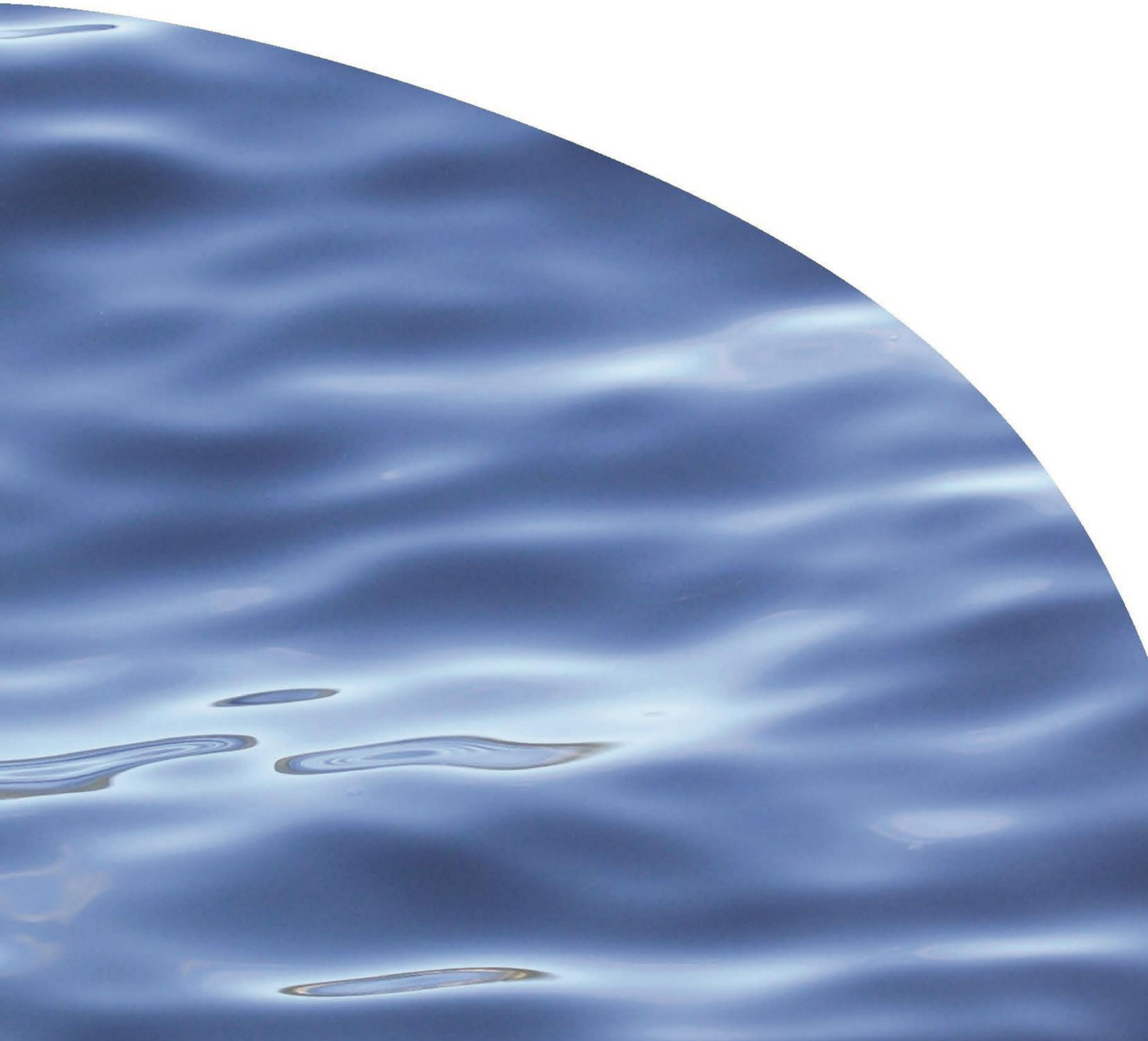
Appendix B: Ecological Monitoring

Port Lyttelton Channel Deepening Project: Benthic Ecological Surveys, Cawthron Institute, April 2018

REPORT NO. 3133

PORT LYTTELTON CHANNEL DEEPENING PROJECT: BASELINE BENTHIC ECOLOGICAL SURVEYS



PORT LYTTELTON CHANNEL DEEPENING PROJECT: BASELINE BENTHIC ECOLOGICAL SURVEYS

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EXECUTIVE SUMMARY

Lyttelton Port Company Ltd (LPC) is implementing a dredging project to deepen and extend its existing approach channel in Lyttelton Harbour - the Channel Deepening Project (CDP). In accordance with condition 8 (Monitoring) of consent CRC172455, three replicate baseline ecological surveys were completed in 2017, each comprised of two components:

1. Reef surveys characterised the habitat and ecological communities at six subtidal and four intertidal sites along the Banks Peninsula coastline of southern Pegasus Bay and within Lyttelton Harbour. Subtidal work by scientific divers comprised quantitative quadrat surveys along paired 30 m long isobathic transects (in 4 m and 7 m water depths) and 50 m littoral fringe (0.5 m Chart Datum) transects focusing on pāua density and size distribution. Intertidal surveys collected semi-quantitative (relative abundance) and photographic data from a 50 m stretch of shoreline.
2. Soft sediments were sampled in triplicate by van Veen grab to provide cores for analysis of substrate and macrofaunal communities from a pre-established series of 19 benthic stations in the vicinity of Lyttelton Harbour, its approaches and the offshore spoil ground. Data from these stations were interpreted according to transects aligned with potential effects gradients from CDP activities.

The baseline surveys were conducted between January and December 2017, although the need for suitable conditions of weather, swell and underwater visibility meant that survey events were not able to be evenly spaced at the target four-monthly intervals. The collected data were compiled with that from an earlier scoping survey in February 2016 (referred to here as Baseline 0) that used the same methodology and included the same reef sites and eight of the 19 benthic sampling sites.

The aim of this report is to compile and present the data in a way that represents a clear characterisation of the existing habitats and ecology. While it is not the intention to fully interpret the survey findings in terms of effects or impacts that may be contributing to existing conditions, the data have been plotted and analysed in several ways to present an exploration of spatial and temporal variability and trends. In this way, the focus has been upon understanding and structuring the data to facilitate the detection and interpretation of any departure from the current state when analysed with subsequent monitoring data collected during and following the dredging project.

Reef surveys

Reef habitats at all sites supported communities considered representative of the wider bioregion. High spatial variability in the subtidal quadrat data is considered to have contributed to apparent temporal variability. This variability is likely to be driven by the complex physical structure and bathymetry of reef habitats and must be accommodated in any interpretation of the data.

There was a high degree of overlap in the dominant taxa and overall community structure for both subtidal and intertidal reef habitats; however, there were also areas of distinctness associated with the communities at individual sites. These were generally consistent with observed differences in physical habitat structure, wave exposure and background turbidity.

Diversity indices from the subtidal reef monitoring show an even distribution in community composition (i.e. not numerically dominated by just a few taxa). Despite some consistent differences between sites, spatial trends were largely quite subtle. However, a gradient of increasing algal cover with distance eastward from Adderley Head was observed, along with higher coverage also for the north Godley Head site where greater water clarity is typically observed.

Pāua were abundant across all sites but littoral fringe count data was highly variable. Size distribution data showed some spatial trends but suggested a stunted local population with only a small proportion reaching legally harvestable shell length.

Soft sediment benthic habitats

Substrates at 16 of the 19 benthic sampling stations were comprised of fine soft muds, with grain size dominated by the silt/clay fraction. A less consolidated surface layer 4-10 cm thick was often present at these sites. Two of the Lyttelton Harbour stations and the eastern-most offshore station were set apart by substrates of fine and very fine sands. While the Harbour stations showed high spatial variability in substrates, there was generally low temporal variability in the dominant particle size fractions at all stations.

Concentrations of trace metals and polycyclic aromatic hydrocarbons in sediments from all of the monitored stations were found to be consistently below levels where a corresponding biological effect may be expected.

Along the station transects identified as potentially exhibiting gradients of effects from CDP activities, the sediment texture, organic content and trace metal concentrations mostly exhibited relatively flat background profiles (little effective gradient). Well-defined baseline spatial gradients were observed only for the South-east and Coastal transects, with the silt/clay fraction, organic carbon and most metals generally decreasing towards the south-east, along with corresponding increases in the very fine sand component.

Macrofaunal community composition varied across stations, but polychaete worms were a consistently dominant group, accounting for over 70% of total abundance overall. Many taxa were common to all sites and no completely distinct assemblages occurred. Consistent with substrate data, the greatest variability in both abundance and taxa richness was for the four Lyttelton Harbour stations.

Indices of macrofaunal community diversity and evenness for individual stations were notably stable across surveys and clear spatial gradients were not identified. Intercorrelation between community indices and other environmental variables generally followed expected

patterns. Abundance, taxa richness and diversity were positively (if weakly) correlated with water depth. Taxa richness was negatively correlated with organic carbon and trace metal concentrations.

Multivariate statistical analysis of the data indicated that water depth explained the largest amount of variation in macrofaunal community data, followed by sediment texture and organic carbon. While community structure tended to follow a consistent progression along most transects (generally aligned with depth and substrate changes), there was little indication of strong spatial gradients.

Although some preliminary analysis of the baseline survey data has been presented in this report, there is a wide range of statistical methods by which project-associated effects may potentially be detected and investigated once the baseline information has been compiled with data collected following commencement of dredging. Nonetheless, examination of clearly observable changes in station data and spatial gradients along transects is expected to be a key first step in such investigations.

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GLOSSARY

Term	Definition	Type
µm	Micron	Unit
ADL	Analytical Detection Limit	Acronym
AEE	Assessment of Environmental Effects	Acronym
ANZECC	Australia and New Zealand Environment and Conservation Council	Acronym
aRPD	Apparent redox potential discontinuity	Acronym
As	Arsenic	Abbreviation
BL0 - BL3	Baseline surveys (0 to 3)	Abbreviation
Cd	Cadmium	Abbreviation
CD	Chart datum	Acronym
CDP	(Port Lyttelton) Channel Deepening Project	Acronym
cm	Centimetre	Unit
cm^2	Square centimetres	Unit
Cr	Chromium	Abbreviation
Cu	Copper	Abbreviation
dbRDA	Distance-based redundancy analysis	Acronym
E	East	Acronym
ENE	East-north-east	Acronym
g	Grams	Unit
GC-MS	Gas Chromatography - Mass Spectrometry	Acronym
GC-MS SIM	Gas Chromatography - Mass Spectrometry Selected Ion Monitoring	Acronym
GPS	Global Positioning System	Acronym
H’	Shannon-Weiner diversity index	Index
ha	Hectare	Unit
Hg	Mercury	Abbreviation
HMW	High molecular weight	Acronym
ICP-MS	Inductively coupled plasma mass spectrometry	Acronym
ISQG	Interim Sediment Quality Guideline	Acronym
ISQG-Low	Interim Sediment Quality Guideline - Low Trigger Value	Acronym
J'	Pielou’s evenness index	Index
km	Kilometre	Unit
LMW	Low molecular weight	Acronym
LOS	Level of similarity	Acronym
LPC	Lyttelton Port Company Ltd	Acronym
m	Metre or metres	Unit
m^2	Square metres	Unit
mahinga kai	Indigenous aquatic species that have traditionally been used as food, tools, or other resources, and the places where these can be found	
mātaitai	Reserves created on traditional fishing grounds of importance to Māori to recognise and provide for customary management practices and food gathering by tāngata whenua	
MfE	Ministry for the Environment	Acronym
mg/kg	Milligrams per kilogram (parts per million)	Unit
mm	Millimetres	Unit
MSA	Maritime Safety Authority (now Maritime NZ; MNZ)	Acronym
MSL	Mean Sea Level	Acronym
MW	Molecular Weight	Acronym
N	Number of individuals in a sample	Abbreviation
n	Number of sample replicates	Variable

Term	Definition	Type
Ni	Nickel	Abbreviation
nMDS	Non-metric multidimensional scaling	Acronym
PAH	Polycyclic aromatic hydrocarbons	Acronym
Pb	Lead	Abbreviation
PCO	Principal coordinates analysis	Acronym
PSDDA	Puget Sound Dredged Disposal Analysis Program	Acronym
PSML	Puget Sound Maximum Level	Acronym
PVC	Polyvinyl chloride	Acronym
S	Number of species (species richness)	Index
SCUBA	Self-contained underwater breathing apparatus	Acronym
SE	Standard error of the mean (or south-east)	Acronym
SIMPER	Similarity percentages (analysis)	Abbreviation
SOP	Standard operating procedure	Acronym
SPE	Solid Phase Extraction	Acronym
TOC	Total organic carbon	Acronym
USEPA	United States Environmental Protection Agency	Acronym
Zn	Zinc	Abbreviation

1. INTRODUCTION AND BACKGROUND

1.1. Background

Lyttelton Port Company Ltd (LPC) is implementing a dredging project to deepen and extend its existing approach channel in Lyttelton Harbour. The Channel Deepening Project (CDP) will extend the maintained channel 4 km beyond the present pilotage limit, out to approximately 4.7 km ENE of Godley Head in southern Pegasus Bay (Figure 1). Dredging will also slightly widen (by 20 m) the existing channel and enlarge the swing basin off Cashin Quay, establishing depths of approximately 17 m (at chart datum - CD). This will result in the removal of approximately 18 million cubic metres (m^3) of benthic sediments. These sediments will be deposited at a spoil ground of some 1,250 ha, to be centred approximately 8.2 km ENE of Godley Head.

The Channel Deepening Project will be undertaken in at least two stages. Stage 1 will see the channel widened to 200 m, increased in length to approximately 9 km and increased in depth by approximately 2 m. The swing basin will also be deepened and enlarged, increasing the width from approximately 450 m to 615 m. This work will involve the dredging of approximately 5 million m^3 of sediment. In addition, a further approximately 1 million m^3 of material will be dredged to achieve the following:

- Deepening of the existing berth pockets at Cashin Quay;
- Creation of new berth pockets to serve the container terminal at Te Awaparahi Bay; and
- Removal of the upper layers of sediment (to approximately -20 m CD) within the proposed Stage 1 reclamation footprint at Te Awaparahi Bay as part of the reclamation construction methodology.

The anticipated duration of Stage 1 of the CDP is 3-6 months, depending on the equipment used.

The increased area of the deepened channel and the ship turning basin will in turn increase the quantity of sediments required to be removed during future maintenance dredging. Part of the CDP therefore includes the establishment of a new offshore maintenance dredge spoil ground in Pegasus Bay offshore from Godley Head (Figure 1).

Consent for the CDP was granted in July 2017. Conditions of consent include requirements for a range of environmental monitoring, including water column parameters and the ecology of reef and soft sediment habitats in areas that may be affected by project activities.

In order to identify and quantify changes in benthic habitats that may be attributable to the CDP during and following its implementation, the prior baseline condition of these habitats must be characterised. The consent conditions therefore require a program of monitoring covering a one-year period preceding commencement of the project. It is expected that Stage 1 of the CDP will commence in 2018. This report summarises the findings of ecological monitoring carried out by the Cawthron Institute (Cawthron) over a series of field surveys over 2016–2017.

1.2. Scope

Surveys of the reef habitat and soft sediment benthic environments were undertaken according to condition 8 (Monitoring) of consent CRC172455. The reef surveys characterised the subtidal and intertidal reef substrate and ecological communities along the Banks Peninsula coastline of southern Pegasus Bay and within Lyttelton Harbour. Soft sediments were sampled for analysis of substrate and ecology from a pre-established series of benthic stations in the vicinity of the approaches to Lyttelton Harbour and the offshore capital spoil ground. The first survey, Baseline 0 (BL0), was completed in February 2016 and formed part of the Assessment of Environmental Effects (AEE) for the proposed dredging and spoil disposal operations. Baseline surveys 1-3 (BL1-BL3) were completed in March, September and December 2017, respectively, and form the baseline monitoring for the first year under the consent. This data report collates the findings of the field surveys to characterise the habitats and communities monitored.

It is not the intention of this report to fully interpret the survey findings in terms of effects or impacts that may be contributing to existing conditions; rather the data are compiled and presented in a way that should facilitate the detection and interpretation of any departure from the current state when analysed with subsequent monitoring data collected during and following the dredging project.

2. METHODS

2.1. Reef monitoring

Surveys of rocky reef habitats were conducted over four periods between February 2016 and December 2017 (BL0-BL3). These covered six subtidal and four intertidal sites along the Banks Peninsula coastline of Pegasus Bay and within Lyttelton Harbour and Port Levy for baseline and future monitoring (Figure 1). The sites were selected from 22 subtidal sites and 5 intertidal sites surveyed as part of a broader scoping and assessment effort (herein referred to as Baseline 0 or BL0) reported by Atalah and Sneddon (2016). The spatial arrangement of the sites is presented in Figure 1, with site coordinates provided in Appendix 1.

The reef monitoring stations were selected to provide spatial coverage of the rocky shorelines assessed as being potentially most exposed to sediment plumes from CDP activities and sited to provide a range of distances from those sources. Constraints on site selection included factors such as availability of suitable habitat (mostly physical conditions of exposure, gradient, substrate, bathymetry etc.) and access and safety considerations; however, reasonable spatial alignment with LPCs deployed water quality monitoring buoys also needed to be accommodated. Avoidance of potentially confounding influence from LPC's ongoing maintenance dredge spoil deposition operations was the principal reason for not siting reef monitoring on the northern shoreline of the outer Harbour.

2.1.1. Subtidal reef transects: Quadrat surveys

Subtidal survey methodology was based on standard quadrat and transect sampling using scientific SCUBA divers (Kingsford & Battershill 1998). At each site a 100 m offshore transect line was positioned perpendicular to the shore, by anchoring one end onto conspicuous low shore rocks and the other end (offshore) to the seabed using a shot weight (Figure 2). The onshore ends were relocated using GPS coordinates and photographs of the shoreline. This enabled exact positioning of the start of the transect. The offshore ends were relocated using GPS coordinates. Two graduated 30 m subtidal transect lines were laid by divers, running transversely out from the offshore transect at two nominal depth ranges and roughly parallel to shore (Figure 2). The deep transect (hereafter 7 m) was laid between 6–8 m depths, chosen to be near the maximum extent of non-coralline macroalgae. The shallow transect (hereafter 4 m) was laid between 3–5 m depths and was within kelp forest habitats (where these were present).

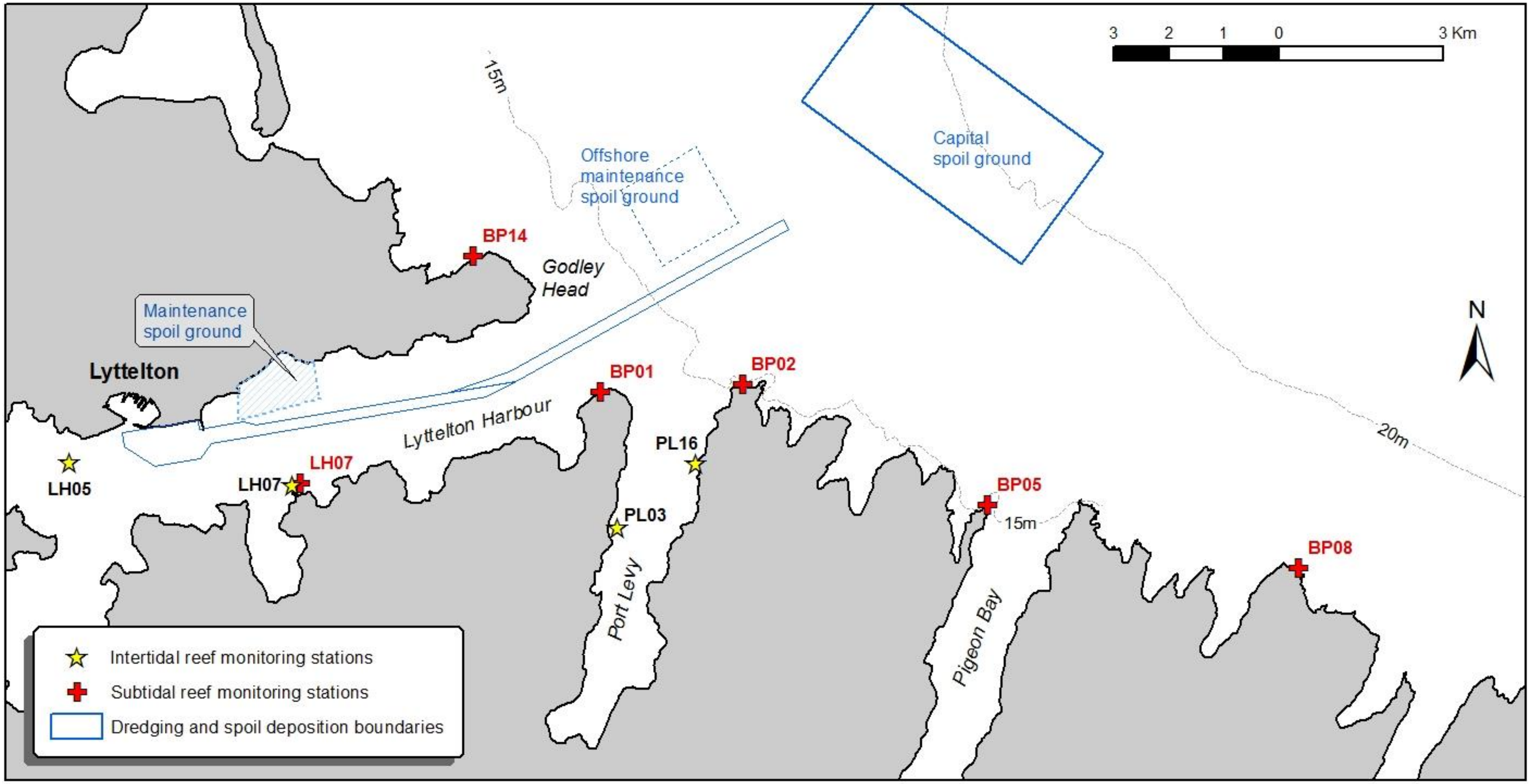

Figure 1. Locations of reef monitoring stations, with dredging and spoil disposal boundaries.

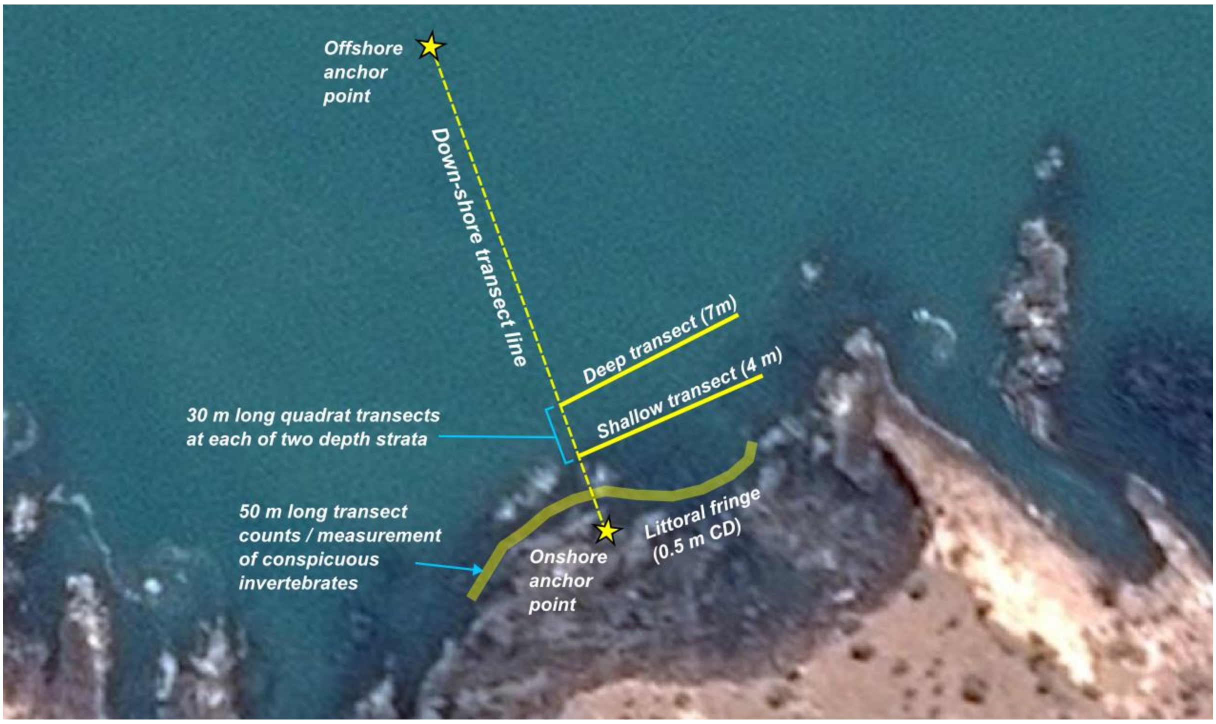

Figure 2. General layout of subtidal shoreline transects used to characterise reef habitats.

The reason for locating transects within nominal depth ranges (as above) rather than at precise depths was that the three-dimensional (and sometimes near-vertical) structure of the reef did not allow precise depth control along a transect line. There was also some variation in the depth of the target habitats from site to site due to changes in substrate and exposure characteristics and it was considered important to survey habitats that were generally comparable between sites. At each site, allowance was made for tidal state to adjust general target depths for the transects at the time surveyed. This was especially important for the littoral fringe transects (Section 2.1.2) to accommodate a difference between chart datum (CD) and mean sea level (MSL) of approximately 1.3 m.

Along each 4 m and 7 m depth transect, eight 1 m^2 quadrats were haphazardly placed, with two divers alternating along the 30 m transect line. It was not possible to survey a 7 m transect at Station LH07 in Lyttelton Harbour due to the absence of suitable rocky reef habitat in that depth band.

For each quadrat, the following data were recorded:

- water depth (from wrist-mounted dive computers)
- an estimate of the percentage cover of substrate type: bedrock (consolidated rock), boulders (> 256 mm), cobble (64–256 mm), sand, silt and shell hash
- an estimate of the percentage cover of canopy forming and understory algae

- estimates of percentage cover of encrusting invertebrates (e.g. sponges, ascidians, mussels)
- counts of solitary epifauna (e.g. snails, sea urchins, sea stars).

Statistical analyses

Subtidal quadrat data were analysed to ascertain levels of abundance (total cover and number of individuals), species richness (diversity) and standardised indices of community diversity and evenness for each station (Table 1). Abundances for different taxa groups (e.g. algae and sessile invertebrates) were examined graphically. Results are reported as mean ± 1 standard error (SE).

Table 1. 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'*)	$H' = -\sum P_i \, log_e \, (P_i)$	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.

Count and coverage data were square-root transformed to de-emphasise the influence of abundant organisms and the differences associated with combining count and coverage scales while preserving information consistently across samples. Analyses were based on Bray-Curtis similarities. Assemblage differences among treatment levels were visualised using Principal Coordinates Analysis ordination (PCA). Similarity Percentages analysis (SIMPER, Clarke 1993) was used to identify the contribution of each species (or taxon) to observed differences between data categories. Taxa that consistently discriminated between categories and yielded a correlation greater than 0.6 with the PCO axes were displayed as vectors in the PCO plots. All statistical analyses were conducted using PRIMER v7 (Clarke & Gorley 2015; Anderson et al. 2008).

2.1.2. Littoral fringe transects

At each site, a 50 m littoral fringe transect was surveyed between depths of 0–1 m (relative to chart datum; CD) within the shallow subtidal (Figure 2). This transect was located near to or intersecting the off-shore transect line, within areas where pāua were abundant.

At each transect, divers counted and measured large invertebrate and mahinga kai species within a 1 m band (i.e. over an area of 50 m^2). Due to the effective absence of kina (*Evechinus chloroticus*) in this depth range, the targeted species were limited to black foot pāua (*Haliotis iris*) and Cook's turban (*Cookia sulcata*). Pāua were counted and measured using digital logging callipers, whereas *C. sulcata* were only counted.

2.1.3. Intertidal surveys

Intertidal biological communities were surveyed semi-quantitatively at low tide at four sites (Figure 1, Appendix 2). These comprised two sites in Port Levy and two sites in Lyttelton Harbour. The Port Levy sites (PL03 and PL16) are representative of the long, sheltered, inlets of Banks Peninsula. The Harbour sites at Ripapa Island (LH07) and Shag Reef (LH05) are representative of the relatively exposed rocky shore of mid-Lyttelton Harbour and the relatively sheltered flat rocky shore of the upper Harbour, respectively.

Approximately 50 m of shoreline was surveyed at each site over a 30 minute time period, with substrate characteristics and zonation patterns of intertidal fauna and flora recorded. The relative abundance of fauna and flora was described at each intertidal zonation (high-, mid-, low-shore) and within tidal pools using a categorical scale, ranked subjectively as 'rare', 'occasional', 'common', or 'abundant'. Guidelines for these abundance categories are listed in Table 2. Representative photographs of both habitats and taxa were also taken. Where field identification was not possible, specimens or photographs of individual fauna and algae were collected and later identified. All taxonomic nomenclature was based on the World Register of Marine Species (WoRMS Editorial Board 2016).

Table 2. Description of the categorical scale used to survey the intertidal sites.

Category	**Description**
Rare	1–2 individuals, or a single cluster or patch of individuals in one small area (e.g. small patch of barnacles or algae)
Occasional	3–10 individuals throughout the site
Common	>10 individuals throughout the site
Abundant	Individuals abundant enough to form a distinct zone or habitat (e.g. mussels, barnacles and some algae), or hundreds to thousands of individuals per m^2 (e.g. *Austrolittorina* spp.).

2.2. Benthic sampling of soft sediment habitats

The collection of benthic samples was based around the establishment of a series of sampling stations within the Harbour, the area of the proposed extended channel and inshore Pegasus Bay within the vicinity of the proposed capital and maintenance spoil grounds. The spatial arrangement of these stations is represented in Figure 3 with location coordinates and depths being listed in Appendix 1.

The benthic stations were arranged spatially to give suitable coverage of the areas of interest as well as those immediately adjacent to the proposed spoil ground and points closer to the Banks Peninsula shoreline. Two stations (CTRL-1 and CTRL-2) were positioned at a distance of approximately 2 km from its north-western and south-eastern boundaries, respectively. These far-field stations were to potentially act as reference stations and to better establish the spatial extent of benthic variables. All stations outside of the Harbour were positioned to lie along transects of potential effects gradients from CDP activities (this was not possible within the Harbour due to the alignment of the shipping channel with its central axis).

The role of the benthic sample stations is to provide data on the physical, chemical and ecological nature of benthic habitats within the surveyed area. At each station, sediments were collected using a 0.1 m^2 stainless steel van Veen grab for several analyses as follows:

- sediment grain size distribution (surficial substrate texture) and organic content
- sediment chemistry; specifically, indicative metal contaminants but also polycyclic aromatic hydrocarbons (PAHs) at selected stations
- sediment-dwelling macroinvertebrate communities (infauna).

Triplicate grabs were conducted at each station and for each, the grab contents were sub-sampled for the sediment and infauna analyses.

2.2.1. Sediment texture and chemistry

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 for other environmental parameters. Chemical contaminants are primarily retained within fine sediments (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.

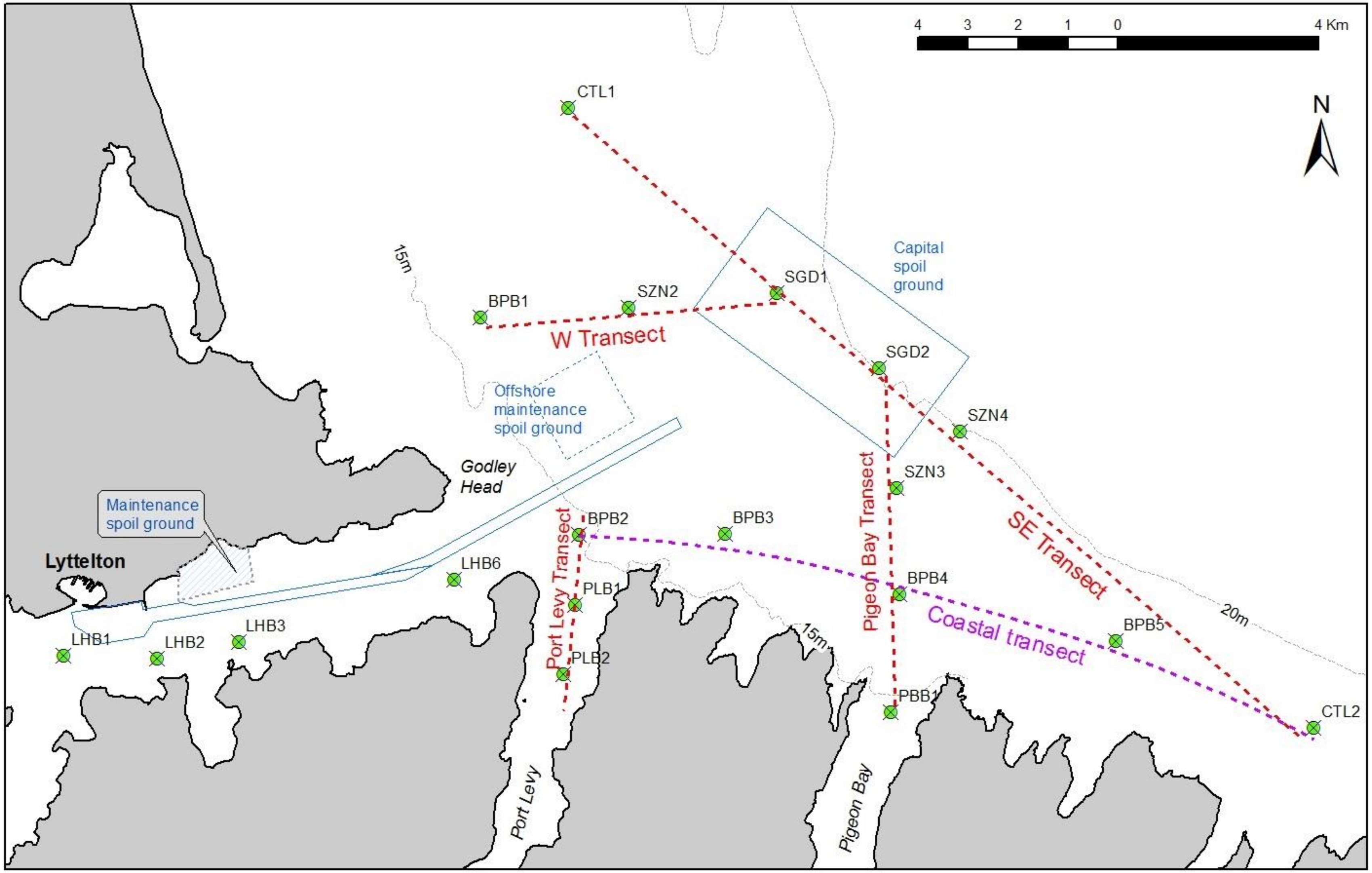

Figure 3. Locations of benthic monitoring stations with transect overlay.

Sub-sampling for sediment physico-chemical analyses

Two 62 mm diameter cores were taken from the contents of each replicate grab. The Perspex® corers were driven into the contents of the grab to a depth of up to 120 mm, then extracted and the cores photographed before sub-sampling. The colour of the sediments, any noticeable odour and the presence/absence of apparent anoxic zones within the sample were noted, as well as the depth to any apparent redox potential discontinuity (aRPD) layer[1].

The two cores were sub-sampled by removing the surface 50 mm of each and combining to provide a sample for the analysis of trace metals [arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb) and zinc (Zn)], organic content and particle size distribution. At four of the offshore stations (BPB2, SZN2, SGD2, SZN3) and one in Port Levy (PLB2), surficial samples from each of the triplicate grabs were combined to provide station composite samples for the analysis of polycyclic aromatic hydrocarbons (PAHs). All samples were chilled with ice for transport to the laboratory. A summary of sediment analyses and analytical methods is listed in Table 3.

Table 3. Summary of analytical methods used for sediment characterisation.

Analyte	Method Number	Description
Particle grain size distribution (sediment texture)	Cawthron SOP No. 33074	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].
Polycyclic aromatic hydrocarbons (PAHs)	USEPA 8270C	Sonication extraction, SPE clean-up, GC-MS SIM analysis (gas chromatography mass spectrometry selected ion monitoring mode).

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[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 continuous in reality, but may be reduced to an average transition point (sediment depth) for descriptive purposes.

2.2.2. Benthic macrofauna

The ecological assemblage of small animals (larger than 0.5 mm) living in the upper 100 mm of the sediment profile is generally referred to as macrofauna or macroinvertebrates. Analyses performed for this study focused on the infauna, animals living within the sediment matrix. Infauna have been used for several decades to assess the effects of human impacts in marine environments, as 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).

One infauna sediment core was extracted from the contents of each of the three grabs conducted at each benthic sample station. The corer consisted of an elliptical section made from PVC pipe. The cross-sectional area of the corer was equivalent to a circular section 130 mm in diameter (133 cm^2). Each corer was manually driven into the contents of the grab to a depth of 100 mm. The core was then gently withdrawn and emptied into a 0.5 mm mesh sieve.

The contents of the corer were gently rinsed with seawater through the sieve to remove the majority of the fine sediment matrix. The residue was transferred to a sample container for preservation in a solution comprising 3% glyoxal and 70% ethanol. In the 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 infauna, species level identification is very difficult and, in such instances, infauna were grouped into recognisable taxa (morphologically similar groups). In this manner a list of taxa and their relative abundance was compiled for each station.

Infauna data analysis

Infaunal count data were analysed to ascertain levels of abundance (individual species density), species richness and standardised indices of community diversity and evenness for each station (Table 1). These indices were compared between stations and significant differences interpreted with respect to key factors such as seasonal timing, water depth and substrate characteristics.

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 fourth-root transformed to de-emphasise the influence of the dominant species (by abundance). The major taxa contributing to the similarities of each grouping of benthic stations were then identified using analysis of similarities (ANOSIM; Clarke et al. 2014). All statistical analyses were conducted using PRIMER v7 (Clarke & Gorley 2015; Anderson et al. 2008).

3. RESULTS AND DISCUSSION

3.1. Schedule of surveys

The survey conducted in February 2016 (referred to here as BL0) was a scoping and assessment effort to identify suitable sites and establish variability in reef habitats over a wide spatial area. The 22 subtidal and six intertidal sites surveyed enabled the selection of the final six subtidal and four intertidal reef sites for ongoing monitoring. However, since the survey methodology was not modified for the subsequent baseline surveys in 2017, the data generated from this earlier work can be can be combined with the 2017 data to better characterise the chosen reef sites.

Since the full set of 19 soft sediment benthic sampling stations was established only following the BL0 survey, this report relies mostly on the soft-sediment habitat data generated from the baseline surveys carried out in 2017[2]. However, there is a large historical data-set of soft sediment habitats for Lyttelton Harbour and inshore Pegasus Bay and this can be drawn upon as important context for background spatial and temporal variability in this environment.

The completion of the baseline surveys at strict four-month intervals was not possible due to the conditions required for the subtidal work. This was principally due to the need for suitable underwater visibility. Water clarity in nearshore waters along the Banks Peninsula and outer Lyttelton Harbour coastline is highly sensitive to even low swell conditions. Turbidity plumes from riverine inputs transported by larger scale coastal circulation can also result in prolonged periods of poor underwater visibility. A swell height as low as 0.5 m could furthermore make the completion of the littoral zone transects hazardous for divers at most sites. These constraints made it necessary to wait for the required weather, swell and visibility windows before conducting the survey work. Sometimes only the less clarity-sensitive components (sediment grab sampling, intertidal surveys) could be completed at a particular time. The timing of completion of survey components is listed in Table 4.

Table 4. Timing of survey components for the baseline surveys.

Survey	Dates	Components
BL0	22 Feb–2 Mar 2016	Intertidal and subtidal reef surveys. Limited benthic sampling.
BL1	19–20 Jan 2017	Benthic sampling, intertidal reef surveys
	28 Feb–1 Mar 2017	Subtidal reef survey
BL2	25–26 July 2017	Benthic sampling, intertidal reef survey
	13–14 Sep 2017	Subtidal reef survey
BL3	5–8 Dec 2017	Benthic sampling, intertidal and subtidal reef surveys

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[2] Eight of the 19 stations were sampled in February 2016 and grain size and organic enrichment data has been incorporated here.

3.2. Reef monitoring

3.2.1. Subtidal reef transects: Quadrat surveys

Reef substrates

A summary of substrate composition derived from the quadrat data at 4 m and 7 m depths is presented graphically in Figure 4 and Figure 5, respectively. Since the transect lines cannot be placed in exactly the same position for each survey, interpretation of survey results must accommodate changes in the mix of reef substrate arising from small-scale spatial variability.

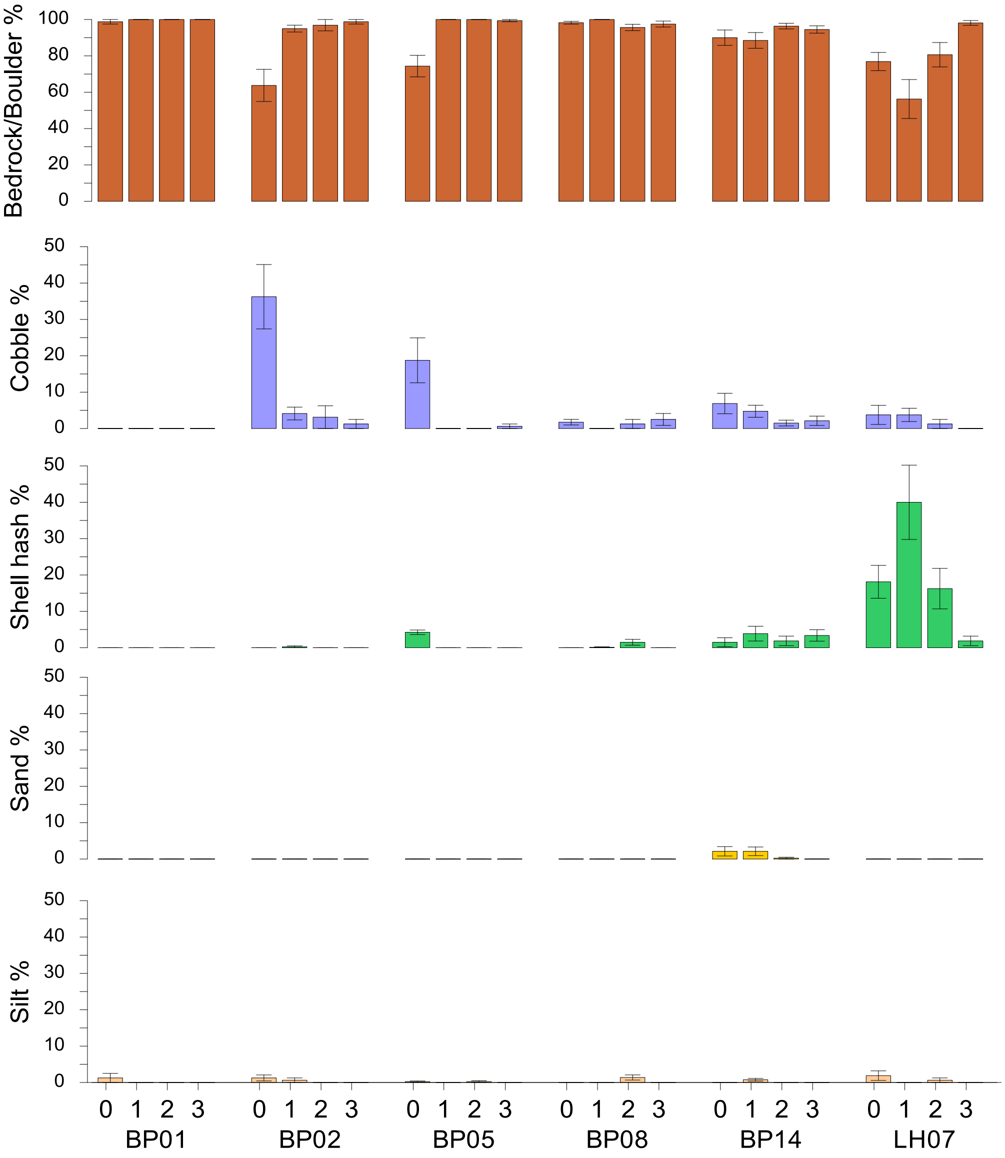

Figure 4. Mean percentage cover of substrate type within quadrats (n = 8) along 4 m depth transects for each survey (0–3 = BL0–BL3) at each site. Categories: bedrock (consolidated rock), boulder (> 256 mm), cobbles (64–256 mm), shell hash, sand (2-0.5 mm) and silt (< 0.5 mm). Error bars represent ±1 SE. Note change in y-axis scale.

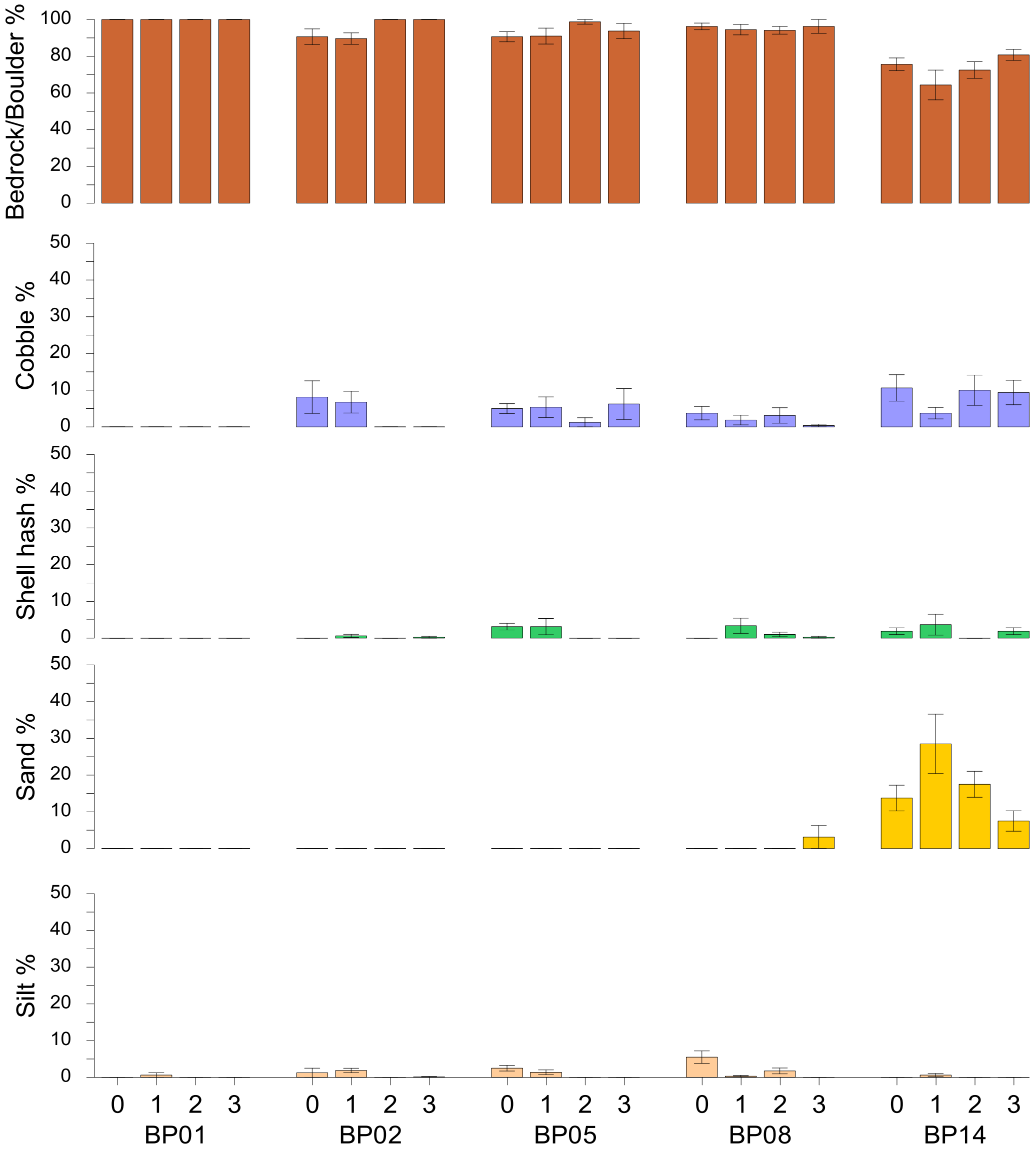

Figure 5. Mean percentage cover of substrate type within quadrats (n = 8) along 7 m depth transects for each survey (0–3 = BL0–BL3) at each site. Categories: bedrock (consolidated rock), boulder (> 256 mm), cobbles (64–256 mm), shell hash, sand (2-0.5 mm), and silt (< 0.5 mm). Error bars represent ±1 SE. Note change in y-axis scale.

For this analysis, boulders and bedrock percentage cover have been combined since. Boulders were often very large (> 2 m diameter) and embedded within the substrate generally. Hence it was frequently difficult for divers to make a distinction between substrates during low visibility conditions. Both categories represent stable large rock surfaces and, in the absence of significant void spaces and over-hangs, can be assumed to be ecologically equivalent.

All sites were dominated by boulders and bedrock at both 4 m and 7 m depths (56 - 100% at 4 m, and 64–100% at 7 m; Figure 4 and Figure 5). Proportions of cobble were much lower and ranged from 0–36% at 4 m, and from 0–11% at 7 m. The apparently higher cobble component at 4 m at BP02 and BP05 during the BL0 survey were most likely due to small changes in the positioning of the transects. Proportions of shell hash, sand and silt were relatively small at all sites and at both depths, with the exception of more prevalent shell hash at 4 m at LH07 (19% ± 7.9), and sand at 7 m at BP14 (average 17% ± 4.4). As noted previously (Atalah & Sneddon 2016), a silt veneer of varying thickness was often evident on the surface of bedrock, boulders and dominant biota (e.g. macroalgae and solitary ascidians), particularly in more sheltered areas such as LH07. However, these veneers were not recorded as a silt substrate.

Reef communities: quadrat data

An inventory of benthic taxa recorded during the subtidal surveys is provided in Appendix 2 along with abundance/coverage data averaged over each of the six sites. Reef habitats at all sites supported communities considered representative of the wider bioregion, being comparable to those previously described for the Banks Peninsula north coast (Schiel & Hickford 2001; Shears & Babcock 2007; Hepburn et al. 2010).

Average abundances (the sum of percentage cover and/or number of individuals for all taxa observed) [3], richness (total number of taxa), community evenness (Pielou's index) and diversity (Shannon-Weiner index) at 4 m and 7 m depths at each site are presented in Figure 6 and Figure 7, respectively. Average abundances of organisms ranged from 62 to 216 individuals or cover/m^2 at 4 m (Figure 6A), and from 57 to 149 individuals or cover/m^2 at 7 m (Figure 7A). Lower abundances at 7 m in comparison to 4 m were due to the lower percentage cover of algae within the deeper transects. The reef habitat was characterised by relatively high taxa richness across depths, sites and surveys (116 taxa overall), ranging between averages of 9.3 to 20.5 taxa/m^2 in quadrats along the 4 m depth transects (Figure 6B), and 9.3 to 19.6 taxa/m^2 in quadrats along the 7 m depth transects (Figure 7B). Shannon-Weiner diversity reflected the same patterns as taxa richness, with averages ranging from 1.2 to 2.0 at 4 mm Figure 6C) and 1.3 and 2.1 at 7 m (Figure 7C). Similarly, Pielou's index values were comparable across sites, depths and surveys, ranging between 0.47 and 0.71 at 4 m (Figure 6D), and between 0.53 and 0.74 at 7 m (Figure 7D), indicative of evenly distributed communities (i.e. not numerically dominated by just a few taxa).

It was expected that taxa richness could increase to some extent over surveys, as identification experience and taxa resolution increased over time. By including additional taxa categories on the field sheet (to facilitate field entry), divers were potentially more likely to observe some taxa if they were prompted to actively search for them. However, sea conditions and visibility could also make the surveys more challenging at times, thereby potentially reducing apparent taxa richness.

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[3] Similarity measures and diversity indices are not usually constructed from such 'mixed' data sets, but there are no impediments to combining and analysing such data (Anderson & Underwood 1994).

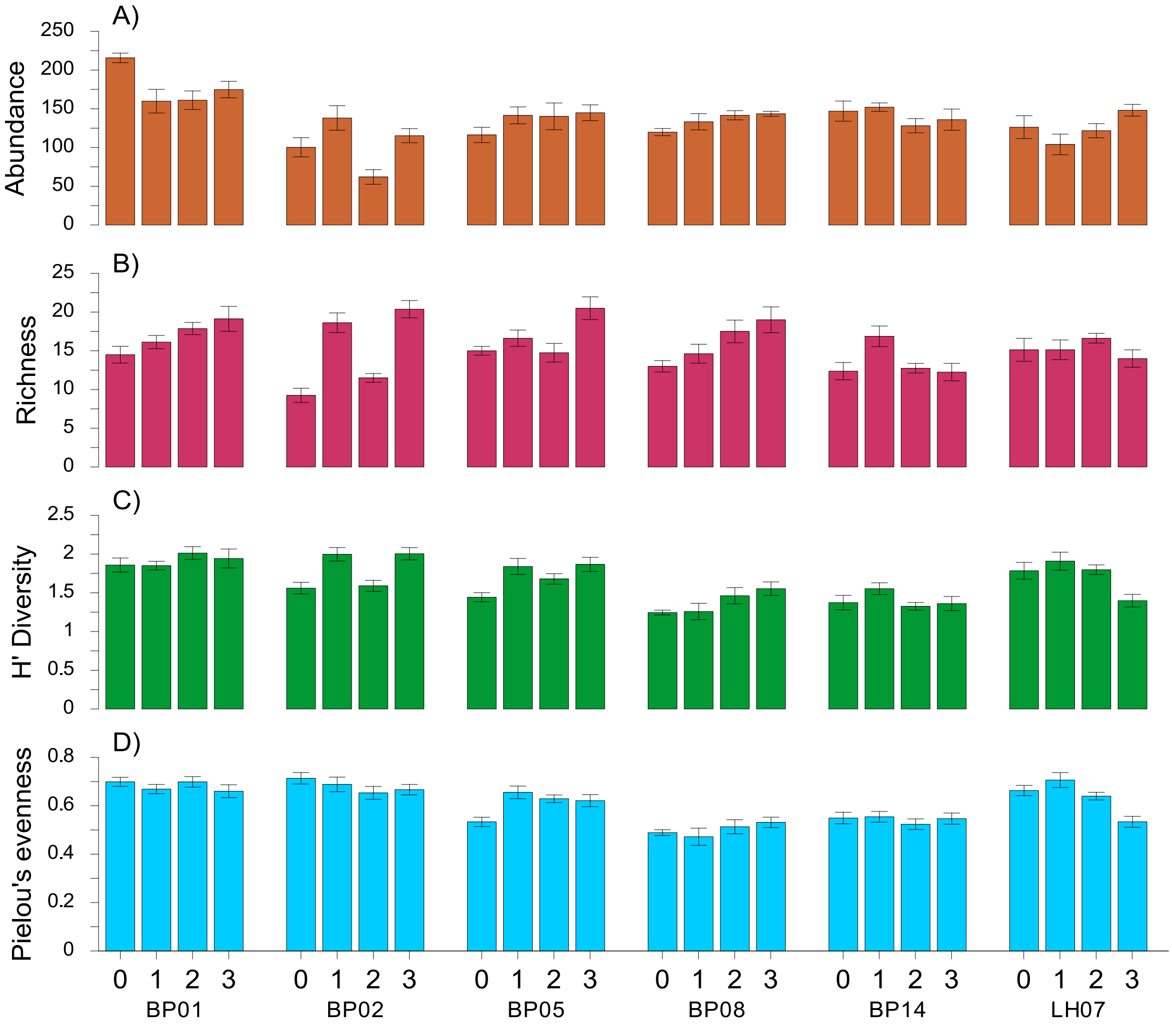

Figure 6. Mean diversity indices for quadrats (n = 8) along the 4 m depth transects for each survey (0-3 = BL0-BL3) at each subtidal reef site. A) Abundance per quadrat. B) Number of taxa per quadrat. C) Pielou's evenness. D) H' Shannon-Weiner Error bars represent ±1 SE.

A trend of increasing taxa richness over time was observed at seven of the 13 individual quadrat transects. These were BP01, BP02 and BP05 at both 4 m and 7 m depth levels, and BP08 at 4 m. At BP02, taxa richness in surveys BL1 and BL3 were higher than in surveys BL0 and BL2, at both 4 m and 7 m. SIMPER revealed that some taxa present in low percentage covers or abundances (averages < 2% and < 2 individuals) in surveys BL1 and BL3 were not recorded as being present in surveys BL0 and BL2. These taxa included brown encrusting algae, some red algal species (e.g. filamentous red algae, *Ballia* sp., *Plocamium* sp.), the annual invasive alga *Undaria pinnatifida*, Cook's turban shells *Cookia sulcata*, bryozoans and hydroids.

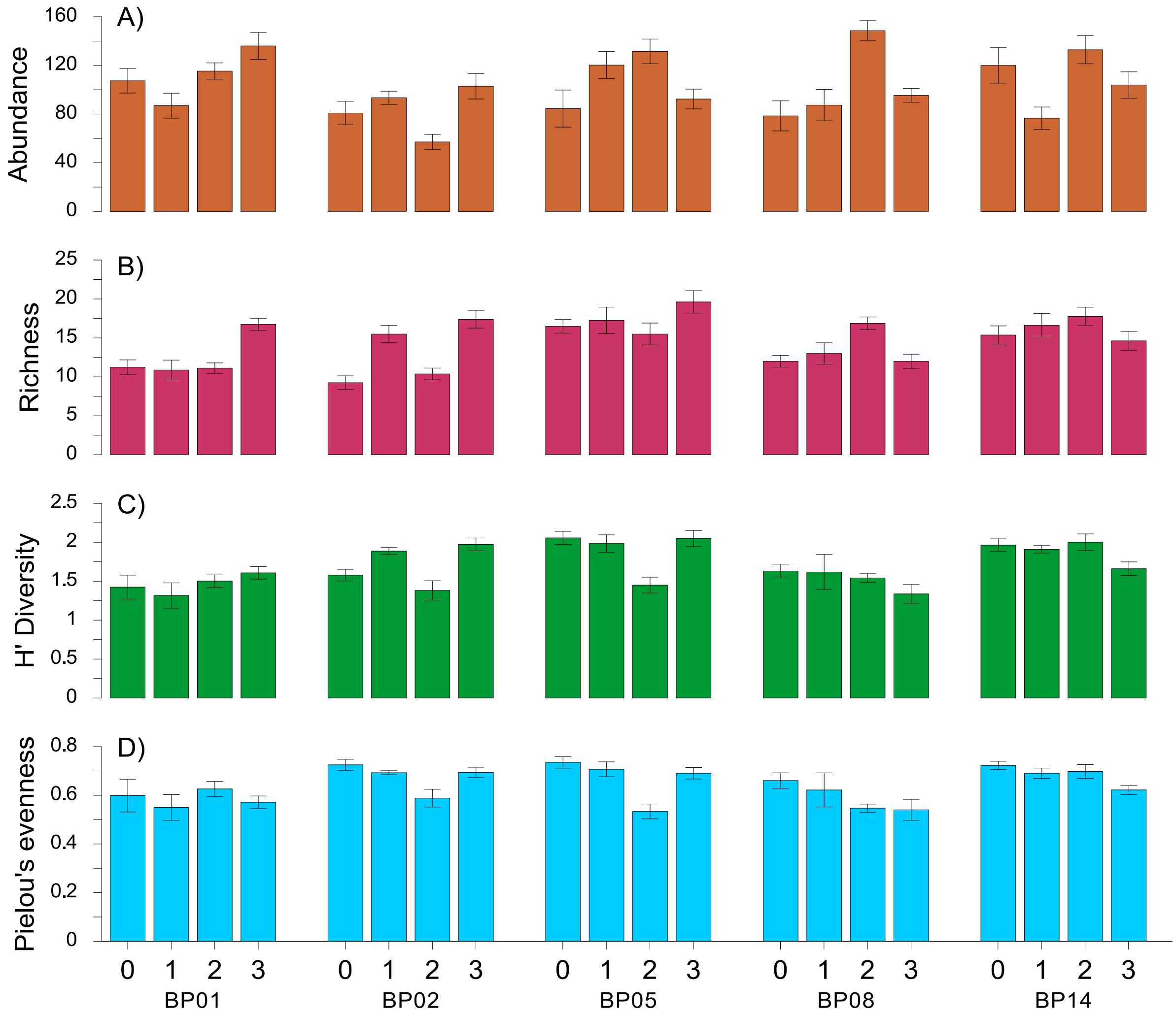

Figure 7. Mean diversity indices for quadrats (n = 8) along the 7 m depth transects for each survey (0-3 = BL0-BL3) at each subtidal reef site. A) Abundance per quadrat. B) Number of taxa per quadrat. C) Pielou's evenness. D) H' Shannon-Weiner Error bars represent ±1 SE.

Community composition at each site through time was generally comparable to that described for BL0 by Atalah and Sneddon (2016). Transects at 4 m at all sites supported a high percentage cover of algae, and this was driven predominantly by encrusting coralline algae, which ranged in cover from 26% to 88% (Figure 8). Brown algae at this shallower depth was also prevalent and was dominated by the common kelp *Ecklonia radiata*. As to be expected with increasing depth, there was significantly less algae at 7 m, particularly at BP01, BP02 and BP05. (Figure 9). Small amounts of red algae were present, but green algae were sparse.

It is a notable feature that there was an increasing prevalence of algal cover (principally encrusting coralline) with distance eastward from Adderley Head. Although this gradient is distinct at the 7 m depth (Figure 9), it is also indicated for the 4 m transect (Figure 8).

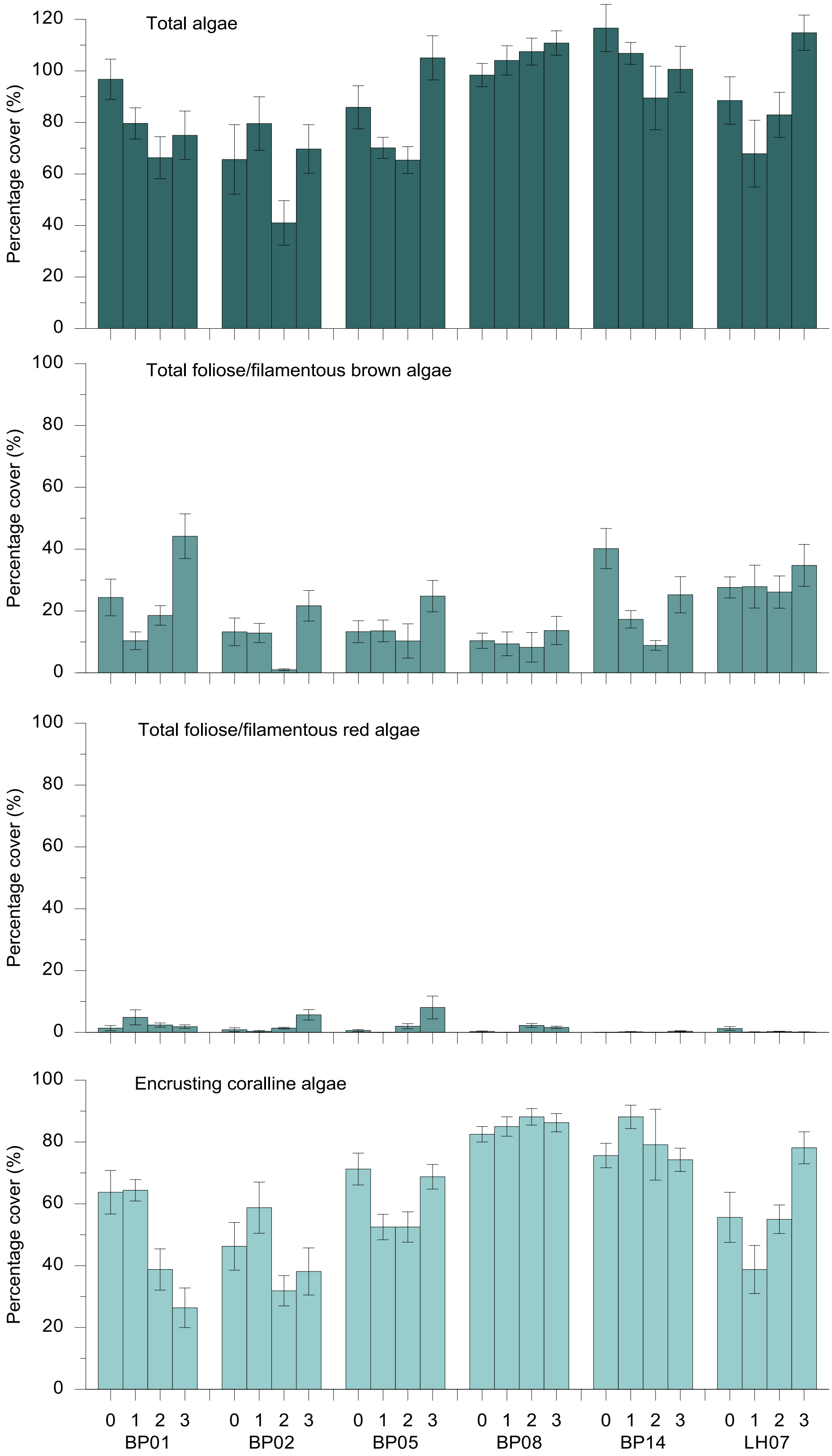

Figure 8. Mean percentage cover of total algae, total foliose and filamentous brown algae, total foliose and filamentous red algae and encrusting coralline algae at 4 m at each site during each survey (n = 8). Note: Error bars represent ±1 SE. Quadrat areas were 1 m^2.

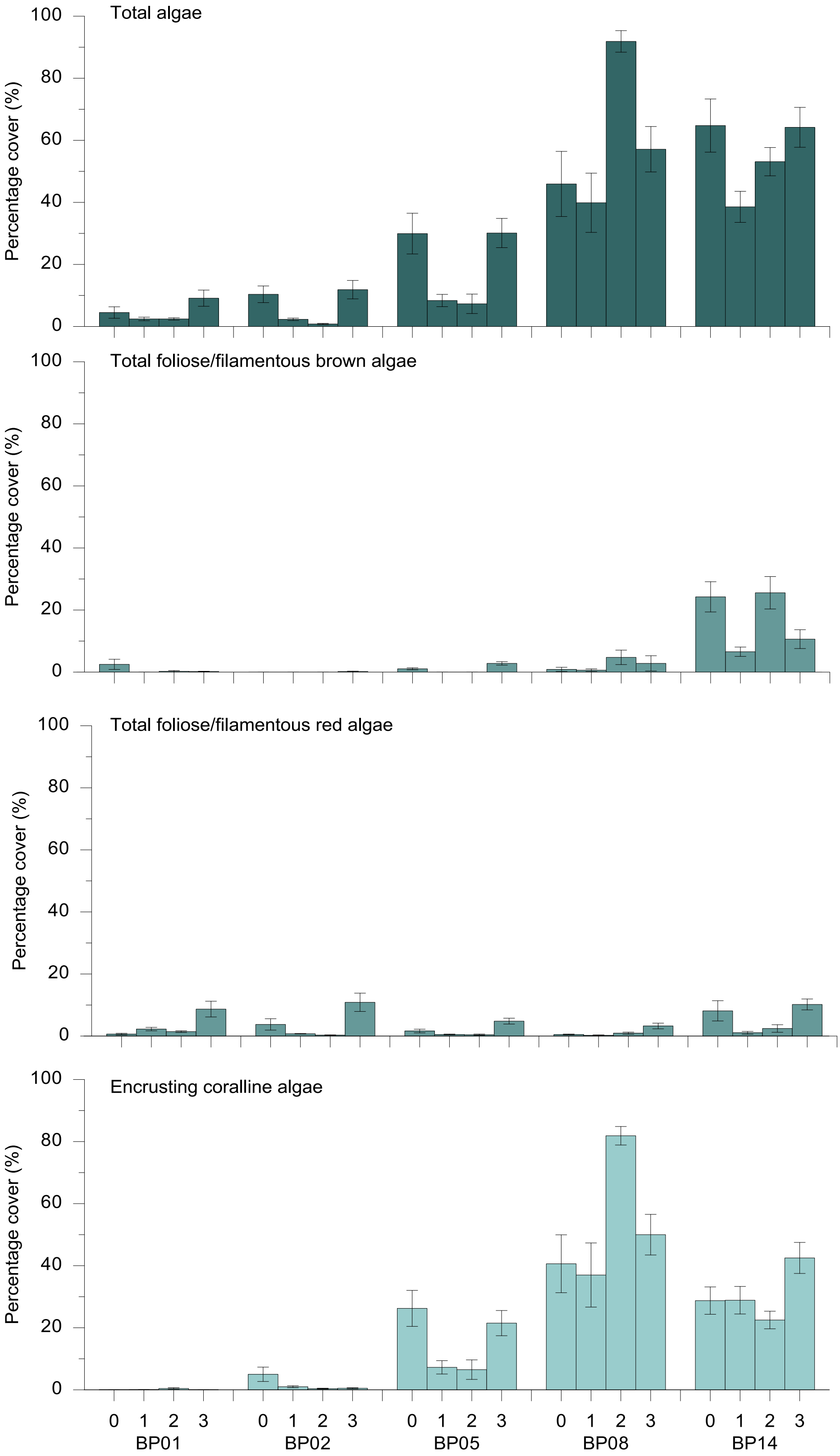

Figure 9. Mean percentage cover of total algae, total foliose and filamentous brown algae, total foliose and filamentous red algae and encrusting coralline algae at 7 m at each site during each survey (n = 8). Note: Error bars represent ±1 SE. Quadrat areas were 1 m^2.

Sessile invertebrate cover was variable between sites and surveys, and the taxa contributing most of the cover at 4 m were solitary ascidians (mostly *Cnemidocarpa* sp.), barnacles (only at BP01) and mussels (with the exception of BP08) (Figure 10). Solitary ascidians contributed most of the cover at 7 m (Figure 11). Sponges, ascidians, bryozoans and hydroids were also present at lower coverage values (Appendix 2).

Quadrat counts of individual taxa also fluctuated, and at both 4 and 7 m the striped anemone (*Anthothoe albocincta*), grazing snails (particularly the top shell *Trochus* sp.) and sea stars were the most prevalent (Figure 12, Figure 13). Other mobile invertebrates such as limpets, chitons, whelks and pāua were present at low abundances (Appendix 2).

Temporal vs spatial variability

Overall, the data indicate significant variability in taxa abundances both spatially (between sites) and temporally (between surveys). However, it is notable that many of the sessile taxa exhibiting fluctuating coverage between surveys have life-spans that are likely to considerably exceed the time-frame of the baseline surveys. This suggests that a component of these apparently distinct temporal changes is likely due to the variability in placement of quadrats rather than seasonal or other temporal variation. An example of this is mussel coverage at the 4 m depth at site BP05. Average percentage cover increased from 0.2% to 33%, then declined to 27% and 2% (Figure 10). Variability in encrusting communities on small spatial scales is supported by high standard errors for the eight-quadrat data-sets along single transects within each survey event.

Divers at all sites recorded a high-relief reef substrate with numerous boulders, outcrops, troughs and walls occurring along individual transects. The requirement to lay the transects within a 2-m depth range, coupled with challenging underwater visibility, frequently results in the transect line taking a non-linear path to negotiate such bathymetric obstacles. With a haphazard placement of quadrats, it is not surprising that such structural variability results in communities adapted to niche habitats of varying gradient, exposure, aspect and surface texture. In characterising the ecology of these sites and interpreting apparent changes, it is therefore necessary to take a wider view of the compiled data that accommodates the natural spatial variability in communities.

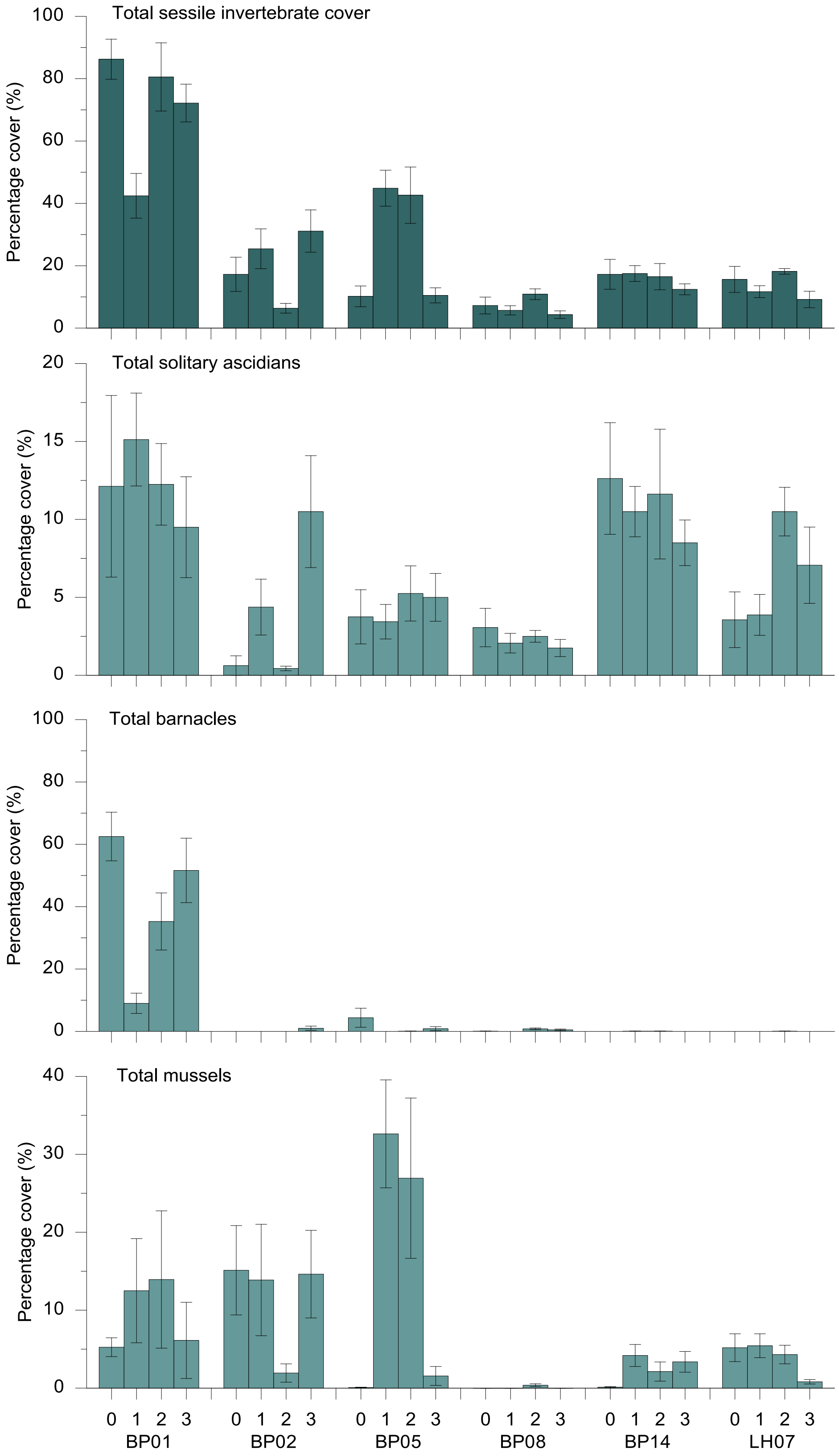

Figure 10. Mean percentage cover of total sessile invertebrates, total solitary ascidians, total barnacles and total mussels at 4 m at each site during each survey (n = 8). Error bars represent ±1 SE. Quadrat areas were 1 m^2. Note change in scale on y-axes.

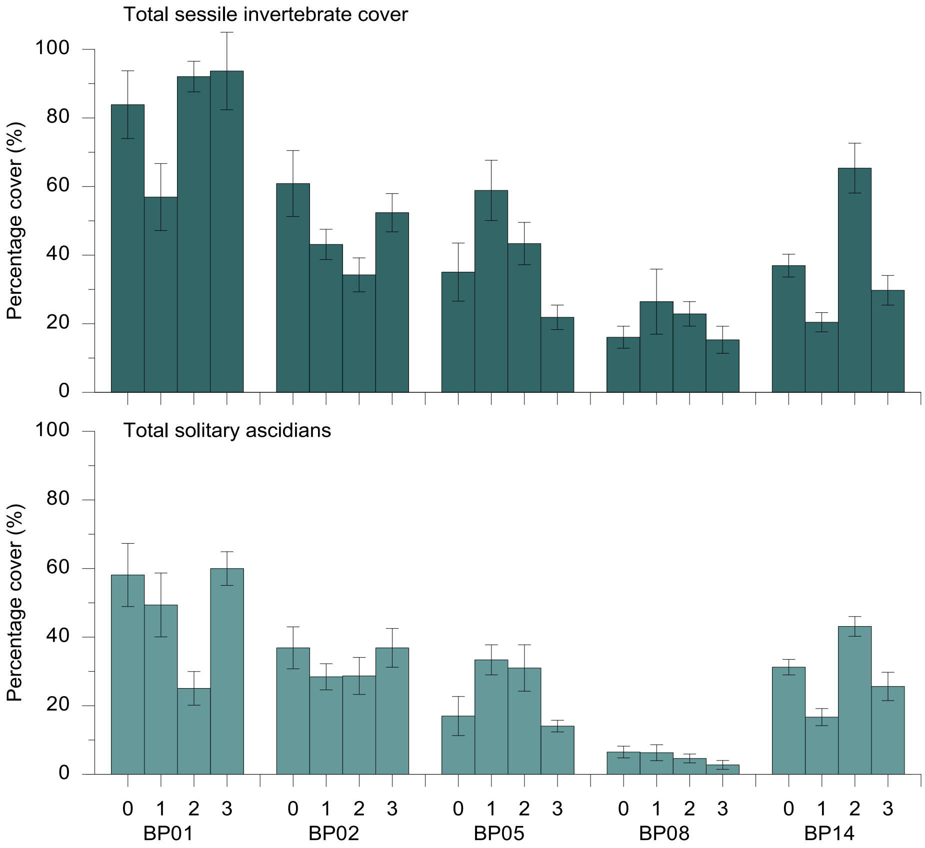

Figure 11. Mean percentage cover of total sessile invertebrates and total solitary ascidians at 7 m at each site during each survey (n = 8). Error bars represent ±1 SE. Quadrat areas were 1 m^2.

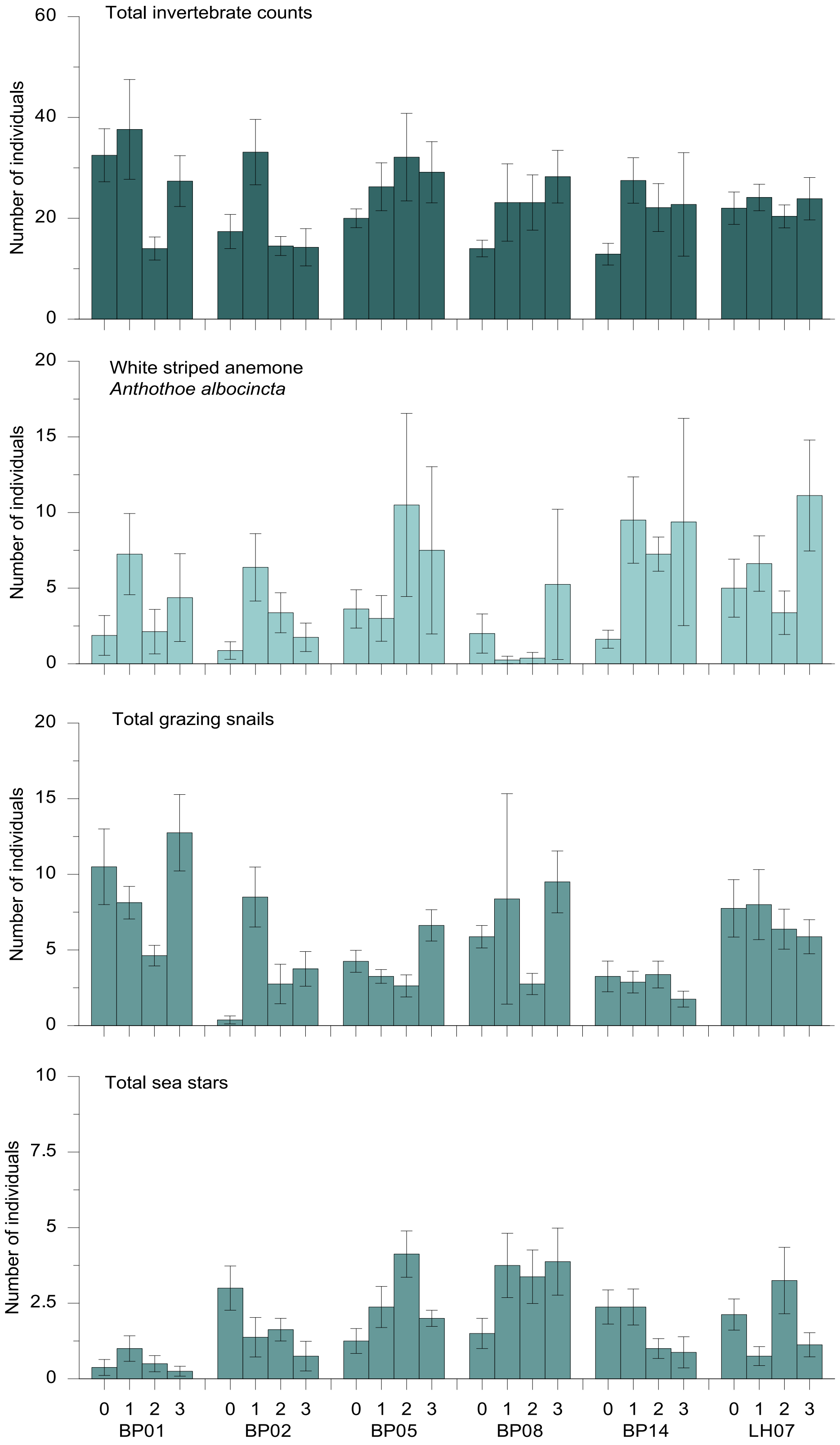

Figure 12. Mean count data for total invertebrates, white-striped anemones (*Anthothoe albocincta*), total limpets and snails and total sea-stars at 4 m at each site during each survey (n = 8). Error bars represent ±1 SE Quadrat areas were 1 m^2. Note change in scale on y-axes.

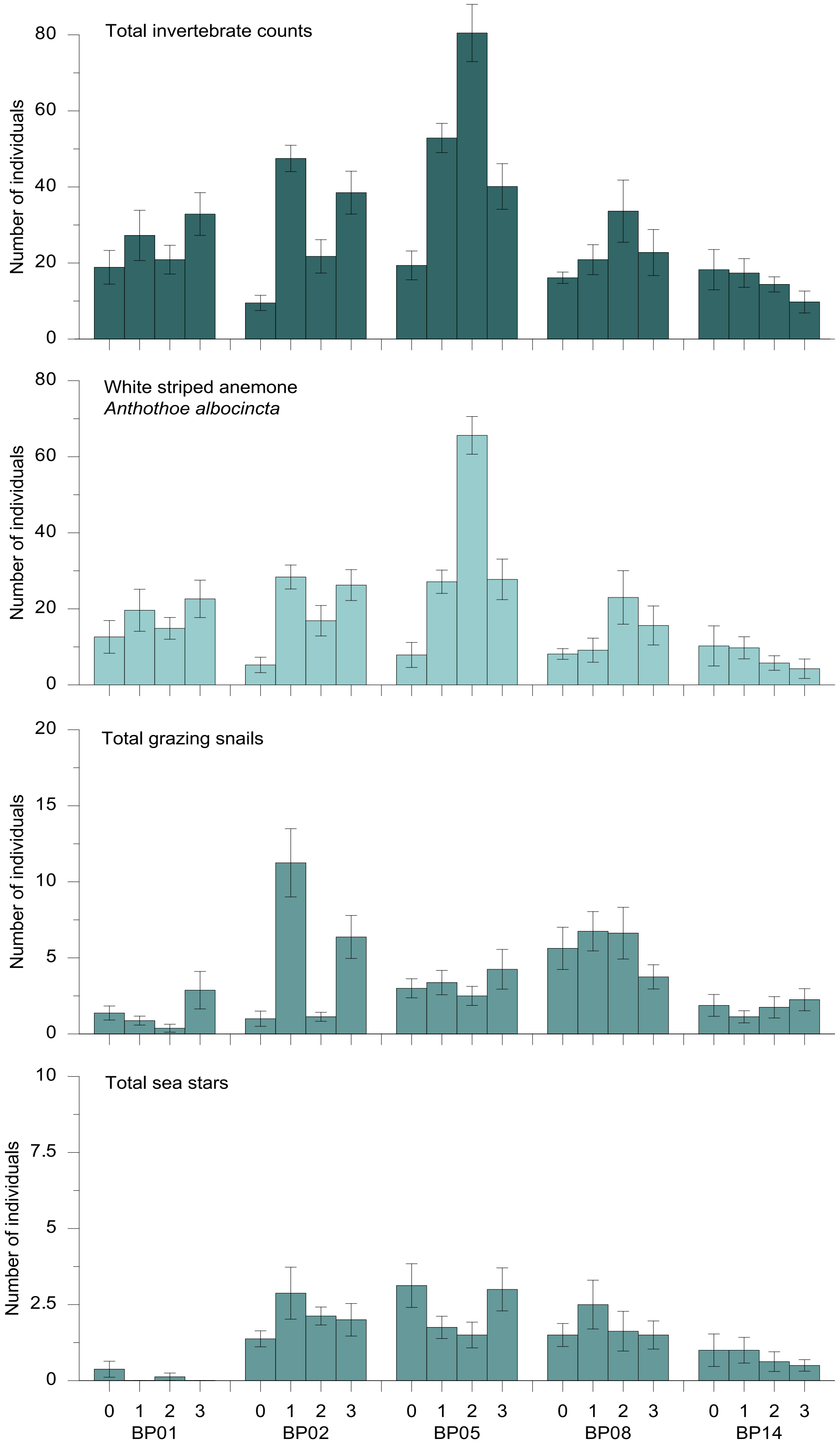

Figure 13. Mean count data for total invertebrates, white striped anemones (*Anthothoe albocincta*), total limpets and snails and total sea-stars at 7 m at each site during each survey (n = 8). Error bars represent ±1 SE Quadrat areas were 1 m^2. Note change in scale on y-axes.

Principal coordinates analysis (PCO) of distances among centroids illustrates the differences between sites and surveys based on the whole community data at 4 m (Figure 14) and 7 m (Figure 15) depths. The vector plot shows the taxa that defined the different sites for each survey. For example, communities at 4 m depth at site LH07 had more cat's eye snails *Lunella smaragda* and common kelp *Ecklonia radiata* than occurred at other sites, and site BP08 consistently featured more coralline turf and the pink golf ball sponge *Tethya bergquistae* (Figure 14).

In general, there was more spatial than temporal variability in community composition, with surveys at individual sites tending to be clumped together, although some overlap was also apparent, consistent with the physical similarities between sites. For example, sites BP02 (at both 4 m and 7 m), and BP05 at 7 m, showed greater spread across surveys. While these communities were variable between surveys, there were no obvious directional changes. The differences between the communities at BP02 were due to the absence of some taxa in surveys BL0 and BL2 (described above), and small differences in the percentage covers or abundances of some taxa. For example, at the 7 m transect, communities at BP02 during survey BL0 featured lower counts of white-striped anemones *Anthothoe albocincta* and top shells *Trochus* sp., but recorded greater coverage by green-lipped mussels *Perna canaliculus* and small barnacles. The communities at 7 m at BP08 in surveys BL0 and BL3 had more encrusting coralline algae compared with survey BL1, fewer brachiopods *Calloria inconspicua* than surveys BL1 and BL2, and more small barnacles than survey BL2.

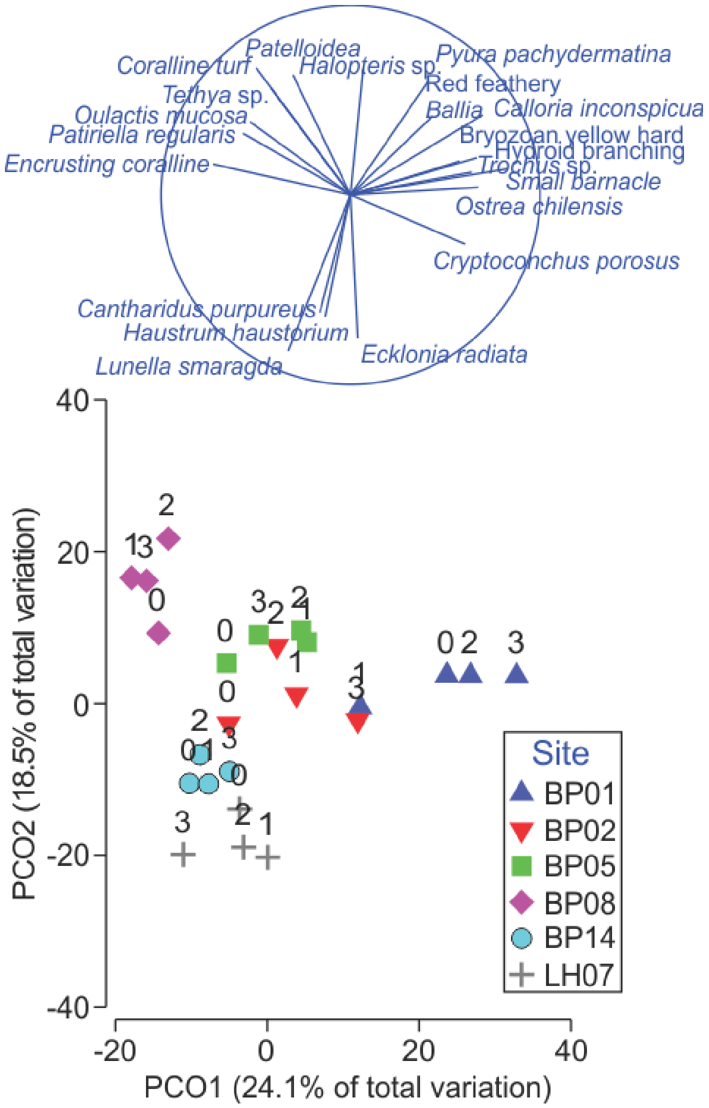

Figure 14. Principal coordinates analysis ordination (PCO) of distance among centroids from quadrat data at 4 m depth for each subtidal reef site and for each survey (labelled 0 to 3), based on a Bray-Curtis similarity matrix of community assemblage data. Vector overlay shows taxa with > 0.6 correlation.

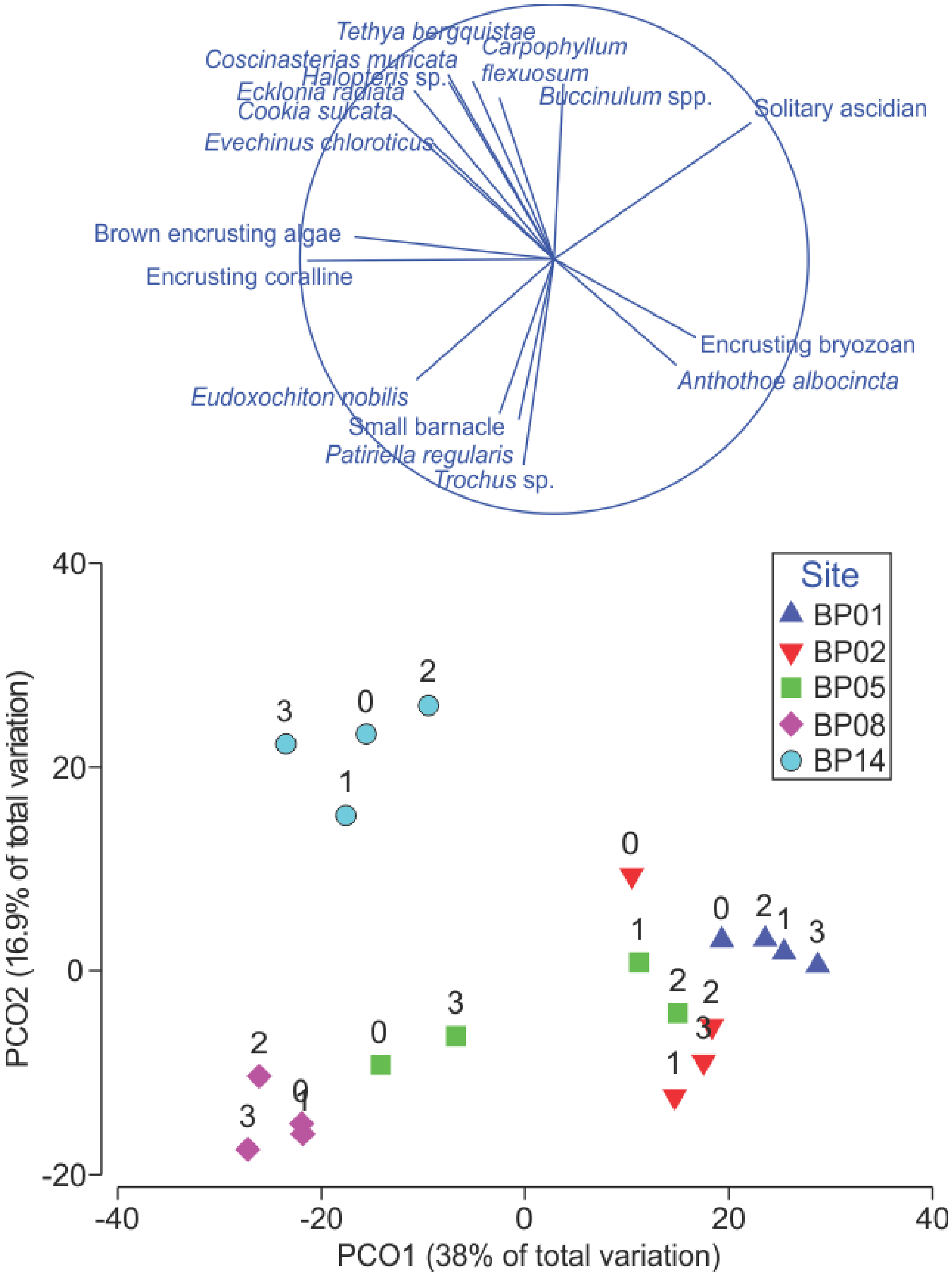

Figure 15. Principal coordinates analysis ordination (PCO) of distance among centroids from quadrat data at 7 m depth for each subtidal reef site and for each survey (labelled 0 to 3), based on a Bray-Curtis similarity matrix of community assemblage data. Vector overlay shows taxa with > 0.6 correlation.

3.2.2. Subtidal quadrat data: Summary of findings and observations on the data

All sites were dominated by boulder/bedrock substrates. Cobble material was a minor secondary substrate and sand and shell-hash were notable at site BP14 (7 m) and site LH07 (4 m), respectively.

Reef habitats at all sites supported communities considered representative of the wider bioregion. These communities were characterised by relatively high taxa richness across depths, sites and surveys (116 taxa overall). Diversity indices were indicative of an even distribution in community composition (i.e. not numerically dominated by just a few taxa).

Transects at the 4 m depth at all sites supported a high percentage cover of algae, and this was driven predominantly by encrusting coralline algae, which ranged in mean coverage from 26% to 88%. Brown macroalgae at this shallower depth was also prevalent and was dominated by the common kelp *Ecklonia radiata*.

Consistent with generally lower light levels, there was significantly less algae at 7 m depths, particularly at sites closer to Lyttelton Harbour (BP01, BP02 and BP05). Small amounts of red algae were a consistent feature, but green algae were generally very sparse.

The data show an apparent spatial gradient of increasing algal cover with distance eastward from Adderley Head, but also high algal coverage for the north Godley Head site (BP14).

Sessile invertebrate cover was variable between sites and surveys and was driven primarily by several taxa which achieved high coverage rates but could be patchy in occurrence. Nonetheless, there were some consistent patterns of occurrence in individual taxa between sites. Invertebrate count data were also variable but showed no clear spatial trends.

High variability in long-lived sessile taxa between surveys indicates that a component of the apparent temporal variability (between surveys) is in fact due to the patchy spatial distribution along transects within individual sites. This spatial variability is likely to be driven by the high local variability in reef physical structure and bathymetry and must be accommodated in any interpretation of the data.

Despite variability in the quadrat data, principal coordinates analysis shows that there is a measure of distinctness to communities at individual sites across the baseline surveys, driven by consistencies in the occurrence of key taxa.

3.2.3. Littoral fringe transects

Pāua

A total of 2,129 pāua were measured within the littoral fringe transects (0.5 m CD) across all sites and all surveys (Figure 16). Pāua abundances were highly variable between sites and across surveys, with no apparent trends. Densities ranged between 16 and 214 individuals per 50 m^2 at different sites and survey events. At site BP05, a significant increase in numbers was due to the transect being shifted in location, from survey BL01 onwards, to include a more favourable habitat for pāua. Diver observations indicated that densities were depth-dependent, with greater abundances consistently occurring just below the transect depth (at approximately 1-2 m CD). With varying tidal and surge conditions, there is likely to have been some variation in the exact depth of the band surveyed between surveys. Hence small changes in the exact area of the transect are likely to account for some of the apparent temporal variability observed.

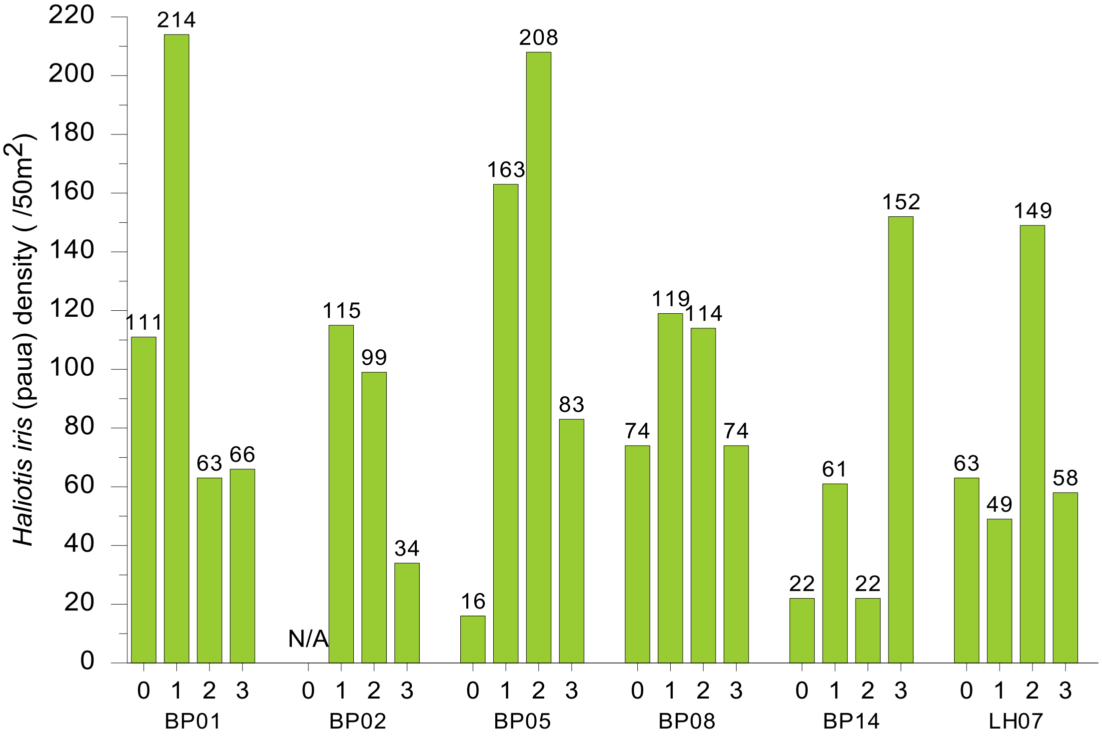

Figure 16. Density of *Haliotis iris* (pāua) within littoral fringe transects for each survey (0-3 = BL0-BL3) at each site. Note that the transect was not surveyed at site BP02 in BL0, and the position of the BP05 site was shifted slightly for the 2017 surveys to encompass a more favourable habitat for pāua.

Pāua sizes within these transects ranged between 41.5 mm and 148.5 mm (Figure 17). Only 58 individuals (2.7%) were measured at above the legal size limit of

125 mm. Average and maximum pāua lengths were greatest at LH07 within Lyttelton Harbour (average 112.5 ± 2.0 mm, maximum 148.5 mm; Figure 17). These results are comparable with earlier surveys undertaken within Port Levy (Hepburn et al. 2010), where an average pāua length of 100 mm was reported and only 0.38% were above the legal size limit.

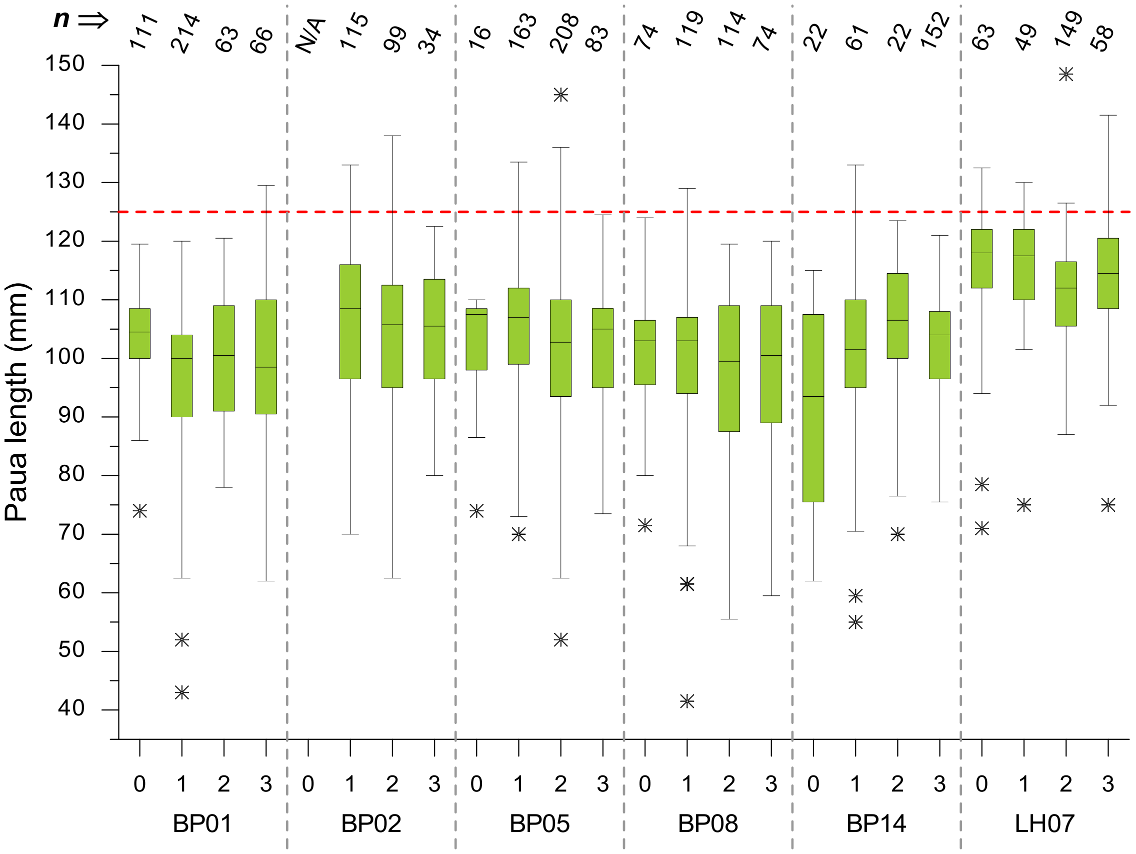

Figure 17. Box-whisker plots showing *Haliotis iris* (pāua) size distribution for each survey (0-3 = BL0-BL3) at each site. Sample counts at top. The red dashed line represents the legal harvesting size of 125 mm. Note that the transect was not surveyed at site BP02 in BL0, and the position of the BP05 site was shifted slightly from BL1 onwards to encompass a more favourable habitat for pāua.

Cook's turban snail

As observed for pāua, *Cookia sulcata* densities were also highly variable between sites and across surveys, with the only consistent trend being lower numbers recorded from site BP01 (Adderley Head) with a range of 3 to 23 individuals recorded from the four surveys (Figure 18). The highest densities were recorded at BP08, with 150 individuals recorded during BL1, and an average of 84 ± 28.8 recorded across the three surveys in 2017.

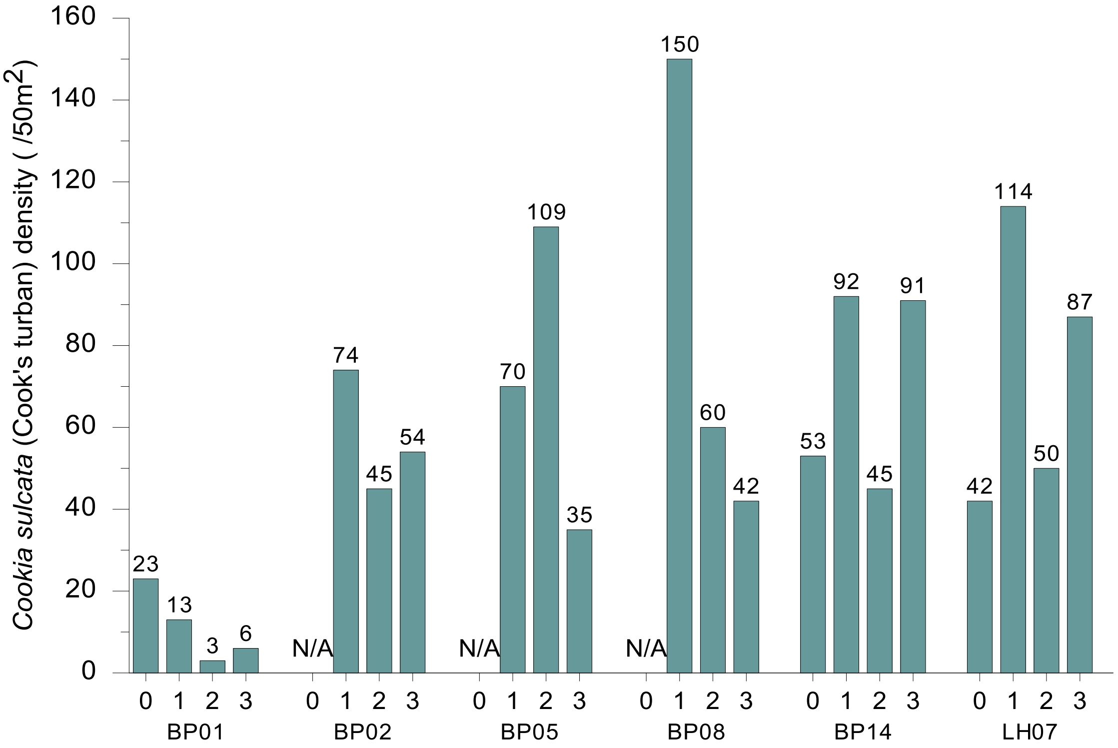

Figure 18. Density of *Cookia sulcata* within littoral fringe transects for each survey (0–3 = BL0–BL3) at each site. Note that counts of this species were not carried out at sites BP02, BP05 and BP08 during BL0.

3.2.4. Littoral fringe data: Summary of observations and findings

Pāua were observed to be common to abundant at all six subtidal monitoring sites but counts on the set transects could be highly variable between sites and across surveys, with no apparent trends. Some of this variability is believed to result from small changes in the exact depth line of the transect due to changing tidal state and surge conditions between surveys.

Pāua measured along the littoral fringe transects occupied a fairly narrow size range with only a small proportion (2.7%) being above legal harvestable size.

Densities of the Cook’s turban snail within the littoral fringe transects were also highly variable between sites and across surveys, with the only consistent trend observed being lower numbers recorded from site BP01 (Adderley Head).

3.2.5. Intertidal reef monitoring

The four intertidal reef sites included in the current monitoring programme were described in detail in Atalah and Sneddon (2016). A full inventory of taxa recorded and relative abundances in each tidal zonation (high, mid- and low shore) and tidal pools for each site and survey is presented in Appendix 3.

Table 5 to Table 8 list the most prevalent taxa for each of the four intertidal zones in order of overall mean dominance. Since the values are based on assigned numerical rankings for the four relative abundance categories used, they do not give an indication of actual abundance but reflect the rank order of numerical abundance for three taxa categories of algae, sessile and mobile invertebrates. The tables give an overview of how patterns of dominance change between the four sites.

The most abundant taxa occurred across all sites. These common species were dominated by sessile invertebrates such as column barnacles (*Chamaesipho columna*), blue mussels (*Mytilus galloprovincialis*), green-lipped mussels (*Perna canaliculus*), blue tube worms (*Spirobranchus cariniferus*), plicate barnacles (*Epopella plicata*) and small black mussels (*Xenostrobus pulex*). In general, a range of common grazing gastropods were also consistently present at all sites across surveys. These included species which are typically abundant such as periwinkles (*Austrolittorina* spp.) but also those that are generally constrained to lower densities such as the limpets *Cellana ornata* and *Cellana radians*, cat’s eye snails (*Lunella smaragda*), spotted top shells (*Diloma aethiops*) and the snakeskin chiton (*Sypharochiton pelliserpentis*), all of which were common.

Most algal taxa were limited to the mid- to low shore and/or within tidal pools. Common across sites were encrusting and turfing coralline algae, Neptune’s necklace (*Hormosira banksii*, zig-zag weed (*Cystophora scalaris*), the red alga *Gelidium caulacantheum* and giant or bladder kelp (*Macrocystis pyrifera*).

Table 5. Taxa characteristic of the high-shore zone in order of average prevalence over the four baseline surveys based on a numerical ranking of relative abundance categories. [Abundant = 4, Common = 3, Occasional = 2, Rare = 1]. Shaded cells represent the most dominant taxa (up to five) for each category in the high-shore zone at each intertidal site. Dash indicates taxon not observed.

	PL03	PL16	LH05	LH07	Mean ranking
ALGAE					
Pyropia plicata	1.8	0.5	2.0	1.5	1.4
Hormosira banksii	3.0	-	-	-	0.8
Ralfsia sp.	0.8	0.5	-	-	0.3
Bostrychia arbuscula	-	1.0	-	-	0.3
Ulva intestinalis	0.8	-	-	0.3	0.3
Ceramium sp.	-	-	0.5	-	0.1
Ulva lactuca	-	-	0.5	-	0.1
Cladophora feredayi	-	0.3	-	-	0.1
SESSILE INVERTEBRATES					
Chamaesipho columna	3.5	3.0	3.5	4.0	3.5
Xenostrobus neozelanicus	4.0	-	3.0	2.3	2.3
Spirobranchus cariniferus	3.0	1.5	1.3	-	1.4
Epopella plicata	2.5	1.5	-	0.8	1.2
Mytilus galloprovincialis	0.8	1.3	1.0	-	0.8
Austrominius modestus	-	0.3	1.0	-	0.3
Ostrea chilensis	-	0.3	-	0.5	0.2
MOBILE INVERTEBRATES					
Austrolittorina antipodum	3.5	4.0	1.3	4.0	3.2
Cellana ornata	3.0	2.3	2.3	2.3	2.4
Austrolittorina cincta	2.8	3.5	-	3.5	2.4
Diloma aethiops	0.8	1.0	0.5	2.3	1.1
Cellana radians	0.8	2.0	0.8	0.8	1.1
Haustrum scobina	0.8	1.5	-	0.8	0.8
Sypharochiton pelliserpentis	-	2.0	-	-	0.5
Notoacmea sp.	0.5	0.8	0.8	-	0.5
Haustrum haustorium	1.5	-	-	-	0.4

Table 6. Taxa characteristic of the mid-shore zone in order of average prevalence over the four baseline surveys based on a numerical ranking of relative abundance categories. [Abundant = 4, Common = 3, Occasional = 2, Rare = 1]. Shaded cells represent the most dominant taxa (up to five) for each category in the mid-shore zone at each intertidal site. Dash indicates taxon not observed.

	PL03	**PL16**	**LH05**	**LH07**	**Mean ranking**
ALGAE					
Hormosira banksii	4.0	0.5	3.0	3.5	2.8
Gelidium sp.	2.3	2.0	3.0	1.5	2.2
Scytothamnus australis	0.8	1.0	1.0	1.3	1.0
Leathesia sp.	1.3	0.5	0.8	0.5	0.8
Pyropia plicata	0.5	-	1.3	0.8	0.6
Coralline turf	1.5	-	-	1.0	0.6
Ralfsia sp.	0.8	0.5	-	0.8	0.5
Ulva intestinalis	0.5	-	1.0	0.5	0.5
Colpomenia sp.	1.3	-	0.5	-	0.4
SESSILE INVERTEBRATES					
Chamaesipho columna	3.5	4.0	4.0	4.0	3.9
Spirobranchus cariniferus	4.0	4.0	3.0	3.0	3.5
Xenostrobus neozelanicus	4.0	2.3	3.8	2.5	3.1
Epopella plicata	3.8	2.3	1.0	2.8	2.4
Mytilus galloprovincialis	2.8	1.5	2.3	1.3	1.9
Austrominius modestus	-	1.0	3.0	1.8	1.4
MOBILE INVERTEBRATES					
Diloma aethiops	3.0	2.8	3.0	2.3	2.8
Cellana ornata	3.0	2.5	3.0	2.3	2.7
Sypharochiton pelliserpentis	3.0	3.0	1.5	2.3	2.4
Cellana radians	1.5	2.5	1.5	3.0	2.1
Haustrum haustorium	2.5	2.5	-	0.8	1.4
Lunella smaragda	0.8	1.5	2.3	0.8	1.3
Siphonaria sp.	0.8	1.0	1.8	1.3	1.2
Haustrum scobina	0.5	1.5	-	1.5	0.9

Table 7. Taxa characteristic of the low-shore zone in order of average prevalence over the four baseline surveys based on a numerical ranking of relative abundance categories. [Abundant = 4, Common = 3, Occasional = 2, Rare = 1]. Shaded cells represent the most dominant taxa (up to five) for each category in the low-shore zone at each intertidal site. Dash indicates taxon not observed.

	PL03	**PL16**	**LH05**	**LH07**	**Mean ranking**
ALGAE					
Coralline turf	2.8	2.3	2.5	2.8	2.6
Undaria pinnatifida	2.0	2.3	2.3	2.8	2.3
Hormosira banksii	1.3	2.0	2.8	3.0	2.3
Ralfsia sp.	2.8	2.0	1.0	3.0	2.2
Gelidium sp.	0.8	3.0	3.0	1.5	2.1
Cystophora scalaris	1.5	1.5	2.0	2.8	1.9
Codium adherens	3.0	1.5	1.0	2.0	1.9
Splachnidium rugosum	2.5	1.8	1.3	0.8	1.6
Colpomenia sp.	-	2.5	1.3	0.8	1.1
SESSILE INVERTEBRATES					
Perna canaliculus	3.8	2.8	2.8	3.0	3.1
Mytilus galloprovincialis	3.0	3.0	3.0	3.0	3.0
Spirobranchus cariniferus	4.0	2.5	3.0	2.3	2.9
Epopella plicata	2.0	1.3	0.5	2.0	1.4
Chamaesipho columna	-	-	4.0	1.5	1.4
Ostrea chilensis	1.0	1.0	2.3	0.8	1.3
Austrominius modestus	-	-	3.0	2.0	1.3
Aulacomya maoriana	0.5	2.3	0.8	1.3	1.2
MOBILE INVERTEBRATES					
Lunella smaragda	2.3	2.8	2.3	2.3	2.4
Cellana radians	2.8	0.8	2.3	2.3	2.0
Diloma aethiops	1.5	1.8	3.0	1.5	1.9
Sypharochiton pelliserpentis	3.0	0.8	1.8	1.8	1.8
Cellana ornata	1.3	0.8	1.5	0.8	1.1
Haustrum haustorium	0.8	2.0	-	1.3	1.0
Notoacmea sp.	1.5	-	1.5	-	0.8

Table 8. Taxa characteristic of tide pools in order of average prevalence over the four baseline surveys based on a numerical ranking of relative abundance categories. [Abundant = 4, Common = 3, Occasional = 2, Rare = 1]. Shaded cells represent the most dominant taxa (up to five) for each category in tide pools at each intertidal site. Dash indicates taxon not observed.

	PL03	**PL16**	**LH05**	**LH07**	**Mean ranking**
ALGAE					
Cystophora scalaris	4.0	1.5	1.5	4.0	2.8
Macrocystis pyrifera	2.3	1.5	2.5	3.0	2.3
Coralline turf	3.8	-	2.5	2.5	2.2
Coralline paint	2.0	1.0	-	2.8	1.4
Carpophyllum maschalocarpum	2.5	1.5	0.5	1.0	1.4
Halopteris sp.	2.0	-	-	3.0	1.3
Hormosira banksii	2.0	0.5	0.5	1.5	1.1
Carpophyllum flexuosum	0.8	-	0.8	2.0	0.9
Colpomenia sp.	1.0	0.5	0.8	1.3	0.9
Undaria pinnatifida	1.3	-	0.5	0.8	0.6
Filamentous green alga	0.5	0.8	-	-	0.3
SESSILE INVERTEBRATES					
Anthothoe albocincta	1.3	-	1.8	1.5	1.1
Perna canaliculus	0.8	-	0.5	2.3	0.9
Oulactis muscosa	1.0	0.8	0.8	0.5	0.8
Watersipora subtorquata	1.5	0.3	0.3	0.8	0.7
Ostrea chilensis	1.8	-	0.5	0.3	0.6
Mytilus galloprovincialis	-	0.8	0.5	1.3	0.6
Pyura pachydermatina	1.8	-	-	0.3	0.5
Encrusting bryozoan	0.5	-	0.3	1.0	0.4
Tethya bergquistae	1.0	-	0.3	-	0.3
Solitary ascidian (cf, *Cnemidocarpa*)	0.3	0.3	0.3	0.3	0.3
Corella eumyota	-	0.3	0.3	0.3	0.2
MOBILE INVERTEBRATES					
Lunella smaragda	2.3	-	0.8	1.5	1.1
Cominella adspersa	0.8	-	1.3	0.8	0.7
Patiriella regularis	0.3	-	0.5	1.3	0.5
Acanthochitona zelandica	1.0	0.3	-	0.5	0.4
Sigapatella novaezelandiae	0.5	-	-	1.3	0.4
Microgastropods	-	-	-	1.8	0.4
Chiton glaucus	1.0	-	0.3	0.3	0.4
Diloma aethiops	-	-	-	1.5	0.4
Siphonaria sp.	1.3	-	-	-	0.3

Table 8, continued.	**PL03**	**PL16**	**LH05**	**LH07**	**Mean ranking**
MOBILE INVERTEBRATES, cont.					
Maurea punctulata	0.3	-	0.5	0.5	0.3
Zeacumantis sp.	1.3	-	-	-	0.3
Petrolisthes elongatus	0.3	-	0.5	0.5	0.3
Sypharochiton pelliserpentis	-	0.8	-	0.3	0.3
Buccinulum lineum	-	0.3	-	0.8	0.3
Haliotis iris	-	0.5	-	0.5	0.3

A total of 131 taxa were recorded over all sites and surveys, with the most taxa (91) recorded at PL03 in Port Levy, followed by LH07 (90), LH05 (78) and PL16 (73). These numbers are consistent with the physical nature of the sites. Both PL03 and LH07 are broad platform reefs with an abundance of tide pools. The combination of a range of habitat niches and the greater intertidal area resulting from a shallow gradient across zones serves to increase the diversity of taxa which may be observed. In contrast, the physical environments of PL16 and LH07 are more constrained; the former by a steep gradient reducing the total intertidal area available and the latter by the absence of a true high- and supra-tidal zone. Both sites also support fewer and smaller tide pools.

Total taxa richness through time followed a similar pattern across sites, with highest numbers observed during survey BL2. This pattern was reflected in the mid shore at PL03, the high and low shore at PL16, and the low shore and tide pools at LH05 and LH07 (Figure 19).

Common and abundant taxa were consistent across surveys, but there were some small differences in zonation over time for some taxa, and the presence/absence of a range of rare or occasional taxa. These differences can be due to seasonal variability, differences in the tidal range (neap/spring) at the time of survey (i.e. some low shore taxa may be missed if the tide is not low enough to expose them or visual identification is constrained by surge conditions) or simply the rarity or relative conspicuousness of the taxa.

Seasonal differences can be particularly noticeable in certain taxa. For example, some algal species are present during certain seasons or have short life cycles (e.g. *Petalonia* sp., *Pyropia* sp. [karengo], and *Scytosiphon lomentaria*). Weather conditions can also influence recorded taxa richness. For example, during hot dry days the leathery sea slug *Onchidella nigricans* is unlikely to be observed on exposed rocks because it is not desiccation-resistant, and other mobile species such as sea stars may also be less conspicuous. The BL2 survey occurred in September, when winter seasonal algae were present and the days were cooler, allowing mobile invertebrates to be more exposed and conspicuous.

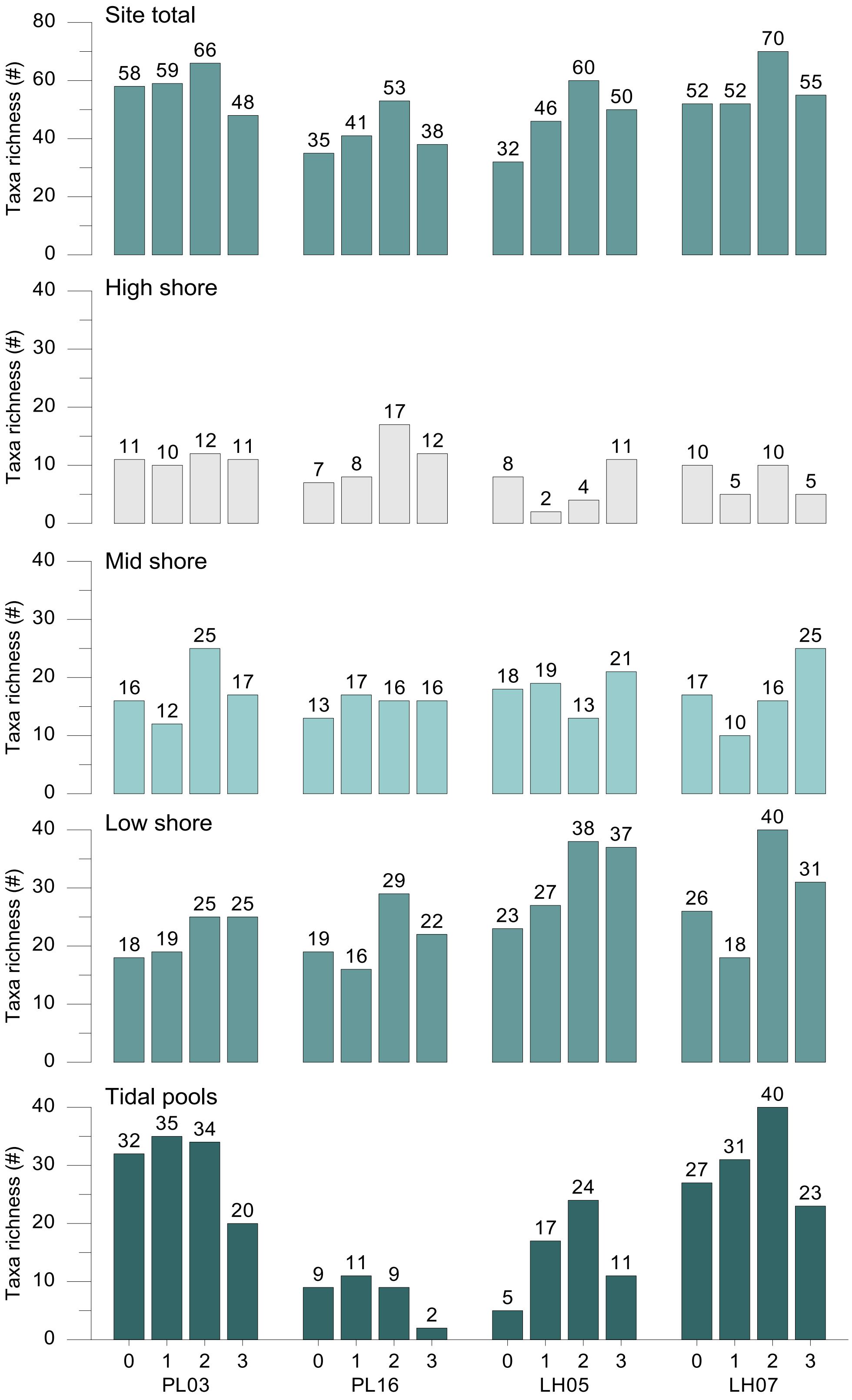

Figure 19. Number of intertidal reef taxa per site for each survey (0-3 = BL0-BL3) with a break-down of zonation. From top: total number of taxa per site, and number of taxa in the high, mid and low shore, and tidal pools.

3.2.6. Intertidal community data: Summary of observations and findings

The intertidal surveys found that the most abundant taxa occurred across all four sites, despite differences in the physical habitat and wave exposure.

The total number of intertidal taxa recorded varied across sites, but these differences were consistent with observed differences in physical habitat structure.

Common and abundant intertidal taxa were also consistent across survey events, but with some small differences in zonation over time for some taxa and indications of seasonal cycles for some algal species.

3.3. Benthic sampling

3.3.1. Field observations

Water depths

Water depths at each station were taken from the vessel sounder and corrected for tidal elevation to give approximate mean sea level (MSL) values. These are plotted in Figure 20, which groups and orders stations according to the transects to which they are principally assigned.

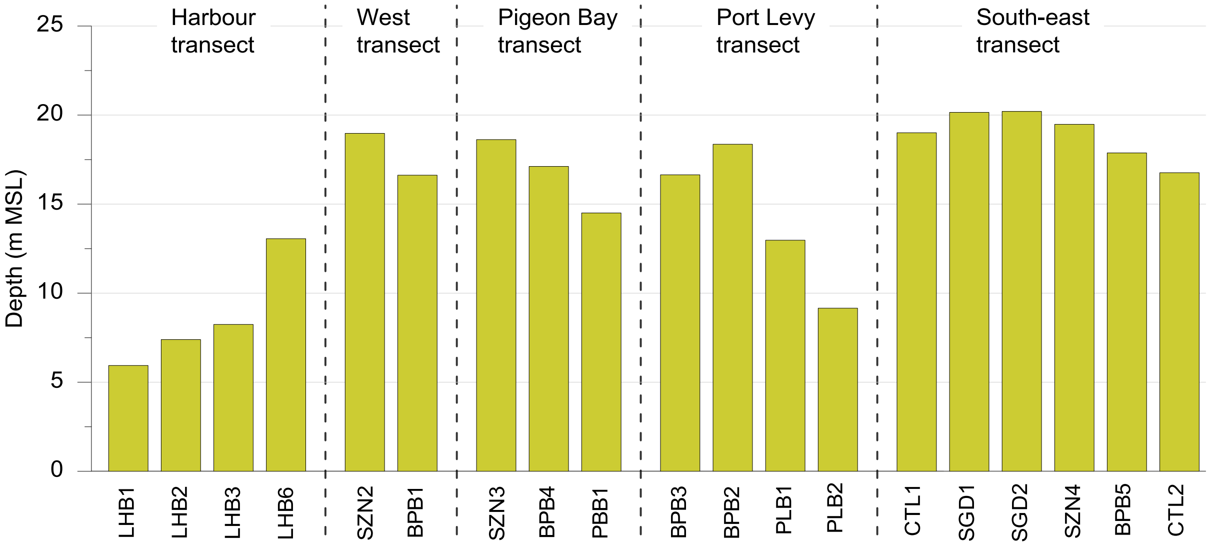

Figure 20. Approximate water depths (m MSL) for each of the 19 benthic sample stations grouped and ordered according to principal transect. Note that the node stations SGD1 and SGD2 are also on the West and Pigeon Bay transects (Figure 3). BPB3 is grouped with the Port Levy transect on the basis of proximity.

With the exceptions of stations CTL2 and BPB5, the stations outside Lyttelton Harbour consistently featured a fine soft grey/brown mud surface layer 4-10 cm thick overlying more consolidated fine grey material. There was some variability in the thickness of the unconsolidated surface layer, both between stations and between surveys. At stations BPB1, BPB2, BPB3 and PLB1, the unconsolidated surface layer extended to the full depth of grab penetration for the 2nd and 3rd baseline surveys (BL2, BL3).

Station CTL2 consistently featured heavy fine sand that was difficult to penetrate with the Van Veen grab. Although fine mud predominated at station BPB5, this was notably more consolidated than at other stations and also posed difficulty with grab penetration. In the later surveys (BL2, BL3), station PLB2 in Port Levy was also observed to yield predominantly consolidated material with little sign of a soft surface layer.

The variation in substrate colour down the core profile (grey/brown to grey) was generally consistent with the transition to more consolidated underlying material. However, the colour transition was consistently indistinct, occurring at 4-7 cm depth where it was observed. A lack of notable sulphide odour in the underlying material was also consistent with the absence of a distinct redox potential discontinuity (aRPD) in the sediment profile.

Harbour stations

Compared to the stations offshore from the heads, sediments from the four Lyttelton Harbour stations were highly variable. Cores from the outer station LHB6 were similar to the soft mud sediments of the Harbour approaches, but tended to be unconsolidated to the full depth of the 10 cm core. In sharp contrast, samples from LHB2 and LHB3 were noticeably sandy and a darker shade of grey with no visible colour change in the top 10 cm of the profile.

The innermost Harbour station (LHB1) featured an overlying ~2 cm layer of unconsolidated grey silt with a transition to darker semi-consolidated mud at ~3-4 cm. LHB1 was also notable in having a higher occurrence of shell fragments and other large particulate debris in the profile.

Despite the darker sediment colouration at the three inner stations, none of the Harbour sediments were noted for any strong sulphide odour.

3.3.2. Sediment texture and organic enrichment

Figure 21 plots the grain size distribution and total organic carbon for sediment samples from all of the baseline surveys including the scoping survey BL0 (February 2016, where eight of the eventual 19 monitoring stations were sampled). Grain size distribution was found to be most spatially variable for sample stations inside Lyttelton Harbour, with LHB1 and LHB6 dominated by the silt/clay fraction (particle sizes of less than 63 µm) and LHB2 and LHB3 dominated by the very fine sand fraction (Figure 21). These stations also exhibited the highest relative variability in sediment texture between replicates and surveys, possibly due to small scale spatial variability of the seabed at these sites.

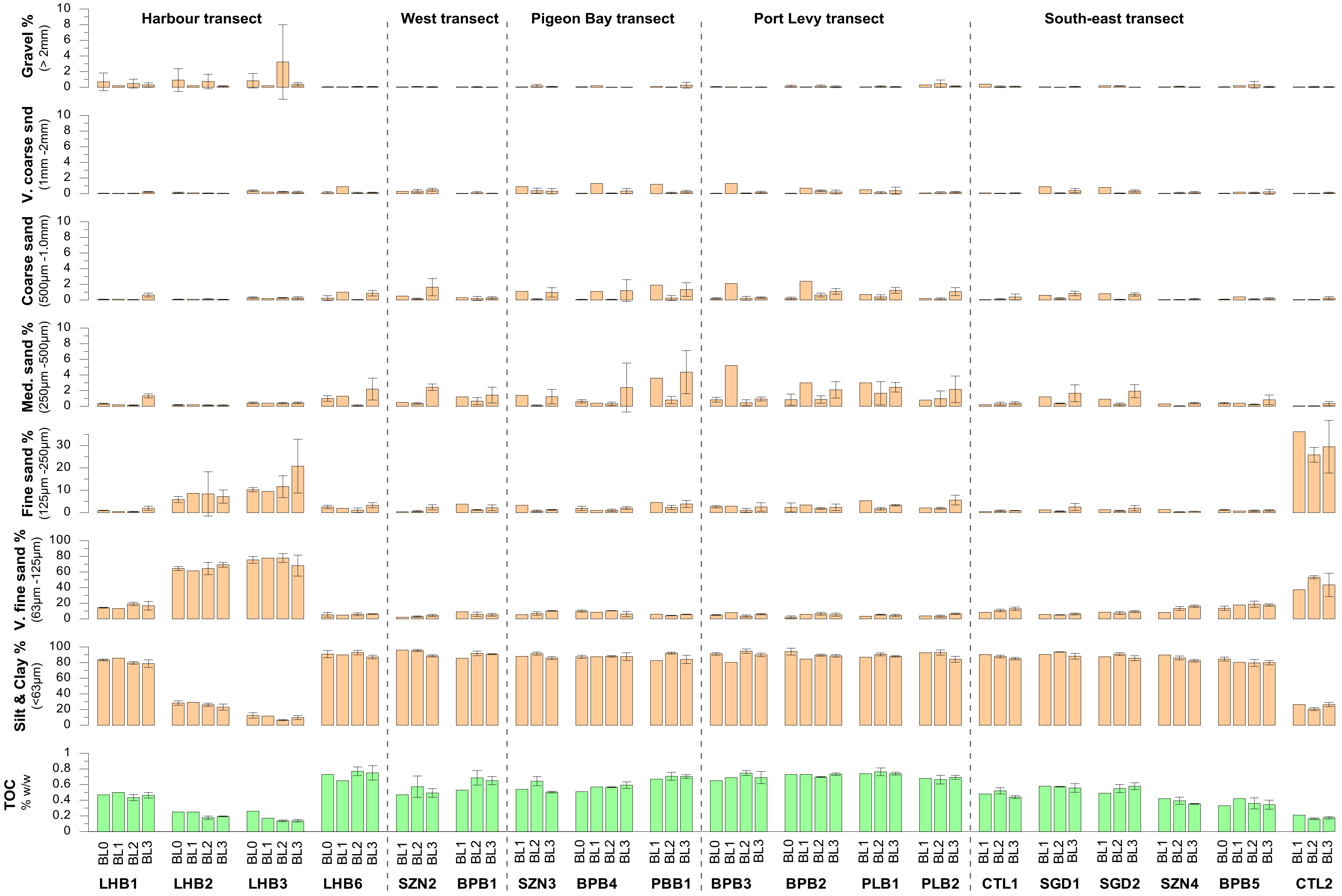

Figure 21. Patterns in sediment texture and organic content across surveys and along transects. Error bars are ±1 standard deviation of triplicate samples.

Sediment samples from all stations outside the Harbour heads, except CTL2, were consistently dominated by the silt/clay fraction (75–98%). The small amount of variation observed for these stations was most notable in the very fine sand component (63–125 µm), especially for stations further offshore and to the south-east. It was noted from more spatially extensive sampling carried out from 2007 that higher proportions of very fine sands occurred sporadically throughout the proposed spoil ground, suggesting small-scale heterogeneity or patchiness in the substrate (Atalah & Sneddon 2016). However, stations along the south-east transect indicate a minimal very fine sand component at the two spoil ground stations (SGD1, SGD2; 5-10%) and increasing gradually further to the south-east until station CTL2 which featured substantially greater very fine (28-57%) and fine sand (19-42%) components. The substrate at this station makes it distinctly different to all other offshore stations, and it would be expected to support a different benthic community assemblage as a result (see Section 3.3.6).

Sediment organic content, as indicated by total organic carbon (TOC), was relatively low overall, ranging from 0.12% to 0.85%, with the lowest values coinciding with sandier sediments from station CTL2, LHB2 and LHB3 (Figure 21). The highest values were generally associated with areas of high silt/clay content, this being generally typical of depositional seafloor environments.

As noted, the extracted cores were generally light grey/brown in colour and did not exhibit distinct layering. The absence of a distinct aRPD layer is consistent with the relatively low organic content of the samples and suggests sufficient oxygenation of the sediments through diffusion, resuspension and bioturbation[4] processes.

Observations of spatial gradients

Grouped according to potential CDP effects gradients, the sediment data plotted in Figure 21 give some indication of baseline spatial variability. The low temporal variability indicated by the multi-survey data suggests that background sediment texture is maintained in a relatively steady state by natural processes. This stability allows the averaging of all sample replicates for individual stations to define spatial gradients along the transects of interest. These established gradients can then be used to detect and quantify subsequent perturbations from natural and anthropogenic drivers.

The transect scatter plots for TOC and sediment grain size fractions finer than medium sands (< 250 µm) are presented in Figure 22 to Figure 24. These show generally low variability in the fine sediment fractions and TOC at the offshore and coastal transect stations and relatively higher variability at stations closer to the Harbour entrance and within the Harbour.

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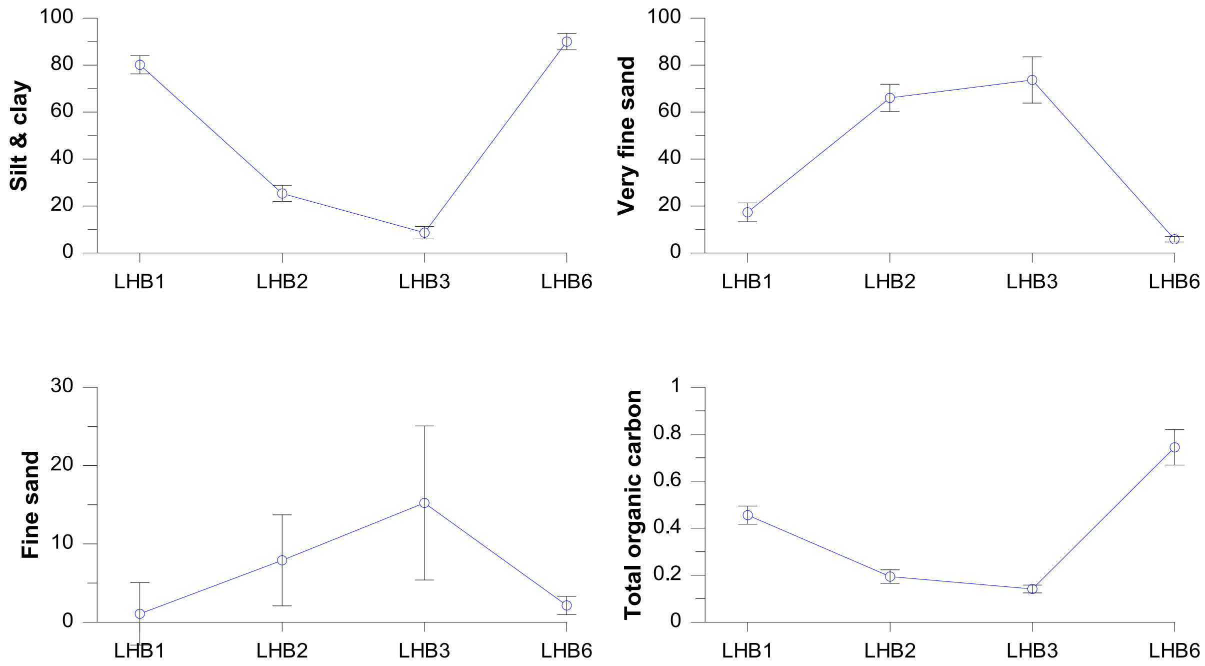
[4] The displacement and mixing of sediment particles by benthic fauna. The mediators of bioturbation are typically annelid worms (e.g. polychaetes, oligochaetes), bivalve and gastropod molluscs and echinoderms (e.g. holothurians, burrowing urchins).

Lyttelton Harbour transect



West transect

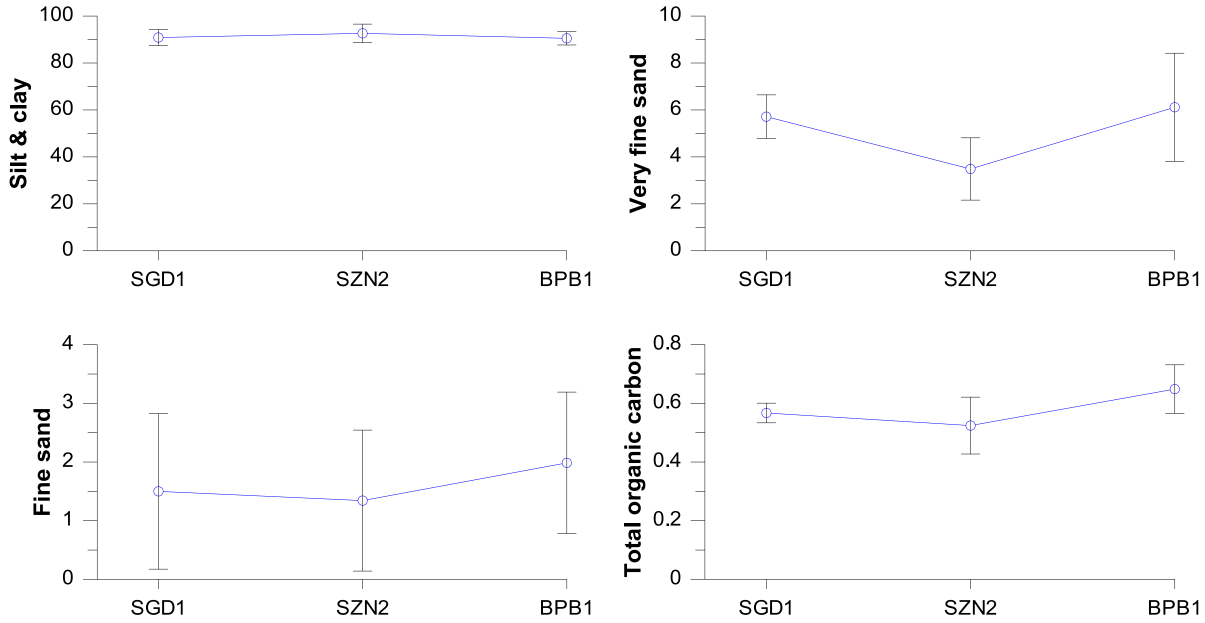
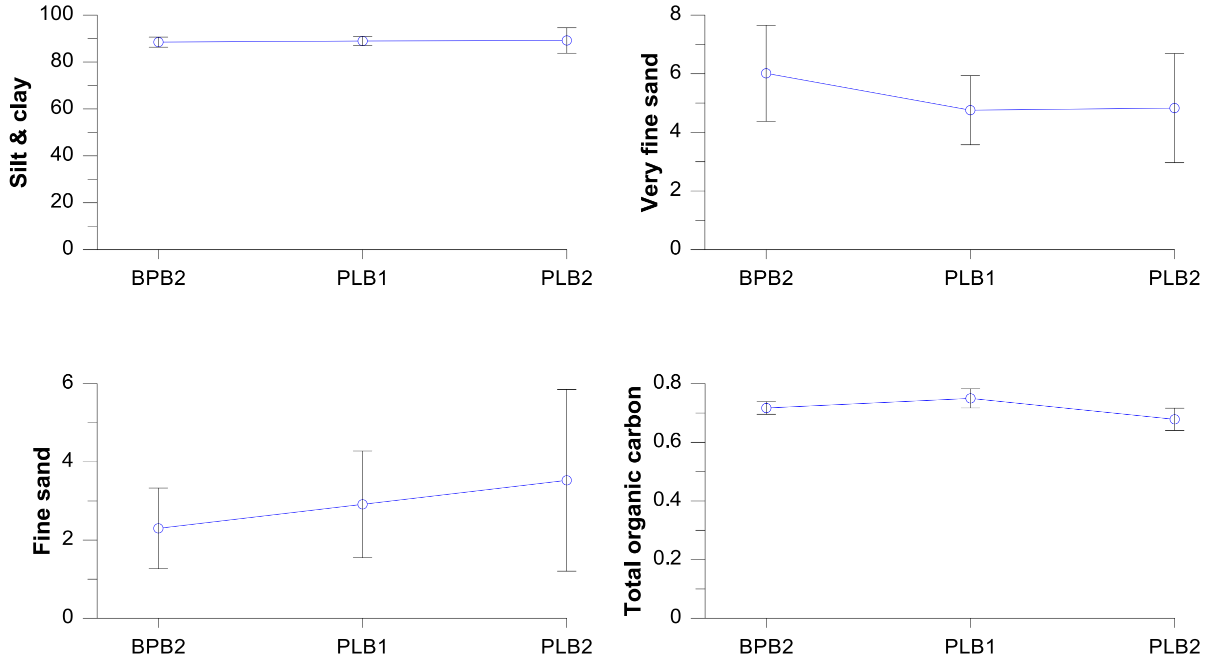


Figure 22. Gradients in grain size fractions and organic content (g/100 g) at stations along the Lyttelton Harbour (top) and West (bottom) transects from the three baseline surveys conducted in 2017. Error bars represent ± 1 std deviation (n = 7).

Port Levy transect



Pigeon Bay transect

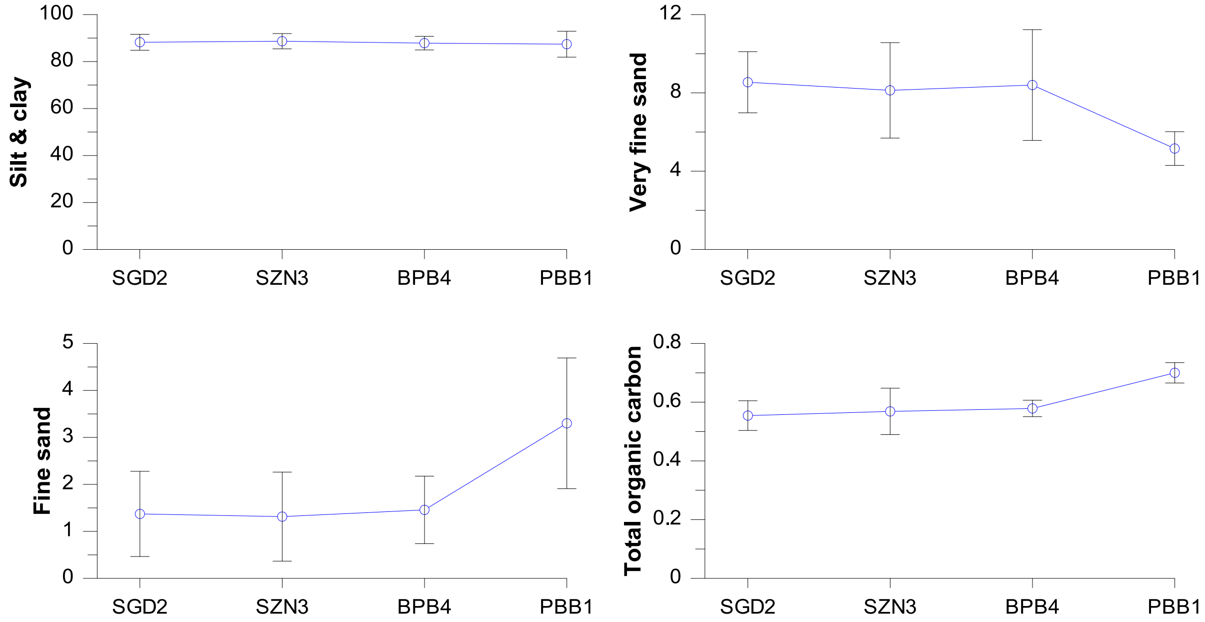
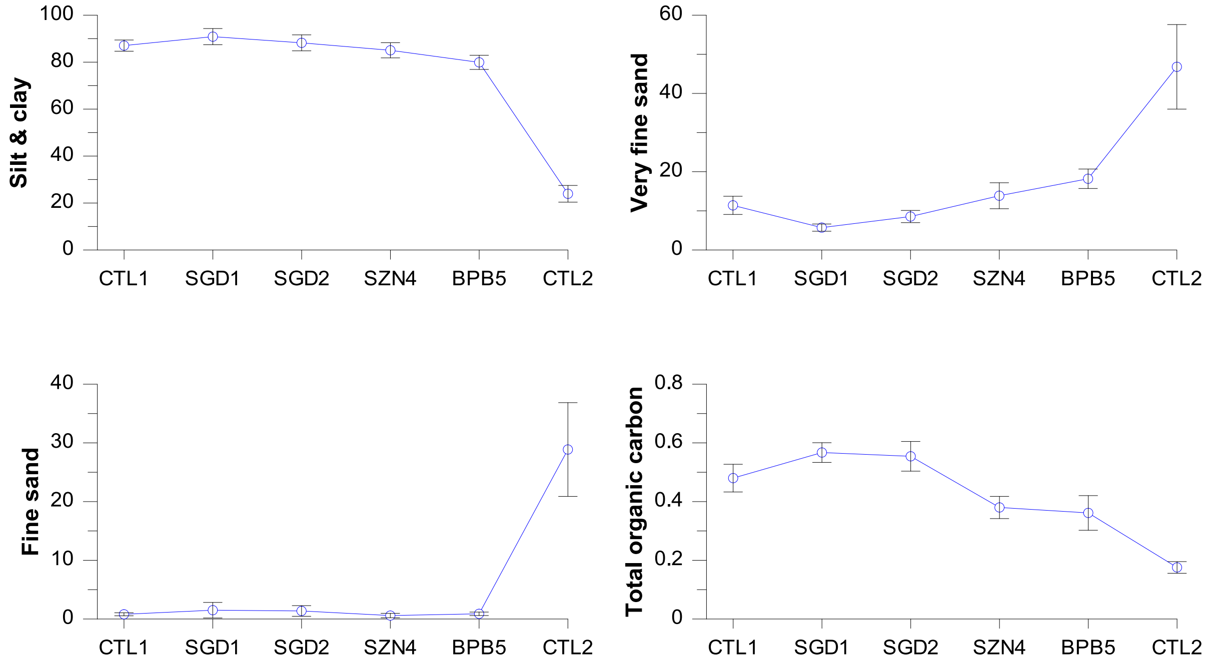


Figure 23. Gradients in grain size fractions and organic content (g/100 g) at stations along the Port Levy (top) and Pigeon Bay (bottom) transects from the three baseline surveys conducted in 2017. Error bars represent ± 1 std deviation (n = 7).

South-east transect



Coastal transect

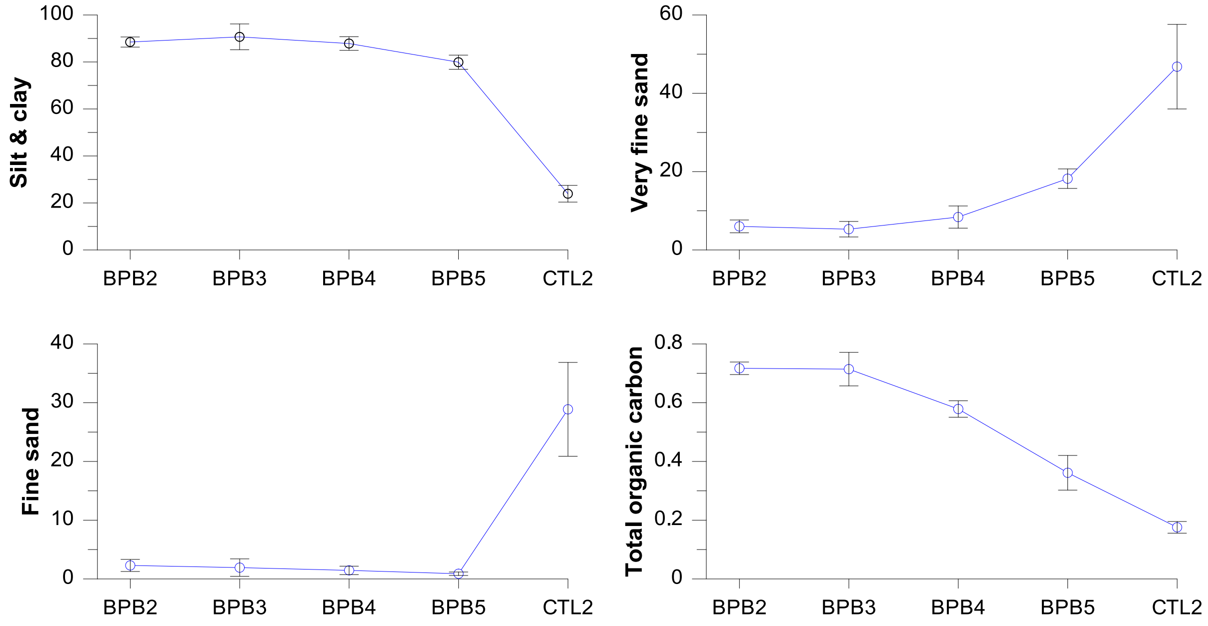


Figure 24. Gradients in grain size fractions and organic content (g/100 g) at stations along the South-east (top) and Coastal (bottom) transects from the three baseline surveys conducted in 2017. Error bars represent ± 1 std deviation (n = 7).

Well-defined background spatial gradients were apparent only for the South-east and Coastal transects, with the silt/clay fraction and TOC generally decreasing towards the south-east, along with corresponding increases in the very fine sand component (Figure 24). For other transects, profiles in these principle sediment constituents tended to be relatively flat, the exception being the Harbour stations. Although broadly consistent across surveys, these reflected the distinct sediment environments of the individual Harbour stations. It should be noted that, not only is the spatial variability of Harbour sediments well documented by previous studies (e.g. Curtis 1986, Hart et al. 2008), but aligned roughly parallel to the shipping channel; these four stations do not constitute a true potential impact gradient from the CDP dredging programme. Sampling results during and following the activity must therefore be considered largely against the baseline characterisation of the individual stations.

3.3.3. Sediment trace metals and contaminants

The sediment trace metal analysis data from the four baseline surveys are shown in Figure 25. As naturally-occurring elements, all metals have a characteristic background level in sediments. With the exception of nickel, which appears to be present at naturally elevated background concentrations[5], levels of indicative trace metals in samples from all 19 benthic sample stations were well below the corresponding trigger levels listed in the ANZECC (2000) sediment quality guidelines[6]. Nickel has an ISQG-Low trigger value of 21 mg/kg. Analytical results for nickel in samples from the 19 benthic stations ranged 10–19 mg/kg. Concentrations for the other metals tested did not generally exceed of half the ISQG-Low value.

Both spatial and temporal variability in metals concentrations was low, although some minor patterns were apparent.

Arsenic[7] was slightly higher in Harbour sediments (5.6–9.2 mg/kg), but the four Harbour stations did not otherwise stand out as featuring higher metals levels than stations further offshore.

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[5] Natural levels of many metals can vary significantly with regional geology.

[6] The Interim Sediment Quality Guidelines (ISQG) -Low and -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 (ISQG-High) indicates a *probable* biological effect.

[7] Technically a metalloid, the inclusion of arsenic under the general term ‘metals’ is undertaken for convenience here.

Figure 25. Patterns in sediment trace metal concentrations across surveys and along transects. Error bars are ±1 standard deviation of triplicate samples. ANZECC (2000) ISQG-Low trigger values at right.

The transect scatter plots for sediment trace metal concentrations are presented in Figure 26, Figure 27, Figure 28, Figure 29, Figure 30 and Figure 31. Consistent with their low variability overall, spatial gradients in sediment metal concentrations tended to be gradual. Marginally increasing gradients for all eight tested metals are suggested by plotted mean values for the West and Pigeon Bay transects (Figure 27 and Figure 29, respectively). More distinct gradients decreasing eastwards are evident for all metals except arsenic in the plots for South-east and Coastal transect stations (Figure 30 and Figure 31, respectively).

It is important to note that, at these generally low concentrations, changes in sediment macrofaunal communities in direct response to the observed variation in metals levels would not be expected. However, the relative stability of metals levels defined by the baseline data means that even quite low-level changes in levels and gradients may be detected from subsequent sampling.

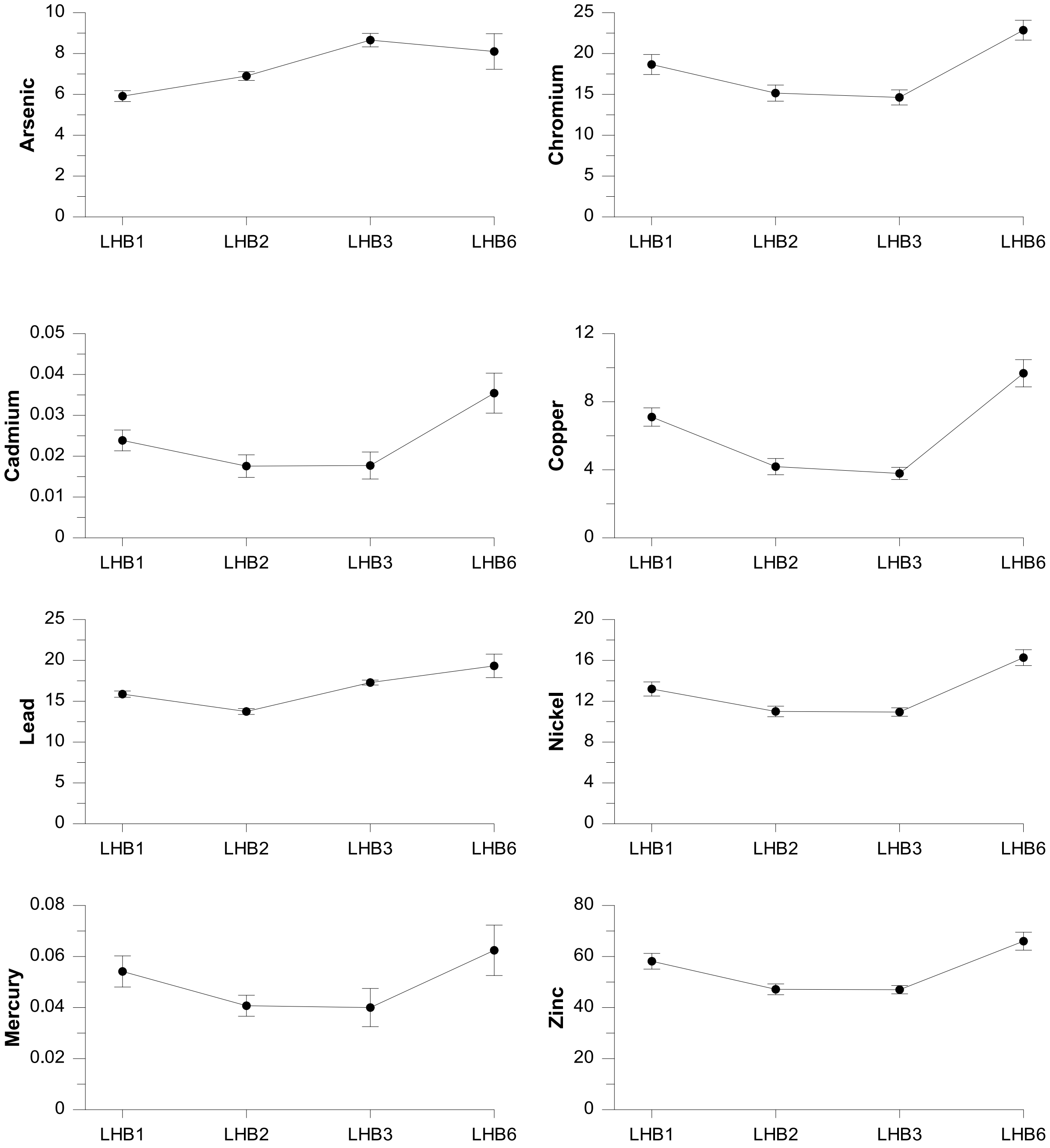

Figure 26. Gradients in trace metal concentrations (mg/kg) at stations along the Lyttelton Harbour transect from the three baseline surveys conducted in 2017. Error bars represent ± 1 std deviation (n = 7).

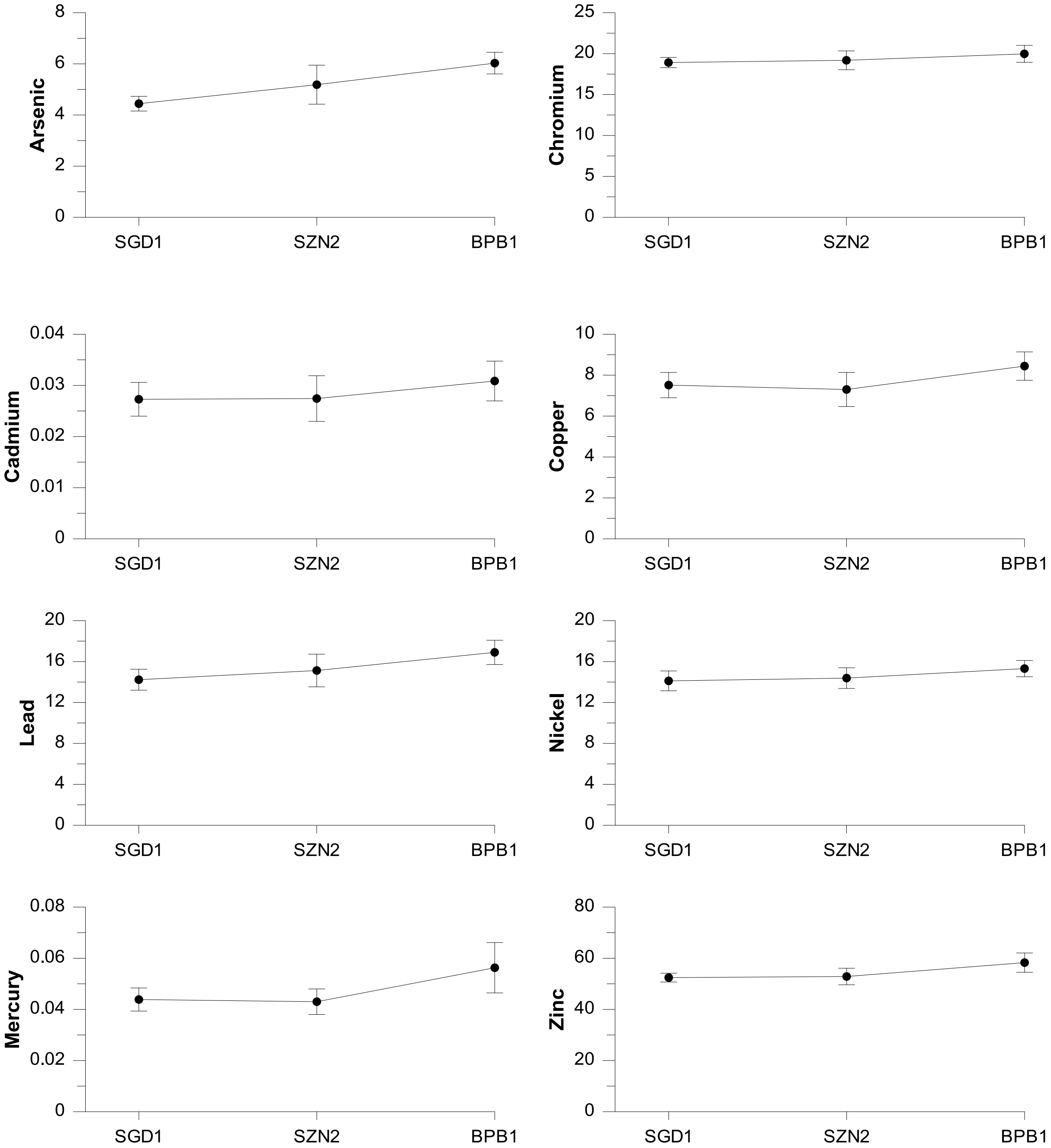

Figure 27. Gradients in trace metal concentrations (mg/kg) at stations along the West transect from the three baseline surveys conducted in 2017. Error bars represent ± 1 std deviation (n = 7).

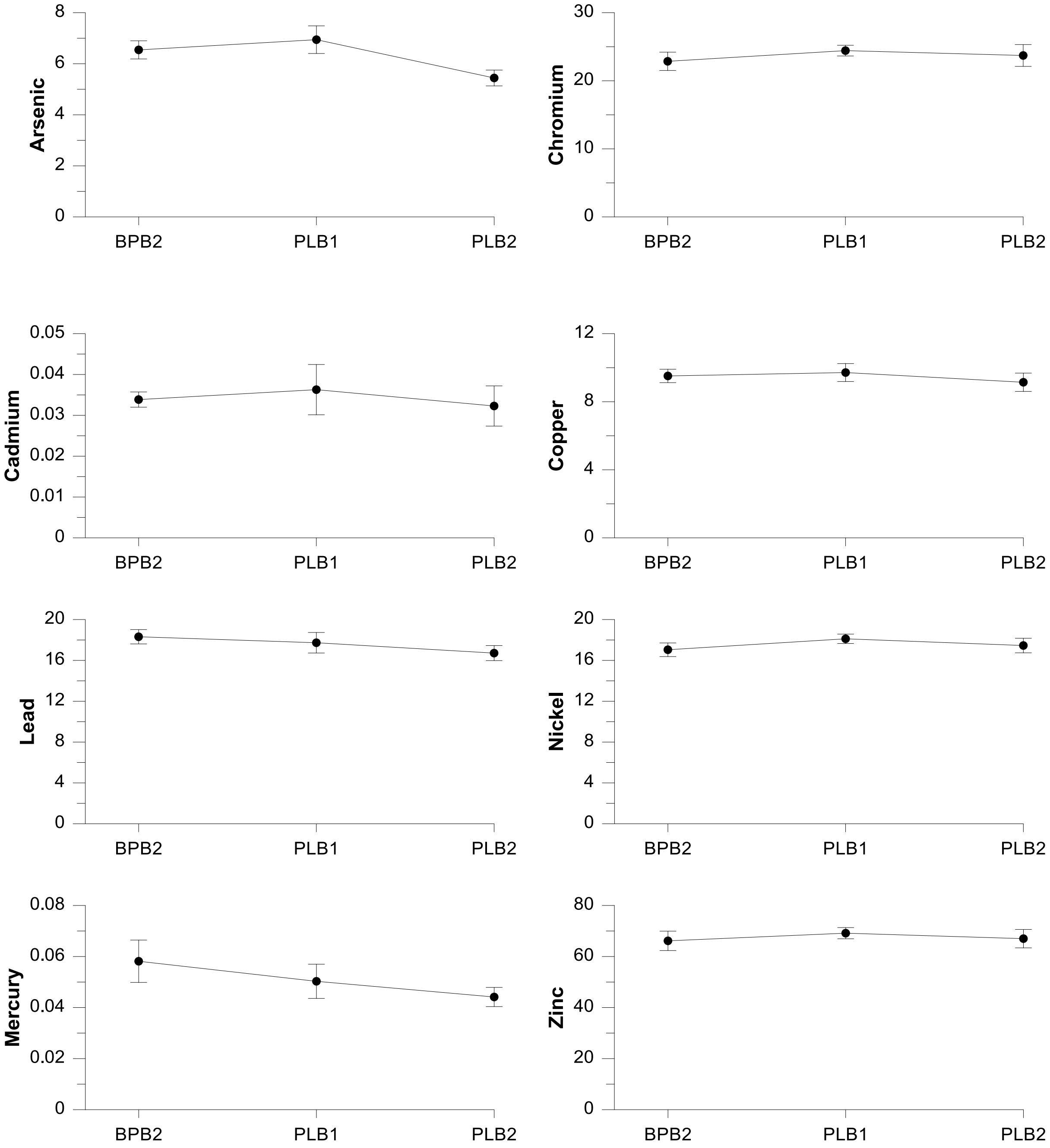

Figure 28. Gradients in trace metal concentrations (mg/kg) at stations along the Port Levy transect from the three baseline surveys conducted in 2017. Error bars represent ± 1 std deviation (n = 7).

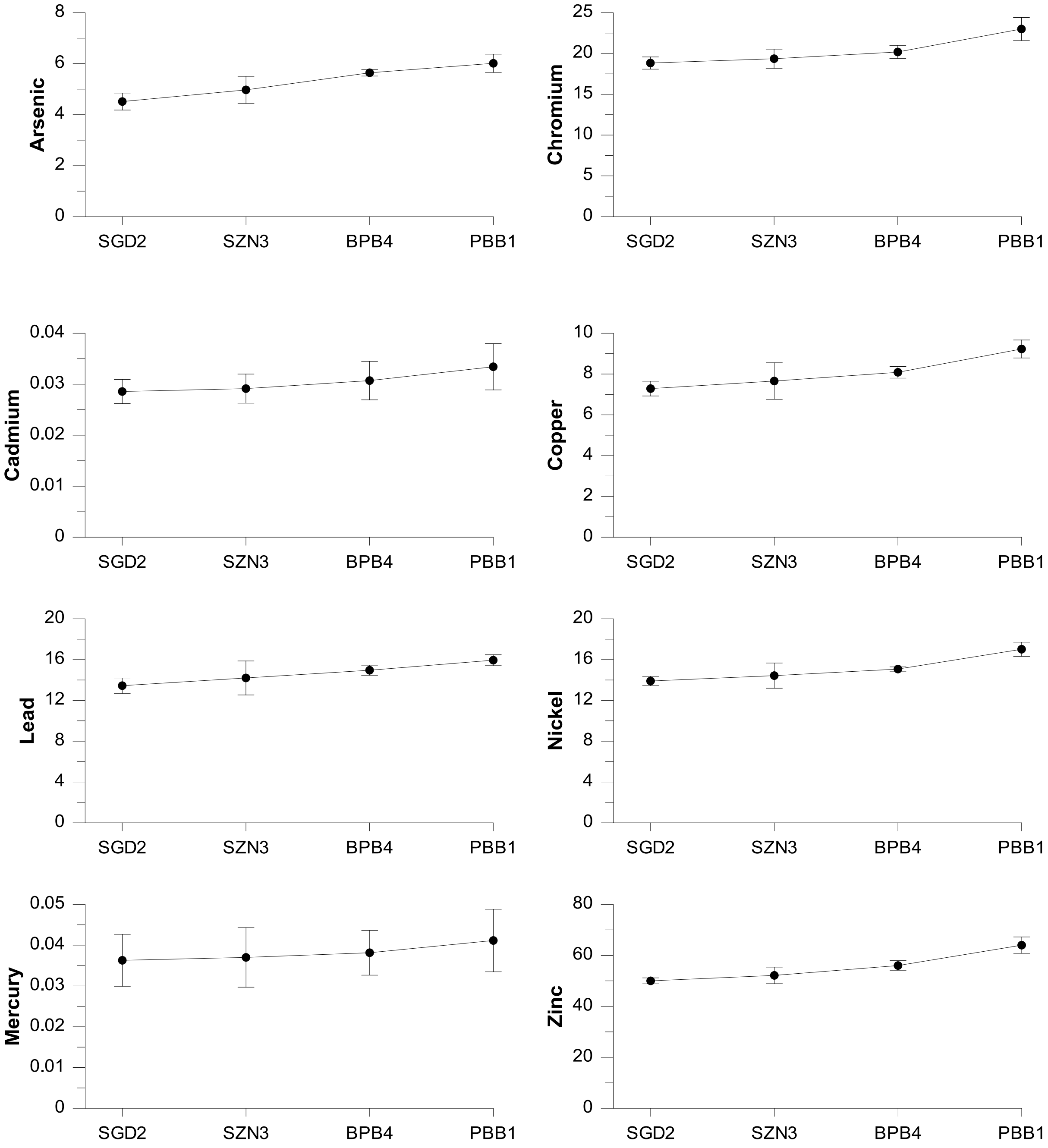

Figure 29. Gradients in trace metal concentrations (mg/kg) at stations along the Pigeon Bay transect from the three baseline surveys conducted in 2017. Error bars represent ± 1 std deviation (n = 7).

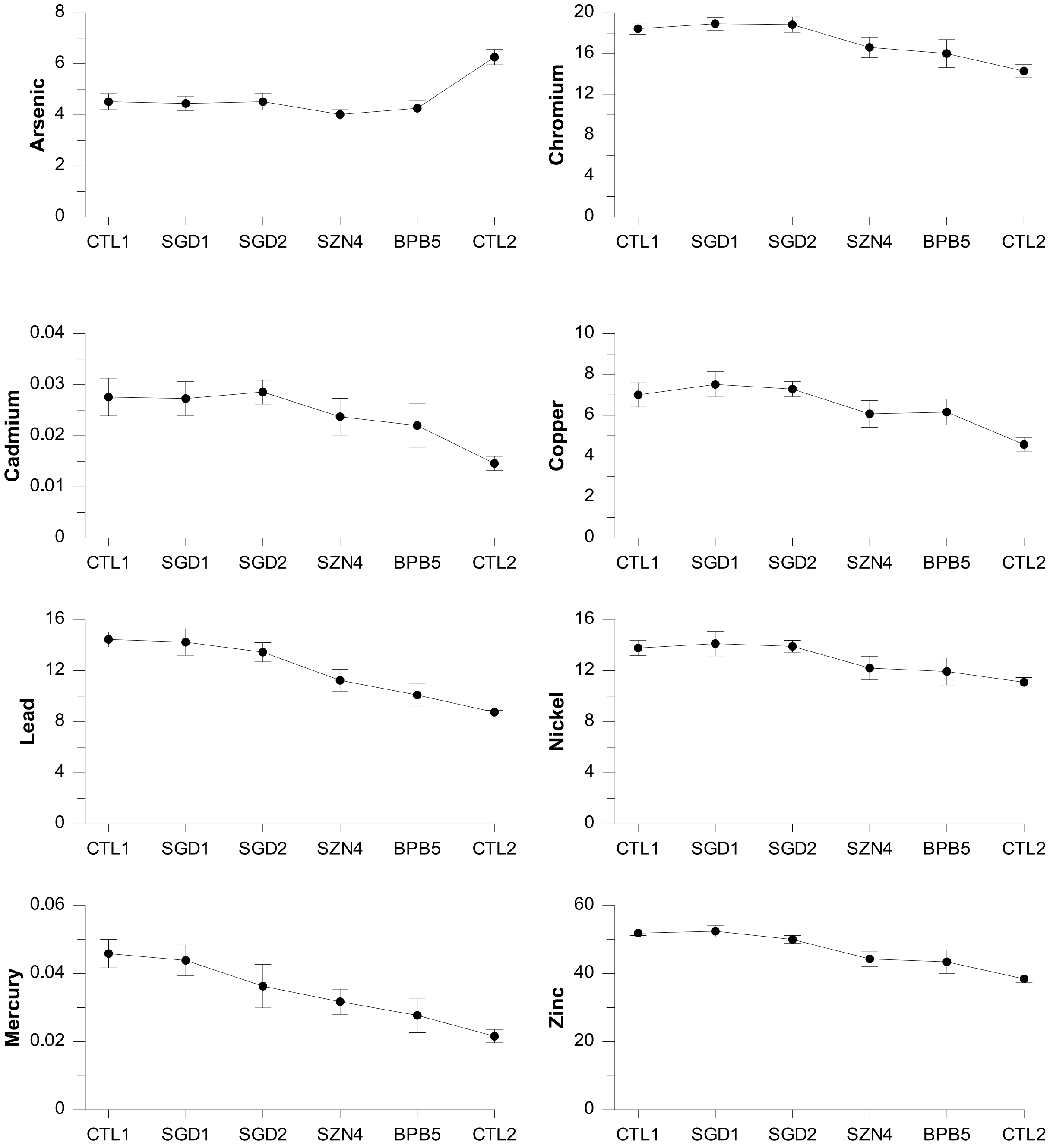

Figure 30. Gradients in trace metal concentrations (mg/kg) at stations along the South-east transect from the three baseline surveys conducted in 2017. Error bars represent ± 1 std deviation (n = 7).

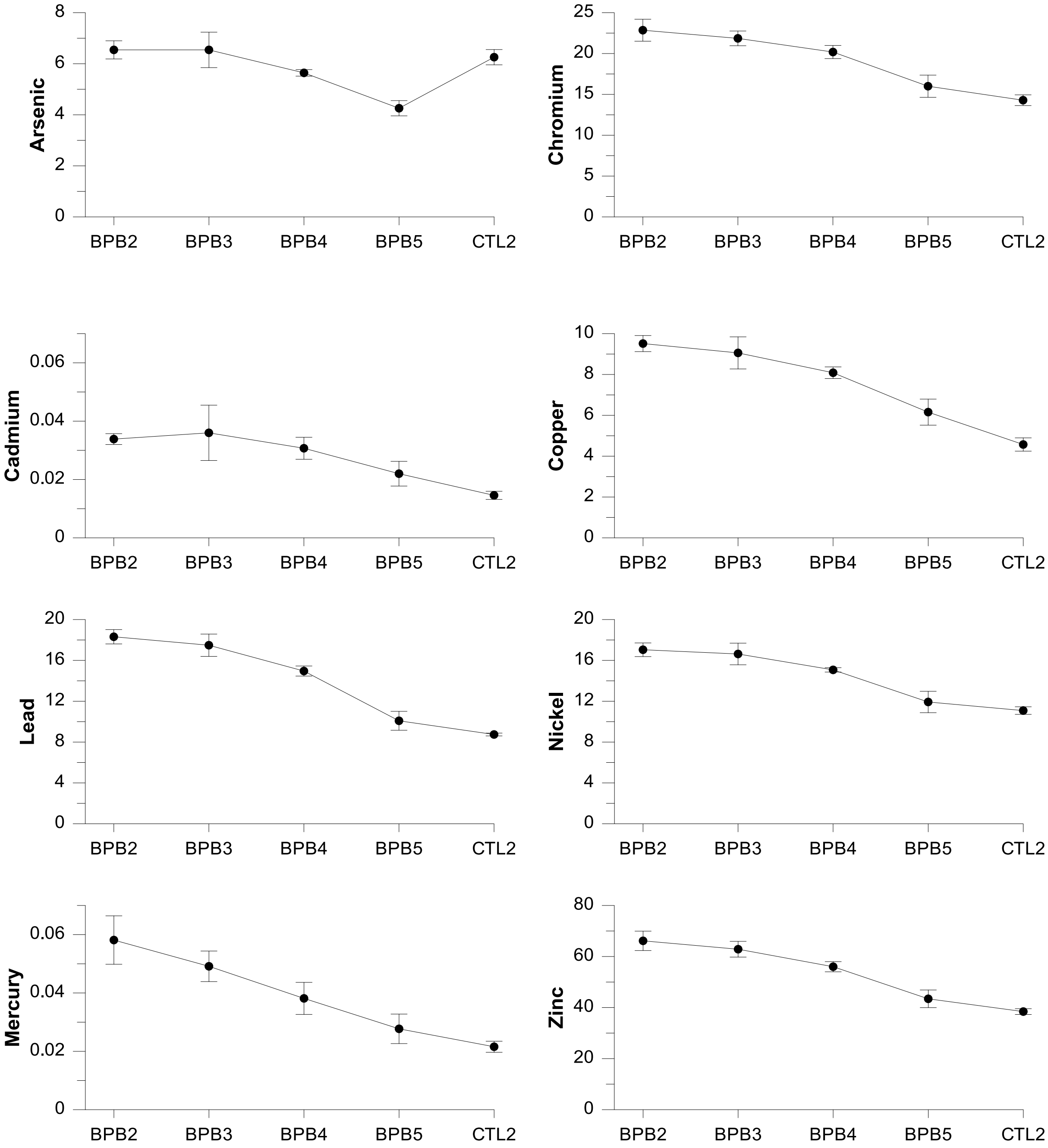

Figure 31. Gradients in trace metal concentrations (mg/kg) at stations along the Coastal transect from the three baseline surveys conducted in 2017. Error bars represent ± 1 std deviation (n = 7).

Sediment organic contaminants

In each of the three 2017 baseline surveys, sediment samples composited from triplicate grabs at five of the 19 benthic stations were analysed for polycyclic aromatic hydrocarbons (PAHs). PAHs are a group of complex hydrocarbons comprised of two or more fused benzenoid rings. They are common constituents of fuels (including coal) and lubricating oils, but most typically arise from the incomplete combustion of organic material. Many PAHs have a number of natural sources (e.g. combustion of organics during forest fires or as primary or secondary products of natural plant and microbial metabolism). However, elevated sediment concentrations derive largely from human activity. Most PAHs will not dissolve easily into water and they tend to bind to sediments and particulate organic matter.

The five stations designated for PAH monitoring are shown in Figure 32 along with three stations (USB1-3) within the hitherto undredged section of the Port Lyttelton swing basin proposed under the CDP. These Harbour stations were sampled by grab during the first baseline survey (BL1) in January 2017 and the results are included here to provide some context for the material to be dredged and deposited offshore.

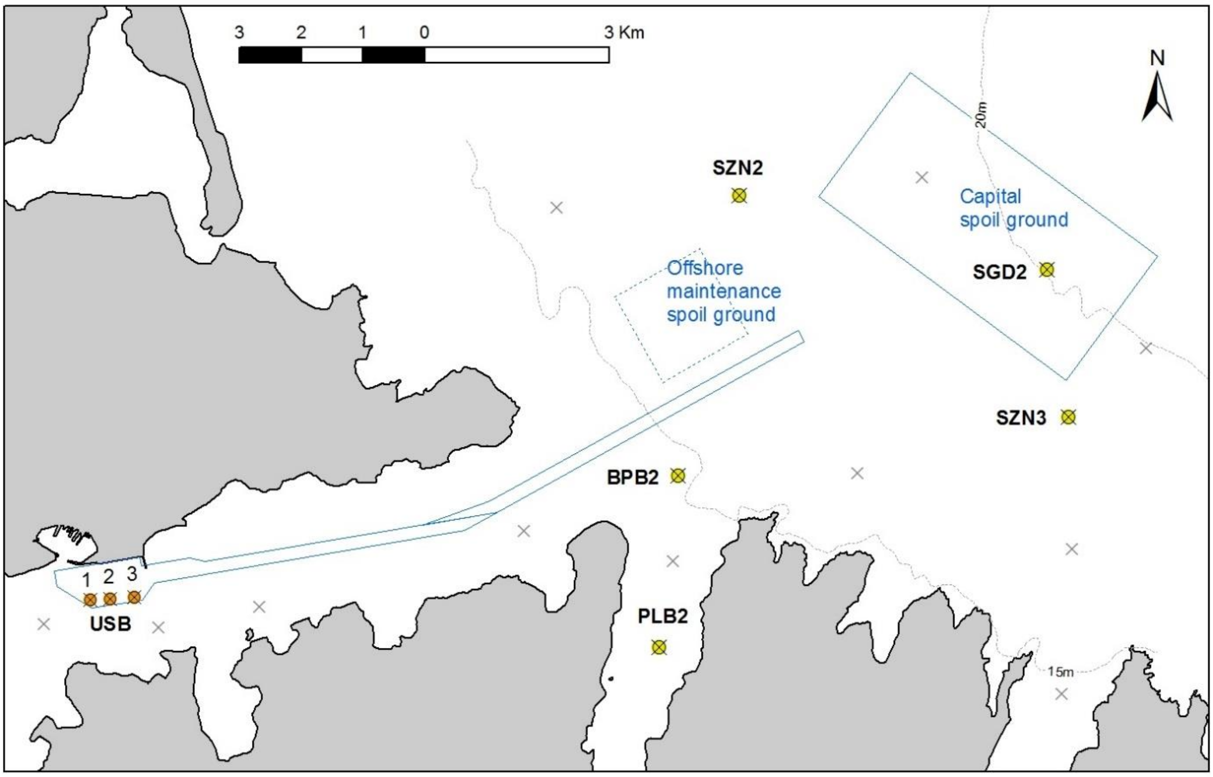

Figure 32. Spatial layout of benthic stations for which analyses for polycyclic aromatic hydrocarbons were conducted. The three (swing basin) stations within Lyttelton Harbour were sampled during the first baseline survey (BL1, Jan 2017) but do not form part of regular monitoring for the CDP.

Figure 33 plots the summations[8] for low- and high-molecular weight and total PAHs in sediment samples. In order to conservatively accommodate analytes below analytical detection limits, values of ADL/2 have been substituted into the summations. Since the primary objective is to establish a baseline against which future change may be measured (as opposed to the current potential for sediment toxicity), the data have not been normalised to sediment organic carbon[9].

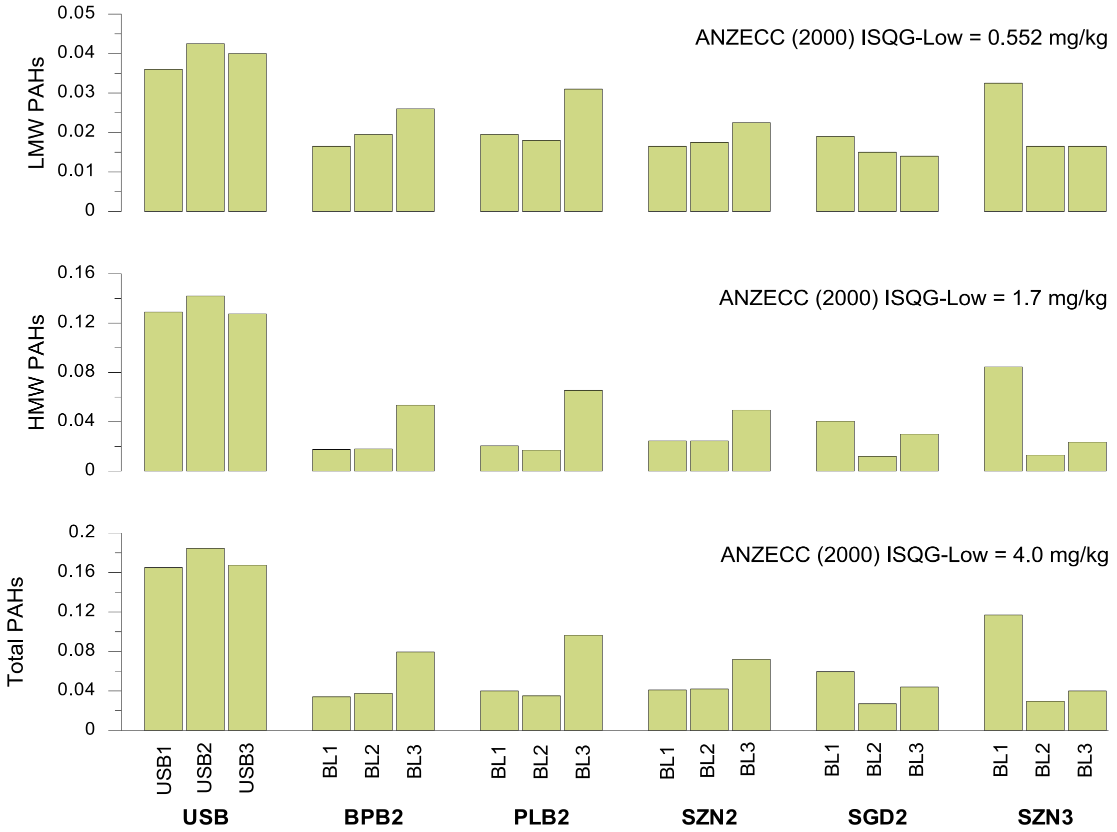

Figure 33. Analytical results for low- and high-molecular weight (LMW and HMW) and total polycyclic aromatic hydrocarbons for the five designated stations across the three baseline surveys. Results for the three swing basin samples (USB) collected in August 2016 are included for comparative purposes.

Figure 33 shows that PAHs were consistently higher in sediments from the proposed swing basin extension area in Lyttelton Harbour than in those from stations from outside the heads. However, the most notable feature of the plot is that, for all

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[8] The ANZECC (2000) sediment quality guidelines stipulate low molecular weight PAHs as the sum of concentrations of naphthalene, acenaphthylene, acenaphthene, fluorene, anthracene and phenanthrene; hence 2-methylnaphthalene is omitted from the summation. For high molecular weight PAHs, contributing analytes are benzo(a)anthracene, benzo(a)pyrene (BAP), chrysene, dibenzo(a,h)anthracene, fluoranthene and pyrene; hence benzo[b]fluoranthene, benzo[k]fluoranthene, indeno(1,2,3-c,d)pyrene and benzo[g,h,i]perylene are omitted from the summation. Total PAHs is the sum of the above high- and low-molecular weight analytes.

[9] ANZECC (2000) requires that concentrations of organic contaminants are first normalised to 1% organic carbon before comparison to trigger levels. This allows for the fact that many organic contaminants bind strongly to organic matter, decreasing bioavailability and hence toxicity.

sediment samples, concentrations of all three PAH summations were more than an order of magnitude lower than the applicable ANZECC (2000) ISQG-Low criteria[10] where a biological effect might be expected.

The results for individual PAH analytes are listed in Table 9 and highlighted by a colour gradient (varying with the concentration relative to ISQG-Low) to aid interpretation. The higher concentrations in the swing basin extension samples (USB1-3) are evident across all analytes detected. Of the low-molecular weight PAHs, only phenanthrene was consistently above ADL. The apparent higher relative concentrations of fluorene in samples where it was detected should be interpreted with caution since this is likely to be as much an artefact of the relative magnitudes of the low ISQG-Low value (0.019 mg/kg) and the ADL (0.003 mg/kg) as any actual prevalence of this compound[11]. Consistently higher concentrations occurred for stations SGD2 and SZN3 in the first baseline survey (BL1) but for the other three stations in the third survey (BL3).

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[10] In a revision of the ANZECC sediment quality guidelines, Simpson et al. (2010) used revised and improved effects data and guideline derivation approaches. They recommended that the ISQG-Low trigger of 4 mg/kg for total PAHs be replaced by an increased SQG-Low value of 10 mg/kg.

[11] By using a ratio to ISQG-High instead of -Low, the apparent relative dominance of fluorene disappears.

Table 9. Sediment concentrations (mg/kg) of polycyclic aromatic hydrocarbons (PAHs; molecular weight order, no normalisation) from the designated stations across three surveys. Shaded values denote concentrations above ADL. Cell colour variation is based on the ratio of the concentration to ISQG-Low or assigned equivalent (increasing green to yellow to red). Note that, where ISQG triggers are not provided by ANZECC (2000) (grey-shaded analytes), values have been assigned proportionately according to ratios between Puget Sound Maximum levels (PSML; PSDDA 1989). This is solely to provide a benchmark to facilitate the visual interpretation of relative elevation and spatial and temporal trends. It should not be taken as an evaluation of toxicity, relative or otherwise.

Station	**Survey**	**Naphthalene**	**2-Methylnaphthalene**	**Acenaphthylene**	**Acenaphthene**	**Fluorene**	**Anthracene**	**Phenanthrene**	**Pyrene**	**Fluoranthene**	**Benzo[a]anthracene**	**Chrysene**	**Benzo[a]pyrene (BAP)**	**Benzo[b+j]fluoranthene**	**Benzo[k]fluoranthene**	**Indeno(1,2,3-c,d)pyrene**	**Benzo[g,h,i]perylene**	**Dibenzo[a,h]anthracene**
USB1	**BL1**	< 0.014		< 0.003	< 0.003	0.003	0.005	0.018	0.037	0.036	0.016	0.017	0.02	0.023	0.012	0.012	0.013	0.003
USB2	**BL1**	< 0.013		< 0.003	< 0.003	0.003	0.008	0.022	0.041	0.04	0.017	0.02	0.021	0.025	0.011	0.013	0.014	0.003
USB3	**BL1**	< 0.014		< 0.003	< 0.003	0.004	0.006	0.02	0.037	0.034	0.017	0.018	0.02	0.025	0.009	0.012	0.014	< 0.003
BPB2	**BL1**	< 0.015		< 0.003	< 0.003	< 0.003	< 0.003	0.003	0.005	0.005	< 0.003	< 0.003	0.003	0.004	< 0.003	< 0.003	< 0.003	< 0.003
	BL2	< 0.019		< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	0.005	0.005	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	0.006	< 0.004	< 0.004
	BL3	< 0.013	0.005	< 0.003	< 0.003	0.004	< 0.003	0.011	0.015	0.014	0.007	0.007	0.009	0.012	0.004	0.007	0.011	< 0.003
PLB2	**BL1**	< 0.015		< 0.003	< 0.003	< 0.003	< 0.003	0.006	0.006	0.006	< 0.003	< 0.003	0.004	0.005	< 0.003	< 0.003	< 0.003	< 0.003
	BL2	< 0.016		< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	0.004	0.005	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	0.004	< 0.004	< 0.004
	BL3	< 0.013	0.007	< 0.003	< 0.003	0.006	< 0.003	0.014	0.02	0.017	0.007	0.009	0.011	0.016	0.004	0.011	0.016	< 0.003
SZN2	**BL1**	< 0.013		< 0.003	< 0.003	< 0.003	< 0.003	0.004	0.007	0.006	0.003	0.003	0.004	0.005	< 0.003	0.003	0.004	< 0.003
	BL2	< 0.013		< 0.003	< 0.003	< 0.003	< 0.003	0.005	0.008	0.008	< 0.003	< 0.003	0.004	0.005	< 0.003	0.004	< 0.003	< 0.003
	BL3	< 0.012	0.003	< 0.003	< 0.003	0.003	< 0.003	0.009	0.014	0.014	0.006	0.006	0.008	0.012	0.003	0.007	0.009	< 0.003
SGD2	**BL1**	< 0.012		< 0.003	< 0.003	< 0.003	< 0.003	0.007	0.012	0.011	0.005	0.005	0.006	0.007	0.003	0.004	0.005	< 0.003
	BL2	< 0.012		< 0.003	< 0.003	< 0.003	< 0.003	0.003	0.003	0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003
	BL3	< 0.010	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	0.005	0.008	0.008	0.004	0.004	0.005	0.006	< 0.002	0.004	0.005	< 0.002
SZN3	**BL1**	< 0.013		< 0.003	< 0.003	0.003	0.004	0.016	0.025	0.024	0.01	0.011	0.013	0.016	0.007	0.008	0.009	< 0.003
	BL2	< 0.015		< 0.003	< 0.003	< 0.003	< 0.003	0.003	0.003	0.004	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003
	BL3	< 0.011	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	0.005	0.006	0.006	0.003	0.003	0.004	0.006	< 0.003	0.003	0.004	< 0.003
ISQG-L		*0.16*	*0.07*[a]	*0.044*	*0.016*	*0.019*	*0.085*	*0.24*	*0.665*	*0.6*	*0.261*	*0.384*	*0.43*	*0.76*[b]	*0.76*[b]	*0.50*[b]	*0.51*[b]	*0.063*
ISQG-H		*2.1*	*0.67*[a]	*0.64*	*0.5*	*0.54*	*1.1*	*1.5*	*2.6*	*5.1*	*1.6*	*2.8*	*1.6*	*6.48*[b]	*6.48*[b]	*4.21*[b]	*4.37*[b]	*0.26*

a. From New Zealand Guidelines for Sea Disposal of Waste (MSA/MfE 1999).

b. Value assigned relative to ISQG for fluoranthene from ratios between PSML values, Puget Sound sediment quality guidelines (PSDDA 1989).

3.3.4. Sediment physicochemical data: Summary of observations and findings

Substrates at 16 of the 19 benthic sampling stations were comprised of fine soft muds, with grain size dominated by the silt/clay fraction (< 63 µm). A less consolidated surface layer 4–10 cm thick was often present at these sites. Two of the Lyttelton Harbour stations and the eastern-most offshore station were set apart by substrates of fine and very fine sands.

Grain size distribution was found to be most spatially variable for stations inside Lyttelton Harbour. Small-scale spatial variability is also considered to have contributed to variability between replicate samples and surveys for individual Harbour stations.

The dominant silt/clay fraction generally displayed low temporal variability (over four baseline surveys) at all sample stations.

Sediment organic content of the sediments, as indicated by total organic carbon, was relatively low overall, with the lowest values coinciding with sandier sediments. The shallow cores extracted from the grab contents featured an indistinct transition to darker sediments deeper in the profile rather than a sharp redox potential discontinuity.

Sediment texture and organic content exhibited relatively flat background profiles (little effective gradient) for most of the potential CDP effects transects. Well-defined spatial gradients were apparent only for the South-east and Coastal transects, with the silt/clay fraction and organic carbon generally decreasing towards the south-east, along with corresponding increases in the very fine sand component.

Concentrations of indicative trace metals in samples from all benthic sample stations were below the corresponding ANZECC (2000) low-risk trigger levels although nickel, which appears to be present at naturally elevated background concentrations, approached the trigger value.

Both spatial and temporal variability in trace metal concentrations was low, although some minor patterns were apparent. Spatial gradients in sediment metal concentrations tended to be gradual. There appeared to be marginally increasing gradients for all eight tested metals along the West and Pigeon Bay transects, but more distinct gradients, decreasing eastwards along the South-east and Coastal transect, were observed for all metals except arsenic.

Despite the identified spatial gradients in metals, concentrations are considered to be below levels where a corresponding biological effect might be expected along the transects involved.

Polycyclic aromatic hydrocarbons analysed in composite sediment samples from five of the benthic stations over the three 2017 baseline surveys. For all samples, concentrations were more than an order of magnitude lower than the applicable ANZECC (2000) ISQG-Low criteria.

3.3.5. Benthic macrofaunal communities

Overall, 172 macrofaunal taxa were identified from the 19 baseline benthic sample stations. A full listing of these taxa is presented in Appendix 4. The 22 most abundant taxa across all stations (encompassing the 10 most abundant taxa from each transect grouping) are listed in Table 10. Deposit feeders generally predominated. Polychaete worms were by far the most dominant taxonomic group, representing cumulatively around 74% of total abundance. Just one species of polychaete, the capitellid *Heteromastus filiformis*, averaged 28% of total abundance. Other taxonomic groups strongly represented were amphipods (5.0%), cumaceans (4.0%) and decapod crustaceans (3.8%; notably the stalk-eyed mud crab *Hemiplax hirtipes*). Mollusca were present as bivalves (3.6%) and gastropods (3.4%).

Changing patterns of dominance between transect areas are evident in Table 10. Within Lyttelton Harbour, the anthozoan *Virgularia gracillima* was far more prevalent than elsewhere, although most of this was down to just one station (LHB1). Further offshore (West and South-east transects), paraonid and ampharetid polychaetes, cumaceans and phoxocephalid amphipods became more prevalent.

Patterns in community indices

Abundance and taxa richness

Average infaunal abundance (number of individuals), richness (number of different taxa) and diversity indices at each station are presented in Figure 34. Average abundance for the station triplicate core samples was quite variable, ranging from 30 to 315 individuals. It is evident from Figure 34 that the six offshore stations comprising the SE transect exhibited consistently greater abundances than other stations, with station/survey means ranging 84–315 individuals and an overall mean of 147. This contrasts with a range and mean for the other (inshore and harbour) stations combined of 30–209 and 78, respectively.

The number of different taxa per sample (richness) displayed a similar pattern, with consistently greater station/survey means along the South-east transect (ranging 15–37 taxa and overall mean 24.5) than for stations further inshore (9–25 taxa and overall mean of 15).

The greatest variability in station means for both abundance and taxa richness was for the four Lyttelton Harbour stations (LHB1-LHB6). This reflects (and is likely to result from) the variability in sediment texture across these stations (Figure 21). The innermost Port Levy station (PLB2) stands out as consistently supporting the lowest macrofaunal abundances (30-38 individuals across surveys), although richness remained moderate at 11-15 taxa.

Table 10. Summary table of the 22 most abundant infaunal taxa sampled during the 2017 baseline sampling, listed in order of overall mean abundance per core sample. The ten most abundant taxa for each transect group of stations are enumerated in bold font in shaded cells. Dashes indicate where no individuals of that taxon were observed in any samples.

Taxonomic group	**Taxa/species**	**Common name**	**Feeding mode**	**Total**	**Harbour**	**Pigeon Bay**	**Port Levy**	**South-east**	**West**
Polychaeta: Capitellidae	*Heteromastus filiformis*		Infaunal deposit feeder	33.5	**37.2**	**20.0**	**21.7**	**46.3**	**31.4**
Polychaeta: Cossuridae	*Cossura consimilis*		Deposit feeder	11.6	**7.2**	**15.4**	**16.0**	**11.7**	**5.2**
Polychaeta: Paraonidae	Paraonidae		Infaunal deposit feeder	6.7	0.1	**4.0**	0.6	**17.6**	**3.1**
Cumacea	Cumacea	Cumaceans	Infaunal filter or deposit feeder	4.5	1.3	**3.6**	**2.5**	**8.7**	**3.7**
Polychaeta: Cirratulidae	Cirratulidae		Deposit feeder	3.3	**2.9**	**6.4**	**4.1**	2.1	1.1
Polychaeta: Nephtyidae	*Aglaophamus* sp.		Infaunal carnivore	3.2	**2.9**	**2.4**	**1.5**	**4.6**	**3.7**
Polychaeta: Sigalionidae	Sigalionidae		Infaunal carnivore	2.5	**3.0**	**2.3**	**1.3**	2.9	**2.8**
Amphipoda	Phoxocephalidae	Amphipods		2.3	1.0	1.1	0.8	**4.2**	**3.9**
Gastropoda	Gastropoda (micro snails)	Snails		2.3	0.7	**2.8**	**2.0**	**3.8**	0.7
Polychaeta: Ampharetidae	Ampharetidae		Surface deposit feeder	2.1	1.1	0.6	0.2	**4.7**	**2.4**
Decapoda	*Hemiplax hirtipes*	Stalk-eyed Mud Crab	Deposit feeder & scavenger	2.1	**3.2**	**2.3**	**2.8**	1.1	1.4
Polychaeta: Trichobranchidae	Trichobranchidae			1.8	**3.0**	1.6	**2.3**	1.0	0.6
Polychaeta: Lumbrineridae	Lumbrineridae		Infaunal carnivore & deposit feeder	1.7	0.2	**2.4**	0.9	2.3	**3.4**
Anthozoa	*Virgularia gracillima*	Sea Pen	Passive suspension feeder	1.5	**6.6**	0.1	0.3	0.3	0.1
Polychaeta: Goniadidae	Goniadidae		Infaunal carnivore	1.5	1.5	0.3	0.3	**3.2**	0.6
Polychaeta: Spionidae	*Spiophanes kroyeri*		Surface deposit feeder	1.2	0.0	0.7	0.1	**3.1**	0.6
Amphipoda	Amphipoda	Amphipods	Epifaunal scavenger	1.2	**1.9**	0.1	0.1	2.2	0.3
Polychaeta: Spionidae	*Prionospio* sp.			1.1	0.8	1.0	**1.1**	1.4	1.0
Nemertea	Nemertea	Proboscis worms	Infaunal carnivore	0.9	0.2	0.8	0.0	2.2	0.6
Polychaeta: Maldanidae	Maldanidae	Bamboo worm	Infaunal deposit feeder	0.9	0.3	0.4	0.3	2.3	0.1
Amphipoda	*Ampelisca* sp.	Amphipod		0.8	**3.2**	0.1	0.7	-	-
Anthozoa	*Edwardsia* sp.	Burrowing anemone		0.8	0.4	0.8	0.3	1.1	**1.6**

Another arresting feature of Figure 34 is the consistently greater abundance values from the second baseline survey (BL2) in July 2017. Of the 12 stations that stand out as featuring abundance peaks in the second survey, all but two of them (LHB6 and BPB1) showed a coincident increase in taxa richness. This suggests that the peak in abundance is not only due to just a few dominant taxa. There is insufficient information to link this pattern unequivocally to seasonal influences and more-random antecedent conditions may play a role.

There were no conspicuous spatial gradients in the abundance data; however, decreasing taxa richness can be discerned along the two offshore-inshore transects SGD1-BPB1 (West transect) and SGD2-PBB1 (Pigeon Bay transect).

Diversity and evenness

Both Shannon-Weiner diversity index (H’) and Pielou’s evenness (J) varied between stations but were notably stable across surveys. Lower spatial variability in both indices was a feature of the offshore (SE transect) stations, with the greatest variability displayed by the Lyttelton Harbour stations. Of the Harbour stations, LHB3 stands out for high values of both indices, a feature that was also noted by earlier sampling at this location (Sneddon et al. 2016). Decreases in H’ for stations BPB1 and BPB4 during the second survey (BL2), and CTL2 for the third survey (BL3), represented minor exceptions to the overall temporal stability. No clear spatial gradients in either index were apparent.

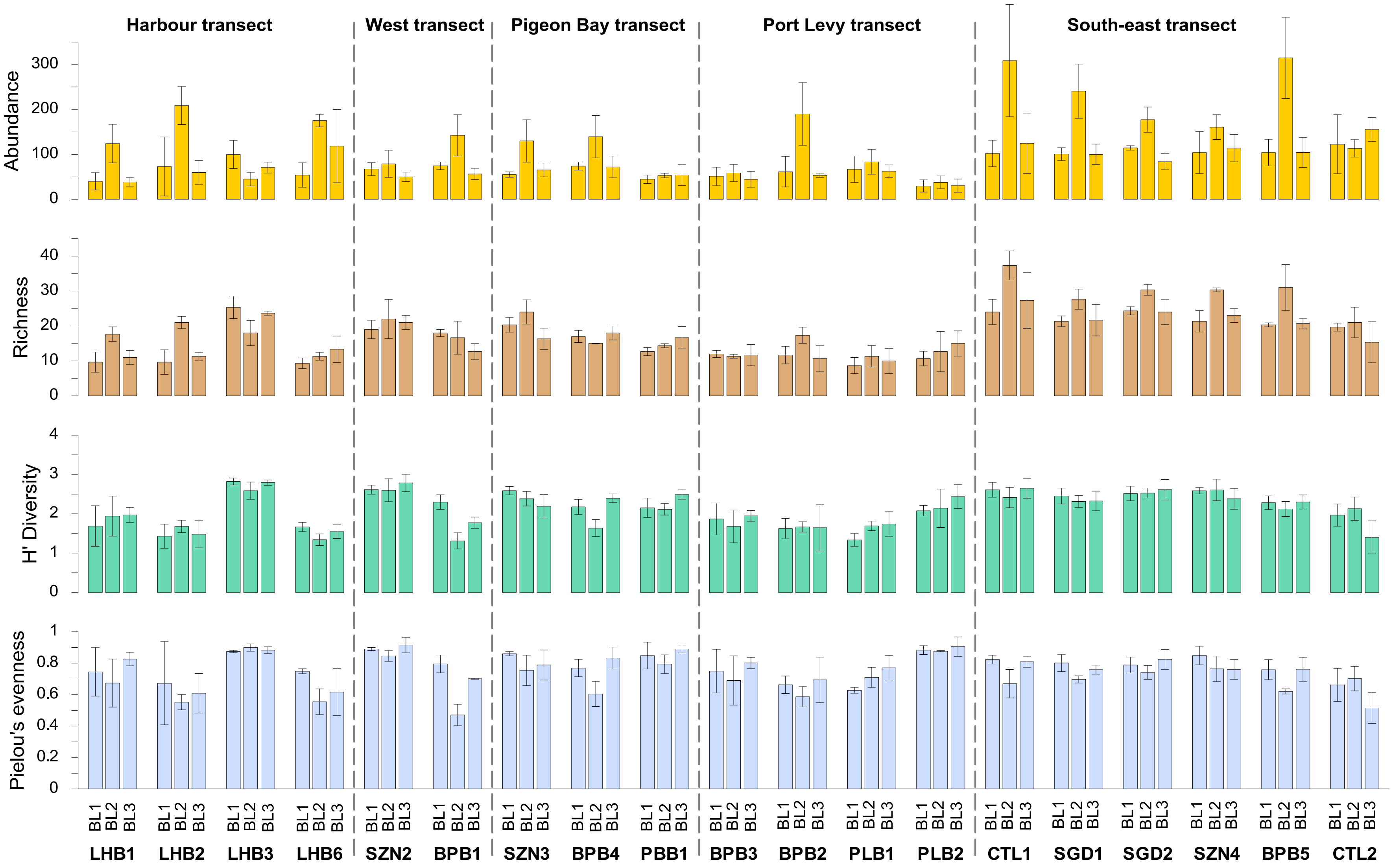

Figure 34. Mean infauna indices for each sample station across the three baseline surveys conducted in 2017 (n = 3). Abundance = no. of individuals per 0.013 m^2 core. Richness = no. of taxa per core. H' Diversity = Shannon-Weiner Diversity index. Error bars represent ±1 std deviation for triplicate samples.

Inter-correlation of benthic station variables

The correlogram (Figure 35) visually presents the degree of correlation between all benthic sample variables and indices (diversity indices, sediment grain size fractions, trace metals and depth). Positive correlations are displayed in blue and negative correlations in red. Colour intensity and symbol size are proportional to the corresponding correlation coefficient (R). The observed patterns of correlation are generally consistent with expectations based on observations of these and similar coastal systems and other exploration of the data.

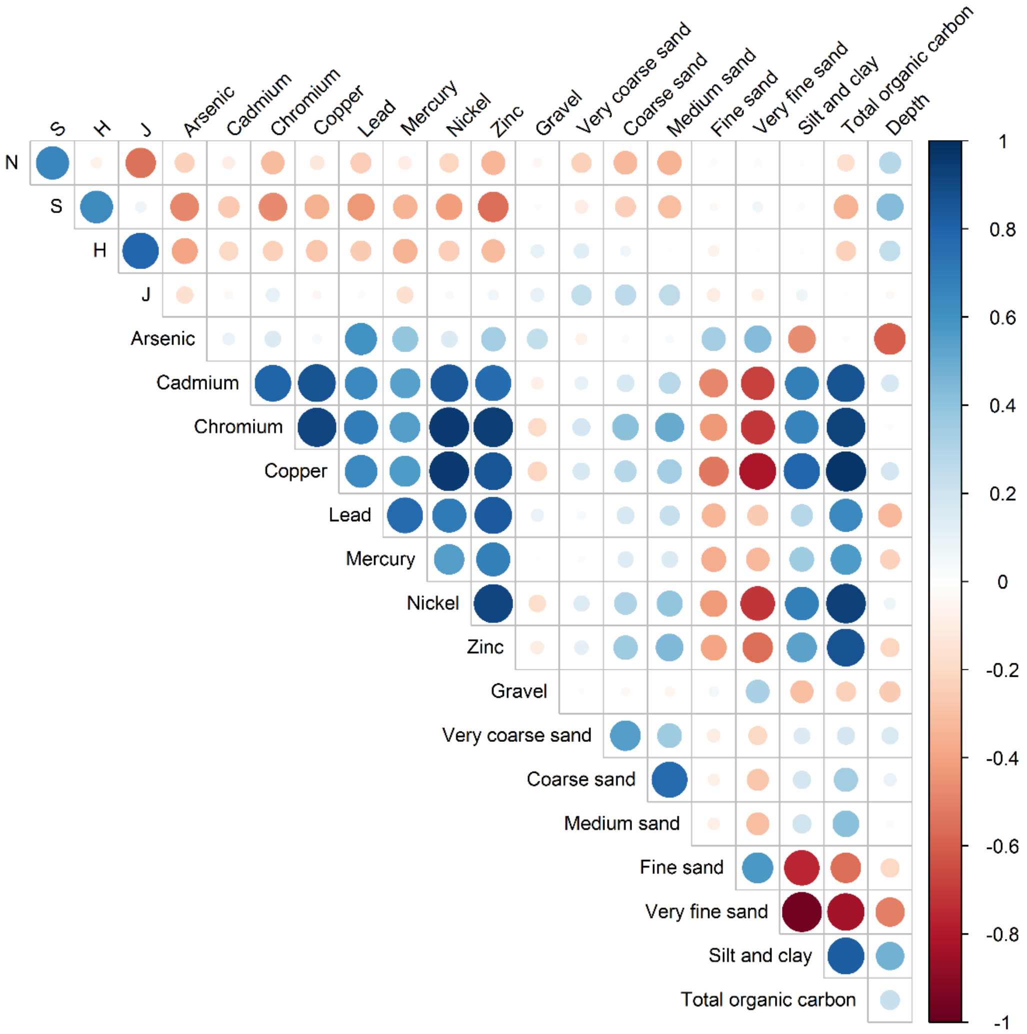

Figure 35. Correlogram of diversity indices and environmental variables for samples from the 19 benthic stations over the three baseline surveys in 2017. Positive correlations are displayed in blue and negative correlations in red. Colour intensity and the size of the circle are proportional to the correlation coefficient (R). The scale bar shows the correlation coefficients represented as a colour spectrum.

The top left of the correlogram indicates positive correlation between macrofaunal abundance (N) and richness (S), S and diversity (H’), and between H’ and evenness (J). A negative correlation indicated between J and N suggests that, notwithstanding coincident increases in taxa richness, high abundances may be influenced by a small number of dominant taxa.

Macrofaunal community indices N, S and H’ were generally weakly and negatively correlated with metals and coarser sediment grain size but positively correlated with depth (top rows Figure 35). Metals displayed generally strong positive inter-correlation (middle-left Figure 35), but this may be an artefact of the recognised affinity of many trace metals for the silt and clay fraction and organic carbon in sediments (also positively correlated in Figure 35). It is noteworthy that, unlike the other metals, arsenic was negatively correlated both with silt/clay and TOC.

Strong negative correlations between the silt/clay fraction and very fine and fine sands reflect the change in sediment texture towards coarser grain size at some stations (notably within Lyttelton Harbour [LHB2, LHB3] and at CTL2; Figure 21).

Depth was not strongly correlated with other variables, although a positive correlation with the silt and clay fraction (and organic carbon) may be logically expected from more depositional conditions at greater depth. The weak positive correlation with macrofaunal abundance and richness reflects the greater values for these parameters for offshore stations identified from Figure 34. The reason for a negative correlation between water depth and sediment arsenic is not clear, although the pattern can be seen in Figure 25 with generally higher levels of sediment arsenic within samples from Lyttelton Harbour stations and lower levels further offshore at South-east transect stations[12].

Multivariate analysis of macrofaunal sample data

Multivariate analysis was used to examine the differences in benthic community composition between stations and sampling events. The complete macrofaunal data set from the three baseline surveys conducted in 2017 is presented as a non-metric multi-dimensional scaling (nMDS) plot in Figure 36. The relatively high stress value of 0.23 associated with this plot means that distances between individual points on the plot may not accurately reflect real magnitude of differences in community composition[13]; however, the plot is still useful in visualising general patterns and groupings of samples.

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[12] While a weak negative correlation between trace metals (including arsenic) and macrofaunal richness and diversity was observed, concentrations were consistently below the level at which biological effects would be expected (ISQG-Low; ANZECC 2000).

[13] 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 a great deal of scepticism, particularly if in the upper half of this range and for sample sizes of < 50.

Station differences

Although there appears to be a visible clustering of data points for most individual stations, there is generally much overlap in the plot (Figure 36, top), reflecting the presence of several key taxa across most samples (Table 10). However, at the 37% level of similarity (LOS), two of the stations (CTL2 and LHB3) are resolved from the general cloud of data points. Although in significantly different water depths (Figure 20) and spatially separated, these two stations are notable for having coarser substrates (Figure 21). At the 40% LOS, another group of stations effectively separate from the main cluster. These include LHB1, LHB2 (eight of nine replicates) and PLB2 within Port Levy. LHB2 shares the coarser substrates of CTL2 and LHB3, and this may drive its proximity to them on the nMDS plot. LHB1 and PLB2 support generally fine substrates but may be related by shallower water depths and the degree of shelter afforded by their locations within Harbour inlets.

Survey differences

The version of the nMDS plot highlighting individual baseline surveys (Figure 36 middle) indicates a high degree of overlap in community structure for samples collected in different surveys. This suggests that seasonal fluctuations in these communities are not substantial. The significantly greater abundances recorded for samples from the second survey (BL2, Figure 34) do not appear to be reflected in any conspicuous spatial pattern in the nMDS plot, suggesting that these high values were not solely attributable to just a few dominant species.

Transect differences

None of the transects represent distinctly different community assemblages, but there is visible clustering of samples with respect to transect (Figure 36, bottom). The apparent gradient in transect points from top right to bottom left of the nMDS plot is consistent with the increasing mean water depth of the transects.

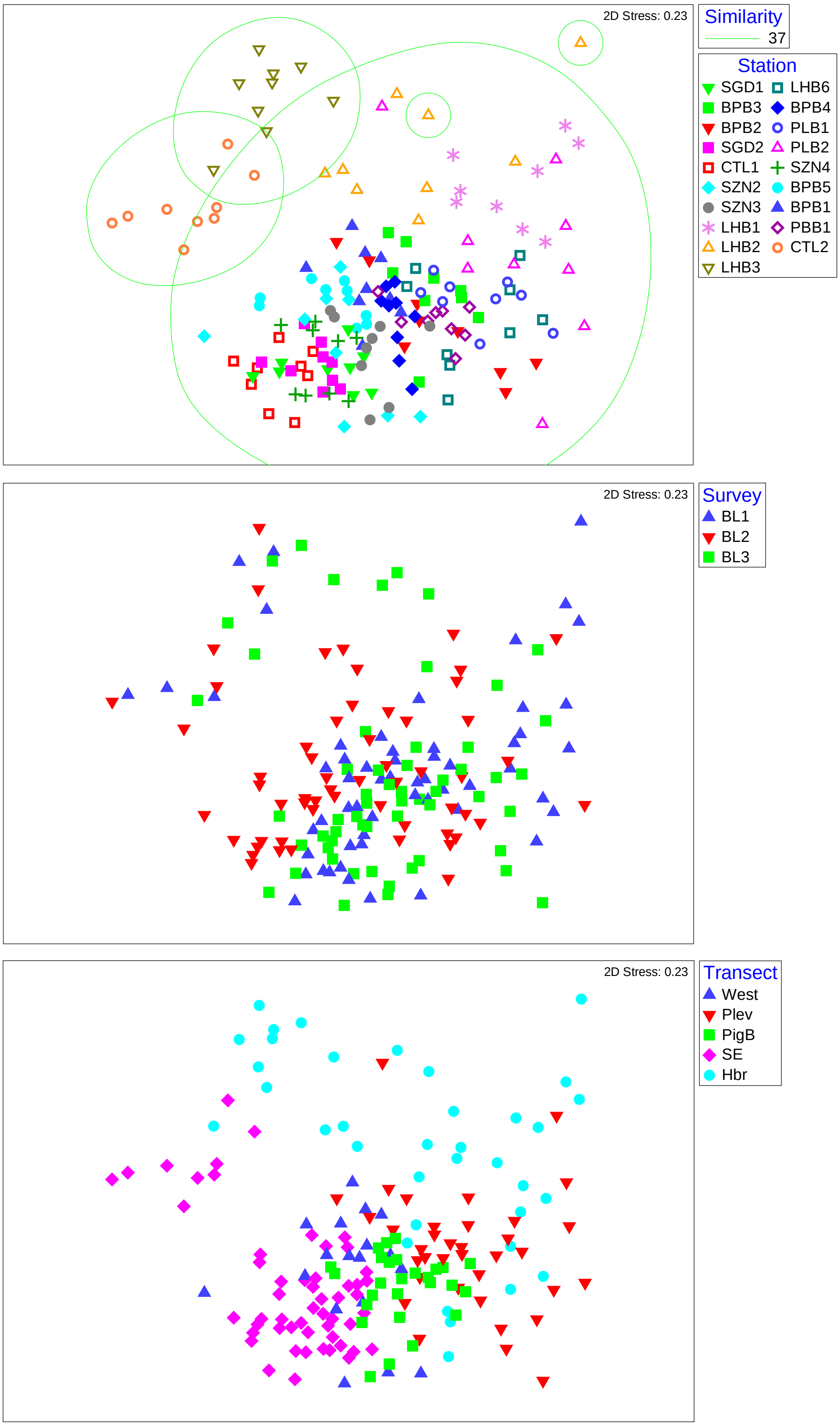

Figure 36. Three representations of an nMDS plot of the overall baseline data set with symbols designating survey (top), transect (mid) and station (bottom). Fourth-root transformation, S17 Bray-Curtis similarity.

Multivariate multiple regression with environmental variables

Multivariate multiple regression indicated that each environmental variable explained a significant proportion of the variability in the infauna data. When variables were considered alone in the marginal test, depth explained the largest amount of variation in macrofaunal community data at 12%, followed by total organic carbon (11%). When considered all together, the set of variables that explained the most variability in the data were depth, very fine sand, total organic carbon, medium sand, silt and clay and fine sand that together explained 43% of the variability. The final model can be visualised by examining the dbRDA ordination displayed in Figure 37. The first two axes captured 63% of the variability in the fitted model and 27.5% of the total variability in the data. The vector overlay shows the first dbRDA axis is related to depth (negatively) and medium sand (positively) and the second axis is related positively to fine sand and negatively to total organic content and silt and clay content.

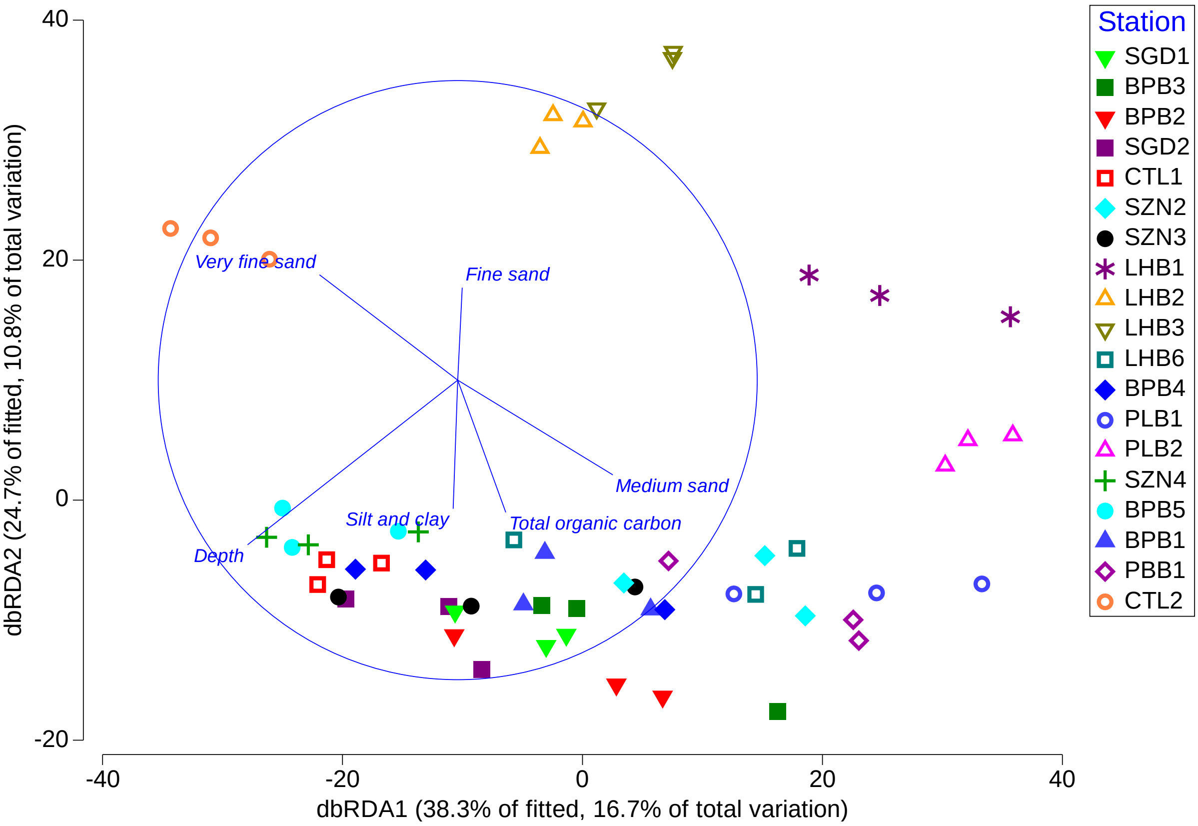

Figure 37. Distance based redundancy analysis ordination for the fitted model of macrofaunal assemblage data based on the Bray-Curtis similarity after fourth-root transformation in relation to environmental variables displayed as vectors. Symbols represent averaged infaunal data per station (n = 3) for each survey.

There was a relatively clear distinction between four stations shown in the top half of Figure 37 and the other stations. The three Harbour sites LHB1, LHB2 and LHB3, and the control station CTL2 are separate from the other stations along the second axis by higher content of very fine and fine sand, and lower total organic carbon and silt/clay content. However, the three Harbour sites were separated along the first axis by depth, because they are shallower than other sites; whereas the CTL2 station is also separated by depth, but in the opposite (deeper) direction. There were no obvious temporal or spatial patterns among the other 15 stations, which showed relatively similar macrofaunal community structure and environmental characteristics.

3.3.6. Macrofaunal community assemblage differences along transects

Since impacts to soft sediment habitats related to dredging and spoil deposition are expected to manifest as spatial gradients in key parameters, it is important to evaluate the presence of any pre-existing gradients. By grouping the stations along the transects identified in Figure 3, differences in benthic community structure can be visualised and the possible drivers assessed.

Since three of the transects intersect, it was necessary to include the ‘node’ stations of SGD1 and SGD2 in the ‘West’ and ‘Pigeon Bay’ transects, respectively, as well as in the ‘South-east’ transect running through the proposed spoil ground.

Lyttelton Harbour stations

The high variability in community structure across the Harbour stations is evidenced by the wide scatter of these stations in the nMDS plot (Figure 38). This is consistent with the variability in substrate type and diversity indices described for Lyttelton Harbour stations above. While this high background variability is a potentially confounding factor in the evaluation of any subsequent gradients in impact effects, a spatial gradient is less likely for the Lyttelton Harbour stations since they are necessarily aligned with the CDP channel itself.

LHB3 was the only station to resolve completely from the data set (at the 39% LOS), likely due to the very low silt/clay content of its sediments (Figure 21). Macrofaunal samples from LHB2 were highly variable and its grouping with LHB1 and LHB6 is notable given it featured a coarser substrate more similar to that of LHB3.

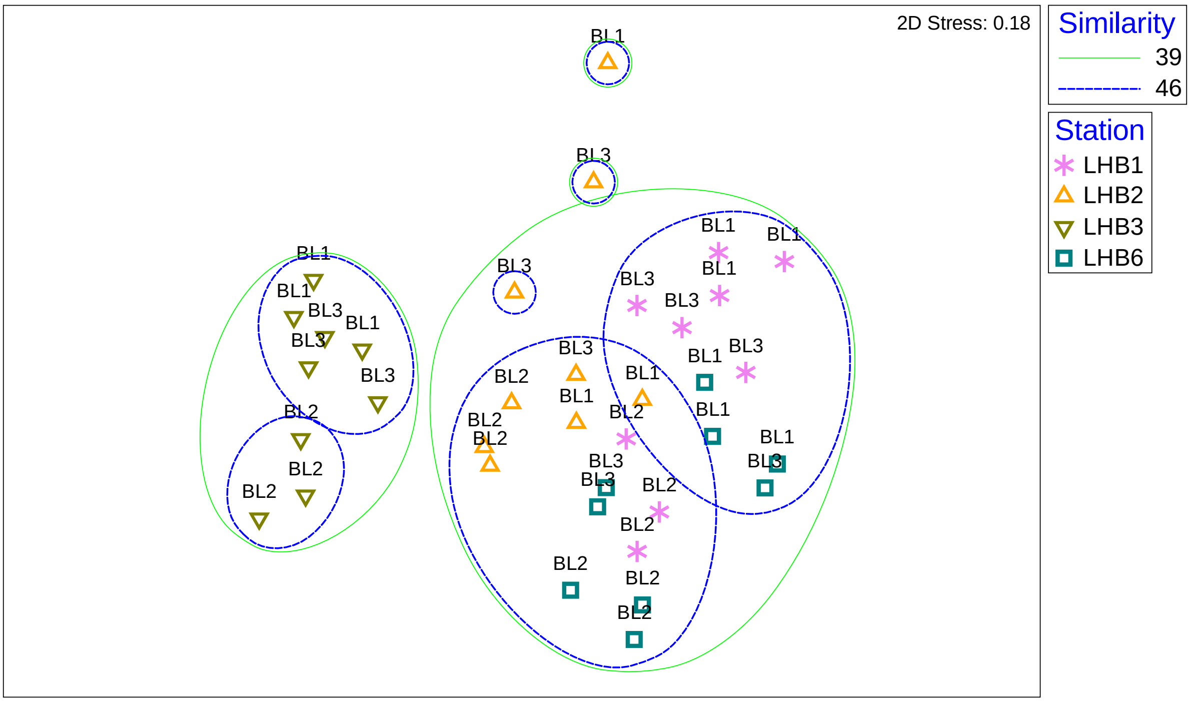

Figure 38. nMDS plot for sample replicates (labelled by survey) from the four Lyttelton Harbour stations. Fourth root transformation, S17 Bray-Curtis similarity.

West transect

Variability in the sample community data for the West transect stations has resulted in a relatively high stress value (0.21) for the nMDS (Figure 39), representing the difficulty of representing the community assemblages of individual replicates in two dimensions. However, stations SGD1 and BPB1 at either end of the transect were resolved at the 56% LOS and a general gradient is apparent in the station data from the top right to bottom left of the plot, in the direction of decreasing water depth. Changes in sample assemblages along this gradient included decreasing numbers of paraonid and maldanid polychaetes and the burrowing anemone *Edwardsia* sp. There was no clear corresponding gradient in sediment texture across the three stations.

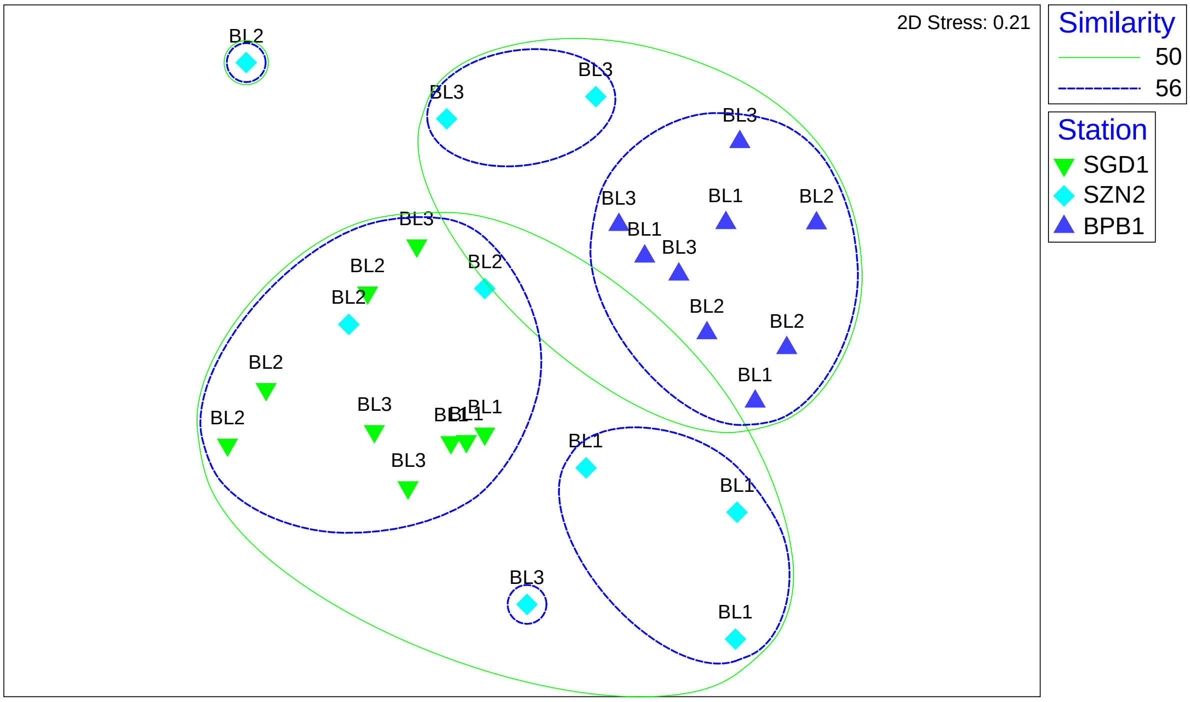

Figure 39. nMDS plot for sample replicates (labelled by survey) from the three stations along the West transect. Fourth root transformation, S17 Bray-Curtis similarity.

Port Levy transect

Although no station macrofaunal data set for the Port Levy transect group was distinct from the others, the nMDS plot (Figure 40) shows an apparent right-to-left pattern consistent with distance south along the transect. Since the gradients in sediment physicochemical properties were generally flat across the three stations (Figure 23), the main drivers of this transition are likely to be decreasing water depth and possibly reduced wave shear at the seabed from reduced exposure to swell. There was also a distinct grouping of the three replicates from BPB2 from the second survey (BL2) at the 50% LOS.

Station PLB2 was notable for markedly lower abundance of the capitellid polychaete *Heteromastus filiformis* and higher numbers of trichobranchid polychaetes. Taxa on this transect that appeared only at PLB2 included the sea pen *Virgularia gracillima* and the gastropod *Stiracolpus pagoda.*

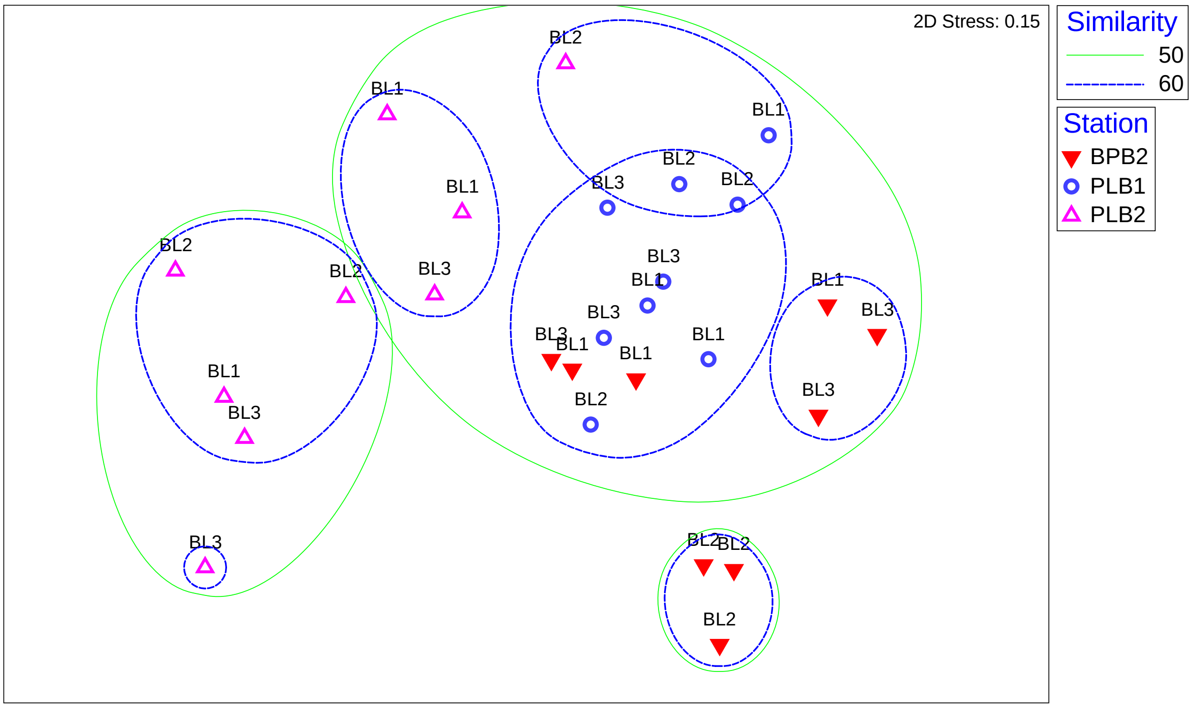

Figure 40. nMDS plot for sample replicates (labelled by survey) from the four stations along the Port Levy transect. Fourth root transformation, S17 Bray-Curtis similarity.

Pigeon Bay transect

Although the nMDS plot for the Pigeon Bay transect (Figure 41) is associated with a moderately high stress coefficient of 0.22, the plot does indicate a general transition in community structure from the spoil ground (SGD2) to the outer section of the inlet (PBB1). At the 54% level of similarity, there was an effective separation of the pairs of stations at either end of the transect. As might be expected, there were some similarities with the Port Levy transect. Although Station PBB1 was characterised by a smaller very fine sand component and slightly higher organic carbon, gradients in sediment physicochemical parameters were generally flat across the other three stations (Figure 23), leaving the decreasing water depth and exposure to swell along this transect as the likely drivers of community change.

With distance south from the spoil ground, this station progression resulted in decreasing prevalence of maldanid and paraonid polychaetes, phoxocephalid amphipods and nemerteans, with increasing numbers of the polychaete family Trichobranchidae.

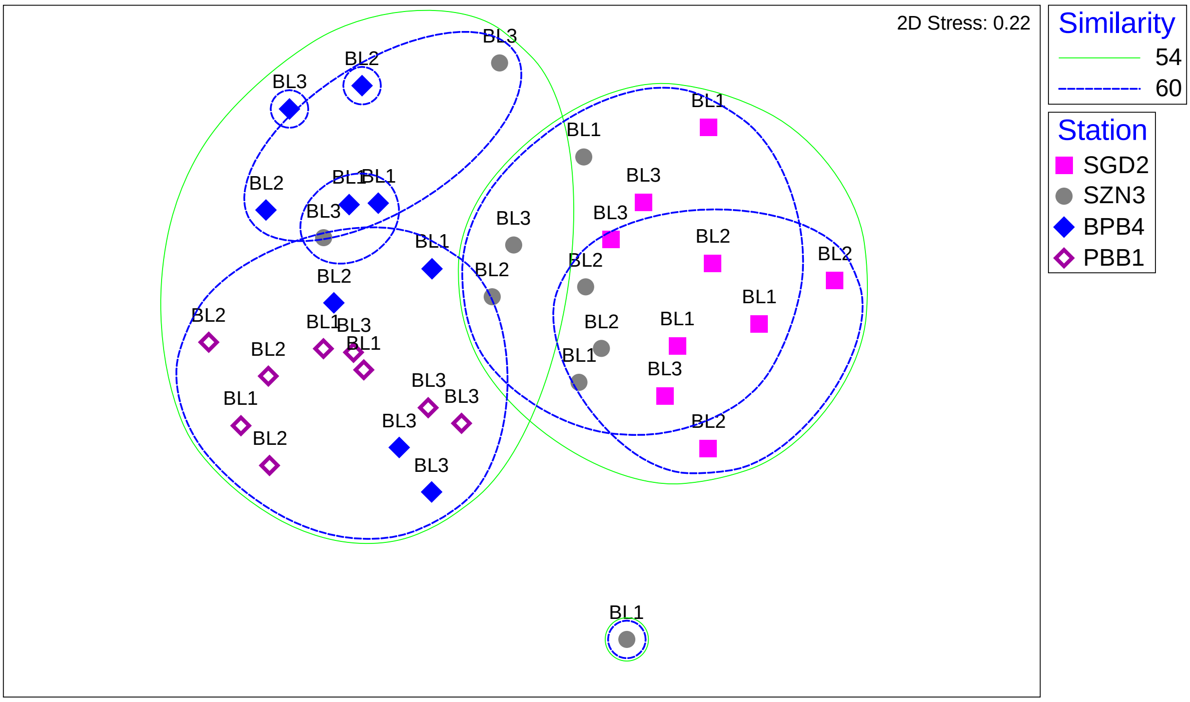

Figure 41. nMDS plot for sample replicates (labelled by survey) from the four stations along the Pigeon Bay transect. Fourth root transformation, S17 Bray-Curtis similarity.

South-east transect

The nMDS plot for macrofaunal communities at stations on the transect running through the spoil ground shows little distinction until station CTL2 at the south-eastern end, which resolved from the main group of stations at the 47% LOS (Figure 42). However, the points representing station BPB5 plot on the side of the main cloud closest to those of CTL2, consistent with the identified gradient of increasing very fine sands in the otherwise muddy substrate (Figure 24). The nMDS plot indicates that the four stations to the north-west support generally similar communities. Several taxa prevalent at CTL1 were absent from samples from CTL2. These included polychaetes of the families Paraonidae and Maldanidae and the species *Cossura consimilis* and *Spiophanes kroyeri* as well as the unsegmented priapulid worms.

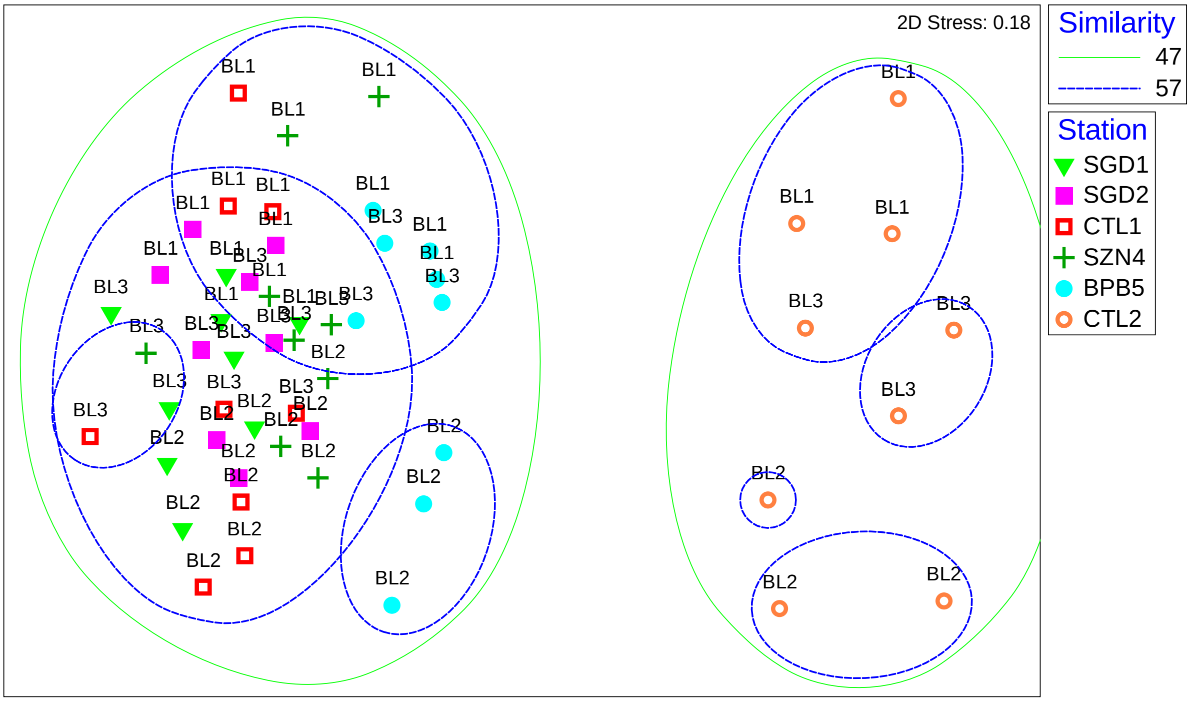

Figure 42. nMDS plot for sample replicates (labelled by survey) from the four stations along the South-east transect. Fourth root transformation, S17 Bray-Curtis similarity.

Coastal transect

The series of stations lying along an isobathic (17–18 m) transect roughly equidistant from the Banks Peninsula shoreline and extending eastward away from the entrance to Lyttleton Harbour (Figure 3) represents a natural transition from Harbour influence to a more open coastal setting. It is therefore possible that it may exhibit natural gradients in sediment physicochemical parameters and/or benthic community assemblages. However, it is not until station BPB5 that a coarsening of sediment texture becomes evident with an increase in very fine sand replacing a proportion of the dominant silt/clay fraction. But a distinct and significant change to a sandy substrate does not occur until Station CTL2, where the fine sand fraction dominates (Figure 21). The changes in community assemblage appear to be largely consistent with the substrate change, with only the CTL2 samples resolving from the general cluster on the nMDS plot (at the 47% LOS; Figure 43). However, in contrast to the South-east transect (Figure 42), the arrangement of the samples by station on the plot does suggest a general transition along an eastward progression over the full length of the transect. Examination of the data-set using SIMPER indicates that stations further eastward had a greater prevalence of ampharetid polychaetes, nemerteans and phoxocephalid amphipods.

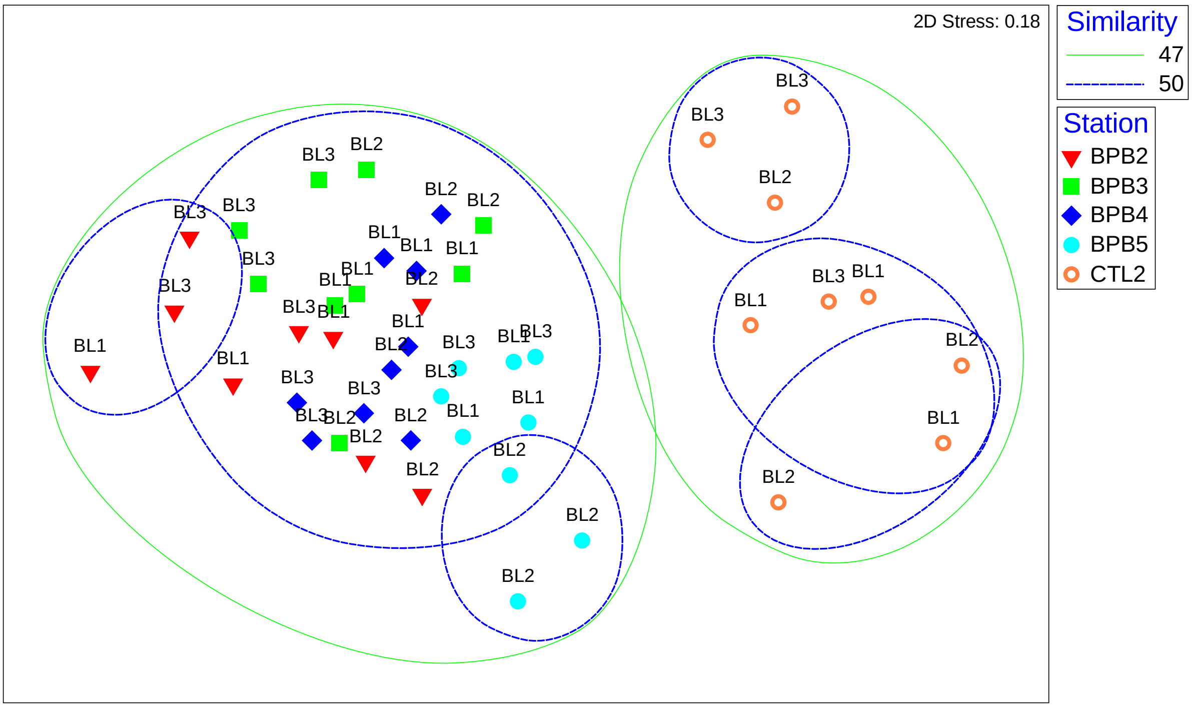

Figure 43 nMDS plot for sample replicates (labelled by survey) from the four stations along the Coastal transect. Fourth root transformation, S17 Bray-Curtis similarity.

3.3.7. Macrofaunal community data: Summary of observations and findings

The soft sediment benthic macrofaunal communities were dominated by a range of polychaete worm families, representing around 74% of total abundance over the 19 stations. Deposit feeding organisms generally predominated. The greatest macrofaunal abundances occurred at the six offshore stations comprising the South-east transect.

Community composition varied across stations, but many taxa were common to all sites and no completely distinct assemblages occurred. The greatest variability in both abundance and taxa richness was for the four Lyttelton Harbour stations (LHB1 to LHB6) and was considered to be a consequence of the variability in sediment texture across these stations.

Consistently greater abundance values were recorded from the second baseline survey (BL2) in July 2017. While there may be seasonal factors, the reasons for this are unclear.

Diversity and evenness indices for individual stations were notably stable across surveys and no clear spatial gradients were apparent. Lower spatial variability in both indices was a feature of the offshore (South-east transect) stations.

Intercorrelation between macroinvertebrate community indices and other environmental variables generally followed expected patterns. Abundance, taxa richness and diversity were positively (if weakly) correlated with water depth.

Taxa richness was negatively correlated with organic carbon and trace metal concentrations, especially arsenic, chromium, lead and zinc, although the generally low levels of metals suggests such correlation should be interpreted cautiously.

The moderately strong intercorrelation of all metals except arsenic possibly relates to common affinities with the fine particulate fraction and organic carbon.

Multivariate statistical analysis indicated sediment texture as the main driver of changes in benthic community structure. Despite overall similarities in grain size distribution between most sample stations, there was a general tendency for samples from individual stations to cluster together on multi-dimensional scaling plots.

A high degree of overlap in community structure was observed for samples collected during different surveys, suggesting that seasonal fluctuations in these communities are not substantial.

While none of the transects supported distinctly different community assemblages, there was a clustering of samples with respect to transect, in patterns that were consistent with changes in water depth. Multivariate multiple regression indicated that depth explained the largest amount of variation in macrofaunal community data, followed by sediment texture and organic carbon.

While community structure tended to follow a consistent pattern along most transects (generally aligned with depth and substrate changes), strong existing gradients were not indicated by the data.

While summaries of the raw macrofaunal data, basic indices and statistical trends are presented and examined in this report, there is a wide range of statistical methods by which a potential impact may be detected and investigated once the baseline information has been compiled with data collected following commencement of dredging. However, examination of any clearly observable changes in station data and spatial gradients along transects is expected to be a key first step.

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5. APPENDICES

Appendix 1. Location details for subtidal and intertidal survey sites and benthic sample stations.

Table A1.1 Subtidal reef survey sites.

Station	Location	Coordinates (WGS84)	
		Latitude (S)	Longitude (E)
BP01	Adderley Head	-43.6042°	172.8236°
BP02	Baleine Point	-43.6031°	172.8556°
BP05	Pigeon Point	-43.6230°	172.9110°
BP08	Otohuao Head	-43.6334°	172.9814°
BP14	Boulder Bay (Nth Godley Head)	-43.5819°	172.7948°
LH07	Ripapa Is (Lyttelton Harbour)	-43.6191°	172.7556°

Table A1.2 Intertidal reef survey sites.

Station	Location	Coordinates (WGS84)	
		Latitude (S)	Longitude (E)
PL03	Pukerauaruhe Is (Port Levy)	-43.6084°	172.6852°
PL16	Port Levy (eastern shoreline)	-43.6044°	172.7415°
LH07	Ripapa Is. (Lyttelton Harbour)	-43.5976°	172.7633°
LH05	Shag Reef (Lyttelton Harbour)	-43.5954°	172.7891°

Table A1.2 Benthic sample stations.

Transect	Station	Coordinates (WGS84)		Depth
		Latitude (S)	Longitude (E)	(m MSL)
Lyttelton Harbour	LHB1	-43.6187°	172.7131°	5.9
	LHB2	-43.6192°	172.7362°	7.4
	LHB3	-43.6161°	172.7564°	8.2
	LHB6	-43.6052°	172.8098°	13.1
West	SZN2	-43.5563°	172.8532°	19.0
	BPB1	-43.5579°	172.8165°	16.6
Pigeon Bay	SZN3	-43.5887°	172.9193°	18.6
	BPB4	-43.6079°	172.9200°	17.1
	PBB1	-43.6291°	172.9179°	14.5
Port Levy	BPB3	-43.5969°	172.8769°	16.6
	BPB2	-43.5971°	172.8409°	18.4
	PLB1	-43.6097°	172.8398°	13.0
	PLB2	-43.6222°	172.8368°	9.2
South-east	CTL1	-43.5203°	172.8384°	19.0
	SGD1	-43.5536°	172.8898°	20.2
	SGD2	-43.5672°	172.9150°	20.2
	SZN4	-43.5786°	172.9350°	19.5
	BPB5	-43.6163°	172.9737°	17.9
	CTL2	-43.6319°	172.0226°	16.8

Appendix 2. Inventory of reef taxa recorded during the subtidal quadrat surveys along with abundance/coverage data averaged over the four baseline surveys (BL0-BL3) for both depth transects at each of the six sites. Taxa in (tan) shaded cells are those for which coverage data was recorded. Data for all other taxa represent counts of individuals. Blank cells indicate taxon not observed at the site.

		BP01		**BP02**		**BP05**		**BP08**		**BP14**		**LH07**
GROUP	**Taxa**	**4m**	**7m**	**4m**	**7m**	**4m**	**7m**	**4m**	**7m**	**4m**	**7m**	**4m**
PHAEOPHYTA	Ecklonia.radiata	14.39	0.06	9.09		7.70	0.09	6.55	2.08	21.44	9.81	24.31
(Brown algae)	Macrocystis.pyrifera	6.73	0.02	0.33		1.47		0.06		1.38	0.92	0.31
	Carpophyllum.maschalocarpum	0.63		0.92		4.08		0.31		0.03	0.63	0.13
	Carpophyllum.flexuosum			0.02		0.13				0.02	0.63	4.19
	Halopteris.sp.	1.56	0.63	0.25		0.98	0.63	1.91	0.11		4.42	
	Microzonaria sp.			0.48		0.08		0.66	0.06		0.17	0.09
	Landsburgia.quercifolia			0.78				0.22				
	Undaria.pinnatifida	1.06		0.17		1.02	0.02	0.42			0.03	0.05
	Brown.blade.recruits		0.03	0.03			0.06	0.06	0.02	0.05	0.06	
	Dictyota.ocellata			0.06	0.05	0.02	0.17				0.08	
	Desmarestia.sp.			0.06		0.03						
	Brown.alga.filamentous											0.02
	Brown.encrusting.algae	3.50	0.19	3.30	0.05	0.53	0.28	0.66	2.58	1.02	1.56	1.92
	Brown film on coralline							0.23				
RHODOPHYTA	Coralline.paint	48.31	0.13	43.75	1.72	61.25	15.38	85.47	52.38	79.28	30.66	56.88
(Red algae)	Coralline.turf	0.14		0.38	0.31	0.81		7.41	0.17	0.05	0.08	0.19
	Plocamium.sp	0.39	0.33	2.16	0.30	0.84	0.44	0.19	0.08		0.66	
	Ballia.sp.	0.45	0.02	0.38		0.59	0.14	0.17	0.02	0.02	1.73	
	Euptiloda.sp.	1.08		0.19				0.03	0.03		0.05	
	Ceramium.sp.					0.02	0.06					
	Fine feather red		0.63	0.06		1.34		0.23				
	Red.foliose.small.blade	1.00	1.06	0.97	3.72	0.20	0.88	0.50	0.89	0.05	2.45	0.45
	Rhodophyllis.sp.		1.00	0.02	0.03		0.03	0.02	0.02		0.17	

Appendix 2, continued

		BP01		BP02		BP05		BP08		BP14		LH07
GROUP	**Taxa**	**4m**	**7m**	**4m**	**7m**	**4m**	**7m**	**4m**	**7m**	**4m**	**7m**	**4m**
	Rhizopogonia.sp			0.22	0.09	0.09	0.19	0.09			0.02	
	V. fine red (on br. hydroid)		0.09									
	Red.filamentous	0.09	0.45	0.25	0.08	0.42	0.55		0.28	0.08	1.03	
CHLOROPHYTA	Ulva.sp.	0.02		0.05								
(Green algae)	Fine green (moss-like)	0.02		0.06			0.03					
	Fine green (filamentous)	0.05										
PORIFERA	Sponge.encrusting.orange	0.63	0.56	0.84	0.70	1.06	0.89	0.88	0.83	0.45	0.48	0.61
(Sponges)	Sponge.encrusting.yellow	0.03	0.23	0.31	0.31	0.05	0.23	0.09	0.03		0.06	
	Sponge.encrusting.Cliona		0.03			0.14	0.03	0.08	0.02	0.17	0.27	0.02
	Sponge.encrusting.brown	0.23	0.17	0.03	0.06				0.06	0.25		0.03
	Sponge.encrusting.cream	0.03	0.06	0.05	0.08	0.02	0.09		0.34	0.03	0.25	0.03
	Sponge.encrusting.blue	0.02	0.03					0.34				0.02
	Sponge.encrusting.grey					0.03						0.03
	Sponge.encrusting.purple				0.02							
	Sponge.lobed.apricot	0.02	0.17								0.02	
	Sponge.lobed.lavender	0.02										
	Sponge.lobed.white	0.02	0.02									
	Finger.sponge.erect	0.02	0.22	0.03	0.11	0.05	0.22			0.03		0.03
	Ecionemia.alata	0.11	0.13			0.03	0.52	0.06	0.33			
	Tethya.bergquistae	0.02	0.03		0.02	0.03	0.02	0.17	0.05	0.02	0.61	
HYDROIDOLINA	Hydroid.fine	3.50	6.50	1.38	0.94	2.48	2.77	0.80	0.70	0.17	3.14	0.92
(Hydroids)	Hydroid.feather	0.55	4.69	0.14	0.03	0.41	0.36	0.08	0.03		0.13	0.02
	Hydroid.branching	0.59	9.38	0.23	0.03	0.25	0.19				0.02	
	Amphisbetia.bispinosa	0.19		0.06	0.02	0.09					0.03	0.05
	Hydroids on Pyura	0.03		0.09								

Appendix 2, continued

		BP01		BP02		BP05		BP08		BP14		LH07
GROUP	**Taxa**	**4m**	**7m**	**4m**	**7m**	**4m**	**7m**	**GROUP**	**Taxa**	**4m**	**7m**	**4m**
HYDROIDOLINA												
(Hydroids)	Hydroid.tree					0.03						
ACTINIARIA	Anthothoe.albocincta	3.91	17.44	3.09	19.19	6.16	32.09	1.97	13.97	6.94	7.50	6.53
(Anemones)	Oulactis.mucosa		0.09		0.06	0.56	0.22	0.81	0.06	0.25	0.06	0.09
	Phlyctenactis.tuberculosa						0.03					0.06
	Anemone.striped			0.03	0.13							
	Stony.coral						0.02				0.09	
	Alcyonium cf. aurantiacum				0.03		0.02					
BRYOZOA	Bryozoan.encrusting	0.55	1.42	0.66	3.28	0.28	0.77	0.16	0.31	0.05	0.22	0.14
(Bryozoans)	Bryozoan.branching	0.27	2.94	0.13	0.91	0.06	0.69		0.08	0.02	0.02	0.02
	Banching.bryozoan.cf.bugula		0.02	0.02								
	Bryozoan.yellow.hard	0.09	0.16	0.08	0.34	0.13	0.16					
	Bryozoan.Catenicellidae					0.03	0.05					0.02
POLYCHAETA	Tube.worm.Serpulid	0.08		0.02	0.05	0.08	0.03	0.09	0.19	0.03	0.39	0.06
(Bristle worms)	Tube.worm.Sabellidae							0.03				
	Spirobid.worms											0.25
CIRRIPEDIA	Barnacle.small	39.50	3.69	0.25	1.63	1.31	5.73	0.09	7.64	0.02	0.02	0.02
(Barnacles)	Barnacle.large	0.09	0.09		0.03	0.02	0.03	0.13	0.06	0.02		
	Barnacle.gooseneck							0.13				
DECAPODA	Pagurid	0.38	0.16	0.09	0.25	0.09	1.22	0.31	0.16	0.16	0.75	0.06
(Crabs, lobster)	Guinusia.chabrus	0.03				0.03		0.03				
	Jasus.edwardsii		0.03									0.19
BRACHIOPODA	Calloria.inconspicua	0.47	0.14			0.22	0.25	0.19	3.23			

Appendix 2, continued

		BP01		BP02		BP05		BP08		BP14		LH07
GROUP	**Taxa**	**4m**	**7m**	**4m**	**7m**	**4m**	**7m**	**GROUP**	**Taxa**	**4m**	**7m**	**4m**
MOLLUSCA												
Bivalvia	Perna.canaliculus	9.45	0.16	11.05	4.55	15.30	2.00	0.09	0.09	2.44	1.25	3.89
(Clams)	Aulacomya.maoriana								0.02			0.11
	Ostrea.chilensis	1.31	1.41	0.03	0.09	0.16	0.09	0.09	0.22	0.09	0.06	0.16
	Mytilus.galloprovincialis			0.34	0.02					0.02	0.03	0.05
Gastropoda	Trochus.viridus	7.97	1.28	2.28	4.50	2.63	2.53	3.69	4.84	0.31	0.47	3.69
(Snails, limpets,	*Cookia.sulcata*	0.94	0.03	0.28	0.19	1.28	0.44	2.00	0.47	1.28	1.19	0.72
pāua)	*Haliotis iris*	0.06		2.69	0.06	0.06	0.03	0.38	0.03	1.03	0.03	0.38
	Lunella.smaragda			0.06		0.09		0.03		1.09		2.00
	Buccinulum.linea.	0.56	0.69	0.16	0.19	0.03	0.22	0.09	0.06	0.47	1.16	0.22
	Penion.sulcatus		0.09	0.44	0.25	0.09	0.38	0.09	0.22	0.03	0.06	0.06
	Calliostoma.punctulatum	0.09	0.06	0.22	0.25	0.19	0.31	0.13	0.22	0.03	0.06	0.06
	Cantharidus.purpureus									0.09		0.41
	Dicathais.orbita	0.09						0.09				
	Haustrum.haustorium											0.31
	Cellana.stellifera			0.31	0.03	0.03		0.03	0.06	0.06	0.03	0.13
	Patelloidea	0.16				0.09		2.00	0.13	0.03		
	Limpet.small					0.16						
	Sigapatella.novaezelandiae		0.19	0.06						0.03	0.03	
	Scutus.breviculus										0.06	0.09
	Trochidae (small globose)			0.84				0.78	0.16			0.13
	Maoricolpus.roseus									0.09		
	Cantheridella			0.16							0.03	
	Whelk.unid	0.03		0.03		0.16	0.03	0.16	0.13		0.13	0.09

Appendix 2, continued.

		BP01		BP02		BP05		BP08		BP14		LH07
GROUP	**Taxa**	**4m**	**7m**	**4m**	**7m**	**4m**	**7m**	**GROUP**	**Taxa**	**4m**	**7m**	**4m**
Polyplacophora	*Cryptoconchus.porosus*	0.78	0.03	0.03	0.13	0.41	0.47			0.34	0.34	0.41
(Chitons)	*Eudoxochiton.nobilis*	0.06				0.03			0.09			0.03
	Chiton cf. *N.violacea*			0.03								
ECHINODERMATA	*Patiriella.regularis*	0.50	0.06	1.53	2.13	2.34	1.66	3.00	1.53	1.09	0.31	1.81
(Seastars, urchins,	*Pentagonaster.pulchellus*			0.03		0.03	0.13	0.03	0.03	0.06	0.03	
sea cucumbers)	*Diplodontias.dilatatus*			0.03	0.06	0.06	0.34	0.09	0.06	0.03	0.16	
	Coscinasterias.muricata	0.03		0.03		0.09		0.06		0.25	0.31	0.06
	Stegnaster.inflatus						0.09		0.03	0.06		
	Astrostole.scabra	0.03										
	Ophiuroid			0.03			0.09		0.03			
	Sclerasterias.mollis						0.03					
	Evechinus.chloroticus	0.06	0.06			0.06	0.03	0.09	0.16	0.50	0.22	0.06
	Australostichopus.mollis	0.03	0.38						0.03		0.09	0.03
ASCIDIACEA	Solitary.ascidian.Cnemidocarpa	12.25	48.13	3.77	31.50	4.30	23.72	2.34	5.02	10.78	28.38	6.25
(Sea Squirts)	Solitary.ascidian.small.red-mouth		0.02	0.22	1.22	0.06	0.14		0.03	0.03	0.80	
	Didemnum.sp.(white)	0.06	0.64	0.30	1.03	0.17	0.34	1.05	0.80	0.70	1.25	0.70
	Didemnum.jucundum.(black)	0.14	0.19			0.08	0.09	0.14	0.02	0.56	0.55	
	Didemnum.(cream/orange)		0.06		0.13	0.03	0.08					
	Botrylloides leachii	0.02	0.09	0.03	0.13	0.14	0.16			0.05	0.05	
	Aplidium benhami											0.11
	Pyura pachydermatina	11.31	3.69	6.22	0.72	10.66	6.13	5.03	0.19	5.94	0.72	0.34
	Colonial ascidian	0.09	0.28		0.42	0.02	0.13		0.08		0.03	0.16
OSTEICHTHYES	Triple.fins	0.84	0.69	1.13	1.19	1.53	1.75	1.22	0.69	1.13	1.19	4.63
(Fish)												
Total no. of taxa	**116**	**66**	**59**	**71**	**52**	**73**	**65**	**62**	**59**	**55**	**66**	**61**

Appendix 3. Inventory and relative abundances of conspicuous taxa recorded at the four intertidal sites over the four surveys (BL0 to BL3). The mean abundance category was derived from average of numerical rankings over all four surveys. Shore elevation: H = High, M = Mid-shore, L = Low and P = Tidal pools/shallow subtidal. Abundance scale: A = abundant (4); C = common (3), O = occasional (2), R = rare/scarce (1; usually 1-2 individuals observed). Blank cells indicate taxon was not recorded from any surveys.

		PL03				PL16				LH05				LH07			
Taxa	**Common name/description**	**H**	**M**	**L**	**P**	**H**	**M**	**L**	**P**	**H**	**M**	**L**	**P**	**H**	**M**	**L**	**P**
PHAEOPHYTA (Brown Algae)																	
Hormosira banksii	Neptune's necklace	C	A	R	O		R	O	R		C	C	R		A	C	O
Macrocystis pyrifera	Bladder or giant kelp			R	O			R	O			R	C			R	C
Cystophora scalaris	Zig-zag weed			O	A			O	O			O	O			C	A
Ralfsia sp.	Brown encrusting algae	R	R	C	R	R	R	O				R	R		R	C	R
Carpophyllum maschalocarpum	Narrow flap jack			O	C			O	O			R	R			O	R
Carpophyllum flexuosum	Flap jack				R							R	R			R	O
Splachnidium rugosum	Gummy weed		R	C				O			R	R			R	R	R
Halopteris sp.	Brown fine branching algae			O	O			O				R				R	C
Scytothamnus sp.			R	O	R		R	R			R	R			R	R	
Colpomenia sp.	Bubble weed		R		R			C	R		R	R	R			R	R
Undaria pinnatifida	Asian kelp			O	R			O				O	R			C	R
Leathesia sp.			R	R	R		R	R			R				R	O	
Microzonia velutina				R					R								
Notheia anomala			R		R												R
Petalonia sp.				R				R								R	
Brown algae unid	Brown algae unid		R														
Ecklonia radiata	Common kelp				R											R	O
Scytosiphon lomentaria					R								R		R	R	R
Dictyota kunthii					R							R					
Ectocarpus sp.									R								
Sargassum sinclairii												R				R	R
Filamentous brown													R				
Dictyota sp.													R				R
RHODOPHYTA (Red Algae)																	
Gelidium sp.	Brown turf-like		O	R			O	C			C	C	R		O	O	R
Pyropia plicata	Karengo	O	R			R				O	R			O	R		

Appendix 3, continued.

		PL03				PL16				LH05				LH07			
Taxa	**Common name/description**	**H**	**M**	**L**	**P**	**H**	**M**	**L**	**P**	**H**	**M**	**L**	**P**	**H**	**M**	**L**	**P**
Gigartina sp.					R											R	
Coralline paint	Coralline paint			R	O			R	R			O			R	O	C
Coralline turf	Coralline turf		O	C	A			O				C	C		R	C	C
Hildenbrandia sp.	Red encrusting algae							R									
Ceramium sp.				R	R		R			R	R	R	R				R
Champia				R	R												R
Cladhymenia												R	R			R	
Laurencia sp.			R									R	R			R	
Lophothamnium sp.				O			R					R				R	
Bostrychia arbuscula	Red moss weed					R											
Red alga unid.	Red alga unid.						R										
Red slimy epiphyte on *C. scalaris*					R												
CHLOROPHYTA (Green Algae)																	
Codium adherens	Velvet weed		R	C	R			O			R	R			R	O	R
Codium fragile											R	R	R				
Chaetomorpha coliformis	Sea emerald				R												R
Ulva intestinalis	Intestine weed	R	R		R				R		R			R	R		R
Ulva lactuca	Sea lettuce		R		R					R	R	R			R		
Cladophora sp.					R							R					
Cladophora feredayi			R		R	R						R	R			R	R
Filamentous green	Filamentous green		R		R				R								
PORIFERA (Sponges)																	
Tethya bergquistae	Pink golf ball sponge				R								R				
Orange sponge	Orange sponge			R	R							R				R	R
Yellow sponge	Yellow sponge																R
Halichondria sp.												R					
ANTHOZOA (Anemones)																	
Diadumene neozelanica	Brown-striped anemone				R							R					
Actinia tenebrosa	Red beadlet anemone			R													
Corynactis australis	Jewel anemone								R								

Appendix 3, continued.

		PL03				PL16				LH05				LH07			
Taxa	**Common name/description**	**H**	**M**	**L**	**P**	**H**	**M**	**L**	**P**	**H**	**M**	**L**	**P**	**H**	**M**	**L**	**P**
Oulactis mucosa	Sand anemone				R			R	R			R	R			R	R
Anthothoe albocincta	White-striped anemone				R			R			R	R	O			O	O
Olive anemone	Olive anemone								R								
Cricophorus nutrix	Brooding anemone												R				
HYDROIDA																	
Hydroids	Small feathery hydroids				R												
Hydroida- Amphisbettia	Mussel beard				R											R	
Hydroids unid (photo) on Cysto																	R
POLYCHAETA																	
Spirobranchus cariniferus	Blue tubeworms	C	A	A		O	A	C		R	C	C	R		C	O	
Spirorbinae	Spiral tube worm				R												
Terebellidae	Spaghetti worm												R				
Nereididae	Rag worm								R								
Serpulidae	Fan worm							R				R	R				R
BRYOZOA																	
Encrusting bryozoan	Encrusting bryozoan				R							R	R				R
Watersipora subtorquata	Encrusting bryozoan				O			R	R			R	R			R	R
Finger bryozoan	Finger bryozoan			R	R			R									
BRACHIPODA (Lantern shells)																	
Calloria inconspicua	Lantern shell				R												
POLYPLACOPHORA (Chitons)																	
Acanthochiton zelandica	Hairy chiton				R				R						R	R	R
Sypharochiton pelliserpentis	Snakeskin chiton		C	C		O	C	R	R		O	O			O	O	R
Chiton glaucus	Green chiton				R		R	R					R		R	R	R
Eudoxochiton nobilis				R													R
Cryptoconchus				R				R								R	R
Large unid chiton	Large unid chiton						R	R									
Ischnochiton maorianus					R							R					R
GASTROPODA (Snails)																	
Scutus breviculus	Shield shell/duck's bill limpet											R				R	R

Appendix 3, continued.

		PL03				**PL16**				**LH05**				**LH07**			
Taxa	**Common name/description**	**H**	**M**	**L**	**P**	**H**	**M**	**L**	**P**	**H**	**M**	**L**	**P**	**H**	**M**	**L**	**P**
GASTROPODA (Snails)																	
Cellana radians	Radiate limpet	R	O	C		O	C	R		R	O	O		R	C	O	
Cellana ornata	Ornate limpet	C	C	R		O	C	R		O	C	O		O	O	R	
Siphonaria sp.			R		R		R				O			R	R		
Notoacmea sp.		R		O		R	R			R	O	O			R		
Sigapatella novaezelandiae	Slipper limpet				R							R					R
Cominella adspersa	Speckled whelk				R						R	R	R		R		R
Calliostoma punctulatum				R	R						R	R	R			R	R
Haustrum scobina	Oyster borer	R	R			O	O							R	O		
Haustrum haustorium	Dark rock shell	O	C	R			C	O							R	R	R
Diloma aethiops	Spotted topshell	R	C	O		R	C	O		R	C	C		O	O	O	O
Lunella smaragdus	Cat's eye		R	O	O		O	C		R	O	O	R	R	R	O	O
Austrolittorina antipodum	Blue-banded periwinkles	A				A				R				A			
Austrolittorina cincta	Brown periwinkles	C				A								A			
Microgastropods	Microgastropods																O
Onchidella nigricans	Leathery sea slug							R	R								
Benhamina obliquata		R															
Buccinulum lineum									R								R
Zeacumantus sp.					R												
Nudibranch	Nudibranch																R
White & brown sea slug	White & brown sea slug																R
Haliotis iris	Pāua								R							R	R
Cantharidella sp.								R									
Risellopsis varia						R											
Muricidae whelk												R					
Cantharidus purpureus	Red opal top shell											R					
Cookia sulcata	Cook's turban																R
BIVALVIA (Bivalves)																	
Aulacomya maoriana	Ribbed mussel		R	R	R		R	O				R	R		R	R	R
Xenostrobus neozelanicus	Small black mussel	A	A				O			C	A	R		O	C		

Appendix 3, continued.

		PL03				PL16				LH05				LH07			
Taxa	**Common name/description**	**H**	**M**	**L**	**P**	**H**	**M**	**L**	**P**	**H**	**M**	**L**	**P**	**H**	**M**	**L**	**P**
BIVALVIA (Bivalves)																	
Perna canaliculus	Green-lipped mussel		R	A	R		R	C			R	C	R		R	C	O
Ostrea chilensis	Flat oyster			R	O	R		R				O	R	R	R	R	R
Protothaca crassicosta	Ribbed venus shell				R												R
Mytilus galloprovincialis	Blue mussel	R	C	C		R	O	C	R	R	O	C	R		R	C	R
Musculus impactus	Nesting mussel											R					
Bivalve unid	Bivalve unid				R												
Magallana (Crassostrea) gigas	Pacific oyster										R	R					
DECAPODA (Crabs)																	
Pagurus sp.	Hermit crab		R	R							R						R
Petrolisthes elongatus	Half crab				R							R	R			R	R
ISOPODA (Sea slaters)																	
Isopod																	R
CIRRIPEDIA																	
Epopella plicata	Plicate barnacle	C	A	O		O	O	R			R	R		R	C	O	
Chamaesipho columna	Column barnacle	A	A			C	A			A	A	A		A	A	O	
Austrominius modestus	Beaked barnacle					R	R			R	C	C			O	O	
Unid. Barnacle																	
Calantica villosa	Goose-neck barnacle			R				R									
ASCIDIACEA (Sea Squirts)																	
Cnemidocarpa sp.	Saddle ascidian				R								R				R
Pyura pachydermatina	Sea tulip			R	O			R				R				R	R
Solitary ascidian	Solitary ascidian				R				R				R			R	R
Corella eumyota	Sea squirt								R				R				R
Aplidium sp.	Orange colonial ascidian				R												
ECHINODERMATA (Seastars, urchins)																	
Patiriella regularis	Cushion sea star				R			R				R	R			R	R
Ophiuroidea	Brittle star															R	R
Evechinus chloroticus	Kina				R												
Astrostole scabra	Seven-armed sea star							R				R				R	

Appendix 3, continued.

		PL03				**PL16**				**LH05**				**LH07**			
Taxa	**Common name/description**	**H**	**M**	**L**	**P**	**H**	**M**	**L**	**P**	**H**	**M**	**L**	**P**	**H**	**M**	**L**	**P**
OSTEICHTHYES (Fish)																	
Forsterygion sp.	Triplefin				R				R								R
Total number of taxa		**18**	**33**	**41**	**62**	**20**	**28**	**43**	**24**	**14**	**31**	**61**	**40**	**14**	**34**	**56**	**66**
Total no. taxa from all zones		**90**				**72**				**77**				**89**			

Appendix 4. List of macroinvertebrate taxa recorded from grab samples of soft sediment habitats within and offshore from Lyttelton Harbour during baseline sampling surveys in 2016 and 2017. Taxonomic level: P=phylum; O=order; C=class; F=family; G=genus. Lower-case “s” designates “sub-”.

General Group	Taxa	Common Name	Level	Feeding
Porifera	**Porifera**	**Sponges**	**C**	
Hydrozoa	**Hydrozoa (athecate)**	**Hydroids**	**C**	
Anthozoa	**Anthozoa**	**Anemones, sea pens, corals**	**C**	
	Arachnanthus sp.	Tube dwelling anemones	G	
	Edwardsia sp.	Burrowing anemone	G	
	Virgularia gracillima	Sea pen	G	
Platyhelminthes	**Platyhelminthes**	**Flat worm**	**P**	**Predator**
Nemertea	**Nemertea**	**Proboscis worms**	**P**	
Nematoda	**Nematoda**	**Roundworm**	**P**	
Priapula	**Priapulida**	**Penis worms**	**C**	
Sipuncula	**Sipuncula**	**Peanut worms**	**O**	**Infaunal deposit feeder**
Mollusca		**Moluscs**	**P**	
Gastropoda		**Snails, limpets, pāua**	**C**	
	Gastropoda (micro snails)	Snails	C	
	Gastropoda Unid. Juv.	Snails	C	
	Pyramidellidae		F	
	Austrofusus glans		G	
	Neoguraleus sinclairi		G	
	Sigapatella tenuis	Small circular slipper shell	G	
	Xymene ambiguus		G	
	Xymene plebeius		G	
	Xymene sp.		G	
	Zeacolpus (Stiracolpus) blacki		G	
	Zeacolpus (Stiracolpus) symmetricus	Small turret	G	
	Zeacolpus sp.		G	

Appendix 4, continued.

General Group	Taxa	Common Name	Level	Feeding
Opisthobranchia	Opisthobranchia Unid.		C	
	Philine powelli	White slug	G	Feeds on small bivalves
	Philine sp.	White slug	G	
Bivalvia		**Clams**	C	
	Bivalvia indent.		C	
	Bivalvia Unid. (juv)		C	
	Mactridae	Bivalve (family)	F	Infaunal suspension feeder
	Nuculidae		F	
	Psammobiidae (juv.)		F	
	Tellinidae (juvenile)		F	
	Thraciidae		F	
	Veneridae (juv.)	Venerid Unid.	F	
	Arthritica bifurca	Small bivalve	G	Infaunal deposit feeder
	Borniola reniformis	Small bivalve	G	
	Dosinia anus	Tuangi-haruru	G	Infaunal suspension feeder
	Dosinia maoriana		G	Infaunal suspension feeder
	Dosinia sp.		G	Infaunal suspension feeder
	Dosinia sp. (Juvenile)	Surf clam	G	Infaunal suspension feeder
	Dosinia subrosea		G	Infaunal suspension feeder
	Ennucula strangei		G	
	Gari lineolata		G	
	Gari sp.		G	
	Leptomya retiaria retiaria		G	
	Maorimactra ordinaria		G	
	Melliteryx parva		G	

Appendix 4, continued.

General Group	Taxa	Common Name	Level	Feeding
Bivalvia	*Myadora novaezelandiae*		G	
	Myadora sp.		G	
	Myadora striata		G	
	Myllitella vivens vivens		G	
	Mysella sp.		G	
	Mytilus galloprovincialis	Blue mussel	G	
	Neilo australis		G	
	Nucula nitidula	Nut shell	G	Infaunal deposit feeder
	Nucula sp.	Nut shell	G	Infaunal deposit feeder
	Serratina charlottae		G	Infaunal suspension feeder
	Soletellina nitida	Golden sunset shell	G	Infaunal suspension feeder
	Soletellina sp.	Sunset shell	G	Infaunal suspension feeder
	Tellinota edgari		G	Infaunal suspension feeder
	Theora lubrica	Window shell	G	
Oligochaeta	**Oligochaeta**	**Oligochaete worms**	**C**	**Infaunal deposit feeder**
Polychaeta		**Polychaete worms**		
Ampharetidae	Ampharetidae		F	Surface deposit feeder
Chrysopetalidae	Chrysopetalidae	Polychaete worm (Family)	F	
Longosomatidae	Longosomatidae		F	
Sphaerodoridae	Sphaerodoridae	Polychaete family	F	
Pectinariidae	*Lagis australis*		G	
	Lagis sp.		G	
Orbiniidae	Orbiniidae juv.		F	
	Naineris sp.		G	Infaunal deposit feeder
	Phylo novazealandiae		G	
	Scoloplos cylindrifer	Polychaete worm	G	Infaunal deposit feeder

Appendix 4, continued.

General Group	Taxa	Common Name	Level	Feeding
Polychaeta				
Orbiniidae	*Scoloplos* sp.		G	
Paraonidae	Paraonidae		F	Infaunal deposit feeder
	Aricidea sp.		G	
Cossuridae	*Cossura consimilis*		G	Deposit feeder
Poecilochaetidae	Poecilochaetidae		F	
Spionidae	Spionidae		F	Surface deposit feeder
	Paraprionospio coora		G	
	Paraprionospio sp.		G	Surface deposit feeder
	Prionospio sp.		G	Surface deposit feeder
	Prionospio yuriel		G	Surface deposit feeder
	Pseudopolydora sp.		G	Surface deposit feeder
	Spiophanes kroyeri		G	Surface deposit feeder
	Spiophanes modestus		G	
	Spiophanes sp.		G	Surface deposit feeder
	Spiophanes spp.		G	
	Polydorid		F	
Magelonidae	Magelonidae		F	Surface deposit feeder
	Magelona sp.		G	Surface deposit feeder
Chaetopteridae	*Phyllochaetopterus socialis*	Parchment worm	G	Filter feeder
Capitellidae	Capitellidae		F	Infaunal deposit feeder
	Barantolla lepte		G	
	Capitella capitata		G	Infaunal deposit feeder
	Heteromastus filiformis		G	Infaunal deposit feeder
	Notomastus sp.		G	Infaunal deposit feeder
Maldanidae	Maldanidae	Bamboo worm	F	Infaunal deposit feeder
Opheliidae	*Armandia maculata*		G	Infaunal deposit feeder

Appendix 4, continued.

General Group	Taxa	Common Name	Level	Feeding
Opheliidae	*Travisia* sp.		G	
Phyllodocidae	Phyllodocidae	Paddle worms	F	Carnivore & scavenger
Piligaridae	Pilargidae		F	
Polynoidae	Polynoidae	Scale worms	F	Infaunal carnivore
Sigalionidae	Sigalionidae		F	Infaunal carnivore
Hesionidae	Hesionidae		F	Carnivore and deposit feeder
Syllidae	Exogoninae		F	
	Syllidae		F	Omnivorous
Glyceridae	Glyceridae		F	Infaunal carnivore & deposit feeder
Goniadidae	Goniadidae		F	Infaunal carnivore
Nephtyidae	Nephtyidae		F	Infaunal carnivore
	Aglaophamus sp.		G	Infaunal carnivore
Onuphidae	*Onuphis aucklandensis*		G	Infaunal surface deposit feeder/omnivore
Lumbrineridae	Lumbrineridae		F	Infaunal carnivore & deposit feeder
Dorvilleidae	Dorvilleidae		F	Facultative carnivore
Oweniidae	Oweniidae		F	Infaunal deposit feeder
	Myriochele sp.		G	
	Owenia borealis		G	
	Owenia petersenae	Polychaete worm	G	Infaunal deposit feeder
Cirratulidae	Cirratulidae		F	Deposit feeder
Flabelligeridae	Flabelligeridae		F	Infaunal deposit feeder
Sternaspidae	*Sternaspis scutata*	Polychaete worm	G	Infaunal deposit feeder
Terebellidae	Terebellidae		F	Infaunal deposit feeder
Trichobranchidae	Trichobranchidae		F	
	Terebellides narribri		G	
	Terebellides stroemii		G	

Appendix 4., continued.

General Group	Taxa	Common Name	Level	Feeding
Trichobranchidae	*Trichobranchus* sp.		G	
Sabellariidae	Sabellariidae	Polchaete worm reef building	F	Infaunal suspension feeder
Serpulidae	*Serpula* sp.		G	Suspension feeder
CRUSTACEA		**CRUSTACEANS**	**sP**	
Tanaidacea	Tanaidacea	Tanaid shrimp	F	
Cumacea	**Cumacea**	**Cumaceans**	**O**	**Infaunal filter or deposit feeder**
Isopoda		**Sea lice**		
	Cirolanidae		F	
	Idoteidae		F	
	Munnidae		F	
	Natatolana sp.	Sea louse	G	
	Paramunna serrata		G	
	Uromunna schauinslandi	Isopod	G	
	Valvifera		O	
Amphipoda		**Amphipods**	O	
	Haustoriidae	Amphipod (family)	F	
	Lysianassidae	Amphipods	F	Epifaunal scavenger
	Phoxocephalidae	Amphipod (family)	F	
	Ampelisca (juv.)		G	
	Ampelisca sp.	Amphipod	G	
	Amphipoda	Amphipods	O	Epifaunal scavenger
	Amphipoda Larvae		O	
Decapoda		**Crabs, prawns, shrimp**		
	Hemiplax hirtipes	Stalk-eyed mud crab	G	Deposit feeder & scavenger
	Hymenosoma depressum	Crab	G	Epifaunal scavenger
	Neommatocarcinus huttoni	Policeman crab	G	

Appendix 4, continued.

General Group	Taxa	Common Name	Level	Feeding
	Ogyrides sp	Shrimp (long eyes)	G	
	Anomura	Hermit crab	O	
	Brachyura (juv.)		O	
Ostracoda		**Seed shrimp**		
	Diasterope grisea	Ostracod	G	Omnivorous scavenger
	Leuroleberis zealandica	Ostracod (Large)	G	Omnivorous scavenger
	Parasterope quadrata	Ostracod	G	Omnivorous scavenger
	Ostracoda	Ostracod	O	Omnivorous scavenger
Copepoda	**Copepoda**	**Copepods**	**C**	
Pycnogonida	**Pycnogonida**	**Sea spider**	**C**	
Phoronida	**Phoronida**	**Horseshoe worm**	**P**	
Bryozoa	Bryozoa (encrusting)	Bryozoans	C	
	Bryozoa	Bryozoans	P	
Echinodermata		**Urchins, seastars, sea cucumbers**		
Echinoidea	Echinoidea	Urchins	C	
	Echinocardium cordatum	Heart urchin	G	
Asteroidea	*Fellaster zelandiae*	Sand dollar	G	
Ophiuroidea	Ophiuroidea	Brittle stars	F	
Holothuroidea	*Heterothyone alba*	Sea cucumber	G	
	Heterothyone ocnoides	Sea cucumber	G	
	Paracaudina chilensis	Sea cucumber	G	
	Placothuria squamata		G	
Chaetognatha	**Chaetognatha**	**Arrow worm**	**C**	
Total no. of taxa	169			