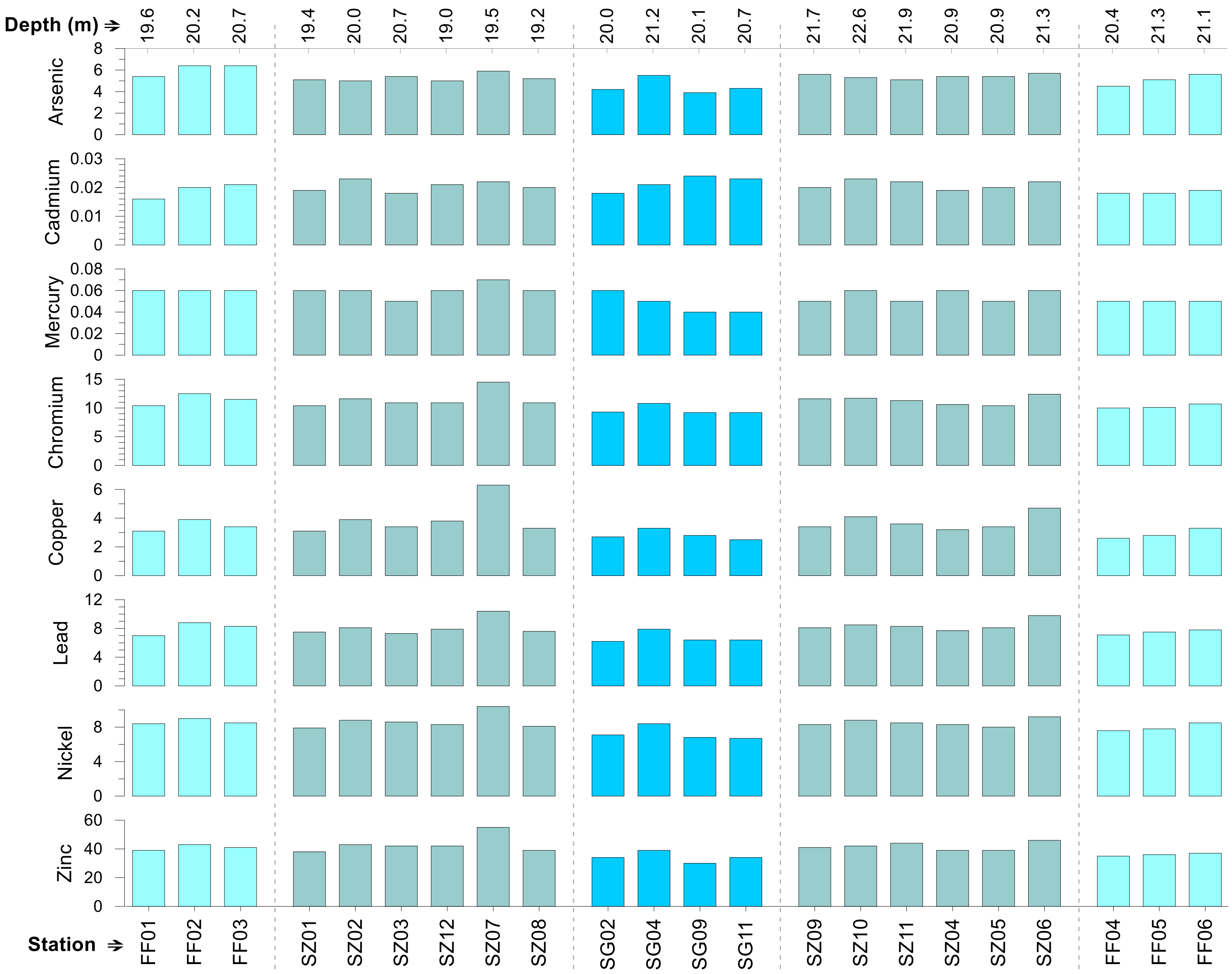

Figure 6. Trace metal concentrations in sediments sampled from the vicinity of the spoil ground 2 October 2020. Divisions and colour-shadings depict the three station zones of spoil ground (SG), spreading zone (SZ) and far-field (FF). Station order: north – south / inshore – offshore.

3.2.3. Comparison with the baseline sediment physicochemical data

Grainsize distribution and organic enrichment

A comparison of the spatial distribution of the silt/clay component of sediments between the baseline and current survey is presented in Figure 7. While there is a suggestion in the plots that the silt/clay fraction may have increased within the spreading zone, the amount by which silt/clay varied between surveys was similar for all three zones. The variability apparent in both plots is consistent with the spatial patchiness in sediment texture observed by survey personnel on both occasions.

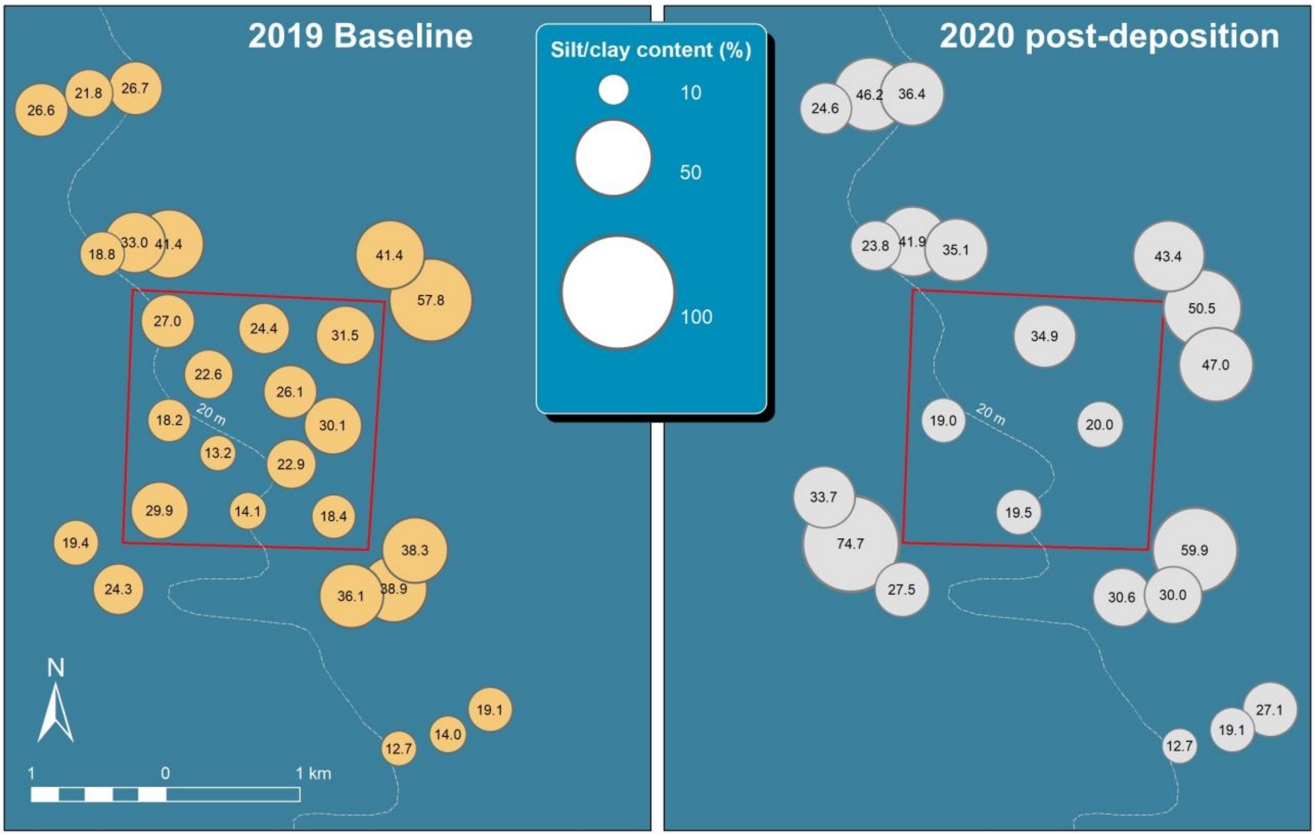

Figure 7. Spatial variability of sediment silt/clay content (% < 63 µm) across the benthic sample stations for the baseline (2019) survey (left) and the current survey (right). Proportional symbols adjusted with Flannery compensation to allow for viewer perception.

Summary data for grain size fractions and organic content from the two surveys is listed in Appendix 2. The changes between surveys for the mean zone values for key sediment components is examined in Table 5. Applied to individual zones, the only instances where the changes from the baseline were statistically significant (single factor ANOVA, $\alpha = 0.05$) were for total organic carbon in the spreading zone (increase of 77%; $p = 0.011$) and for fine sand in the spoil ground ($p = 0.024$). Since the fine sand component of the spoil ground was already low (at 5.3 g/100 g in 2019), the increase (despite doubling to 10.2 g/100 g) was still quite small in absolute terms.

Table 5. Summary table of mean organic carbon content (TOC) and fine sediment classes (g/100 g) in the three zones, with change since the 2019 baseline (shaded cells).

Zone	TOC		Fine sand		Very fine sand		Silt & clay	
Spoil ground	0.11	-0.01	10.2	+4.9	65.6	-4.9	23.4	+0.2
Spreading zone	0.27	+0.12	3.0	+0.6	55.4	-6.3	41.5	+6.6
Far field	0.17	+0.05	4.3	-6.0	67.9	-1.6	27.7	+7.5

It is notable that, while the spoil ground grab samples showed little difference either to the baseline or to samples from outside its boundaries, the one epifaunal trawl conducted within the spoil ground during the current survey collected a substrate that was distinctly different from that of the surrounding area. It is possible that the trawl collected some recently deposited spoil material while the four single grabs missed areas of recent direct deposition. The value of post deposition monitoring is not to define the nature of recently deposited material but to ascertain whether a significant lasting change has occurred. Hence, in contrast to monitoring of the spreading zone (which should detect the effects of subsequently transported bed material), meaningful interpretation of effects on substrate within the spoil ground must wait until it is no longer in use.

Sediment metals concentrations

Changes in sediment metals concentrations between the baseline and current survey are plotted by zone in Figure 8. Due to the correlations established in Table 4, the slight increases in copper, lead, nickel and zinc at the spreading and far-field zones are likely to be related to concomitant increases in the silt/clay fraction (Table 5). Allowing for this influence, changes in sediment metals since the baseline at the spoil ground and spreading zone were generally of the same order and direction as those occurring at the far-field sites. This suggests that the deposition of spoil has had minimal influence on metals levels in seabed sediments. While the increase in cadmium concentration appears slightly greater for the spoil ground, the range of values for the 2020 data set (0.016–0.024 mg/kg) was far below the DGV guideline value of 1.5 mg/kg (Table 3).

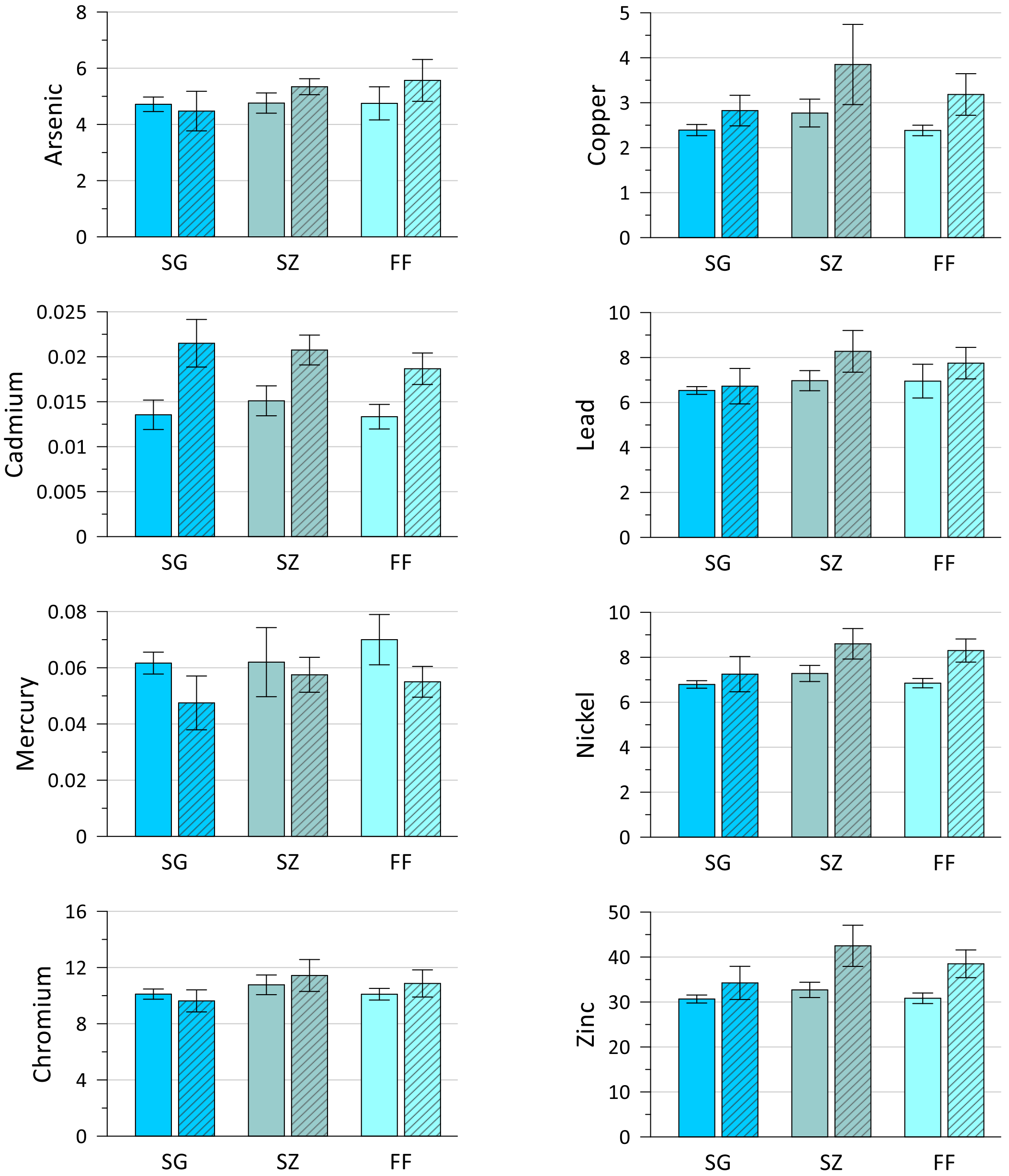

Figure 8. Comparison of mean sediment trace metal concentrations (by zone) for samples collected for the 2019 baseline (solid colour) and 2020 (diagonal hatching) surveys. SG = spoil ground, SZ = spreading zone, FF = far-field zone. Error bars represent ± 1 std deviation.

3.3. Macrofaunal communities

Across all stations, 96 macrofaunal taxa were identified, including 41 polychaete worms and 15 bivalve molluscs as well as crustaceans of the classes Ostracoda and Malacostraca (orders Amphipoda, Decapoda, Isopoda and Cumacea) and three holothurians (sea cucumbers). Of the 15 most abundant taxa, eight were polychaetes, three were bivalves, two were amphipods and two were holothurians. The dominant taxa by abundance were the capitellid polychaete *Heteromastus filiformis,* the nut shell (*Nucula nitidula*) and phoxocephalid amphipods.

3.3.1. Patterns in community indices

The macrofaunal core samples yielded greater numbers of organisms than for the baseline survey. Counts averaged 120 and ranged 41 to 249 individuals per 133 cm^2 sample (compared to 85 and 34–157, respectively, for the baseline). However, these increased abundances were spread approximately evenly over the three zones (Figure 9), suggesting a seasonal or interannual effect. The inshore and northern spreading zone samples yielded slightly greater numbers than the stations located on the seaward side and south of the spoil ground. Otherwise, there was little in the spatial patterns of index values (taxa richness, Shannon-Weiner diversity and Pielou's evenness; Figure 9) to suggest meaningful differences according to zone. The small amount of variability across stations was similar to spatial patchiness observed for the baseline (Sneddon 2019). This is consistent with the absence of significant differences in key sediment physicochemical properties (Figure 5, Figure 6) and suggests that any changes in community make-up from the ongoing deposition of spoil are not affecting diversity (at least outside the area of direct impact from each hopper load).

3.3.2. Multivariate statistical analysis

The dendrogram from cluster analysis of the October 2020 samples in PRIMER (Figure 10) shows no consistent grouping of benthic stations based on either spatial proximity or zone category. All except three samples (two from the spreading zone, one from the far-field) were grouped together at the relatively high level of similarity (LoS) of 50%, this being quite typical of coastal soft sediment environments[4]. A high degree of overlap between zones was evident at LoS lower than 60%, indicating little to no difference in community structure and suggesting that the primary factors driving dissimilarity were not related to spatial gradients at the zone scale.

[4] The lower the level of similarity at which a group of samples resolves from others, the more fundamentally different the macrofaunal community (i.e. at very high LoS, all samples will become distinct from one another).

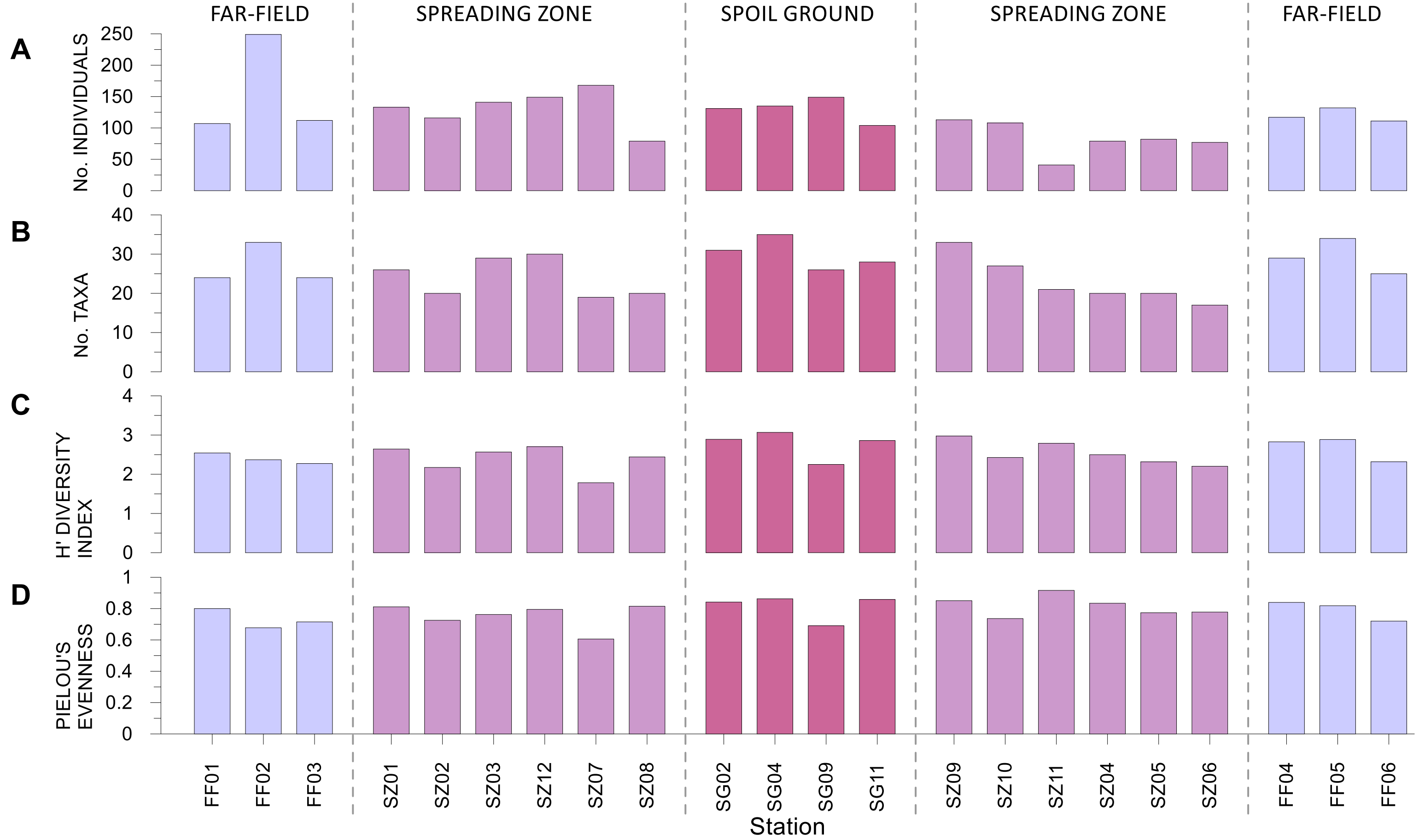

Figure 9. Benthic macrofaunal community indices for each of the 0.013 m^2 core samples from the 22 stations sampled in October 2020. H' Diversity = Shannon-Weiner Diversity index. Divisions and colour-shadings depict the three station zones of spoil ground (SG), spreading zone (SZ) and far-field (FF). Station order reflects symmetry about the spoil ground (north-south; inshore-offshore).

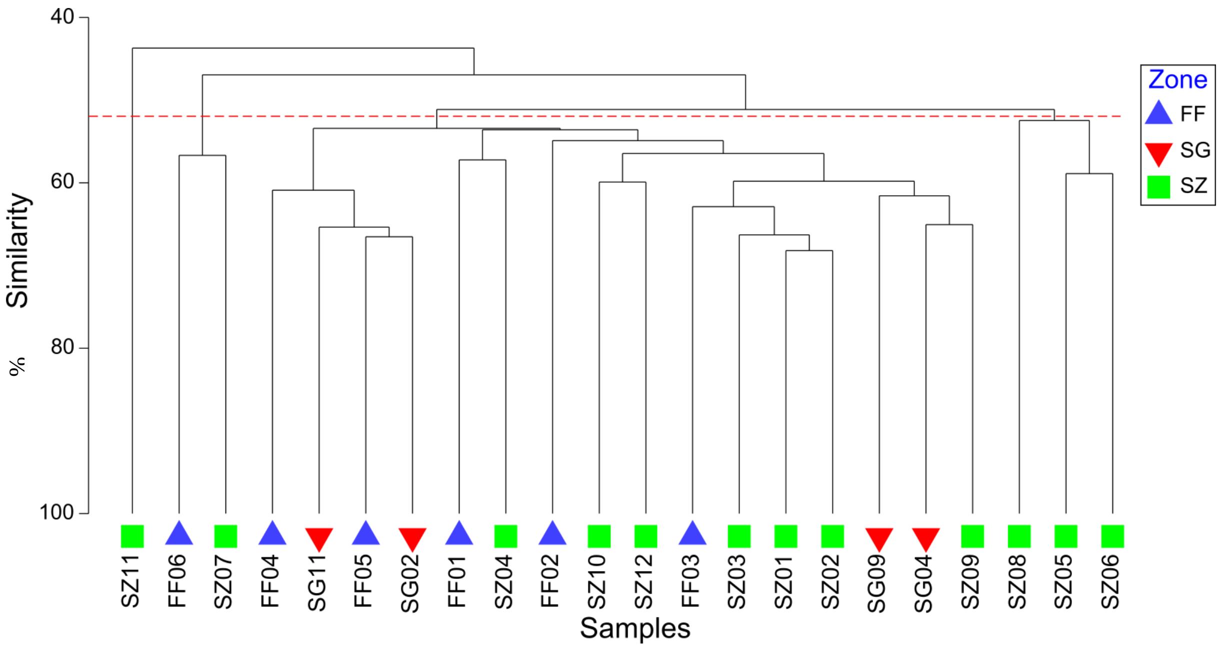

Figure 10. Dendrogram of square-root-transformed macrofaunal abundance data across station categories, showing clustering of individual benthic samples according to (S17) Bray-Curtis similarity. Slice (dashed line) at 52% similarity.

Figure 11 shows two forms of the nMDS plot for the 2020 data, categorised according to zone. The size of the symbols in the lower plot is proportional to the silt/clay content of the sediments. The moderate associated stress value[5] of 0.20 means that there is a limit to how accurately distances between individual points on the plot reflect the real magnitude of differences in community composition, but the plot is useful to examine general trends and groupings of samples.

The abundance of several taxa was correlated with the 2-dimensional space (Pearson $r > 0.6$)[6]. The bubble plot version of the nMDS indicates that the principal (left to right) gradient in the distribution of most of these taxa aligns with increasing silt/clay content of sediments. In common with the baseline data (Sneddon 2019), the bivalve *Myllita vivens* and haustoriid amphipods were associated with lower silt content and the polychaetes *Heteromastus filiformis, Paraprionospio* sp. and Ampharetidae were associated with siltier sediments.

[5] Distances on the nMDS plot have only relative, not absolute, meaning. The stress value is a dimensionless quantity and is a measure of the difficulty involved in compressing the sample relationships into two dimensions. A stress value of < 0.1 corresponds to a good ordination with no real prospect of a misleading interpretation, while a stress value of < 0.2 still gives a potentially useful 2-D picture. Stress values within the range of 0.2 to 0.3 should be treated with caution, particularly if in the upper half of this range and for sample sizes of < 50.

[6] The vector overlay of taxa correlated with the principal axes of the nMDS plot does not necessarily show all of the organisms contributing significantly to dissimilarity across samples. This is because the correlation assumes linearity in the change in (transformed) abundances across the space represented.

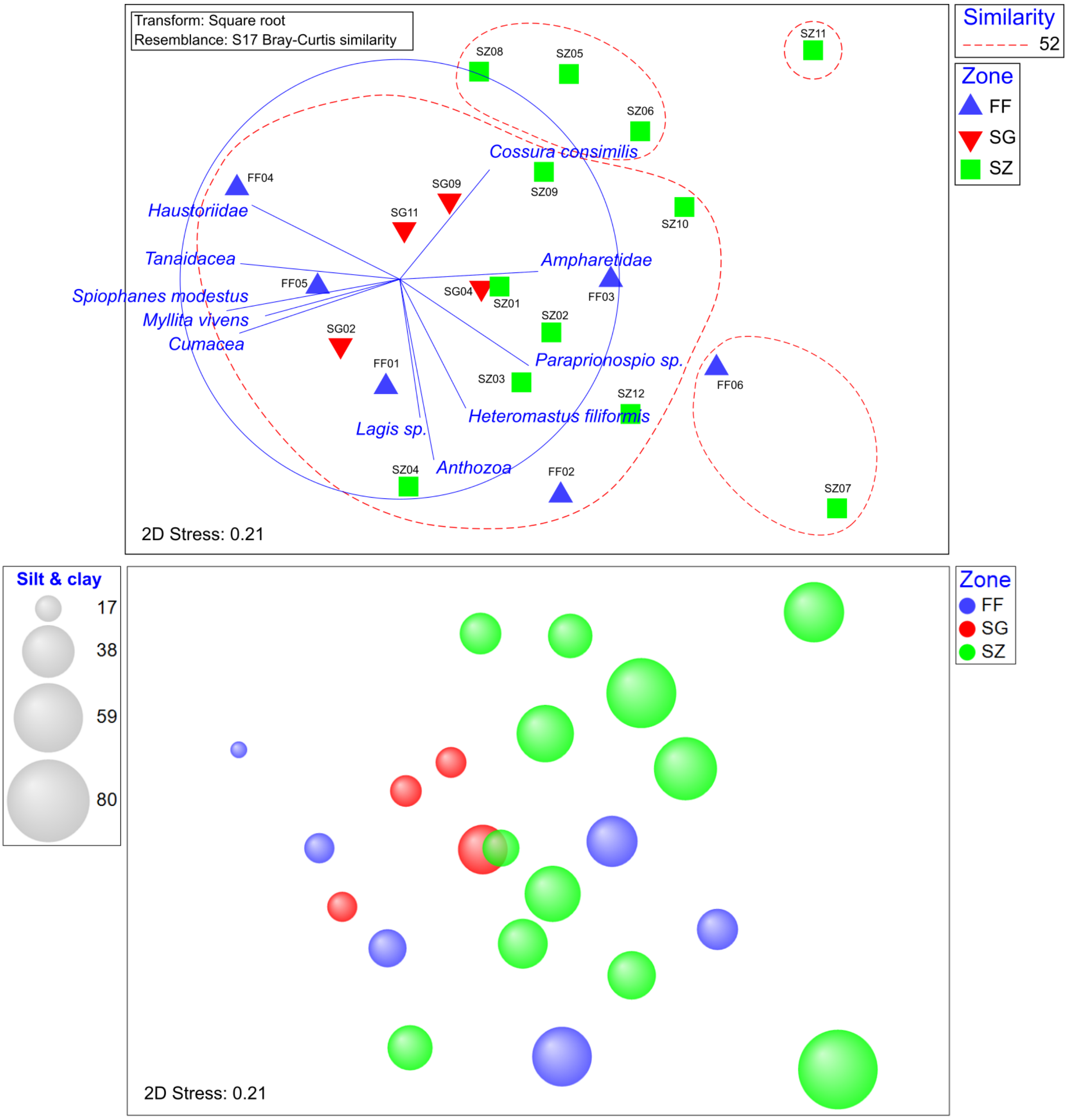

Figure 11. Non-metric multidimensional scaling (nMDS) plot for the benthic macrofaunal samples according to station zone. **Top:** Station labels with vector overlay showing taxa correlated (r > 0.6 [Pearson]) with the plot. (FF = far-field; SG = spoil ground; SZ = spreading zone). **Bottom:** Bubble plot representation of the nMDS showing variation in silt/clay content across stations. The size of the bubble represents the percentage of silt/clay in the sample.

3.3.3. Comparison with the baseline macrofaunal data

Community indices

A combined macrofaunal data set was generated from the results of the baseline and current survey. The mean community indices from the two surveys are contrasted according to sampling zone in Figure 12 and the percentage change from the baseline is listed in Table 6.

Table 6. Summary of percentage changes in community index averages for the three sampling zones since the 2019 baseline survey. N = number of individuals, S = species richness, J' = Pielou's evenness, H' = Shannon-Weiner diversity. Shading designates where changes were statistically significant.

	N	S	H'	J'
Spoil ground	75%	41%	7%	-4%
Spreading zone	15%	6%	2%	0%
Far field	45%	10%	-5%	-8%

The only statistically significant changes in indices were for abundance and species richness within the spoil ground (single factor ANOVA, $\alpha = 0.05$). Given the recent spoil deposition program, impacts to communities within the spoil ground boundaries may be expected, but changes in diversity and evenness were not significant. This indicates that the increases in abundance were spread across several taxa rather than reflecting an increase in dominance by just one or two.

Community structure

Multidimensional scaling plots (nMDS) for each zone in the combined survey data set are presented in Figure 13. They show a divergence between surveys at LoS ranging 45-50%, indicating that changes have generally been both minor and similar in scale across all zones. This is similar to the 51% LoS at which the baseline data for the spoil ground site separated from samples collected in 2005 (Sneddon 2019). The vector overlays in Figure 13 show that the taxa most correlated with the changes between surveys tended to vary across zones. Callianassidae (ghost shrimps) were absent from the 2019 samples and, although they were present (in low numbers) in all zones in the current survey, they were more prevalent within the spoil ground. Nonetheless, the nMDS plot for the current 2020 data (Figure 11) suggests that any impacts from spoil deposition have not set up strong spatial gradients in these communities across the monitored area.

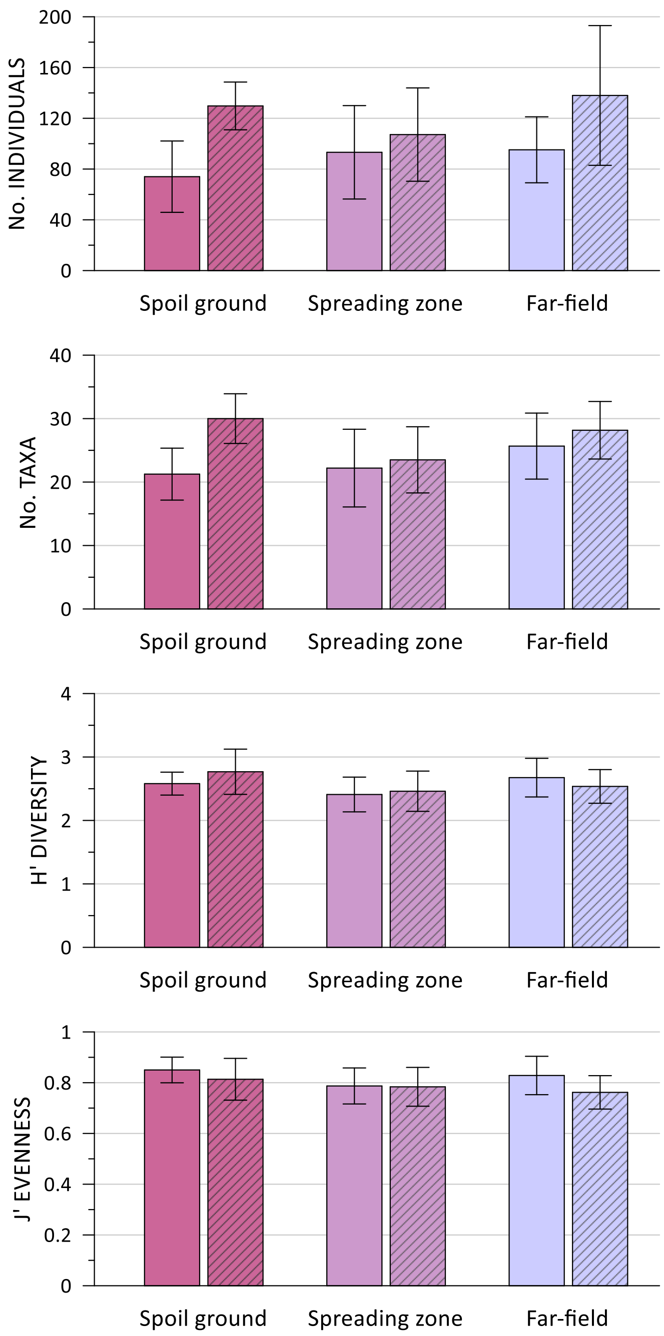

Figure 12. Comparison of mean macrofaunal community indices (by zone) for samples collected for the 2019 baseline (solid colour) and 2020 (diagonal hatching) surveys. Error bars represent ± 1 std deviation.

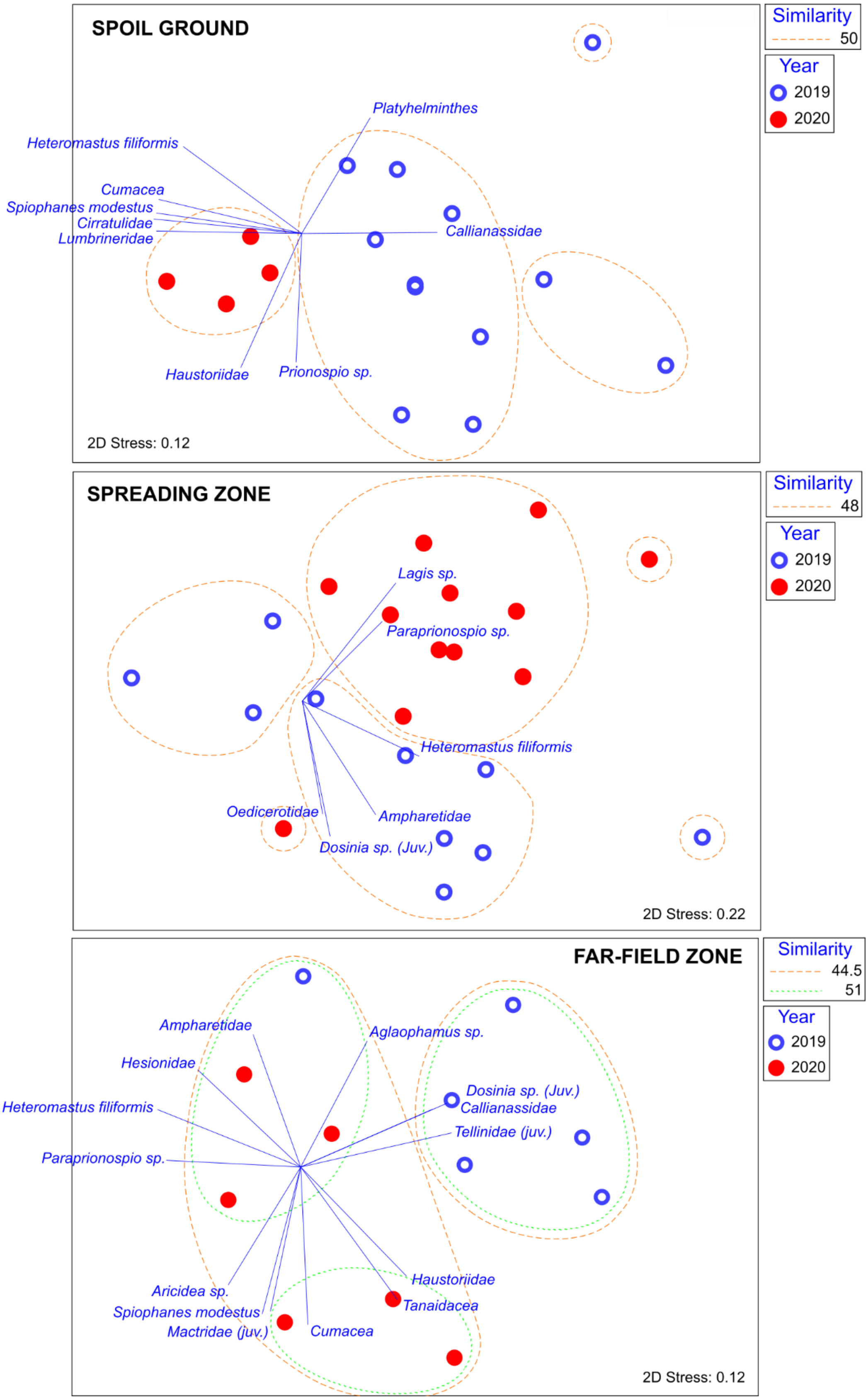

Figure 13. nMDS plots showing clustering within the combined baseline (2019) and 2020 infauna data set within the three zones. Vector overlays show taxa correlated to plot coordinates for spoil ground (r > 0.7), spreading (r > 0.6) and far-field (r > 0.7) zones.

Table 7 shows how the average abundance of the key macrofaunal taxa has changed according to zone since the baseline. The hierarchy of numerically dominant macrofaunal taxa was very similar between surveys. The three most abundant taxa were common to both surveys (*H. filiformis*, *Nucula nitidula* and phoxocephalid amphipods). Ten taxa were common to the most abundant 15 from both surveys. Although *H. filiformis* and *N. nitidula* were both more abundant in 2020, they were also more abundant than the baseline for samples collected in 2005 (Sneddon 2019).

Table 7. Comparison of mean macrofaunal densities (per 0.013 m^2 core) between the 2019 baseline and current survey (shaded columns) for the 20 most abundant taxa identified across all stations in both surveys. Values are sample averages for the three zones.

	Zone	Spoil ground		Spreading zone		Far-field	
	Year	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
	n	12	4	10	12	6	6
Polychaeta: Capitellidae	*Heteromastus filiformis*	11.2	18.5	28.6	28.0	19.0	36.5
Bivalvia	*Nucula nitidula*	11.8	28.3	11.8	13.9	11.5	20.8
Amphipoda	Phoxocephalidae	7.8	11.5	5.4	5.7	9.7	8.2
Polychaeta: Spionidae	*Spiophanes modestus*	1.3	6.0	2.0	4.4	2.0	9.8
Polychaeta: Spionidae	*Paraprionospio* sp.	0.0	1.3	0.6	10.2	0.3	5.7
Polychaeta: Spionidae	*Prionospio* sp.	5.5	2.5	3.1	0.9	5.2	2.2
Holothuroidea	*Heterothyone ocnoides*	3.9	3.8	3.3	2.1	3.2	3.5
Polychaeta: Paraonidae	*Aricidea* sp.	1.8	7.3	1.3	4.6	1.5	4.0
Cumacea	Cumacea	0.5	5.8	1.2	4.0	1.3	5.7
Amphipoda	Haustoriidae	3.5	6.3	0.5	0.8	2.7	4.7
Polychaeta: Goniadidae	Goniadidae	2.8	2.5	2.6	2.0	3.0	1.5
Polychaeta: Nephtyidae	*Aglaophamus* sp.	2.0	1.3	2.8	2.8	2.8	1.0
Bivalvia	*Dosinia* sp. (Juvenile)	2.6	0.0	3.4	0.0	5.7	0.0
Polychaeta: Oweniidae	*Myriochele* sp.	0.3	2.0	0.6	4.4	0.8	1.2
Bivalvia	*Myllita vivens*	2.8	1.8	0.7	0.2	2.0	1.8
Polychaeta: Pectinariidae	*Lagis* sp.	0.3	3.3	0.1	2.9	1.2	2.3
Polychaeta: Ampharetidae	Ampharetidae	0.5	0.0	3.5	0.6	1.2	0.8
Polychaeta: Spionidae	*Prionospio australiensis*	0.8	0.5	1.7	0.0	4.2	0.3
Polychaeta: Lumbrineridae	Lumbrineridae	0.3	1.5	1.5	1.4	0.7	1.3
Holothuroidea	*Paracaudina chilensis*	1.4	2.0	1.3	0.8	0.3	0.2

While there have been changes since the baseline in the abundance of some taxa, the variability in such changes extended across all zones. There were no taxa for which changes were indicative of a meaningful shift, especially against the context of the spatial variability exhibited by the baseline (when all evidence had indicated a fairly uniform benthic environment across the sampled area).

Spionid polychaetes of the genus *Paraprionospio* were more abundant in the current survey but this increase was present across all three zones and was influenced by high abundance in just one spreading zone sample (SZ07; 84 /core).

The only key taxon recorded as absent from one of the surveys was the juvenile of the surf clam genus *Dosinia* (present only in 2019), but *Dosinia lambata* were identified (in lower densities) from the current survey. Hence, this can be attributed to seasonal or other factors affecting the recruitment and establishment of juvenile life phases.

A SIMPER analysis on the (square-root transformed) count data confirmed that the mean dissimilarity between the baseline and October 2020 macrofaunal samples varied across a narrow range for the three zones (53.7% for the spoil ground vs 55.4% for each of the spreading and far-field zones). Across the three zones, the ten taxa contributing most to dissimilarity in community structure between the baseline and current surveys accounted for between 33% and 35% of total dissimilarity. Of these taxa, four were common to all zones (Appendix 3).

Overall, the small changes in community structure were not consistent with a fundamental change attributable to spoil deposition. That such change was not discernible inside the spoil ground suggests a significant resilience in these communities but may also be an artifact of the large size of the spoil ground relative to the incremental deposition over a year-long period. While the dynamic nature of this seabed environment and its communities is undoubtedly a factor in such resilience, it cannot be known how the four spoil ground samples coincided with areas of recent direct deposition of spoil.

3.4. Epifauna

A list of the biota identified from the epifaunal dredge trawls is provided in Table 8, including identifiable shell debris and fragments. Photographs of the trawl contents are provided in Appendix 4.

Only one trawl was completed within the spoil ground boundaries—ESG1 in the northern sector (Figure 3). A planned second trawl in the south of the area was prevented by the operation of the barge depositing sediments from dredging operations.

As was found during the 2019 baseline survey, the epifaunal community in the vicinity of the spoil ground was relatively sparse. The only taxa that were consistently present in the trawl contents were the small sea cucumber *Heterothyone ocnoides* and the knobbed whelk *Austrofusus glans* (Table 8). Several decapod crustaceans were collected in low numbers in four or more trawls, including hermit crabs (Paguridae), the policeman crab (*Neommatocarcinus huttoni*) and an introduced spider crab (*Pyromaia tuberculata*).

The bivalve mollusc *Gari stangeri* was collected in trawls EFF3 (3 individuals) and ESZ1 (1 individual). One or two individuals of *Dosinia* sp., *Spisula aequilatera* and *Bassina yatei* were also collected in ESZ1.

For the trawls conducted outside of the spoil ground boundaries (all but ESG1; Figure 3) very little debris was collected along with the biota. However, sparsely occurring shell fragments suggested that additional bivalve mollusc species may either live deeper in the sediments than were reached by the bite of the dredge or have populations occurring within the wider vicinity of the survey area.

The spoil ground trawl (ESG1) was full when it was retrieved to the surface. The contents were mainly lumps of cohesive mud of various sizes but also included plentiful small rock pieces (see photo Appendix 2). Such was the consolidation of the silt/clay clumps that they could not effectively be washed through the 10 mm mesh, requiring that the entire contents be brought aboard and sorted by hand. Although this substrate was distinct from the unconsolidated sands occurring outside the spoil ground, the assemblage of fauna collected by ESG1 was effectively no different to that collected in the other trawls (Table 8). The common taxa (*H. ocnoides* and *A. glans*) were present in comparable numbers. The only taxon that was unique to ESG1 was a single individual of the ostrich foot snail (*Struthiolaria papulosa*). There was more shell fragment debris in ESG1 than in trawls from the other zones but this may have been because it was retained with the consolidated sediment rather than being washed through the dredge mesh. It was notable, however, that several of these empty shells and fragments belonged to species that were unrecorded by the baseline and may be more typical of the inshore dredged area (e.g. *Serratina charlottae*, *Chlamys zelandica*, *Maoricolpus roseus* and *Cominella adspersa*).

Table 8. Biota identified within the October 2020 epifaunal dredge trawls. NR = not recorded.

Trawl no.		**EFF1**	**EFF2**	**EFF3**	**EFF4**	**ESZ1**	**ESZ2**	**ESZ3**	**ESZ4**	**ESG1**
Trawl distance (m)		516	481	493	425	549	442	563	400	525
Trawl depth (MSL, m)		19.5	20.2	NR	21.6	19.3	21.4	19.1	21.9	20.3
Taxa	**Common name**									
Struthiolaria papulosa	Ostrich foot snail									1
Austrofusus glans	Knobbed whelk	45	13	23	15	22	7	104	2	8
Amalda australis	Olive shell	1						2		
Tanea zelandica	Moon snail				1					
Alcithoe arabica	Volute snail								2	
Gari stangeri	Sunset clam			3		1				
Dosinia sp.	Venus clam					2				
Spisula aequilatera	Triangle shell					1				
Bassina yatei	Frilled cockle					1				
Pyromaia tuberculata	Spider crab		1	2	15	3	3	8		
Ebalia sp.	Spider crab						1			
Paguridae	Hermit crabs	2	1	2		1	1	3		2
Neommatocarcinus huttoni	Policeman crab	1			2	3	1	9	1	1
Ophiuroid	Brittle star	1							1	1
Echinocardium australe	Heart urchin				1					
Paracaudina chilensis	Sea cucumber			3		5				
Heterothyone ocnoides	Sea cucumber	153	12	17	36	190	7	12	24	>45
Aphrodita australis	Sea mouse (polychaete)				1	2			1	
Maldanidae	Polychaete worm	2	1		5	13				
Peltorhamphus novaezeelandiae	New Zealand sole				1			1		
Shell fragments (excl. those associated with pagurids)										
Dosinia sp.	Venus clam	1		1						1
Serratina charlottae	Wedge shell									3
Gari stangeri	Sunset clam	1								
Chlamys zelandica	Fan shell									1
Amalda sp.	Olive snail									1
Maoricolpus roseus	Turret shell									4
Cominella adspersa	Speckled whelk									1

3.4.1. Comparison with the baseline epifaunal data

The semi-quantitative nature of sampling by epibenthic trawl and the apparently sparse epifauna of the area mean that differences between the data recorded by the two surveys should be interpreted cautiously. Table 9 shows a comparison between the trawl results of the current survey with those of the 2019 baseline based on the most common taxa collected. The same dredge was used in both surveys.

Table 9. Comparison between the 2019 baseline and current survey of mean numbers of epifauna in trawls from the three zones. Includes only those taxa averaging one individual or greater in any zone in either survey. Note that no trawls were completed within the spreading zone in 2019; however, the pre-deposition spoil ground area is likely to serve for comparison.

	Zone	Spoil ground		Spreading zone	Far-field	
	Year	2019	2020	2020	2019	2020
	n	5	1	4	4	4
Taxa	**Common name**					
Struthiolaria papulosa	Ostrich foot snail	0.2	1			
Austrofusus glans	Knobbed whelk	4.8	8	33.8	10.3	24.0
Pyromaia tuberculata	Spider crab	0.4		3.5		4.5
Paguridae	Hermit crabs	1.8	2	1.3	7.5	1.3
Neommatocarcinus huttoni	Policeman crab		1	3.5		0.8
Ophiuroid	Brittle star	0.4	1	0.3		0.3
Paracaudina chilensis	Sea cucumber	0.4		1.3	0.5	0.8
Heterothyone ocnoides	Sea cucumber	24.8	> 45	58.3	69.5	54.5
Aphrodita australis	Sea mouse (polychaete)			0.8	0.3	0.3
Maldanidae	Polychaete worm			3.3	0.5	2.0

The two taxa most characteristic of the area (*A. glans* and *H. ocnoides*) were present in comparable[7] numbers across both surveys, including within the spoil ground itself. Hermit crabs were also similarly common in both surveys.

No taxa collected in 2019 at a mean incidence of one individual per trawl or greater in either the spoil ground or far-field zone was absent in 2020. However, the policeman crab (*Neommatocarcinus huttoni*) was notably present in trawls from all three zones in 2020 but was not collected at all during the baseline. Since this species was present at the far-field sites, it is considered unlikely that its occurrence is a consequence of spoil deposition.

[7] Noting that the sampling method is only semi-quantitative.

The triangular surf clam (*Spisula aequilatera*), which was recorded from just one individual in the spreading zone during the current survey (Table 8), was absent from the 2019 trawl data but had been collected from the area in 2005 (6 individuals from two trawls; Sneddon 2019). It is possible that this and other bivalve species may bury to a depth largely below the bite of the epifaunal dredge.

4. CONCLUSIONS

Other than the obvious presence of deposited dredge spoil in the contents of the single epifaunal trawl conducted within the spoil ground boundaries, there is little evidence for a generalised change in substrate characteristics in the vicinity since the baseline survey. The key parameter of silt/clay content of sediments remains spatially variable but with almost no significant cumulative change apparent within the three monitored zones. This consistency is most likely due to the dynamic nature of the seabed, with sediments regularly moved and sorted by swell events.

All of the trace metals analysed in sediments were well below their respective low-risk trigger levels. No strong spatial gradients in metal concentrations were evident although, similar to the baseline data, some metals were correlated with silt/clay content. Changes in sediment metals since the baseline at the spoil ground and spreading zone were generally of the same order and direction as those occurring at the far-field sites, suggesting that influence from the deposition of dredge spoil has been minimal.

The sediment macrofaunal communities were comprised of the same taxonomic groups as the baseline and the hierarchy of numerically dominant macrofaunal taxa remains the same for the current survey. Greater abundances in the current survey were spread approximately evenly over the three monitored zones, suggesting a background seasonal or interannual effect. However, consistent with the absence of significant differences in key sediment physicochemical properties, there was little in the spatial patterns in community index values to suggest meaningful differences between the monitored zones. Variation in community structure was subtle and predicated mostly by the silt/clay content of sediments rather than zone. The changes observed were not attributable to effects from spoil deposition.

As for the baseline, epifaunal communities sampled by dredge trawl were quite sparse. Although the substrate retrieved in the single trawl within the spoil ground was distinct from that occurring outside its boundaries, the assemblage of fauna was effectively no different to that collected in trawls of the other zones. It is concluded that the epifaunal community across the monitored area was effectively no different to that recorded by the baseline survey.

5. ACKNOWLEDGEMENTS

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7. APPENDICES

Appendix 1. Photographs of benthic sediment core samples.


SZ07
SZ08
SZ09
SZ10
NO IMAGE
SZ11
SZ12
FF01
FF02
FF03
FF04
FF05
FF06

Appendix 2. Summary data (mean and standard deviation) for sediment grainsize distribution and organic carbon content from the baseline and current surveys.

Spoil ground	**2019 (n=12)**		**2020 (n=4)**	
	Mean	**Stdev**	**Mean**	**Stdev**
Depth	21.0	0.8	20.5	0.5
Gravel	0.05	0	0.14	0.18
Very coarse sand	0.05	0	0.14	0.18
Coarse sand	0.05	0	0.14	0.18
Medium sand	1.04	2.3	0.53	0.43
Fine sand	5.32	2.78	10.20	4.80
Very fine sand	70.48	5.82	65.60	3.70
Silt/clay	23.20	6.16	23.40	7.70
Total organic carbon	0.12	0.02	0.11	0.05

Spreading zone	**2019 (n=10)**		**2020 (n=12)**	
	Mean	**Stdev**	**Mean**	**Stdev**
Depth	20.7	1.1	20.6	1.2
Gravel	0.05	0.00	0.05	0.00
Very coarse sand	0.05	0.00	0.05	0.00
Coarse sand	0.05	0.00	0.05	0.00
Medium sand	0.94	1.28	0.05	0.01
Fine sand	2.4	2.90	3.00	2.00
Very fine sand	61.7	10.60	55.40	14.30
Silt/clay	34.9	11.80	41.50	14.80
Total organic carbon	0.16	0.04	0.27	0.13

Far-field zone	**2019 (n=6)**		**2020 (n=6)**	
	Mean	**Stdev**	**Mean**	**Stdev**
Depth	20.7	0.7	20.6	0.6
Gravel	0.05	0.00	0.05	0.00
Very coarse sand	0.05	0.00	0.05	0.00
Coarse sand	0.05	0.00	0.05	0.00
Medium sand	0.08	0.06	0.07	0.03
Fine sand	10.30	7.60	4.30	2.00
Very fine sand	69.50	6.10	67.90	10.70
Silt/clay	20.20	6.00	27.70	12.10
Total organic carbon	0.12	0.02	0.17	0.07

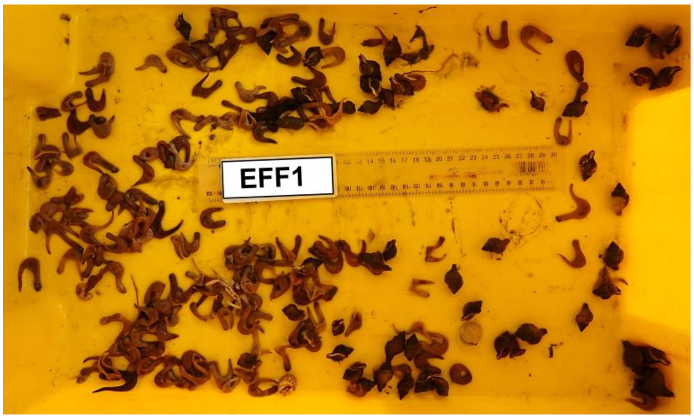
Appendix 3. Outputs of SIMPER analysis (PRIMER v.7). Ten taxa contributing most to dissimilarity in (square-root transformed) macrofaunal community structure between the baseline (2019) and current surveys for each of the three benthic sampling zones.

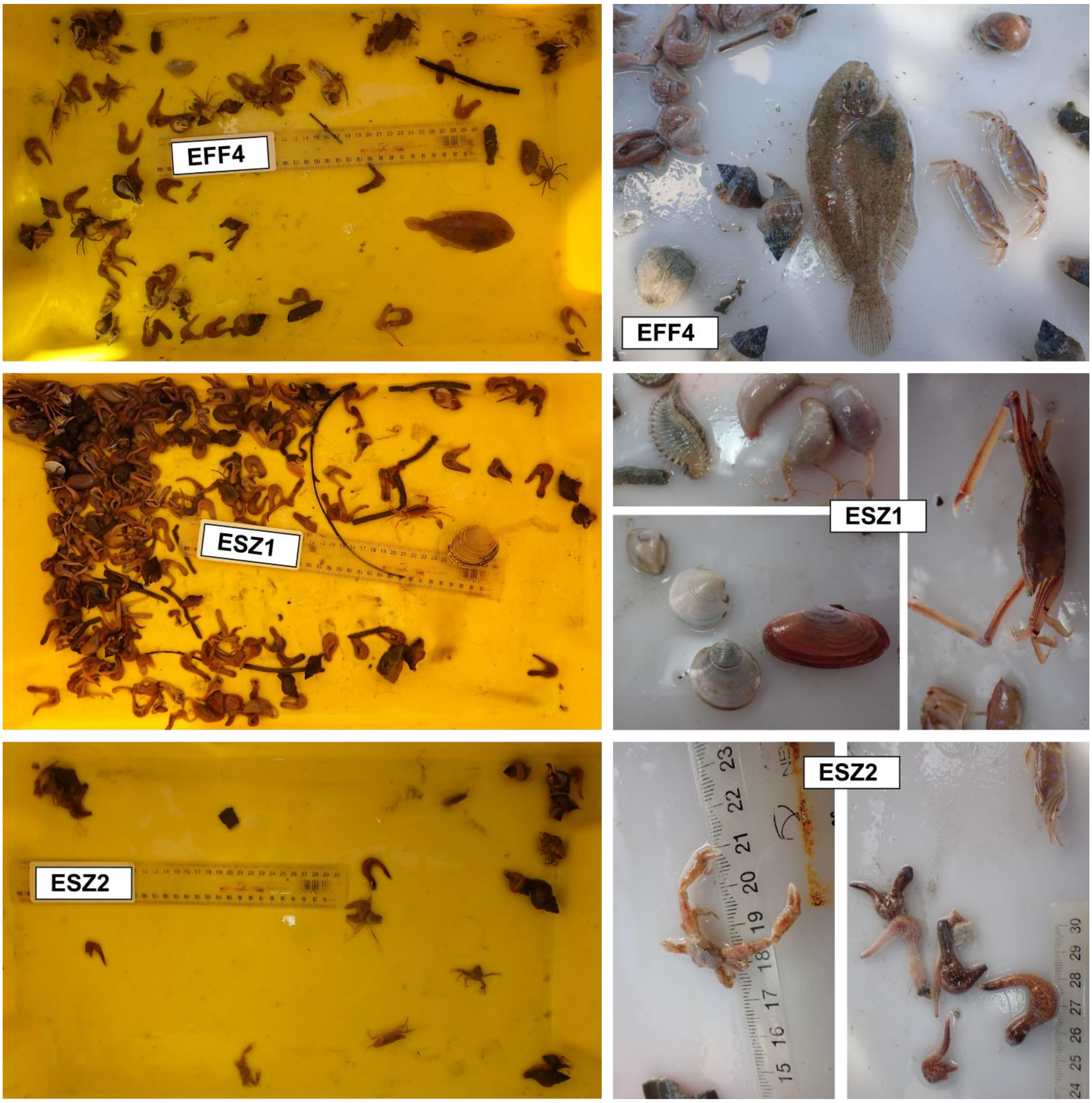
FAR-FIELD ZONE	**2019**	**2020**				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Heteromastus filiformis	4.05	5.4	2.89	1.36	5.22	5.22
Spiophanes modestus	1.04	2.78	2.32	1.62	4.19	9.41
Dosinia sp. (Juvenile)	2.11	0.00	2.22	1.88	4.00	13.42
Paraprionospio sp.	0.33	1.97	1.85	1.35	3.35	16.76
Nucula nitidula	3.17	4.51	1.80	1.45	3.25	20.01
Haustoriidae	1.31	1.23	1.79	1.34	3.23	23.24
Prionospio australiensis	1.60	0.24	1.63	1.26	2.95	26.19
Cumacea	1.02	2.09	1.59	1.56	2.87	29.05
Prionospio sp.	1.90	1.34	1.25	1.22	2.26	31.31
Lagis sp.	0.57	1.18	1.21	1.23	2.19	33.50

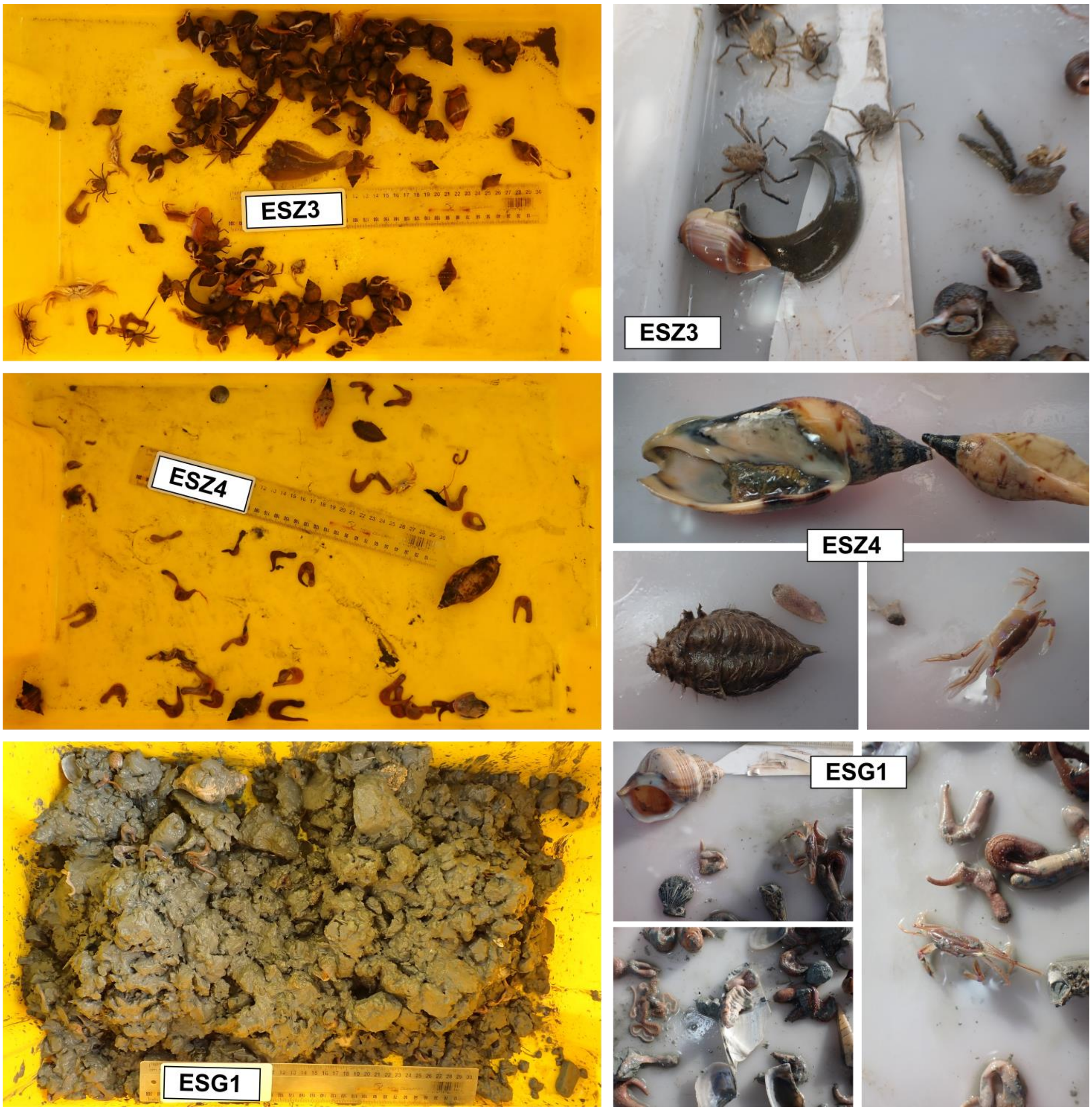
SPREADING ZONE	**2019**	**2020**				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Paraprionospio sp.	0.42	2.35	2.63	0.91	4.76	4.76
Heteromastus filiformis	5.07	5.08	2.39	1.30	4.32	9.07
Myriochele sp.	0.48	1.52	1.75	1.03	3.15	12.22
Nucula nitidula	3.20	3.57	1.74	1.06	3.15	15.37
Lagis sp.	0.10	1.37	1.66	1.24	2.99	18.36
Ampharetidae	1.44	0.43	1.62	1.37	2.93	21.29
Aricidea sp.	0.91	1.99	1.62	1.69	2.92	24.21
Dosinia sp. (Juvenile)	1.38	0.00	1.57	1.22	2.83	27.04
Heterothyone ocnoides	1.40	1.07	1.54	1.34	2.78	29.82
Prionospio sp.	1.39	0.72	1.52	1.12	2.74	32.56
Cumacea	0.81	1.82	1.51	1.32	2.73	35.29

SPOIL GROUND	**2019**	**2020**				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Nucula nitidula	3.21	4.94	2.61	1.06	4.86	4.86
Cumacea	0.40	2.25	2.18	1.80	4.05	8.92
Heteromastus filiformis	2.91	4.21	2.03	1.15	3.78	12.69
Spiophanes modestus	0.74	2.40	1.93	1.60	3.6	16.29
Aricidea sp.	1.11	2.60	1.69	1.58	3.14	19.43
Lagis sp.	0.25	1.56	1.66	1.67	3.09	22.52
Callianassidae	1.37	0.00	1.57	2.74	2.93	25.45
Heterothyone ocnoides	1.42	1.90	1.52	1.76	2.83	28.28
Cirratulidae	0.08	1.39	1.5	3.41	2.78	31.06
Haustoriidae	1.53	2.46	1.38	1.31	2.56	33.63

Appendix 4. Photographs of the contents of epifaunal dredge trawls. Photographs of yellow bin (left) show total trawl contents. Other photos show selected taxa detail.




EFF4
EFF4
ESZ1
ESZ1
ESZ2
ESZ2


ESZ3
ESZ3
ESZ4
ESZ4
ESG1
ESG1