CAWTHRON

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SAMPLING SURVEY OF PORT OF NAPIER OFFSHORE SPOIL GROUND: OCTOBER 2021

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Prepared for Port of Napier Ltd

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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 disposal area to accept the dredged material. Conditions 11-16 of the consent set out requirements for monitoring of the benthic environment in the vicinity of this spoil ground. Following a baseline survey of the area and its immediate vicinity in April 2019, use of the spoil ground commenced in late 2019. The first repeat survey following commencement was conducted in October 2020 after deposition of 235,000 m^3 of material. This report describes the implementation and findings of a second post-baseline survey conducted 19 October 2021. At the time of the survey, spoil deposition by barge was ongoing, and had amounted to a total volume for the previous year of 773,650 m^3. To ensure comparability, the methodology was identical to that of the previous 2020 survey. Benthic sediments and associated macrofaunal and epifaunal communities were sampled across three designated zones relative to the spoil ground.

The benthic substrate outside the spoil ground boundaries was generally similar to that observed in previous surveys although the silt/clay fraction of sediments had increased in all three zones since the baseline. While the increase in silt/clay content had been progressive in the spreading and far-field zones, the latter exhibited both the greatest relative increase and the greatest variability. Nonetheless, the deposition of spoil cannot be ruled out as a possible source. Trace metal concentrations in sediments had changed little since the baseline, remaining well below applicable low-risk guideline criteria. However, there was a moderate correlation between some metals and both the silt/clay and organic carbon fractions.

Sediment macrofaunal communities were also little changed from the baseline. Small progressive shifts in community structure were similar across all sampling zones and did not align with sediment textural changes. There were no spatial patterns indicative of a relationship with spoil ground proximity, and the shifts are likely to be primarily attributable to drivers other than spoil deposition. The limited changes observed within the spoil ground indicate a degree of resilience in these communities arising from adaptation to a dynamic inshore sediment environment.

The sparse nature of benthic epifaunal communities and the semi-quantitative nature of the dredge trawl method used to sample them mean that the data should be interpreted cautiously. However, all historically characteristic taxa continued to be represented across the monitoring area, with similar rates of occurrence. Hence the survey results suggest no more than minor changes in this community since the baseline.

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GLOSSARY

Item	Description	Type
µm	Micron or micrometre	Unit
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
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.

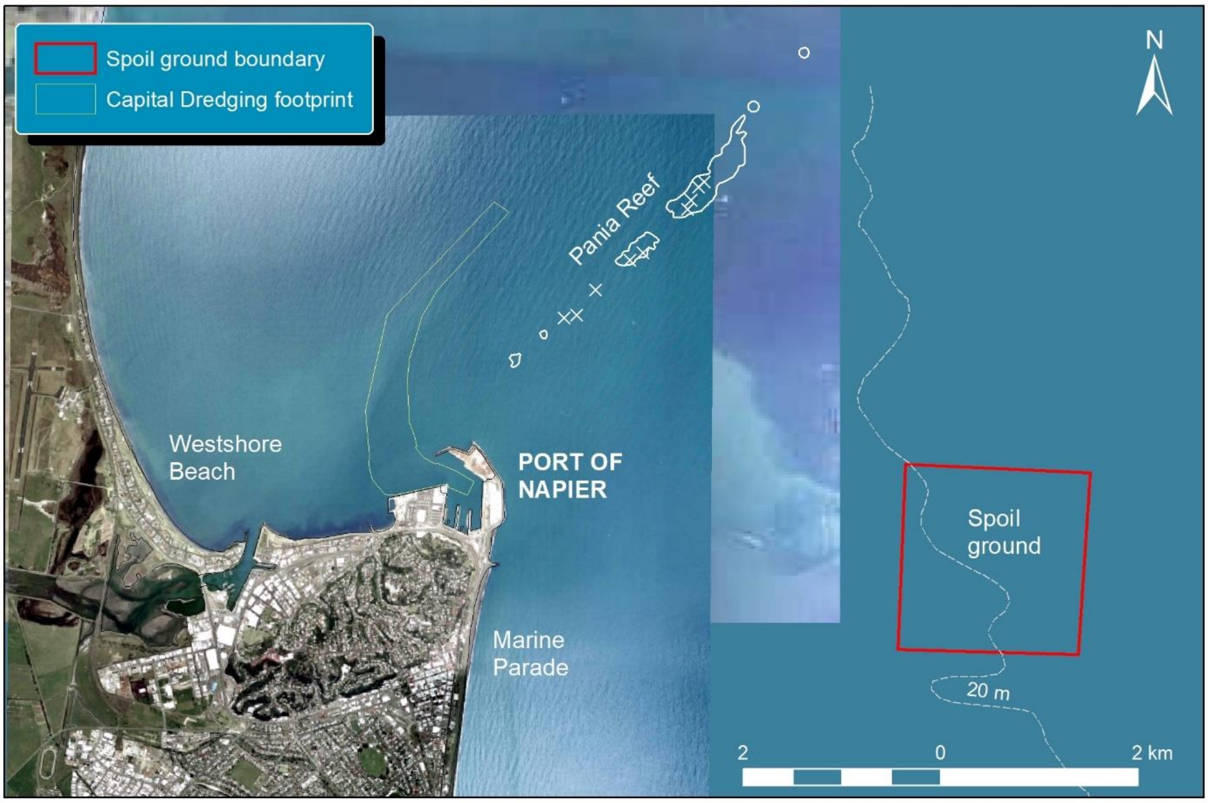

Figure 1. Composite image showing the location of the offshore spoil ground in relation to the Port of Napier, Pania Reef and the capital dredging footprint.

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 this 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.* The 50,000 m^3 of dredge spoil generated was the first to be deposited at the offshore disposal ground. Capital dredging for the No.6 berth project commenced in June 2020. By the date of the first post-baseline benthic survey conducted by Cawthron in October 2020, deposition of 185,721 m^3 of marine sediments had been recorded (Sneddon 2021).

In the subsequent year to 11 October 2021, deposition of a further 773,650 m^3 had been recorded. The pattern of deposition of this material for the year preceding the current survey is shown in Figure 2. Cawthron was again contracted by PONL to conduct the second post-baseline survey in October 2021 using the same methodology to that of the first.

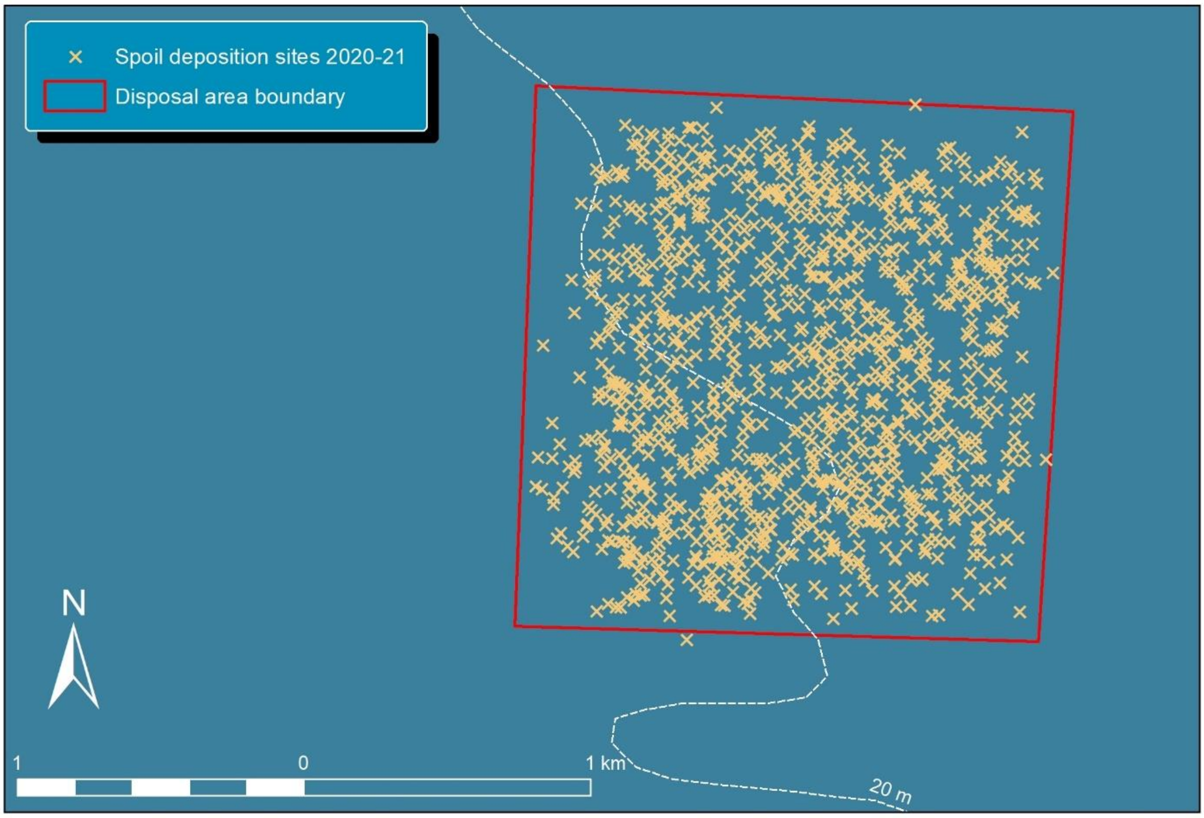

Figure 2. Pattern of spoil deposition from capital dredging between 3 October 2020 and 11 October 2021. Represents 1192 barge loads. Source: Port of Napier Ltd.

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.*

This report presents the data from the second post-baseline survey and provides a comparison to the results of previous surveys (including the baseline) with the aim of establishing the nature and scale of any changes that may have occurred as a result of dredge spoil deposition.

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).

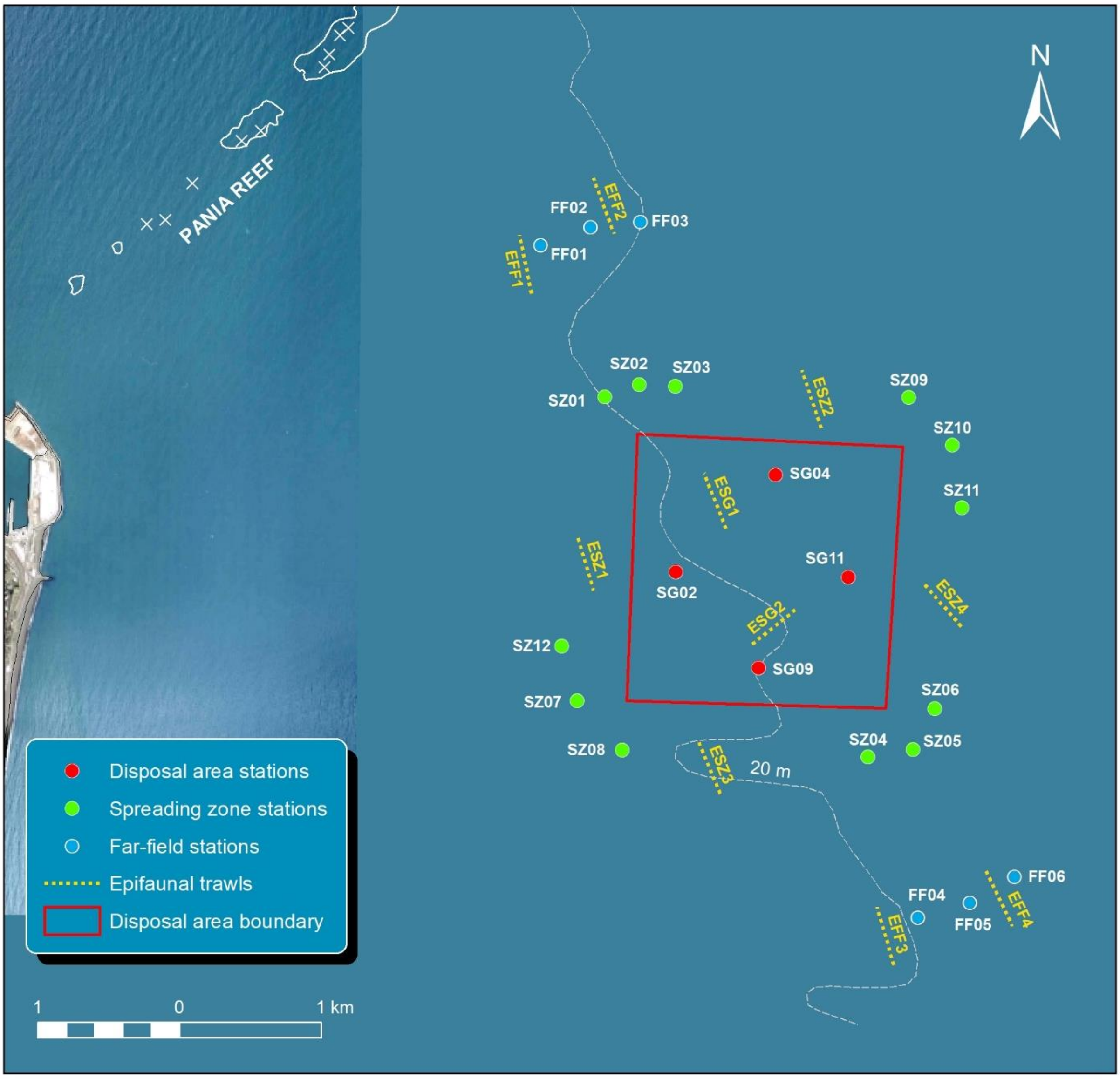

Figure 3. Spatial layout of principal sampling elements of the October 2021 survey; benthic grab stations and epifaunal dredge trawls. The 20-m depth contour from hydrographic chart NZ571 has been overlaid.

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 two locations; inshore and offshore from the NE and SW vertices of the spoil ground (Four of these were established for the 2019 baseline. An extra station has been added 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 19 October 2021 from the 18-m survey vessel *Shoman.*

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 were 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 data from previous surveys.

[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 a 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. 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 those of the 2020 and pre-deposition baseline surveys 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.

Ten epifaunal dredge trawls were completed, each covering a distance between approximately 400 m and 500 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. Two trawls were 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 semi-consolidated silty sands. However, muddier substrates were observed on the seaward side of the spoil ground (SZ06, SZ10, SZ11) and at some far-field sites (FF01, FF02, FF05, FF06). Similar to the baseline, there appeared to be some patchiness in the spatial distribution of these substrates. Still images of the substrate from grab-sampler-attached GoPro video are presented in Appendix 1.

None of the sampled sediments were characterised by significant odour (which, if present, can indicate organic enrichment). Although darker coloured patches in the sediment profile and in underlying sediments were sometimes observed where conditions were siltier, there were no core samples exhibiting a distinct aRPD layer. Photographs of the core samples are presented in Appendix 2.

Of the four grab samples collected from within the spoil ground, all but SG04 exhibited a very similar range of characteristics to those from the spreading and far-field zones, being described in field notes as grey silty sand. The sample from SG04 comprised firm consolidated clay.

Substrate differences were most notable from the two epifaunal dredge trawls conducted within the spoil ground, where clogging of the dredge with consolidated clay clumps and rock debris became an issue. This was considered to derive from recently deposited dredge spoil (see Section 3.4).

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 divided between very fine sands (average 46%) and the silt/clay fraction (average 47%) (Figure 5). Although there was some variability across stations within zones, there was little consistent difference in grain size structure between zones outside the spoil ground. However, samples from within the spoil ground tended to have a greater fine sand component.

Ranging from 0.11% to 0.82% (average 0.29%), the organic carbon content of the sediments was generally very low, reflecting the mobile nature of the substrate. There was little in the way of spatial trends in the organic carbon component although this tended to be lower in spoil ground sediments compared to those from outside its boundary. Overall, changes in the organic carbon content tended to reflect those of the silt fraction (Figure 5; $R^2 = 0.53$).

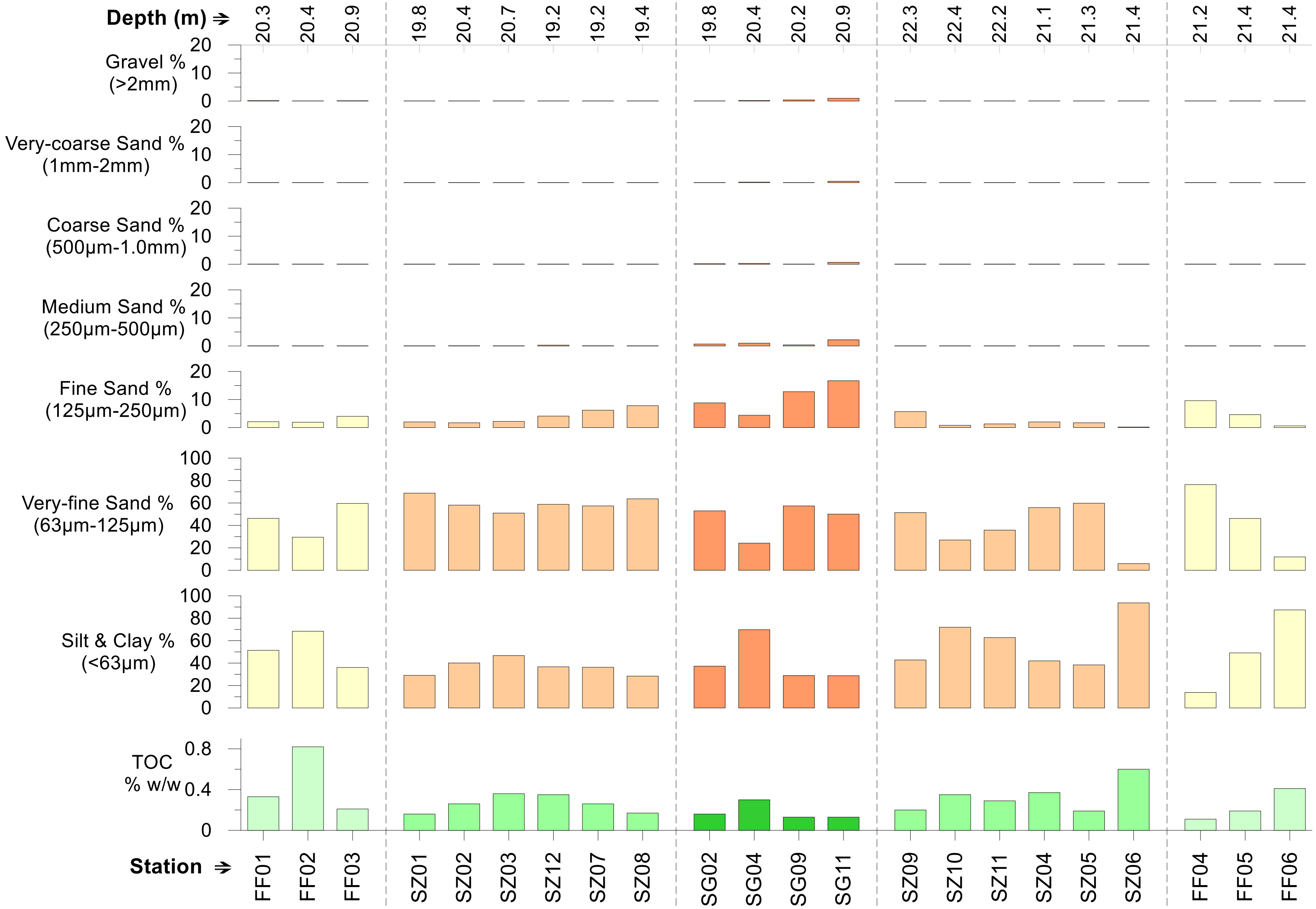

Figure 5. Grain-size distribution and organic content of sediments sampled from the vicinity of the spoil ground in October 2021. Divisions and colour-shadings depict the three station zones of spoil ground (SG), spreading zone (SZ) and far-field (FF). Station order: north–south / inshore–offshore.

3.2.2. Sediment trace metals

None of the trace metals analysed in the sediment samples were elevated relative to national guideline criteria (DGV; Table 3). Variability across stations was low to moderate with no distinct spatial trends relative to zone (Figure 6). As has been noted in the previous survey reports, some metals were moderately to strongly correlated with the sediment silt/clay and organic components, especially chromium, copper, nickel, lead and zinc (Table 3). Except for the high silt/clay sample from SG04, metals concentrations within the spoil ground tended to be slightly lower. Otherwise, differences in mean concentrations between zones were minimal (see Section 3.2.3).

Table 3. Summary statistics for metals concentrations in sediments sampled from the 22 benthic stations. ANZG (2018) Default guideline values (DGV) are presented for comparison. Units are mg/kg. For each analyte, coefficients of determination (Pearson R^2) with the silt/clay and organic carbon (TOC) components of sediments are also listed.

					Pearson R^2	
Metal	**Mean**	**Maximum**	**(station)**	**DGV**	**Silt/clay**	**TOC**
Arsenic	5.0	6.6	(FF02)	20	0.16	0.43
Cadmium	0.019	0.034	(SG04)	1.5	0.51	0.34
Chromium	11.6	17.7	(SZ06)	80	0.79	0.83
Copper	3.7	7.0	(SZ06)	65	0.84	0.76
Lead	7.9	11.4	(SZ06)	50	0.72	0.78
Mercury	0.052	0.070	(FF02)	0.15	0.59	0.57
Nickel	8.1	11.1	(SZ06)	21	0.81	0.77
Zinc	37.5	54.0	(SZ06)	200	0.85	0.76

Figure 6. Trace metal concentrations in sediments sampled from the vicinity of the spoil ground 19 October 2021. 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

Grain size distribution and organic enrichment

Given that most of the variability in physico-chemical properties of the sediment samples continues to relate to its silt/clay content, analysis focussed on how this has changed across surveys and whether any spatial trends can be identified. Variability in the principal grain size components and organic content of sediments is presented graphically in Figure 7. Summary data for grain size fractions and organic content from all three surveys are tabled in Appendix 3. Silt/clay content has increased in all three zones since the baseline, but more progressively in the spreading and far-field zones. Both the greatest relative increase and the greatest variability have occurred in the far-field zone.

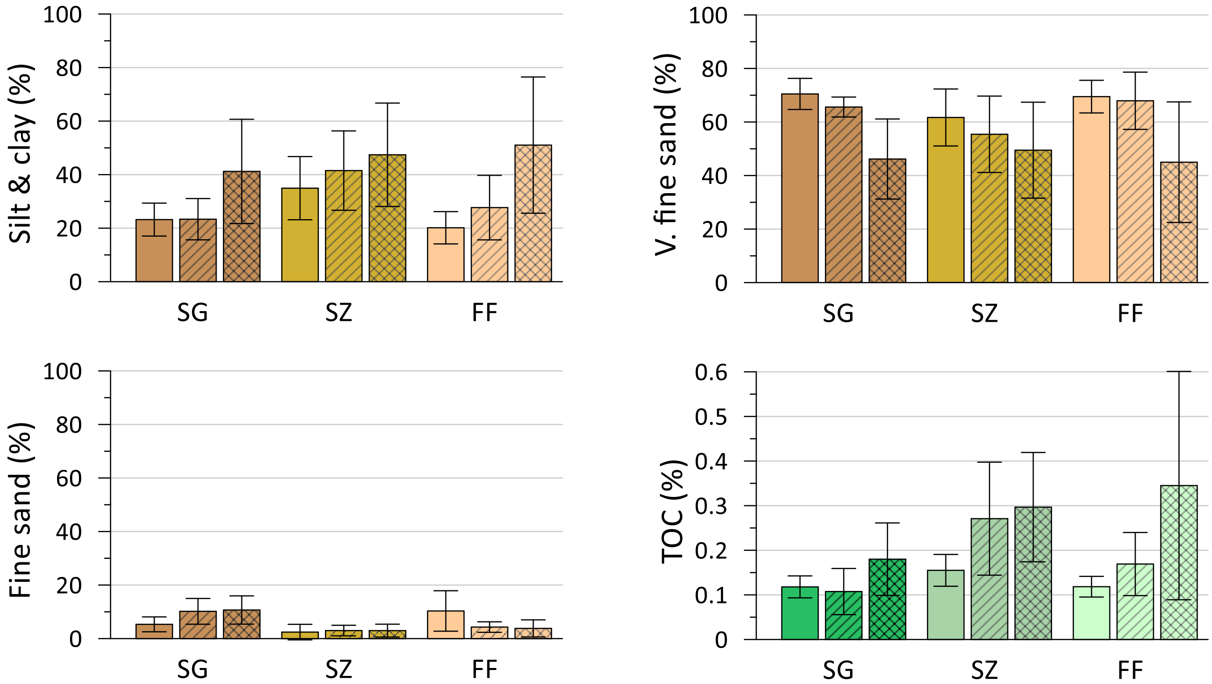

Figure 7. Change in mean sediment grain size fractions and organic carbon for each zone across surveys. Solid colour, diagonal hatching and cross-hatching designate 2019 (baseline), 2020 and 2021 surveys, respectively. TOC = total organic carbon. SG = spoil ground, SZ = spreading zone, FF = far-field zone. Units (%) of g/100 g dry weight. Error bars represent ± 1 std deviation.

Because groups of stations in the far-field zone (and to a lesser extent those of the spreading zone) are spatially separated, a focus on average values could potentially hide important spatial disparities that may arise from directionality in sediment transport processes. Hence, a comparison of the spatial distribution of the silt/clay component of sediments between surveys is presented in Figure 8.

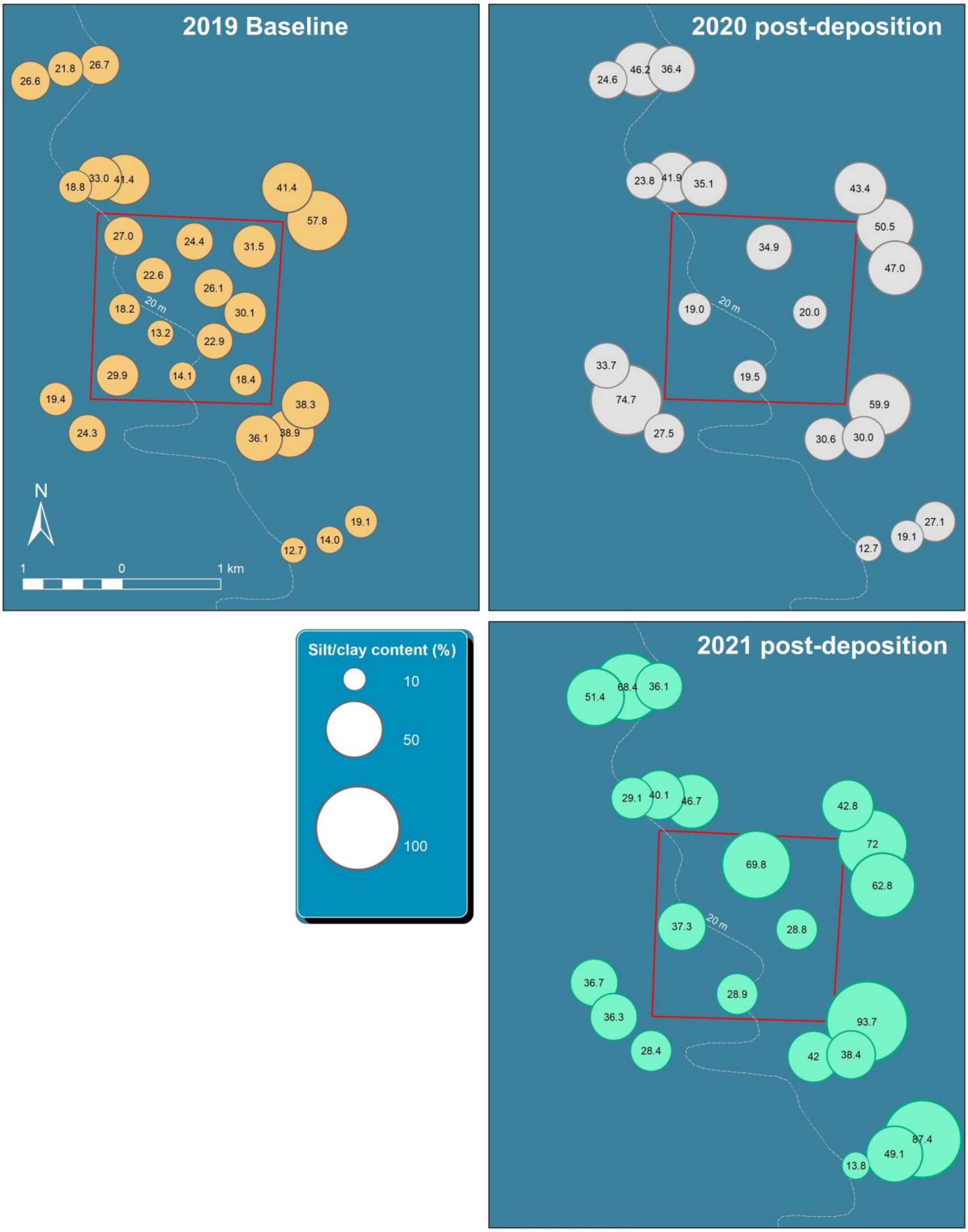

Figure 8. Spatial variability of sediment silt/clay content (% < 63 µm) across the benthic sample stations for the baseline (2019) and two subsequent surveys (current survey at bottom) Proportional symbols adjusted with Flannery compensation to allow for viewer perception.

The plot representing the 2021 data in Figure 8 shows a distinct grading of the silt/clay content of sediments according to distance offshore[4] (perpendicular to the alignment of the 20 m depth contour). However, there was no suggestion of an alongshore gradient or distinct differences between stations north-west and south-east of the spoil ground. While this spatial pattern was not a clear feature of either the 2020 survey or the pre-deposition baseline, both earlier surveys showed a similar absence of spatial gradients relative to the spoil ground area.

Although there are no clear spatial gradients relative to the spoil ground in the 2021 plot, this does not necessarily preclude spoil deposition as a source in the overall increase in silt/clay content. In such a dynamic seabed environment, it is possible that dispersal of such sediments could occur over an area encompassing the far-field stations. However, in order to effect the observed change over such a wide area, the deposited spoil would likely need to be comprised of a relatively much higher silt/clay content than appears to be the case (acknowledging that four sediment samples may not be sufficient to characterise the disposal area).

Even with the high spatial variability in the silt/clay data (error bars in Figure 7), the difference between the overall baseline silt/clay data and that from both subsequent surveys was statistically significant (single factor ANOVA on logit transformation[5]; $p = 0.037$ for 2020, $p = 0.00005$ for 2021). However, these differences were driven mainly by changes at the far-field sites. Importantly, shifts in the silt/clay fraction from the baseline within the spreading zone were not significant in either year.

The interpretation of increases in the silt/clay fraction since the baseline is challenging since there is little information with which to assess the background temporal variability of the area. However, 18 sediment samples were collected from the spoil ground area in 2005 and analysed for grain size distribution (Sneddon 2019). While the mean silt/clay fraction (23.0%) had been almost identical to that of the 2019 baseline survey (23.2%), the distribution between the very fine sand (30.4%) and fine sand (46.2%) classes (compared to 70.5% and 5.3%, respectively, in 2019) indicated that the substrate in 2005 had been generally coarser. While it remains somewhat speculative to report an increasing fine sediment trend based on four data points over 16 years, the 2005 data suggest that, if such a trend exists, it may have been progressing over a longer time period than that of the current No.6 berth project.

Sediment metals concentrations

Changes in sediment metals concentrations between the baseline and current survey are plotted by zone in Figure 9. For most trace metals/metalloids, the correlations with

[4] Despite the logical relationship with water depth, silt/clay was poorly correlated to recorded depth ($R^2 = 0.18$). Bathymetric gradient across the study area was low (ranging 19.2–22.4 m over > 3 km). Although recorded depth was adjusted for tidal state, values were transcribed from the vessel sounder so precision was limited.

[5] Conducting ANOVA on variables expressed as percentages can be problematic, especially if many lie outside the range 20–80%, and this data may fail tests of homogeneity of variance and normality unless first transformed appropriately.

the silt/clay and organic fractions established in Table 3 were found to hold across all three surveys (Table 4). Hence, the increases in some metals (especially copper, lead, nickel and zinc) at the spreading and far-field zones are likely to be related to concomitant increases in sediment grain size distribution (see Appendix 3 for summary data). Cadmium was the only trace metal that exhibited an increase within spoil ground sediments disproportionate to changes in silt/clay content when compared to the other two zones. However, cadmium concentrations (0.017–0.034 mg/kg) have remained very small compared to the ANZG (2018) low-risk trigger level (DGV = 1.5 mg/kg).

Table 4. Correlation of individual metals with the silt/clay and total organic carbon (TOC) content of sediments across all surveys (n = 72).

	Pearson R^2	
	Silt/clay	**TOC**
TOC	0.68	-
As	0.21	0.36
Cd	0.34	0.30
Cr	0.77	0.81
Cu	0.80	0.84
Pb	0.69	0.78
Hg	0.02	0.02
Ni	0.67	0.73
Zn	0.64	0.70

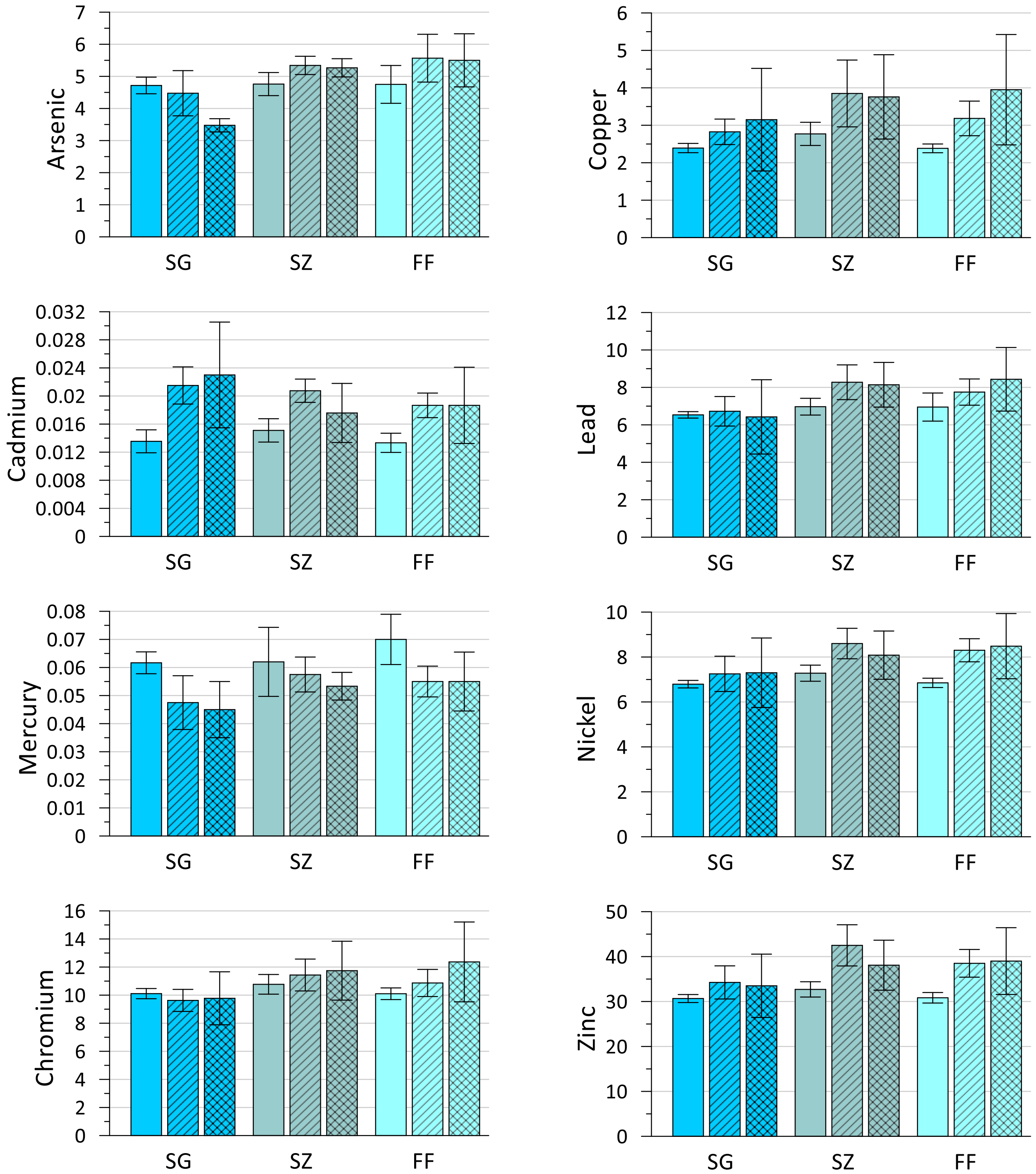

Figure 9. Comparison of mean sediment trace metal concentrations (by zone) for samples collected for the 2019 baseline (solid colour) and the subsequent 2020 (diagonal hatching) and 2021 (cross-hatching) surveys. SG = spoil ground, SZ = spreading zone, FF = far-field zone. Error bars represent ± 1 std deviation.

3.3. Macrofaunal communities

Across all stations, 87 macrofaunal taxa were identified, including 39 polychaete worms and 13 bivalve molluscs as well as crustaceans of the classes Ostracoda and Malacostraca (orders Amphipoda, Decapoda, Isopoda and Cumacea) and two holothurians (sea cucumbers). Of the 15 most abundant taxa, 11 were polychaetes, two were bivalves, with one amphipod (Phoxocephalidae) and one holothurian. The dominant taxa by abundance were the capitellid polychaete *Heteromastus filiformis* and the nut shell (*Nucula nitidula*).

3.3.1. Patterns in community indices

As for the 2020 survey, the 2021 macrofaunal core samples yielded greater numbers of organisms than for the baseline survey. Counts averaged 112 and ranged from 10 to 220 individuals per 133 cm^2 sample (compared to 85 and 34–157, respectively, for the baseline). The lowest abundances (and taxa richness) occurred at two stations within the spoil ground (SG04, SG09; Figure 10).

Shannon-Weiner diversity and Pielou's evenness were mostly quite similar across stations, remaining high even for the four spoil ground stations. Depressed diversity and evenness at two of the northern far-field stations (FF01, FF02) was due to particularly high abundances of *H. filiformis* (82% and 76% of total abundance, respectively). This polychaete taxon was also the primary reason for the slightly greater abundances at the inshore and northern spreading zone stations compared to those located on the seaward side and south of the spoil ground.

While the differences manifest at two spoil ground stations are very likely related to the deposition of dredged material, the reasons for the variability observed across non-spoil ground stations is less clear. There was no correlation with silt/clay content for either total abundance (R^2 = 0.09) or abundance of *H. filiformis* (R^2 = 0.03). Such patchiness in the spatial distribution of sediment macrofauna was also observed for the baseline data and is not unusual in such coastal settings. Certainly, there was no indication that the variability observed was related to spoil ground proximity.

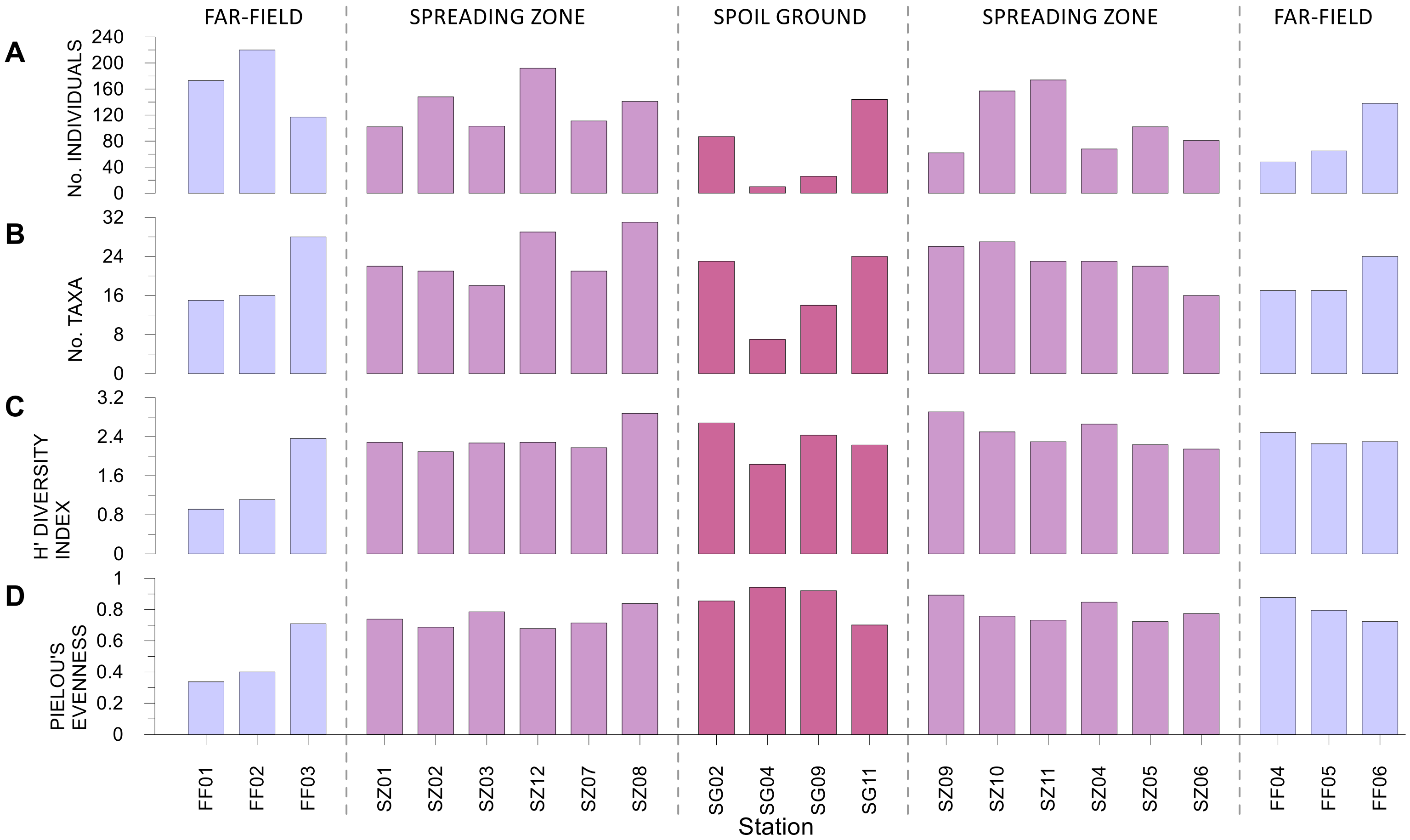

Figure 10. Benthic macrofaunal community indices for each of the 0.013 m^2 core samples from the 22 stations sampled in October 2021. H' Diversity = Shannon-Weiner Diversity index. Divisions and colour-shadings depict the three station zones of spoil ground (SG), spreading zone (SZ) and far-field (FF). Station order reflects symmetry about the spoil ground (north–south; inshore–offshore).

3.3.2. Multivariate statistical analysis

The dendrogram from cluster analysis of the October 2021 samples in PRIMER (Figure 11) shows no consistent grouping of benthic stations based on either spatial proximity to the spoil ground or zone category. All samples except two from the spoil ground were grouped together at a level of similarity (LoS) of 45%.

With only ten individuals across seven taxa, the SG04 sample from the spoil ground was unusually depauperate and too dissimilar to the other samples to generate an interpretable non-metric multidimensional scaling (nMDS) plot of the total data without a stronger transformation, so it was left out of the data set for Figure 12. While none of the zones separate as distinct clusters in Figure 12, the three spoil ground stations all locate on the left side of the plot[6]. Like SG04, Station SG09 was characterised by low abundance and taxa richness (Figure 10), hence it presents as an outlier point in the nMDS plot. Due to the ongoing deposition of dredged material in the spoil ground, and the probability that a recently impacted site could be sampled, it is not surprising that such outliers occur.

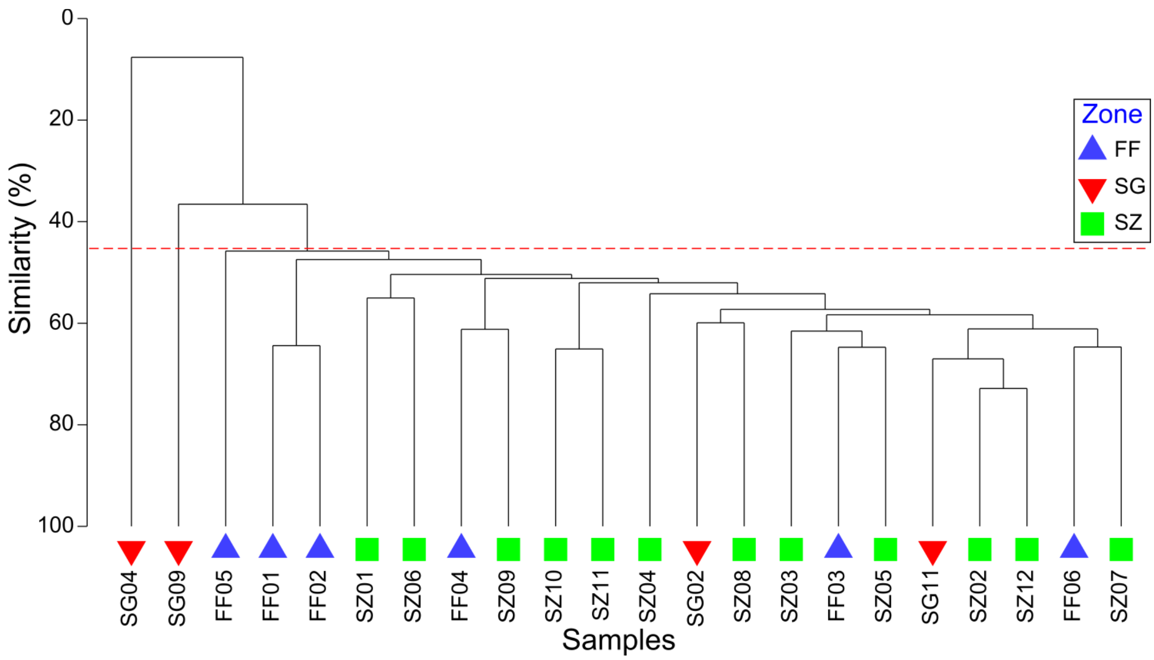

Figure 11. Dendrogram of square-root-transformed 2021 macrofaunal abundance data across station categories, showing clustering of individual benthic samples according to (S17) Bray-Curtis similarity. Slice (dashed line) at 45% similarity.

[6] It should be noted, though, that the stress value of 0.21 means that the accuracy with which the plot represents dissimilarity as relative distances between points is limited and should be interpreted with some caution.

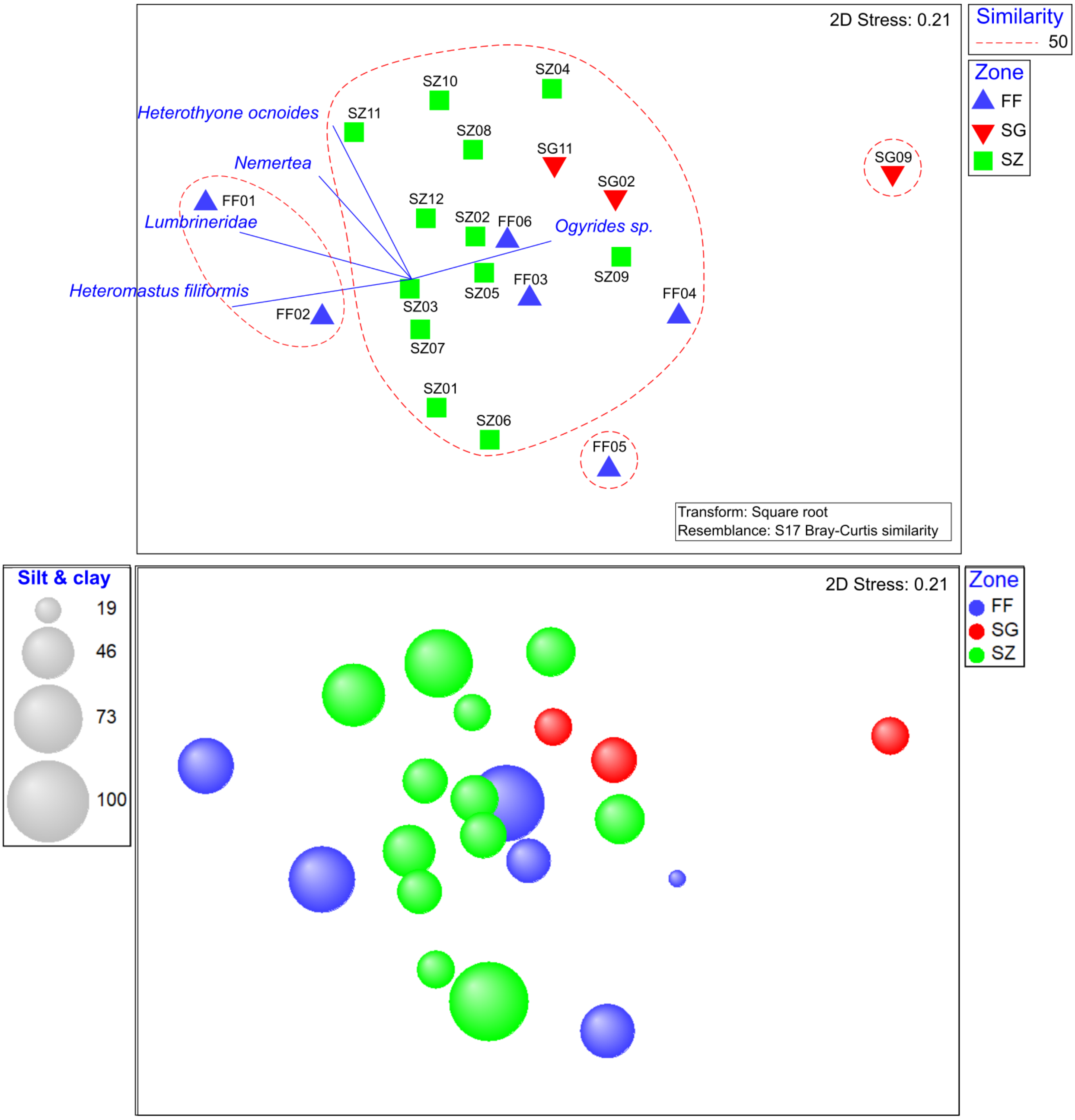

Figure 12. Non-metric multidimensional scaling (nMDS) plot for the benthic macrofaunal samples (excluding SG04) according to station zone. **Top:** Station labels with vector overlay showing taxa correlated (r > 0.6 [Pearson]) with the plot. (FF = far-field; SG = spoil ground; SZ = spreading zone). **Bottom:** 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.

Overall, the level of similarity between communities from stations outside of the spoil ground was similar to that observed with the two earlier surveys. It is notable from Figure 12 that, not only did communities appear more variable across the far-field zone than the spreading zone, but far-field stations did not group according to relative location (i.e. NW vs SE of the spoil ground). Samples on the right-hand side of the plot tended to be defined by their generally lower abundances overall (Figure 10) and the taxa associated with the left-hand side were among those contributing most to abundance[7].

The bubble plot version of the nMDS in Figure 12 uses symbols proportional to the silt/clay content of the sediments. The absence of clear patterns or gradients suggests that any relationship between silt/clay content and community structure was weak.

3.3.3. Comparison with the baseline macrofaunal data

Community indices

A combined macrofaunal data set was generated from the results of the three surveys to date. The mean community indices from these surveys are contrasted according to sampling zone in Figure 13.

Variability in communities within surveys may be expected for the spoil ground due to direct deposition effects. This is reflected in the large error bars for abundance and taxa richness in 2021.

The proximity of the spreading zone stations logically exposes them to indirect impacts from subsequent dispersion of deposited material. However, variability in total abundance has been higher for the far-field zone than for the spreading zone, both between surveys and among stations. This presumably reflects spatial variability at the scale of distances between stations.

Two north-western far-field sites (FF01, FF02) recorded low taxa richness with high abundance, leading to decreased diversity and evenness indices and contributing to the high variability for the 2021 far-field data (Figure 13). Nonetheless, there was little consistency in the data according to the spatial relationship of far-field sites to the spoil ground and hence no clear directional trends.

In contrast, spreading zone sites have been stable across surveys in the principal measures of richness, diversity and evenness. While the plot in Figure 13 suggests a trend of increasing total abundance in the spreading zone, variability between stations has been quite high in each survey. For all indices, this variability has meant that differences to the baseline were not statistically significant for any zone in the 2021 survey (single factor ANOVA, $\alpha = 0.05$).

[7] 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.

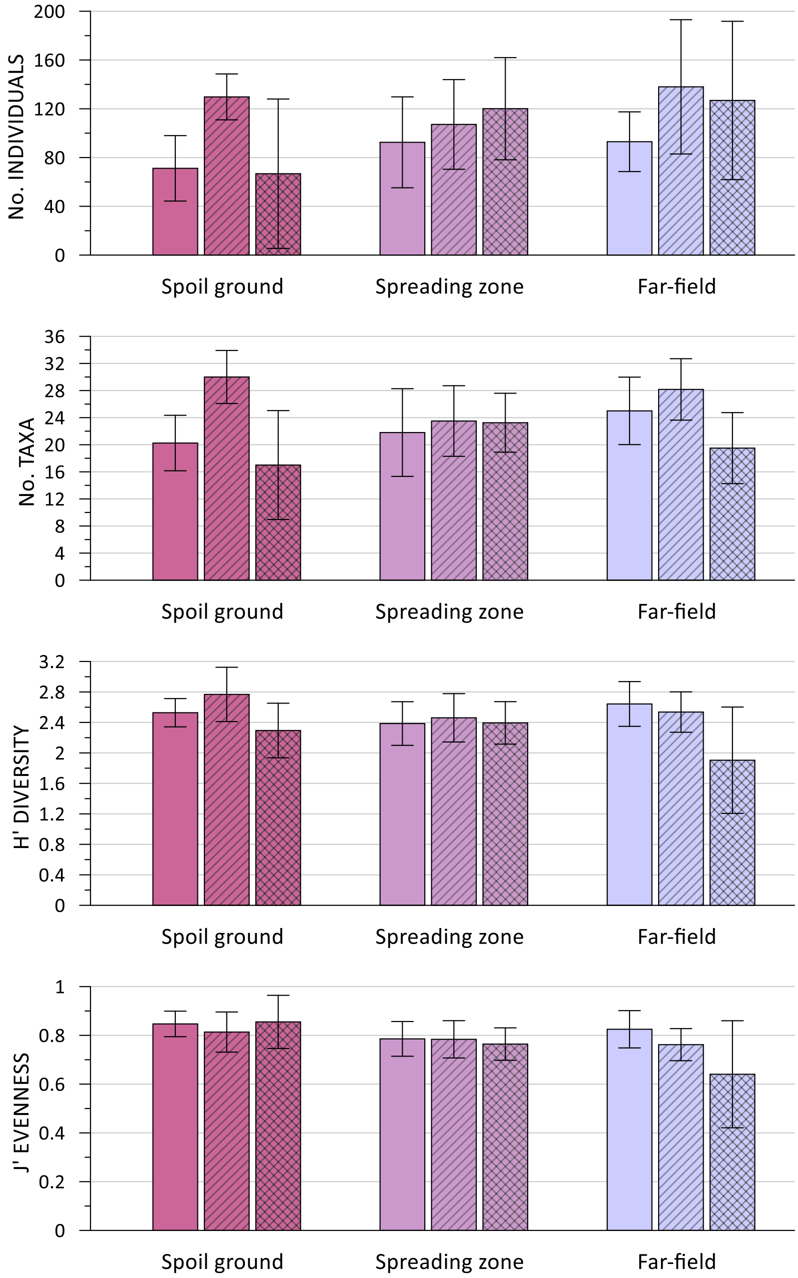

Figure 13. Comparison of mean macrofaunal community indices (by zone) for samples collected for the 2019 baseline, 2020 and 2021 surveys. Solid colour = baseline; diagonal hatching = 2020; cross hatching = 2021 (current survey). Error bars represent ± 1 std deviation.

Community structure

Multidimensional scaling plots (nMDS) for each zone in the combined survey data set are presented in Figure 14. They show some clustering of samples according to survey for all three zones. However, the level of similarity at which these groups of samples resolve (48–50% LoS) does not vary much between zones, suggesting that the principal drivers of such change may be common to all three. This is supported by a common progressive trajectory (2019-2020-2021) apparent in each plot. Nonetheless, there is low consistency across zones in the taxa correlated with this progression (vector overlays in Figure 14), indicating that some divergence in these communities may exist.

Table 5 shows how the average abundance of the key macrofaunal taxa has changed according to zone since the baseline. Overall, the hierarchy of numerically dominant macrofaunal taxa was similar between surveys, although the prevalence of phoxocephalid amphipods and the holothurian *Heterothyone ocnoides* have decreased across all three zones while spionid polychaetes of the genus *Paraprionospio* have increased since the baseline. The most abundant taxon, the polychaete *H. filiformis*, has increased in abundance outside the spoil ground, markedly so at the far-field sites. An increase in the oweniid polychaete *Myriochele* sp. has also occurred outside the spoil ground. Juvenile bivalves of the genus *Dosinia* were common in samples from all three zones during the baseline. Their absence from the subsequent two surveys may be due to seasonal influences upon recruitment and establishment (the baseline was conducted in April compared to October for the dredging phase surveys). Non-juvenile *Dosinia lambata* have been present at low levels across all three surveys.

Although characterised by lower abundances generally during the current survey (Figure 13), the spoil ground samples contained most of the key taxa prevalent at other stations (Table 5). However, spionid polychaetes of the genus *Prionospio* had increased notably in spoil ground samples for the current survey. The only taxon to disappear solely from the spoil ground were polychaetes of the family Ampharetidae, but these had not been very prevalent during the baseline (mean 0.5 individuals/sample).

A SIMPER analysis on the (square-root transformed) count data showed that the mean dissimilarity between the baseline and the October 2021 macrofaunal samples was comparable for the three zones (57.5%, 53.7% and 59.5% for the spoil ground, spreading zone and far-field, respectively). Across the three zones, the ten taxa contributing most to dissimilarity in community structure between the baseline and current surveys accounted for between 35% and 43% of total dissimilarity (see Appendix 4). Between 13 and 17 taxa contributed cumulatively to 50% of the dissimilarity with the baseline. While eight of these were common to all zones, two exhibited disparities in the direction of change (*Prionospio* spp. increased only in the spoil ground; *Nucula nitidula* increased only in the spreading zone).

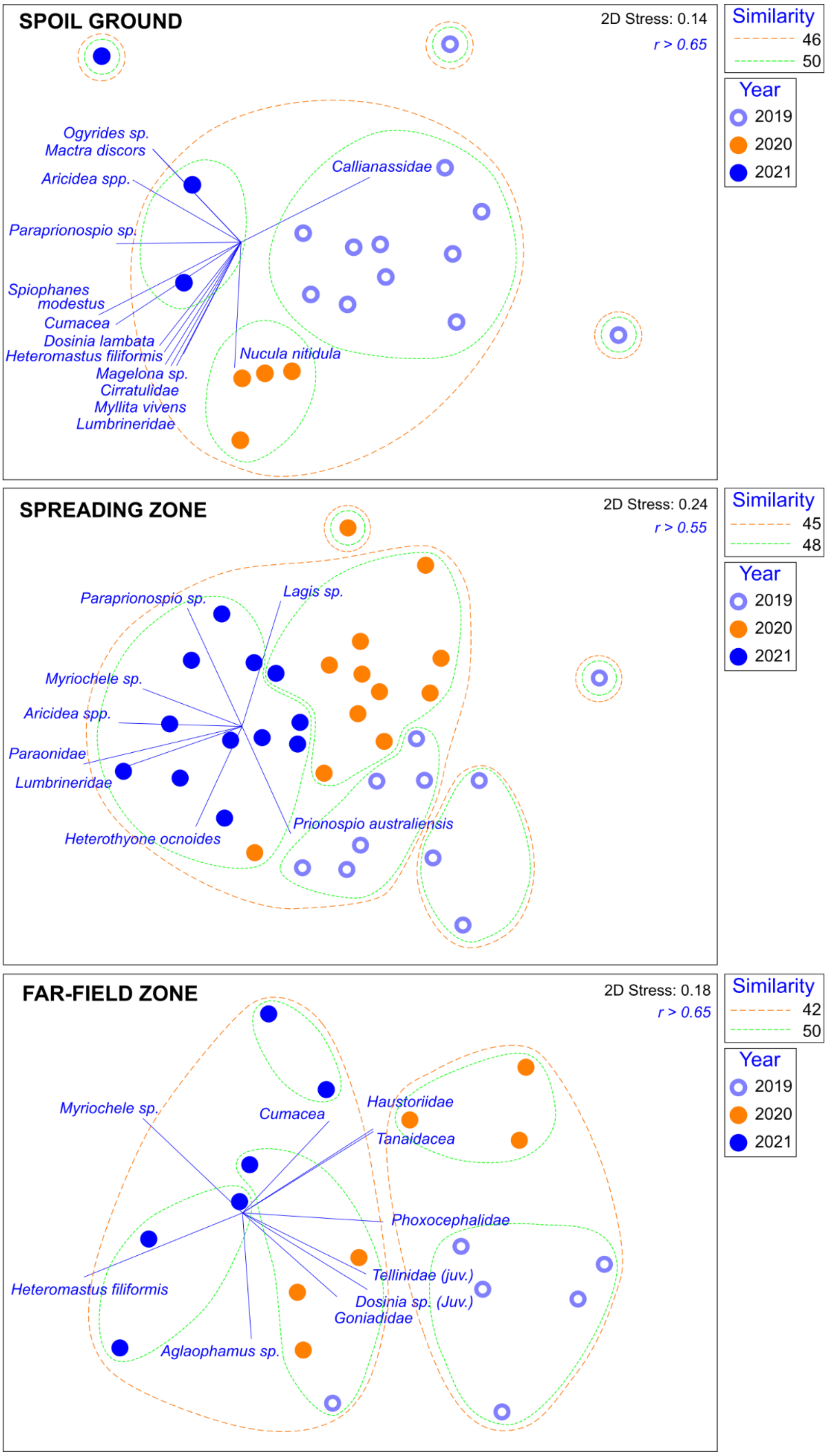

Figure 14. nMDS plots showing clustering within the combined data set from the baseline (2019) and two subsequent surveys within the three zones. Vector overlays show taxa correlated to plot coordinates (r = Pearson coefficient) for each zone. Note that sample SG04 for 2021 is omitted from the spoil ground plot.

Table 5. Comparison of mean macrofaunal densities (per 0.013 m^2 core) between the three surveys (shaded columns = current survey) for the 20 most abundant taxa identified across all stations in all surveys. Values are sample averages for the three zones.

		Zone	**Spoil ground**			**Spreading zone**			**Far-field zone**		
		Year	**2019**	**2020**	**2021**	**2019**	**2020**	**2021**	**2019**	**2020**	**2021**
GenGroup		**n**	**12**	**4**	**4**	**10**	**12**	**12**	**6**	**6**	**6**
Polychaeta: Capitellidae	*Heteromastus filiformis*		11.2	18.5	9.3	28.6	28.0	36.7	19.0	36.5	71.3
Bivalvia	*Nucula nitidula*		11.8	28.3	5.5	11.8	13.9	17.2	11.5	20.8	9.7
Amphipoda	Phoxocephalidae		7.8	11.5	1.8	5.4	5.7	2.0	9.7	8.2	3.2
Polychaeta: Spionidae	*Prionospio* spp.		5.5	2.5	18.5	3.1	0.9	3.6	5.2	2.2	1.8
Polychaeta: Spionidae	*Paraprionospio* sp.		0.0	1.3	2.3	1.0	10.2	5.5	1.3	5.7	3.5
Polychaeta: Spionidae	*Spiophanes modestus*		1.3	6.0	5.5	2.0	4.4	3.4	2.0	9.8	4.5
Polychaeta: Paraonidae	*Aricidea* sp.		1.8	7.3	3.8	1.3	4.6	4.0	1.5	4.0	3.7
Holothuroidea	*Heterothyone ocnoides*		3.9	3.8	2.0	3.3	2.1	2.3	3.2	3.5	1.2
Polychaeta: Oweniidae	*Myriochele* sp.		0.3	2.0	1.0	0.6	4.4	6.3	0.8	1.2	4.8
Polychaeta: Nephtyidae	*Aglaophamus* sp.		2.0	1.3	1.5	2.8	2.8	3.8	2.8	1.0	2.0
Polychaeta: Goniadidae	Goniadidae		2.8	2.5	1.5	2.6	2.0	2.3	3.0	1.5	0.5
Cumacea	Cumacea		0.5	5.8	1.0	1.2	4.0	0.9	1.3	5.7	1.0
Amphipoda	Haustoriidae		3.5	6.3	0.5	0.5	0.8	0.5	2.7	4.7	0.5
Polychaeta: Lumbrineridae	Lumbrineridae		0.3	1.5	0.3	1.5	1.4	4.5	0.7	1.3	3.2
Bivalvia	*Dosinia* sp. (juvenile)		2.6	0.0	0.0	3.4	0.0	0.0	5.7	0.0	0.0
Polychaeta: Paraonidae	Paraonidae		0.3	0.0	2.3	0.4	0.5	3.8	0.2	1.7	1.7
Polychaeta: Sigalionidae	Sigalionidae		0.7	2.3	0.8	0.3	1.1	1.9	0.7	1.7	1.7
Polychaeta: Ampharetidae	Ampharetidae		0.5	0.0	0.0	3.5	0.6	0.6	1.2	0.8	1.7
Polychaeta: Pectinariidae	*Lagis* sp.		0.3	3.3	0.0	0.1	2.9	0.1	1.2	2.3	0.0
Nemertea	Nemertea		0.2	1.3	1.8	1.0	0.8	1.5	0.8	0.8	1.5

Overall, the relatively small changes in infauna community structure outside the spoil ground did not suggest a clear impact attributable to spoil deposition. There was a different pattern to changes within the spoil ground than in those occurring outside its boundaries, but these changes were no greater in extent than those observed at the far-field sites. Apart from bivalve recruits that were uniformly absent from the entire study area in the current survey, no taxa that had been prevalent within the spoil ground during the baseline were now absent. Given that over one million cubic metres of sediment has been deposited in the spoil ground over the past two years, this suggests a degree of resilience in these communities. The principal reason for this is likely to be their adaptation to a dynamic seabed environment where native sediments are regularly moved by swell events. The large size of the spoil ground relative to the incremental deposition by barge also allows time for recovery and recolonisation of directly impacted areas even as deposition continues.

3.4. Epifauna

Ten epifaunal dredge trawls were completed. These matched in location the nine completed in 2020, with an additional trawl (ESG2) conducted within the spoil ground (Figure 3). A list of the biota identified from the epifaunal dredge trawls is provided in Table 6. Photographs of the trawl contents are provided in Appendix 5.

Like both earlier surveys, the trawls continue to indicate a fairly sparse epifaunal community. The only taxa consistently present in the trawl contents were the small sea cucumber *Heterothyone ocnoides,* the knobbed whelk *Austrofusus glans* and hermit crabs (Paguridae) (Table 6)*.* Additional taxa collected in low numbers in three or more trawls included an introduced spider crab (*Pyromaia tuberculata*), a small clam (*Mactra* cf. *ordinaria*), another small sea cucumber (*Paracaudina chilensis*) and the polychaete *Aphrodita australis.*

Four epifaunal taxa were new to the inventory that had been compiled over the previous two surveys. These included two bivalve molluscs, *Serratina charlottae* and *Mactra* cf. *ordinaria*, the shells of both of which had been previously collected, indicating their presence within the area. Single individuals of a camouflage crab (*Notomithrax* sp. from ESG2) and the cushion sea star (*Patiriella regularis* from ESZ1) were also collected.

For trawls conducted outside of the spoil ground boundaries, very little debris was collected along with the biota. However, sparsely occurring shell fragments suggested the occurrence of additional bivalve mollusc species (such as the scimitar mactra—*Zenatia acinaces*) living either deeper in the sediment profile or within the wider vicinity of the survey area.

Table 6. Biota identified within the October 2021 epifaunal dredge trawls. Accurate counts were not possible for the two trawls from the spoil ground (ESG1, ESG2) due to the nature of the substrate which could not be fully sieved out. P = present.

Trawl no.		**EFF1**	**EFF2**	**EFF3**	**EFF4**	**ESZ1**	**ESZ2**	**ESZ3**	**ESZ4**	**ESG1**	**ESG2**
Trawl distance (m)		492	495	508	510	462	524	491	471	508	490
Trawl depth (MSL, m)		20.3	20.7	21.2	21.4	19.5	21.4	20.2	21.8	20.1	20.2
Taxa	**Common name**										
Struthiolaria papulosa	Ostrich foot snail								2		
Austrofusus glans	Knobbed whelk	78	26	62	16	25	9	34	6	10	<10
Amalda australis	Olive shell					2					
Alcithoe arabica	Volute snail		1								
Gari stangeri	Sunset clam			2	4						
Dosinia sp.	Venus clam		4		1						
Bassina yatei	Frilled cockle				1						
Atrina zelandica	Horse mussel			2							
Serratina charlottae	Wedge shell				2				1		
Mactra cf. *ordinaria*	Small mactra clam	3						5	2		
Pyromaia tuberculata	Spider crab	6	2		3	1	4	4	1		
Paguridae	Hermit crabs	11	4	5	14	4	28	1	7	>20	P
Neommatocarcinus huttoni	Policeman crab									1	
Notomithrax sp.	Camouflage crab										1
Ophiuroid	Brittle star		1						3		
Patiriella regularis	Cushion star					1					
Paracaudina chilensis	Sea cucumber	2						7	4		
Heterothyone ocnoides	Sea cucumber	323	159	72	53	139	145	108	310	5	<10
Aphrodita australis	Sea mouse (polychaete)	2	1	1							
Peltorhamphus novaezeelandiae	New Zealand sole	1		2							

3.4.1. Spoil ground epifauna trawls

The contents of the two spoil ground trawls (ESG1 and ESG2) were different to those collected outside its boundaries. In both cases, the dredge bag was packed full when it was retrieved to the surface. The contents consisted of lumps of cohesive silt/clay and rock pieces of various sizes (see the photo in Appendix 5). Such was the consolidation of the silt/clay clumps that they could not be washed through the 10-mm mesh, requiring that most of the contents be brought aboard and sorted by hand. The collection of this material no doubt reflected the presence of dredge spoil material within the disposal area.

There was less biota collected generally by the spoil ground trawls and only two species (present as single individuals) that were unique to them; the policeman crab (*Neommatocarcinus huttoni*) and a camouflage crab (*Notomithrax* sp.). Of the three epifaunal taxa most characteristic of the area, only hermit crabs were collected in numbers approaching those of the spreading and far-field zones. However, *A. glans* and *H. ocnoides* were still present in the contents of both trawls (Table 6).

Because the coarse or consolidated substrate would not pass through the mesh of the epifaunal dredge, it is likely that the mesh bag filled quickly during these two trawls, preventing the collection of further material and biota. Hence the low abundance of biota in the dredge contents cannot be assumed to reflect low abundance within the spoil ground generally. It is worth noting too that the four grab samples (and incidental video footage) collected from the spoil ground suggest that the substrate collected in the epifaunal dredge was not uniform across the area. However, it would only have taken a small patch of coarse or consolidated substrate within the path of the dredge to fill it.

It was notable that empty mollusc shells and fragments belonging to species unrecorded during the baseline were collected in the spoil ground epifaunal trawls. These included *Chlamys zelandica*, *Maoricolpus roseus, Cominella adspersa*, *Turbo smaragdus, Calliostoma punctulatum, Penion sulcatus* and *Pholadidea suteri*. It is likely that this shell material had been translocated with spoil material from the inshore dredged area.

3.4.2. Comparison with the baseline epifaunal data

The semi-quantitative nature of sampling by epibenthic trawl and the evidently sparse epifauna of the area mean that differences between both individual trawls and surveys should be interpreted cautiously. Table 7 shows a comparison between the trawl results of the current survey with those of the previous two, including the 2019 baseline. The same epifaunal dredge was used in all three surveys.

The three taxa most characteristic of the area (*A. glans, H. ocnoides* and hermit crabs) were present across all three surveys and, although fewer were collected within the spoil ground, they remained the dominant epibiota in all three zones.

Table 7. Comparison between the 2019 baseline and subsequent surveys of mean numbers of epifauna in trawls from the three zones. Includes only those taxa averaging one individual or greater in any zone in any 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. Grey-shaded cells highlight the current survey.

Zone	**Spoil ground**			**Spreading zone**		**Far-field**		
Year	**2019**	**2020**	**2021**	**2020**	**2021**	**2019**	**2020**	**2021**
n	5	1	2	4	4	4	4	4
Taxa								
Struthiolaria papulosa	0.2	1.0			0.5			
Austrofusus glans	4.8	8.0	5.0	34	19	10	24	46
Gari stangeri				0.3			0.8	1.5
Dosinia sp.				0.5				1.3
Mactra sp.					1.8			0.8
Pyromaia tuberculata	0.4			3.5	2.5		4.5	2.8
Paguridae	1.8	2.0	> 12	1.3	10.0	7.5	1.3	8.5
Neommatocarcinus huttoni		1.0	0.5	3.5			0.8	
Ophiuroid	0.4	1.0		0.3	0.8		0.3	0.3
Paracaudina chilensis	0.4			1.3	2.8	0.5	0.8	0.5
Heterothyone ocnoides	25	> 45	< 10	58	176	70	55	152
Aphrodita australis				0.8		0.3	0.3	1.0
Maldanidae				3.3		0.5	2.0	

No taxon that was collected in 2019 at a mean incidence greater than one individual per trawl, in either the spoil ground or far-field zone, was absent in 2021. The only taxon that has appeared in any numbers since the baseline was the policeman crab (*N. huttoni*) in 2020. However, this species was recorded from only one trawl in the current survey, as a single individual in ESG1 (Table 7). Since it was present at the far-field sites in 2020 and has not increased in prevalence, it is considered unlikely that its appearance since the baseline is a consequence of spoil deposition.

Although the epifaunal sampling method is only semi-quantitative, there is a suggestion Table 7 shows that hermit crabs have become more prevalent. The spider crab *Pyromaia tuberculata* has also been collected more frequently since the baseline. It is unlikely that the dredged material in the spoil ground represents an increased food source for these taxa, but it may have increased (by translocation) the availability of the gastropod shells used by hermit crabs.

Most fish should easily be able to avoid capture by the slow-moving epifaunal dredge. The fact that juvenile sole (*Peltorhamphus novaezeelandiae*) have regularly been identified in the dredge contents in all three surveys suggests that they have remained prevalent in the area.

4. SUMMARY AND CONCLUSIONS

Assessed visually, substrate characteristics in the vicinity of the spoil ground appeared little changed from the baseline. However, analysis of grain size distribution in the samples showed an increase in the prevalence of the silt/clay component compared to the baseline. The patchy spatial distribution of these siltier sediments, occurring as often at the far-field sites as those adjacent to the spoil ground, did not strongly implicate spoil deposition as a driver although this cannot be ruled out.

Of the four grab samples taken from within the spoil ground, only one exhibited a distinctly different substrate (consolidated clay) from the silty sands of the surrounding area. However, both epifaunal trawls undertaken in the spoil ground became clogged with rock and compacted clay material, assumed to be from deposited dredge spoil.

All of the trace metals analysed in sediments were well below the applicable low-risk trigger levels from national guidelines and no clear spatial gradients in concentrations were evident. As in the previous two surveys, some metals (as well as organic carbon) were correlated with sediment silt/clay content. Changes in sediment metals since the baseline at all sample sites have been generally small, with increases largely dictated by shifts in the silt/clay fraction. This metals association with fine sediments is likely to occur over the wider area of inshore Hawke Bay.

The sediment macrofaunal communities comprised the same taxonomic groups as the baseline and the hierarchy of numerically dominant macrofaunal taxa had changed little in the current survey. Community indices varied across stations but those outside the spoil ground boundaries exhibited no clear spatial gradients. Moreover, an influence of sediment texture on community structure was apparent only for two stations within the spoil ground.

Small shifts in macrofaunal community structure were evident across the three surveys to date but these have been similar in scale for all three sampling zones. The absence of a distinct spatial trend in in these shifts (scale or direction) relative to the spoil ground suggests that background variability in the wider area is a more likely cause than spoil deposition. The apparent resilience of spoil ground communities is likely to derive from adaptation to an already dynamic inshore environment and the large size of the disposal area allowing recovery from direct inundation even as deposition continues.

As in the previous two surveys, epifaunal communities sampled by dredge trawl were quite sparse, with only three taxa consistently collected. While the two trawls conducted in the spoil ground were hampered by clogging with the altered substrate, all historically characteristic taxa continued to be represented across the wider area with similar occurrence in the dredge contents. Hence, the data indicate no more than minor changes in this community since the baseline.

5. ACKNOWLEDGEMENTS

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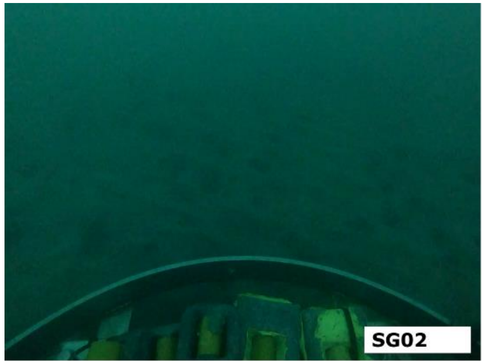
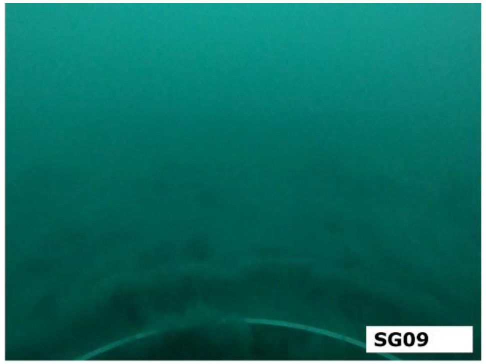
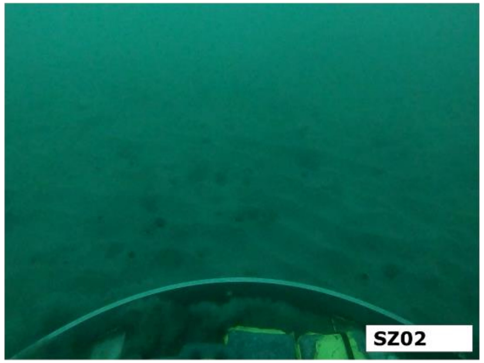
Appendix 1. Seabed images. Snapshots from video footage (GoPro camera mounted to grab frame).

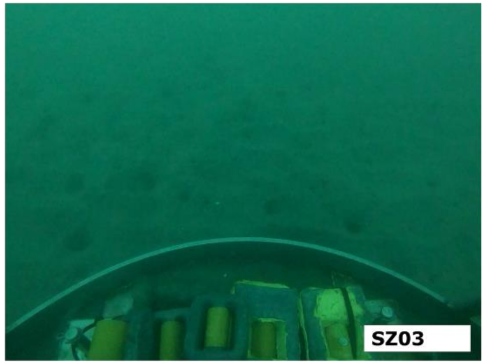


NO VISIBILITY AT SEABED

SG04

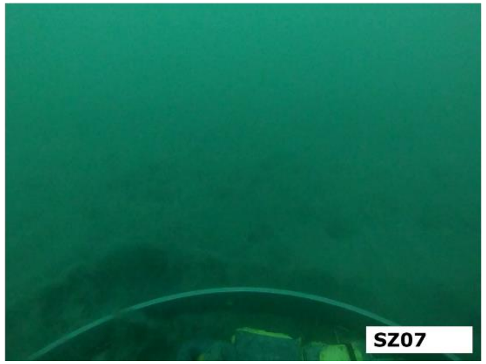


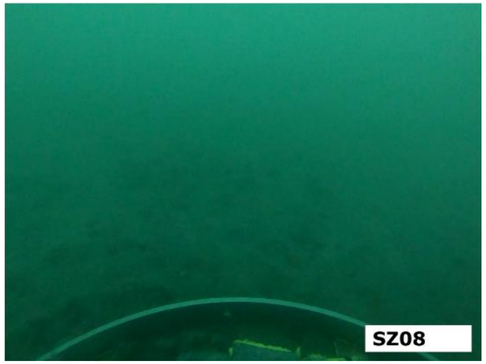


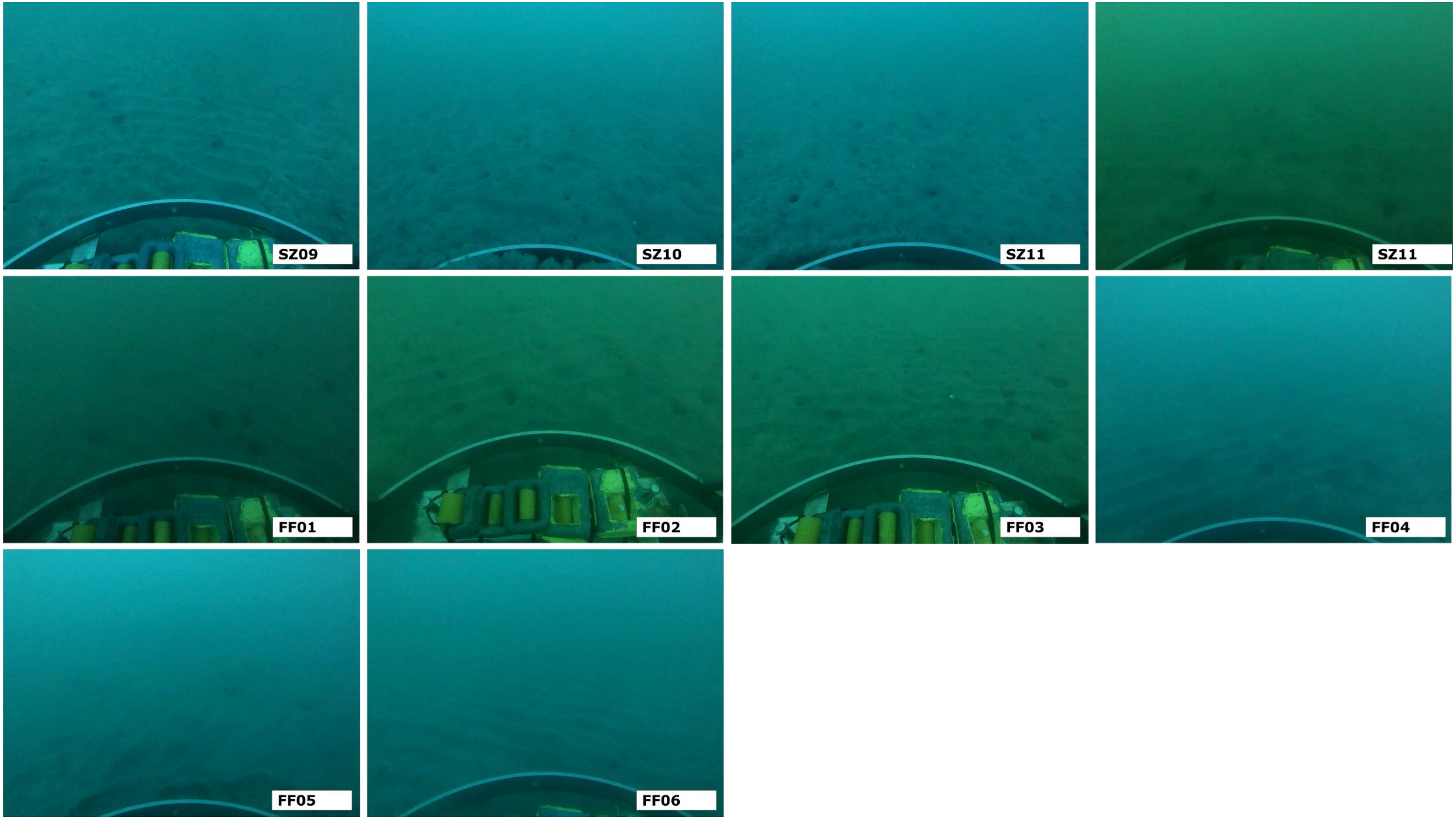


NO IMAGE

SZ05






SZ09
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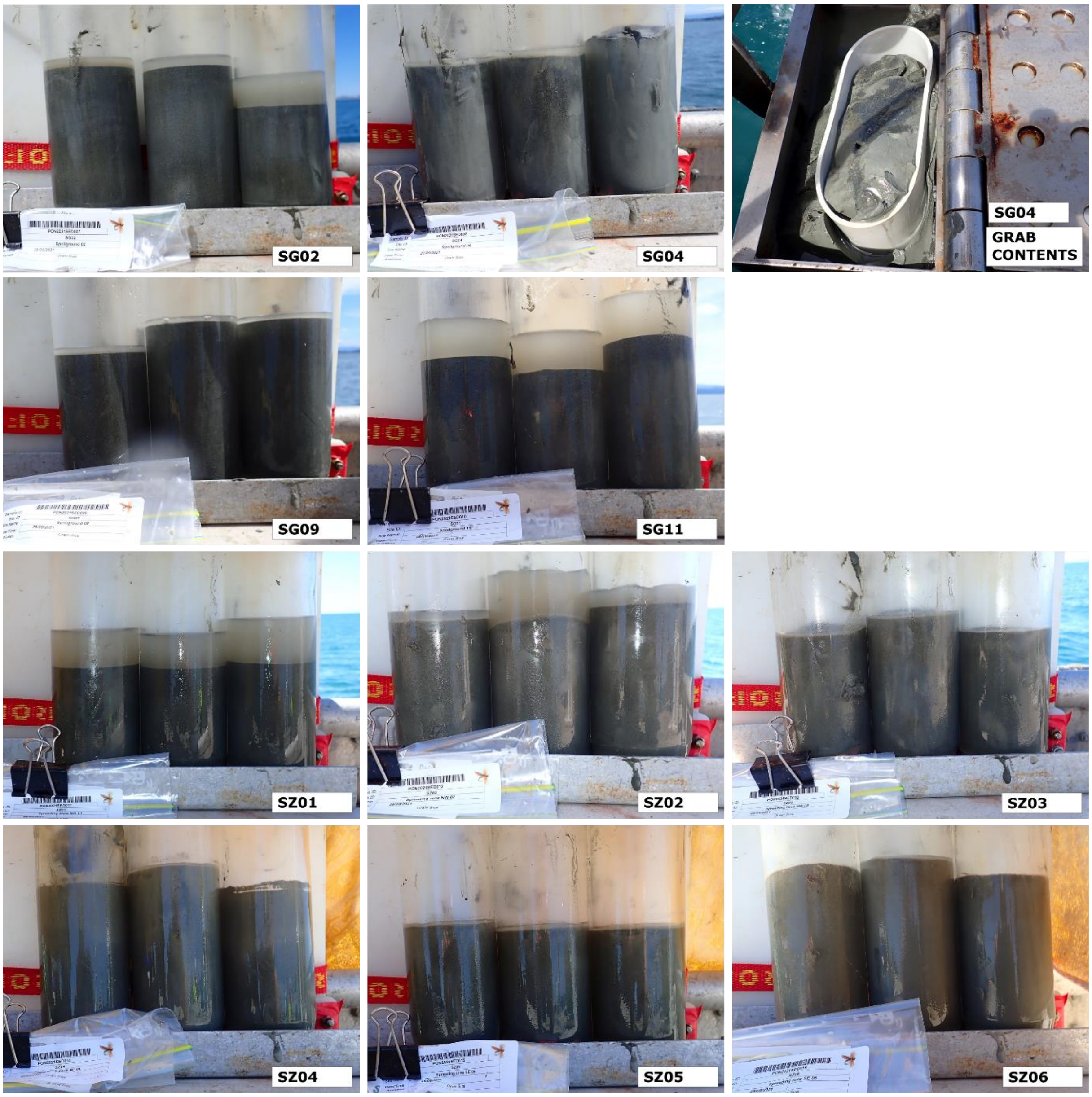
Appendix 2. Sediment core samples - Core photographs.

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Appendix 3. Sediment analysis summary data across surveys. Grain size and total organic carbon.

Spoil ground	2019 (n = 12)		2020 (n = 4)		2021 (n = 4)	
	Mean	**Stdev**	**Mean**	**Stdev**	**Mean**	**Stdev**
Depth	21.0	0.8	20.5	0.5	20.3	0.5
Gravel	0.05	0.00	0.14	0.18	0.4	0.4
Very coarse sand	0.05	0.00	0.14	0.18	0.2	0.2
Coarse sand	0.05	0.00	0.14	0.18	0.3	0.3
Medium sand	1.04	2.30	0.53	0.43	1.1	0.8
Fine sand	5.32	2.78	10.20	4.80	10.7	5.3
Very fine sand	70.48	5.82	65.60	3.70	46.2	15.0
Silt/clay	23.20	6.16	23.40	7.70	41.2	19.5
Total organic carbon	0.12	0.02	0.11	0.05	0.2	0.1

Spreading zone	2019 (n = 10)		2020 (n = 12)		2021 (n = 12)	
	Mean	**Stdev**	**Mean**	**Stdev**	**Mean**	**Stdev**
Depth	20.7	1.1	20.6	1.2	20.8	1.2
Gravel	0.05	0.00	0.05	0.00	0.1	0.0
Very coarse sand	0.05	0.00	0.05	0.00	0.1	0.0
Coarse sand	0.05	0.00	0.05	0.00	0.1	0.0
Medium sand	0.94	1.28	0.05	0.01	0.1	0.1
Fine sand	2.40	2.90	3.00	2.00	3.0	2.4
Very fine sand	61.7	10.60	55.40	14.30	49.5	17.9
Silt/clay	34.90	11.80	41.50	14.80	47.4	19.3
Total organic carbon	0.16	0.04	0.27	0.13	0.3	0.1

Far-field zone	2019 (n = 6)		2020 (n = 6)		2021 (n = 6)	
	Mean	**Stdev**	**Mean**	**Stdev**	**Mean**	**Stdev**
Depth	20.7	0.7	20.6	0.6	20.9	0.5
Gravel	0.05	0.00	0.05	0.00	0.1	0.1
Very coarse sand	0.05	0.00	0.05	0.00	0.1	0.0
Coarse sand	0.05	0.00	0.05	0.00	0.1	0.0
Medium sand	0.08	0.06	0.07	0.03	0.1	0.0
Fine sand	10.30	7.60	4.30	2.00	3.8	3.2
Very fine sand	69.50	6.10	67.90	10.70	45.0	22.5
Silt/clay	20.20	6.00	27.70	12.10	51.0	25.4
Total organic carbon	0.12	0.02	0.17	0.07	0.3	0.3

Appendix 4. Sediment infauna.

Outputs of SIMPER analysis (PRIMER v.7). The 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. Note that the 2021 data omit the 2021 SG04 sample from the spoil ground due to its status as an outlier.

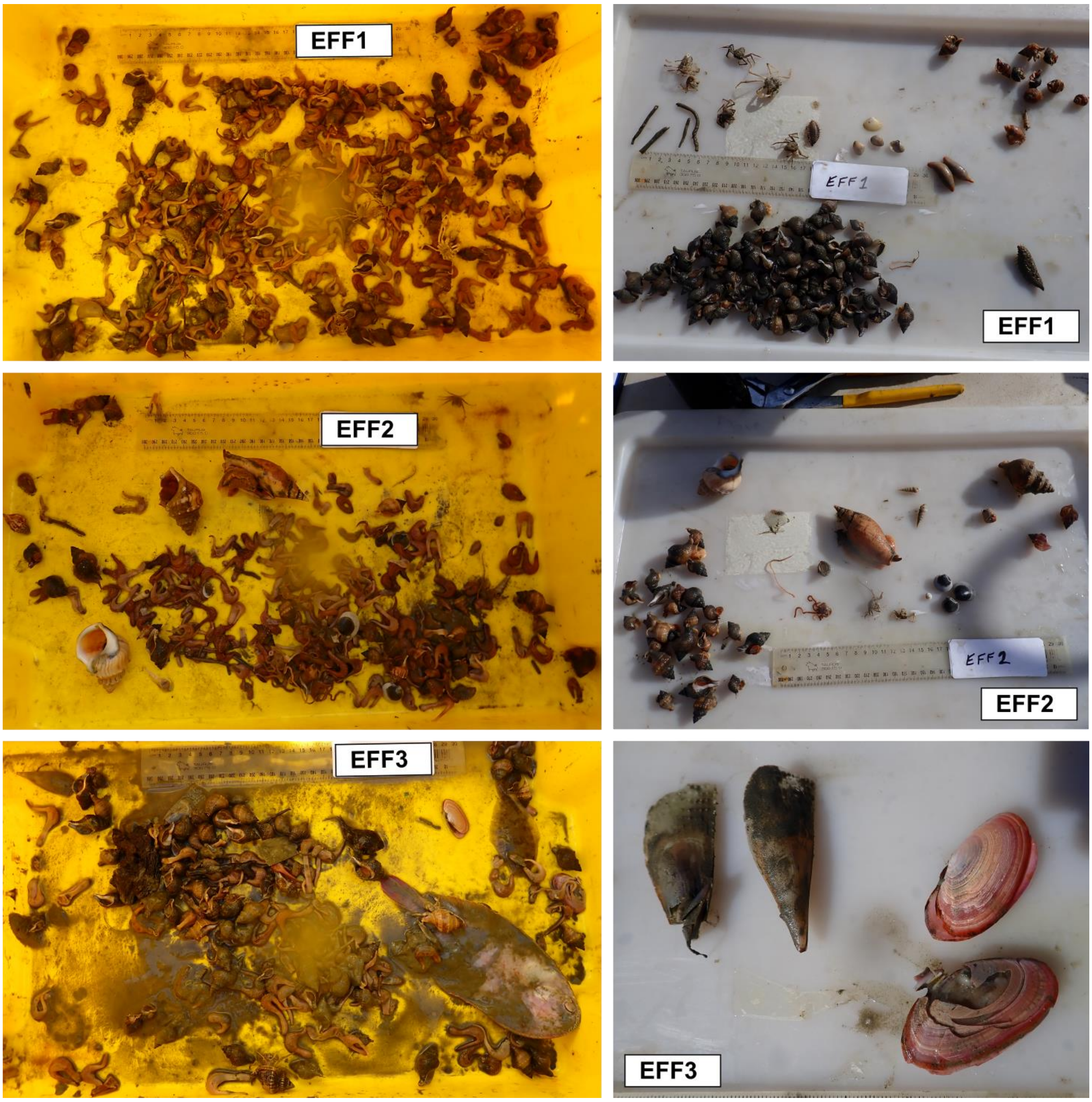
Spoil ground	**2019**	**2021**				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Prionospio spp.	2.08	4.57	3.83	1.45	6.66	6.66
Nucula nitidula	3.21	2.08	3.22	1.25	5.59	12.25
Spiophanes modestus	0.74	2.54	2.71	1.52	4.72	16.97
Heteromastus filiformis	2.91	3.31	2.58	1.27	4.48	21.45
Paraprionospio sp.	0.00	1.47	2.19	4.30	3.81	25.26
Callianassidae	1.37	0.00	2.13	2.30	3.71	28.97
Heterothyone ocnoides	1.42	1.22	2.12	1.21	3.68	32.65
Haustoriidae	1.53	0.47	2.06	1.15	3.59	36.24
Dosinia sp. (juvenile)	1.19	0.00	1.85	1.06	3.22	39.46
Phoxocephalidae	2.63	1.52	1.80	1.55	3.13	42.60

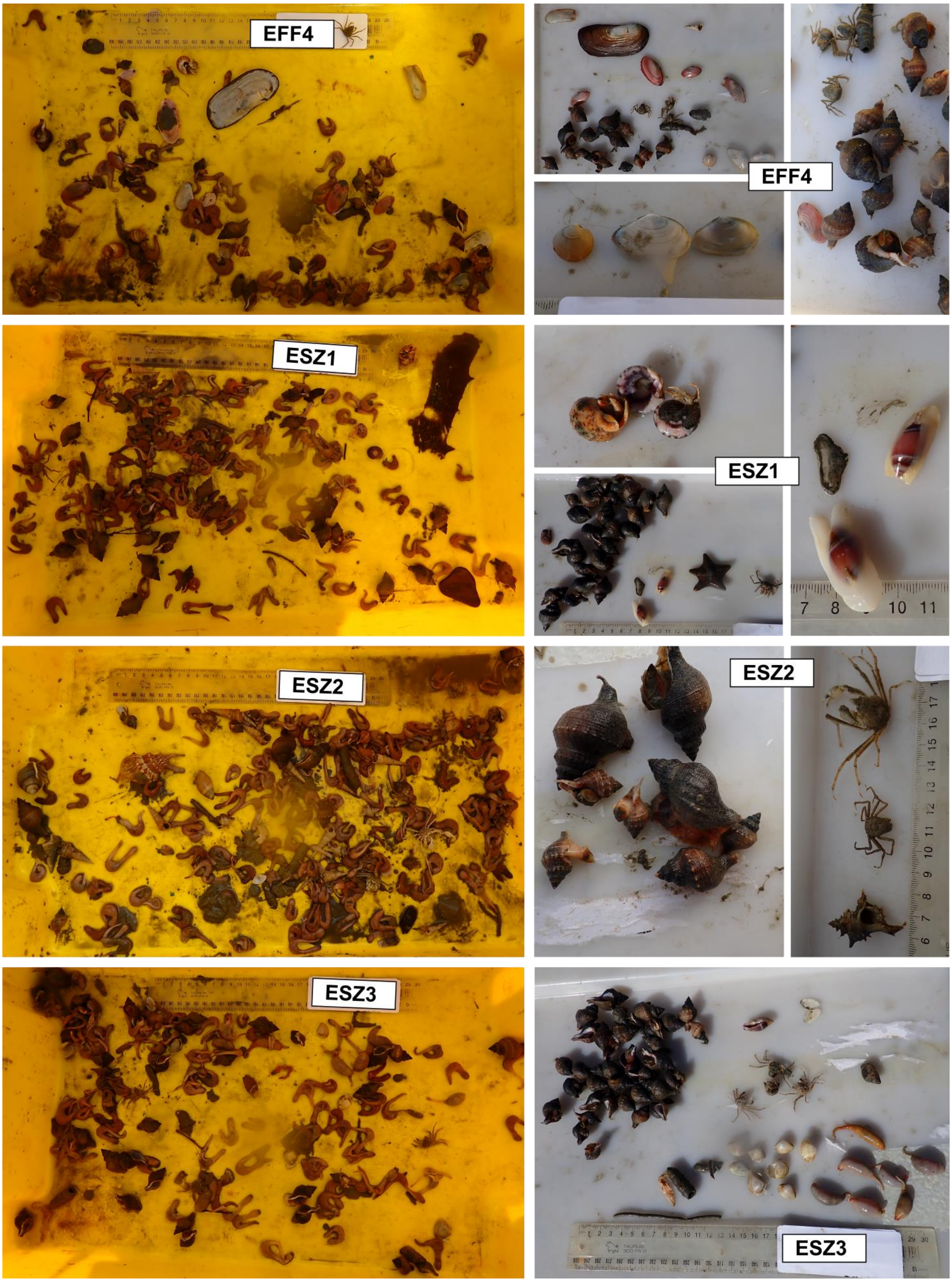
Spreading zone	**2019**	**2021**				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Heteromastus filiformis	5.07	5.82	2.59	1.24	4.83	4.83
Myriochele sp.	0.48	2.40	2.48	1.80	4.62	9.45
Paraprionospio sp.	0.71	2.20	2.09	1.26	3.88	13.33
Paraonidae	0.34	1.74	1.90	1.59	3.54	16.87
Nucula nitidula	3.20	3.95	1.78	1.03	3.31	20.18
Prionospio spp.	1.39	1.26	1.70	1.18	3.16	23.34
Ampharetidae	1.44	0.29	1.64	1.18	3.04	26.38
Phoxocephalidae	2.09	1.20	1.59	1.41	2.96	29.34
Dosinia sp. (juvenile)	1.38	0.00	1.54	1.22	2.87	32.22
Lumbrineridae	0.98	1.98	1.49	1.24	2.78	35.00

Far-field zone	**2019**	**2021**				
Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Heteromastus filiformis	4.05	7.62	5.47	1.21	9.19	9.19
Dosinia sp. (Juvenile)	2.11	0.00	2.66	1.86	4.47	13.67
Phoxocephalidae	3.06	1.31	2.62	2.46	4.40	18.06
Myriochele sp.	0.50	2.13	2.24	1.85	3.77	21.83
Prionospio australiensis	1.60	0.00	2.06	1.26	3.46	25.29
Goniadidae	1.70	0.40	1.82	1.81	3.05	28.34
Nucula nitidula	3.17	2.84	1.78	1.31	3.00	31.34
Heterothyone ocnoides	1.46	0.57	1.73	1.44	2.91	34.25
Paraprionospio sp.	0.64	1.41	1.72	1.18	2.89	37.14
Spiophanes modestus	1.04	1.71	1.67	1.27	2.80	39.94

Appendix 5. Contents of epifaunal dredge trawls.

Photographs of yellow bin (left hand side) show total trawl contents. Other photos show selected taxa detail.

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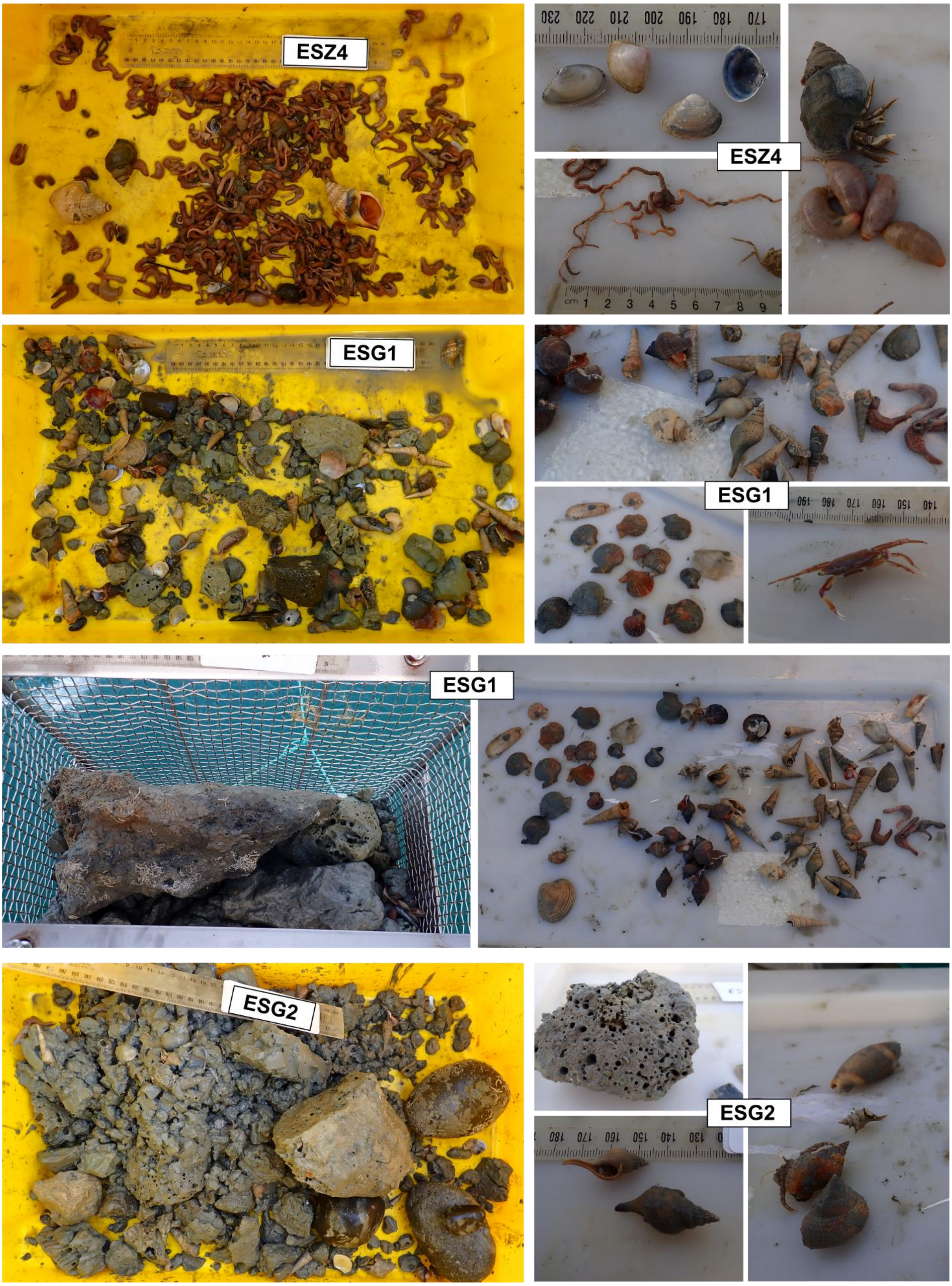
ESZ1
ESZ2
ESZ2
ESZ3
ESZ3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ESZ4
ESG1
ESG1
ESG1
ESG2
ESG2