SALT ECOLOGY

Fine Scale Intertidal Monitoring of Blueskin Bay, Waitati Inlet

Prepared for

Otago Regional Council

July 2023

Salt Ecology
Report 110

Cover and back photo: View across the extensive sandy intertidal flats of Blueskin Bay looking towards Site B and the entrance, November 2022.

RECOMMENDED CITATION

O'Connell-Milne S, Forrest BM, Rabel H. 2023. Fine Scale Intertidal Monitoring of Blueskin Bay, Waitati Inlet. Salt Ecology Report 110, prepared for Otago Regional Council, July 2023. 40p.

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for

Otago Regional Council
July 2023

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GLOSSARY

AMBI	AZTI Marine Biotic Index
ANZECC	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000)
ANZG	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018)
aRPD	Apparent Redox Potential Discontinuity
As	Arsenic
Cd	Cadmium
Cr	Chromium
Cu	Copper
DGV	Default Guideline Value
ETI	Estuary Trophic Index
Hg	Mercury
NCC	Otago Regional Council
NEMP	National Estuary Monitoring Protocol
Ni	Nickel
ORC	Otago Regional Council
Pb	Lead
SACFOR	Epibiota categories of Super abundant, Abundant, Common, Frequent, Occasional, Rare
SOE	State of Environment (monitoring)
TN	Total nitrogen
TOC	Total organic carbon
TP	Total phosphorus
Zn	Zinc

ACKNOWLEDGEMENTS

Many thanks to Sam Thomas (ORC) for his support in undertaking this work and peer review of the report. We are grateful to Fiona Gower (Cawthron Institute) and Sarah Hailes and team (National Institute of Water and Atmospheric Research) for taxonomic identifications, and Gary Stephenson (Coastal Marine Ecology Consultants) for taxonomic QA checks of 2021 data. Thanks to Keryn Roberts (Salt Ecology) for review comments on a draft report. Andrew Spurgeon (www.mollusca.co.nz) kindly allowed us to use the bivalve and gastropod images shown in Table 5.

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BACKGROUND

As part of its State of the Environment (SOE) programme, Otago Regional Council monitors the ecological condition of significant estuaries in its region. This report summarises three years of baseline ecological monitoring and sedimentation surveys that were conducted at two sites in Blueskin Bay, in January 2021, November 2021, and November 2022. The surveys largely followed the 'fine scale' approach described in New Zealand's National Estuary Monitoring Protocol (NEMP), with 'sediment plates' also installed in January 2021 to enable monitoring of sedimentation at the two fine scale sites. Results are assessed against condition rating criteria for estuary heath in the Table below.

KEY FINDINGS

- Sedimentation rates differed between the two sites with both erosion and accretion observed over the monitored period. In November 2022 mean annual sedimentation at Site B exceeded the guideline for New Zealand estuaries of 2mm/yr (a condition rating of 'poor'), however, these results are not necessarily reflective of long-term patterns, which may be resolved over a period of 5 to 10 years.
- Sediment quality for most variables was rated as 'good' or 'very good'. The survey revealed that sediments at both sites were sand-dominated with very low concentrations of total organic carbon, total nitrogen, and contaminants.
- While sediments at centrally located Site A appeared more enriched and less oxygenated (shallower aRPD) than at Site B (to the south of the estuary), there were no severe symptoms of eutrophication, such as a black, anoxic and sulphide-smelling sediment, and no excessive surface growths of opportunistic macroalgae.
- The high sediment quality at both fine scale sites was reflected in the diverse and abundant macrofauna present. Compared to other estuaries in the Otago SOE programme, Blueskin Bay stands out as clearly having the greatest macrofaunal richness and some of the highest abundances.
- The species-rich assemblages in Blueskin Bay are dominated by a variety of taxa, and both sites were characterised by a range of organisms generally considered to be sensitive to habitat disturbance.

Overall, the main tidal flats of Blueskin Bay are in a healthy condition. This situation has persisted despite historic modification of the estuary's margins, loss of salt marsh, and catchment land-use changes that have increased the threat from muddy sediment inputs. However, the estuary is considered vulnerable to likely future increases in sediment loads; for example, due to harvest of exotic plantation forest, which comprises almost a quarter of the catchment land use. These and other future threats should be managed so that the current healthy state of the estuary is maintained.

Summary of scores of estuary condition based on mean values of key indicators.

Site	Survey	Sed rate (mm/yr)	Mud (%)	aRPD (mm)	TN	TP	TOC (%)	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn	AMBI na
A	Jan-21	-	5.0	13	<500	177	0.13	2.0	<0.01	4.1	0.9	1.1	<0.02	2.5	8.4	1.9
	Nov-21	-5.4	3.9	22	<500	181	0.15	2.2	<0.01	4.1	0.8	0.9	<0.02	2.5	7.8	2.2
	Nov-22	2.0	5.7	14	<500	160	0.15	2.3	<0.01	4.4	0.9	1.1	<0.02	2.8	8.7	2.0
B	Jan-21	-	5.7	26	<500	260	0.12	3.0	<0.01	7.1	1.1	1.3	<0.02	5.8	11.7	2.4
	Nov-21	-1.6	5.1	29	<500	270	0.12	3.4	<0.01	7.0	1.0	1.3	<0.02	5.7	11.6	2.6
	Nov-22	5.6	6.4	34	<500	213	0.13	3.2	<0.01	6.8	1.0	1.3	<0.02	5.3	11.2	2.4

< All values below lab detection limit. Units are mg/kg except where noted. See Glossary for abbreviations and Table 3 for condition rating thresholds.

Very Good	Good	Fair	Poor

RECOMMENDATIONS

On the basis of the findings and discussion in this report, and in view of the recommendations that arose from a NEMP broad scale habitat mapping survey in 2021, additional recommendations for Blueskin Bay are as follows:

- Evaluate likely future sediment sources to the estuary, and investigate options for a reduction of inputs.
- Continue annual sediment plate monitoring, with concurrent sampling of sediments for grain size analysis to track changes in sediment mud content.
- Undertake fine scale monitoring at a minimum of every five years, based on the current approach, except for a reduction in macrofauna sampling effort to nine cores per site.
- Given that ORC has now undertaken ecological assessments of the main estuaries in Otago, it would be timely to also consider management and monitoring in Blueskin Bay alongside the priorities for other estuaries regionally.

1. INTRODUCTION

Monitoring the ecological condition of estuarine habitats is critical to their management. Estuary monitoring is undertaken by most councils in New Zealand as part of their State of the Environment (SOE) programmes. The most widely-used monitoring framework is that outlined in New Zealand's National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002). The NEMP is intended to provide resource managers nationally with a scientifically defensible, cost-effective and standardised approach for monitoring the ecological status of estuaries in their region. The results establish a benchmark of estuarine health in order to better understand human influences, and against which future comparisons can be made. The NEMP approach involves two main types of survey:

- Broad scale mapping of estuarine intertidal habitats. This type of monitoring is typically undertaken every 5 to 10 years.
- Fine scale monitoring of estuarine biota and sediment quality. This type of monitoring is typically conducted at intervals of 5 years after initially establishing a baseline.

One of the key additional methods that has been put in place subsequent to the NEMP being developed is 'sediment plate' monitoring. This component typically involves an annual assessment of patterns of sediment accretion and erosion in estuaries, based on changes in sediment depth over buried concrete pavers. Sediment plate monitoring stations are often established at NEMP fine scale sites, or nearby. In addition to providing information on patterns of sediment accretion and erosion, sediment plate monitoring aids interpretation of physical and biological changes at fine scale sites.

Monitoring of selected estuaries in the Otago region has been undertaken using the above methods for several years, recently expanding to locations including Pleasant River, Papanui Inlet, Akatore, Shag River, Waikouaiti, Kaikorai, Tokomairiro and Catlins estuaries. ORC added Blueskin Bay (Waitati Inlet) to the estuary monitoring programme in January 2021. Blueskin Bay is a large estuary to the north of Dunedin (Fig. 1). Salt Ecology undertook a NEMP broad scale habitat mapping and a fine scale survey in parallel in January 2021, and installed sediment plates for future sedimentation monitoring (Forrest et al. 2021; Roberts et al. 2021). Fine scale monitoring was repeated in November 2021 and 2022 to form a baseline dataset, which informs understanding of the estuary's condition and the interannual variability within the system.

This report describes the methods and results of the fine scale and sediment plate components from the three consecutive annual baseline monitoring surveys, with the broad scale work described by Roberts et al. (2021). Results of the present survey are discussed in the context of existing knowledge of Blueskin Bay (e.g., from University of Otago studies) and in relation to various criteria for assessing estuary health.

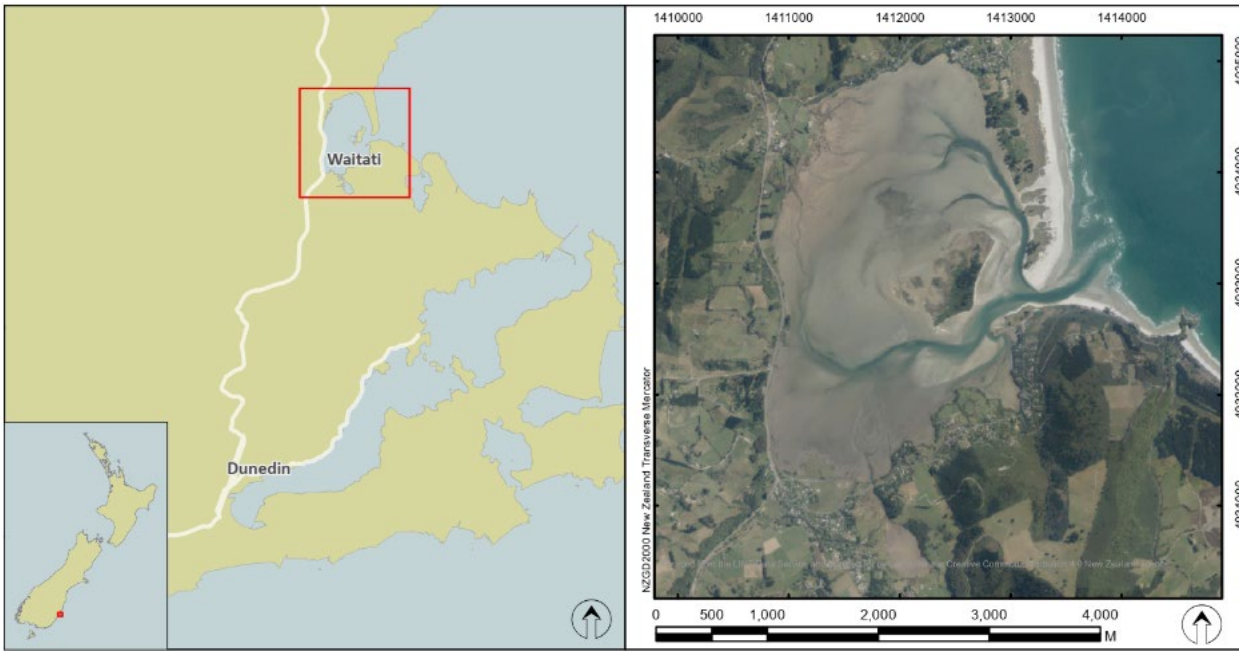

Fig. 1. Location of Blueskin Bay (Waitati Inlet).

2. BACKGROUND TO BLUESKIN BAY

The following background information on Blueskin Bay has been updated from Roberts et al. (2021) and incorporates the findings of the broad scale habitat mapping survey described in that report.

Blueskin Bay is a large (690ha) shallow, intertidally dominated, tidal lagoon type estuary (SIDE) located approximately 25km north of Dunedin. The estuary mouth at the south end is permanently open to the sea and the main body is protected from the open ocean by a sandspit (see Fig. 1). The estuary is well flushed, with the majority of tidal water exchanged with the ocean on each tidal cycle (Zhang 2018; O'Connell-Milne et al. 2020). At low tide, 91% of the estuary is exposed, revealing extensive sandflats consisting of firm sand-dominated sediments (437ha). The tidal flats are classified as an extremely well-defined landform of international significance (ORC 2012). Mud-dominated sediments (>50% mud) are a minor component, comprising only 25.2ha (3.7%) of the intertidal area (Roberts et al. 2021). These muddy sediments were recorded in localised areas of freshwater inflow, within salt marsh, and in Orokonui Inlet at the south end.

Macroalgae are widespread across parts of Blueskin Bay and blooms of *Ulva* spp. have been observed through summer months, with an event in 2017/18 persisting over winter (Chai et al. 2020; Otis & Schallenberg 2020). Roberts et al. (2021) recorded two localised patches (0.6ha or 0.1% of the intertidal area) of sediment-entrained *Agarophyton* spp. (formerly known as *Gracilaria chilensis*) near channels in the north-west corner of the estuary. These areas comprised patches of >90% cover, having a high biomass (>1kg/m^2), and exhibiting associated eutrophic sediments (high mud content and low sediment oxygenation).

Extensive seagrass (*Zostera muelleri*) beds are a dominant feature of the central intertidal flats, comprising 33.5ha (5.2%) of the intertidal area (Roberts et al. 2021). That report attributed the extensive seagrass to the low sediment and nutrient input to the estuary, strong flushing, and high water clarity.

The lower estuary supports occasional dredge oysters (*Tiostrea chilensis*) and a healthy supply of cockles (*Austrovenus stutchburyi*). Roberts et al. (2021) mapped a total of 30.8ha (4.9% of the intertidal area) of cockle beds and shell banks in the estuary, where recreational, customary, and commercial fishing of cockles occurs, with an estimated cockle biomass of ~14,000T (MPI 2021). Several studies have demonstrated that coastal phytoplankton is a primary food source for these filter feeders, highlighting the important interaction between estuaries and open coastal waters (Kainamu 2010; Zhang 2018; O'Connell-Milne et al. 2020).

Around the margins of the estuary, the area of salt marsh measured in 2021 was 35.4ha, representing 5.7% of the intertidal area and comprising 54.1% herbfield. Historically salt marsh would have been more extensive, with losses resulting from urban and infrastructure development on the estuary margins for rail, roading and the settlements of Warrington and Waitati.

Like many estuaries, Blueskin Bay is regarded as an important habitat for nesting birds and a nursery for fish. Overall, Blueskin Bay is considered to have high ecological, cultural and social values. As such, both Blueskin Bay and adjacent Orokonui Inlet are within coastal protection areas in the 'Otago Regional Plan: Coast', for their Kai Tahu cultural and spiritual values, in addition to their estuarine values.

The high ecological values of Blueskin Bay can be attributed, in part, to ~62% of the catchment being densely vegetated (Fig. 2), and having low freshwater inputs; flows from Waitati River (south) and Careys Creek (northwest) (mean freshwater flow 0.8m^3/s) contribute only a small portion of the total estuary volume. However, ~23% of the catchment in is exotic plantation forestry and the lower catchment is dominated by high-producing pasture (28% of the catchment area), which are both potential sources of muddy sediment and/or nutrients. Despite <1% of the plantation forestry being harvested in 2018, as indicated in the land use classifications shown in Fig. 2, satellite imagery reveals clear-felling of large areas occurred in 2019. Leachate from the Warrington wastewater treatment plant and residential septic tanks are likely to produce an additional source of nitrogen to the estuary (Otis & Schallenberg 2020).

Salt marsh herbfield, Blueskin Bay.

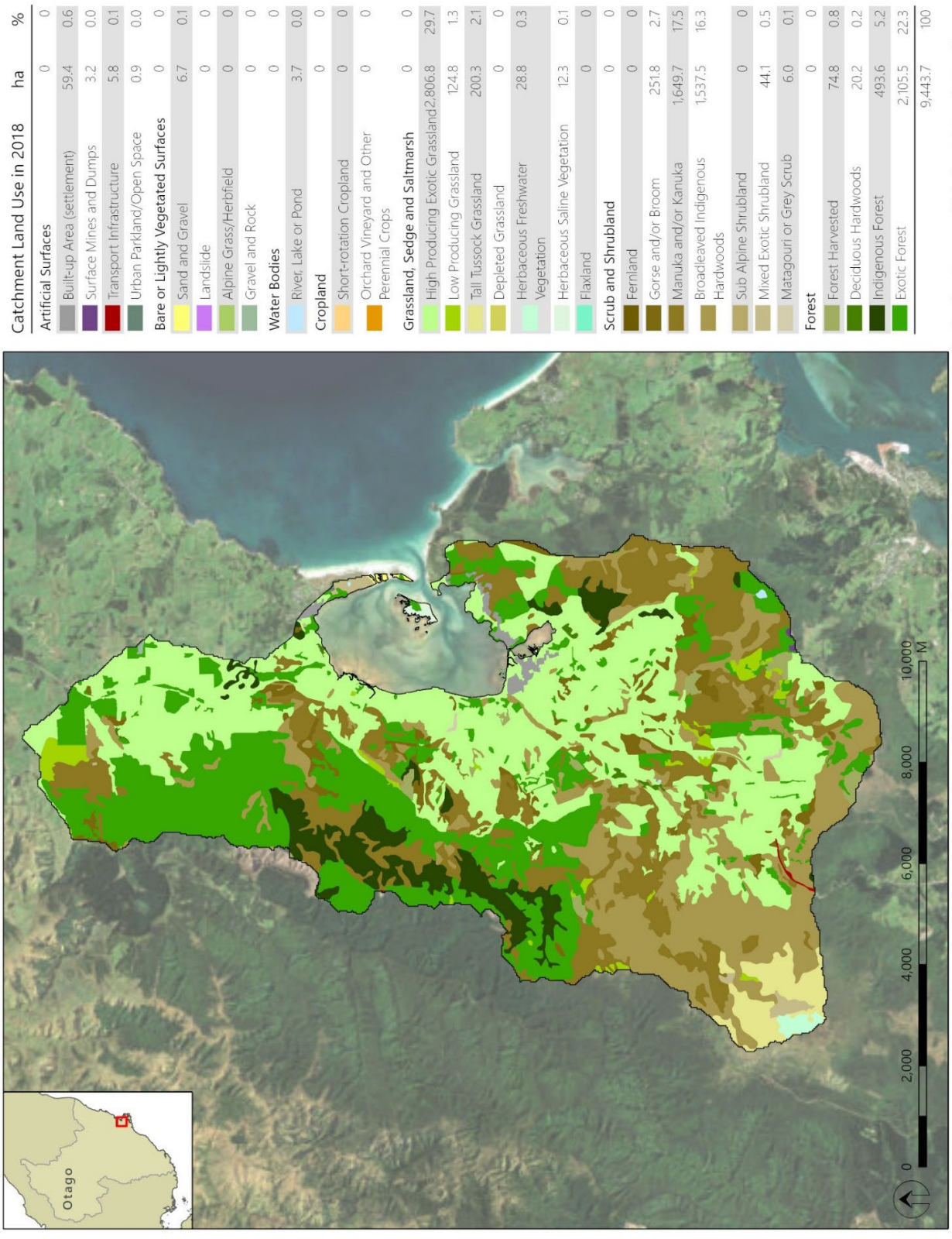

Fig. 2. Blueskin Bay and surrounding catchment land use classifications from LCDB5 (2017/18) database.

3. FINE SCALE METHODS

3.1 OVERVIEW OF NEMP FINE SCALE APPROACH

Mapping the main habitats in an estuary using the NEMP broad scale approach provides a good basis for identifying representative areas to establish fine scale and sediment plate sites. The NEMP advocates that fine scale monitoring is undertaken in soft sediment (sand/mud) habitat in the mid to low tidal range of priority estuaries.

The environmental characteristics assessed in fine scale surveys incorporate a suite of common benthic indicators, including biological attributes such as the 'macrofaunal' assemblage and various physico-chemical characteristics (e.g., sediment mud content, trace metals, nutrients). A summary of the benthic indicators, the rationale for their inclusion, and the field sampling methods, is provided in Table 1.

Extensions to the NEMP methodology that support the fine scale approach include the development of various metrics for assessing ecological condition according to prescribed criteria, and inclusion of sediment plate monitoring as noted in Section 1. These additional components are included in the present report and are described in the subsections below.

3.2 BLUESKIN BAY FINE SCALE AND SEDIMENT PLATE SITES

As Blueskin Bay consists of an extensive area of relatively uniform intertidal flat comprising firm muddy sand, it was considered that monitoring at two sites would be sufficiently representative of the wider estuary.

Accordingly, Site A was positioned near the centre of Blueskin Bay and Site B toward the south. Both sites having surface macroalgae but no seagrass. Each fine scale site was set up as a 30 x 60m rectangle, and sediment plates were installed along the landward 30m margin. The sites were positioned at approximately mid-tide, with Site B at a slightly lower tidal height than Site A.

To assist relocation, fine scale site corners and the locations of sediment plates were marked with wooden pegs. Coordinates for each of these features are provided in Appendix 1. A map showing the site locations, and a schematic of the sampling approach described below, is provided in Fig. 3.

Plate installation and fine scale site set-up and sampling was undertaken on 15 Jan 2021. On that day there was a 0.32m low tide at 11:35 (NIWA tide forecast, Blueskin Bay), with conditions suitable for sampling until ~14:30.

3.3 SEDIMENT PLATES

Concrete 'plates' (pavers, 19cm x 23cm) for sediment plate monitoring were installed at the two sites. Four plates were installed along the 30m length of each fine scale site boundary, spaced at 5, 10, 20 and 25m. As well as the fine scale site corner pegs, an additional relocation peg was placed at the 15m mid-point (see Fig. 3).

Plates were buried and levelled at ~50mm depth in the sediment. Actual baseline depths (from the sediment surface to each buried plate) were then measured. For this purpose, a 2m straight edge was placed over each plate position to average out any small-scale irregularities in surface topography. The depth to each plate was measured in triplicate by vertically inserting a probe into the sediment until the plate was located. Depth was measured to the nearest millimetre.

At each site, a single sediment sample (composited from 20mm deep sub-samples taken next to each plate) was collected and retained for laboratory analysis of grain size, using the methods described for fine scale monitoring (see next section). As the sediment plate measurements are expected to be undertaken annually, the grain size data can be used to assess ongoing changes in sediment muddiness.

Measuring sediment plates at Site B, November 2022.

Table 1. Summary of NEMP fine scale benthic indicators, rationale for their use, and sampling method. Any significant departures from NEMP are described in footnotes.

Indicator	General rationale	Sampling method
Physical and chemical		
Sediment grain size	Indicates the relative proportion of fine-grained sediments that have accumulated.	Composited surface scrape to 20mm sediment depth.
Nutrients (nitrogen and phosphorus), organic matter & total sulfur	Reflects the enrichment status of the estuary and potential for algal blooms and other symptoms of enrichment.	Surface scrape to 20mm sediment depth. Organic matter measured as Total Organic Carbon (TOC) (note 1).
Trace elements (arsenic copper, chromium, cadmium, lead, mercury, nickel, zinc)	Common toxic contaminants generally associated with human activities. High concentrations may indicate a need to investigate other anthropogenic inputs, e.g., pesticides, hydrocarbons.	Surface scrape to 20mm sediment depth (note 2).
Substrate oxygenation (depth of apparent Redox Potential Discontinuity layer; aRPD)	Measures the enrichment/trophic state of sediments according to the depth of the aRPD. The aRPD can occur closer to the sediment surface as organic matter loading or sediment mud content increase.	Sediment core, split vertically, with average depth of aRPD recorded in the field where visible. The aRPD depth represents the visual transition between brown oxygenated surface sediments and deeper less oxygenated black sediments.
Biological		
Macrofauna	Abundance, composition and diversity of infauna living with the sediment are commonly-used indicators of estuarine health.	130mm diameter sediment core to 150mm depth (0.013m^2 sample area, 2L core volume), sieved to 0.5mm to retain macrofauna.
Epibiota (epifauna)	Abundance, composition and diversity of epifauna are commonly-used indicators of estuarine health.	Abundance based on SACFOR in Appendix 1, Table B3 (note 3).
Epibiota (macroalgae)	The composition and prevalence of macroalgae are indicators of nutrient enrichment.	Percent cover based on SACFOR in Appendix 1, Table B3 (note 3).
Epibiota (microalgae)	The prevalence of microalgae is an indicator of nutrient enrichment.	Visual assessment of conspicuous growths based on SACFOR in Appendix 1, Table B3 (notes 3, 4).

[1] Since the NEMP was published, Total Organic Carbon (TOC) has become available as a routine low-cost analysis which provides a more direct and reliable measure than the NEMP recommendation of converting Ash Free Dry Weight (AFDW) to TOC.

[2] Arsenic and mercury are not specified in the NEMP, but can be included in the trace element suite by the analytical laboratory.

[3] Assessment of epifauna, macroalgae and microalgae uses the SACFOR approach instead of the quadrat sampling outlined in the NEMP. Quadrat sampling is subject to considerable within-site variation for epibiota that have clumped or patchy distributions.

[4] NEMP recommends taxonomic composition assessment for microalgae but this is not typically undertaken due to clumped or patchy distributions and the lack of demonstrated utility of microalgae as a routine indicator.

3.4 FINE SCALE SAMPLING AND BENTHIC INDICATORS

Each fine scale site was divided into a 3 x 4 grid of 12 plots (see Fig. 3). Fine scale sampling for sediment indicators was conducted in 10 of these plots, with Fig. 3 showing the standard numbering sequence for replicates at both sites, and the designation of 'zones' X, Y and Z (for compositing sediment samples; see below).

Although the sampling approach generally adhered to the NEMP, a review undertaken for Marlborough District Council (Forrest & Stevens 2019) highlighted that alterations and additions to early NEMP methods have been introduced in most surveys conducted over the last 10-15 years. For present purposes we adopted these modifications as indicated in Table 1.

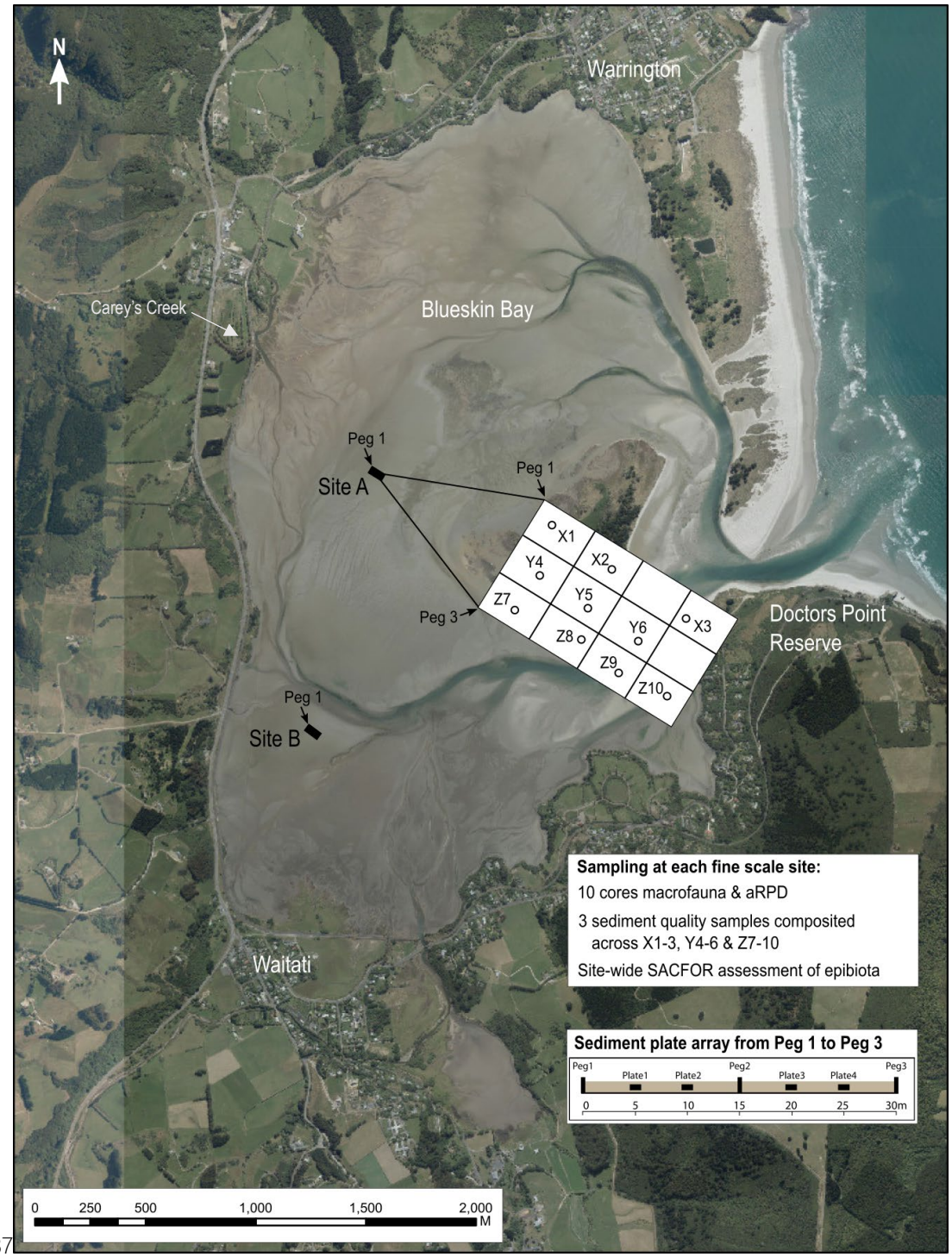

Fig. 3. Locations of the sites in Blueskin Bay, and schematics illustrating fine scale and sediment plate methods.

3.4.1 Sediment quality assessment

At each fine scale site, three composite sediment samples (each ~250g) were pooled from sub-samples (to 20mm depth) collected across each of zones X, Y and Z (replicates 1-3, 4-6 and 7-10, respectively; see Fig. 3). Samples were stored on ice and sent to RJ Hill Laboratories for analysis of: particle grain size in three categories (%mud <63µm, sand <2mm to ≥63µm, gravel ≥2mm); organic matter (total organic carbon, TOC); nutrients (total nitrogen, TN; total phosphorus, TP); and trace metal contaminants (arsenic, As; cadmium, Cd; chromium, Cr; copper, Cu; mercury, Hg; lead, Pb; nickel, Ni; zinc, Zn). Details of laboratory methods and detection limits are provided in Appendix 2.

3.4.2 Field sediment oxygenation assessment

To assess sediment oxygenation, the apparent redox potential discontinuity (aRPD) depth was measured (Table 1). The aRPD depth in all surveys was measured (to the nearest mm) after extracting a large sediment core (130mm diameter, 150mm deep) from each of the 10 plots, placing it on a tray, and splitting it vertically. Representative split cores (X1, Y4 and Z7) were also photographed.

3.4.3 Biological sampling

Sediment-dwelling macrofauna

To sample sediment-dwelling macrofauna, each of the large sediment cores used for assessment of aRPD was placed in a separate 0.5mm sieve bag, which was gently washed in seawater to remove fine sediment. The retained animals were preserved in a mixture of 75% isopropyl alcohol and 25% seawater for later sorting and taxonomic identification. Macrofauna were initially identified by Cawthron Institute (January 2021 survey) with subsequent identification completed by NIWA (November 2021 and 2022 surveys). The types of animals present in each sample, as well as the range of different species (i.e., richness) and their abundance, are well-established indicators of ecological health in estuarine and marine soft sediments.

Surface-dwelling epibiota

In addition to macrofaunal core sampling, epibiota (macroalgae, and conspicuous surface-dwelling animals nominally >5mm body size) visible on the sediment surface at each site were semi-quantitatively categorised using 'SACFOR' abundance (animals) or percentage cover (macroalgae) ratings shown in Table 2. These ratings represent a scoring scheme simplified from established monitoring methods (MNCR 1990; Blyth-Skyrme et al. 2008).

The SACFOR method is ideally suited to characterise intertidal epibiota with patchy or clumped distributions. It was conducted as an alternative to the quantitative quadrat sampling specified in the NEMP, which is known to poorly characterise scarce or clumped species. Note that our epibiota assessment did not include infaunal species that may be visible on the sediment surface, but whose abundance cannot be reliably determined from surface observation (e.g., cockles).

Table 2. SACFOR ratings for site-scale abundance, and percent cover of epibiota and algae, respectively.

SACFOR category	Code	Density per m^2	Percent cover
Super abundant	S	> 1000	> 50
Abundant	A	100 - 999	20 - 50
Common	C	10 - 99	10 - 19
Frequent	F	2 - 9	5 - 9
Occasional	O	0.1 - 1	1 - 4
Rare	R	< 0.1	< 1

3.5 DATA RECORDING, QA/QC AND ANALYSIS

All sediment and macrofaunal samples were tracked using standard Chain of Custody forms, and results were transferred electronically to avoid transcription errors. Field measurements from the fine scale and sediment plate surveys were recorded electronically in templates that were custom-built using software available at www.fulcrumapp.com. Pre-specified constraints on data entry (e.g., with respect to data type, minimum or maximum values) ensured that the risk of erroneous data recording was minimised. Each sampling record created in Fulcrum generated a GPS position for that record (e.g., a sediment core). Field data were exported to Excel, together with data from the sediment and macrofaunal analyses.

Excel sheets for the different data types and survey years were imported into the software R 4.2.3 and merged by common sample identification codes. All summaries of univariate responses (e.g., totals, means ± 1 standard error) were produced in R, including tabulated or graphical representations of data from sediment plates,

laboratory sediment quality analyses, and macrofauna. Where results for sediment quality parameters were below analytical detection limits, averaging (if undertaken) used half of the detection limit value, according to convention.

Before macrofaunal analyses, the data were screened to remove species that were not regarded as a true part of the macrofaunal assemblage; these were planktonic life-stages and non-marine organisms (e.g., terrestrial beetles). To facilitate comparisons with future surveys, and other Otago estuaries, cross-checks were made to ensure consistent naming of species and higher taxa. For this purpose, the adopted name was that accepted by the World Register of Marine Species (WoRMS, www.marinespecies.org/). Taxonomy QA cross-checks were undertaken as follows:

- In January 2021, Cawthron sent samples from four macrofauna cores (2 samples per site) to Gary Stephenson, Coastal Marine Ecology Consultants (CMEC).
- For November 2021 and 2022, identifications by NIWA para-taxonomists were checked by different specialists within NIWA.

Macrofaunal response variables included richness and abundance by species and higher taxonomic groupings. In addition, scores for the biotic health index AMBI (Borja et al. 2000) were derived. AMBI scores reflect the proportion of taxa falling into one of five eco-groups (EG) that reflect sensitivity to pollution (in particular, eutrophication), ranging from relatively sensitive (EG-I) to relatively resilient (EG-V). To meet the criteria for AMBI calculation, macrofauna data were reduced to a subset that included only adult 'infauna' (those organisms living within the sediment matrix), which involved removing surface dwelling epibiota and any juvenile organisms. AMBI scores were calculated based on standard international eco-group classifications (http://ambi.azti.es), which were last updated in 2020. To reduce the number of taxa with unassigned eco-groups, international data were supplemented with more recent eco-group classifications for New Zealand (Keeley et al. 2012; Robertson et al. 2015; Robertson et al. 2016c; Robertson 2018). Note that AMBI scores were not calculated for macrofaunal cores that did not meet operational limits defined by Borja et al. (2012), in terms of the percentage of unassigned taxa (>20%), or low sample richness (<3 taxa) or abundances (<6 individuals).

Multivariate representation of the macrofaunal community data used the software package Primer v7.0.13 (Clarke et al. 2014). Patterns in site similarity as a function of macrofaunal composition and abundance were assessed using an 'unconstrained' non-metric multidimensional scaling (nMDS) ordination plot, based on pairwise Bray-Curtis similarity index scores among samples grouped within each site-zone and sampling year (see Fig. 3). The purpose of grouping was to smooth over the 'noise' associated with a core-level analysis, enable the relationship to patterns in sediment quality variables to be determined, and enable comparison with the 2021 and 2022 data. Due to a change in taxonomic provider after January 2021, for multivariate analysis it was also necessary to aggregate some of the species or taxa to higher groups (e.g., genus, family, phylum), to minimise uncertainty associated with taxonomic differences that existed despite the QA procedure described above. Appendix 3 provides information on the taxonomic aggregation undertaken.

Prior to the multivariate analysis, the macrofaunal abundance data were transformed (using both square-root and presence-absence approaches) to down-weight the influence on the ordination pattern of the dominant species or higher taxa. The purpose of the presence-absence transformation was to explore site differences that were attributable to species occurrences irrespective of their relative abundances.

Overlay vectors and bubble plots on the nMDS were used to visualise relationships between multivariate biological patterns and sediment quality data, which were log(x+1)-transformed and normalised to a standard scale. Additionally, the Primer procedure Bio-Env was used to evaluate the suite of sediment quality variables that best explained the similarity of sites in terms of their species composition.

3.6 ASSESSMENT OF ESTUARY CONDITION

To supplement our analyses and interpretation of the data, results were assessed within the context of established or developing estuarine health metrics ('condition ratings'), drawing on approaches from New Zealand and overseas. These metrics assign different indicators to one of four rating bands, colour-coded as shown in Table 3. Most of the condition ratings in Table 3 were derived from those described in a New Zealand Estuary Trophic Index report (Robertson et al. 2016b, a), which includes purpose-developed criteria for eutrophication, and also draws on wider national and international environmental quality guidelines. Key elements of this approach are as follows:

- *New Zealand Estuary Trophic Index (ETI) report:* The ETI report provides screening guidance for assessing where an estuary is positioned on a eutrophication

gradient. While many of the constituent metrics are intended to be applied to the estuary as a whole (i.e., in a broad scale context), site-specific thresholds for %mud, TOC, TN, aRPD and AMBI are also provided, and adopted or modified as described in footnotes to Table 3.

- *ANZG (2018) sediment quality guidelines*: The condition rating categories for trace metal contaminants were benchmarked to ANZG (2018) sediment quality guidelines as described in Table 3. The Default Guideline Value (DGV) indicates the concentration below which there is a low risk of unacceptable effects, whereas the 'upper' guideline value (GV-high) provides an indication of concentrations at which toxicity-related adverse effects may already be observed.

In addition, for assessing and managing sedimentation effects, Townsend and Lohrer (2015) propose a DGV of 2mm of sediment accumulation per year above natural deposition rates. The 2mm/yr value has been used as the threshold between the 'fair' and 'poor' bands in Table 3 on the basis that exceeding the DGV is expected to result in an increased likelihood of adverse ecological effects.

Note that the scoring categories described above and in Table 3 should be regarded only as a general guide to assist with interpretation of estuary condition. Accordingly, it is major spatio-temporal changes in the categories that are of most interest, rather than their subjective condition descriptors; i.e., descriptors such as 'poor' condition should be regarded more as a relative rather than absolute rating.

Table 3. Condition ratings used to characterise estuarine health for key indicators. See footnotes and main text for explanation of the origin or derivation of the different metrics.

Indicator	Unit	Very good	Good	Fair	Poor
Sediment quality and macrofauna					
Mud content[1]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD depth[2]	mm	≥ 50	20 to < 50	10 to < 20	< 10
TN[1]	mg/kg	< 250	250 to < 1000	1000 to < 2000	≥ 2000
TP			Requires development		
TOC[1]	%	< 0.5	0.5 to < 1	1 to < 2	≥ 2
TS			Requires development		
Macrofauna AMBI[1]	na	0 to 1.2	> 1.2 to 3.3	> 3.3 to 4.3	≥ 4.3
Sediment trace contaminants[3]					
As	mg/kg	< 10	10 to < 20	20 to < 70	≥ 70
Cd	mg/kg	< 0.75	0.75 to <1.5	1.5 to < 10	≥ 10
Cr	mg/kg	< 40	40 to <80	80 to < 370	≥ 370
Cu	mg/kg	< 32.5	32.5 to <65	65 to < 270	≥ 270
Hg	mg/kg	< 0.075	0.075 to <0.15	0.15 to < 1	≥ 1
Ni	mg/kg	< 10.5	10.5 to <21	21 to < 52	≥ 52
Pb	mg/kg	< 25	25 to <50	50 to < 220	≥ 220
Zn	mg/kg	< 100	100 to <200	200 to < 410	≥ 410
Sedimentation					
Sedimentation rate[4]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2

1. Ratings from Robertson et al. (2016).
2. aRPD based on FGDC (2012).
3. Trace element thresholds scaled in relation to ANZG (2018) as follows: Very good <0.5 x DGV; Good 0.5 x DGV to <DGV; Fair DGV to <GV-high; Poor >GV-high. DGV = Default Guideline Value, GV-high = Guideline Value-high.
4. Sedimentation rate adapted from Townsend and Lohrer (2015).

4. KEY FINDINGS

4.1 GENERAL FEATURES OF FINE SCALE SITES

The selected sites were typical of the intertidal flats across the estuary. Within each site the sediment textural characteristics were uniform. The photos below show the similarity in the general appearance of the two sites, with both having a conspicuous cover of macroalgae. Shell hash was common within the sediment and on the surface.

Firm muddy sand sediments at Site A with a conspicuous cover of macroalgae in January 2021 (left), and in November 2022 (right).

Firm muddy sand sediments at Site B with a conspicuous cover of macroalgae in January 2021 (left), and patches of *Agarophyton* spp. visible in November 2022 (right).

4.2 SEDIMENT PLATES

Sediment plate data are provided in Appendix 4. Fig. 4 shows mean sedimentation each year relative to the baseline depth, revealing variable patterns across the sites. Initially, erosion occurred at both sites as captured when surveyed in November 2021. Over the following year accretion occurred at both sites (Fig. 4).

When sedimentation rates were averaged across all three years, Table 4 shows that mean sedimentation has ranged from erosion of -1.4mm/yr at Site A to accretion of 2.2mm/yr at Site B. At Site B, mean annual sedimentation data suggest a slow accrual that slightly exceeds the guideline for New Zealand estuaries of 2mm/yr (a condition rating of 'poor'). However, due to the short interval of monitoring and initial erosion observed following installation of the plates, these results are not necessarily reflective of long-term patterns, which may be resolved over a period of 5 to 10 years. It may be the case that the variable patterns of erosion and accretion reflect the mobile nature of the sandy sediments at the sites (e.g., enabling sand movement due to water currents and waves) rather than a catchment influence.

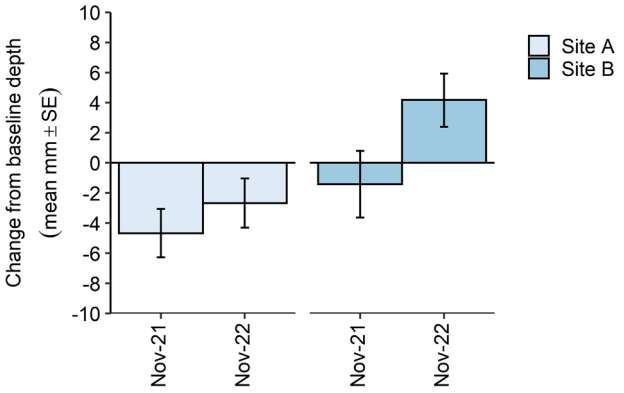

Fig. 4. Mean change (±SE) in sediment depth over buried plates since the baseline was established in January 2021.

Table 4. Sedimentation data for the three-year baseline.

Sample period	Site	Net change relative to baseline (mm)[1]	Mean annual sedimentation (mm/yr)[2]
Nov-2022	A	-2.7	-1.4
Nov-2022	B	4.2	2.2

[1] Net change compares sediment depth in November 2022 to depth at the date of plate installation in January 2021.

[2] Mean annual sedimentation rate is the average annual sedimentation rate since the date of plate installation.

4.3 SEDIMENT QUALITY

4.3.1 Sediment grain size, TOC and nutrients

Composite sediment sample raw data are tabulated in Appendix 5. Laboratory analyses of sediment grain size confirmed the field observations of sand-dominated sediments; the mud component was only 5-6% at both sites (Fig. 5).

To provide a visual impression of sediment quality relative to the Table 3 condition ratings, Fig. 6 compares the mean percentage mud, total organic carbon (TOC) and total nitrogen (TN) from composite samples against the rating thresholds. Site A and B both had low sediment mud content, with an increase of ~1% mud across the surveyed years which is likely to be within the range of natural variation. TOC was consistently low at both sites between surveys. The low values of all analytes placed them in rating categories of 'good' or 'very good'.

Note that TN levels in all samples were less than the laboratory detection limit and are presented as 50% of the detection limit value. Levels of total phosphorus (TP) were not high at either site, but TP at Site A was consistently lower than Site B, with a mean concentration over the three years of 172 and 247mg/kg, respectively (Appendix 5).

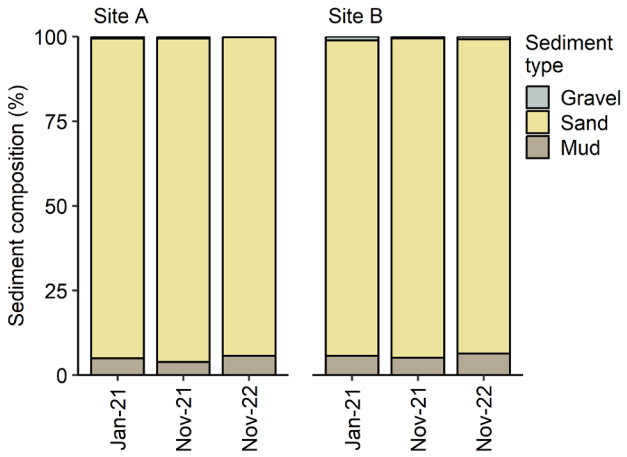

Fig. 5. Mean (n=3) sediment particle grain size based on composite samples. Grain size fractions are mud (<63µm), sand (≥63µm to <2mm) and gravel (≥2mm).

Sandy sediment at Site A with an aRPD of ~20mm.

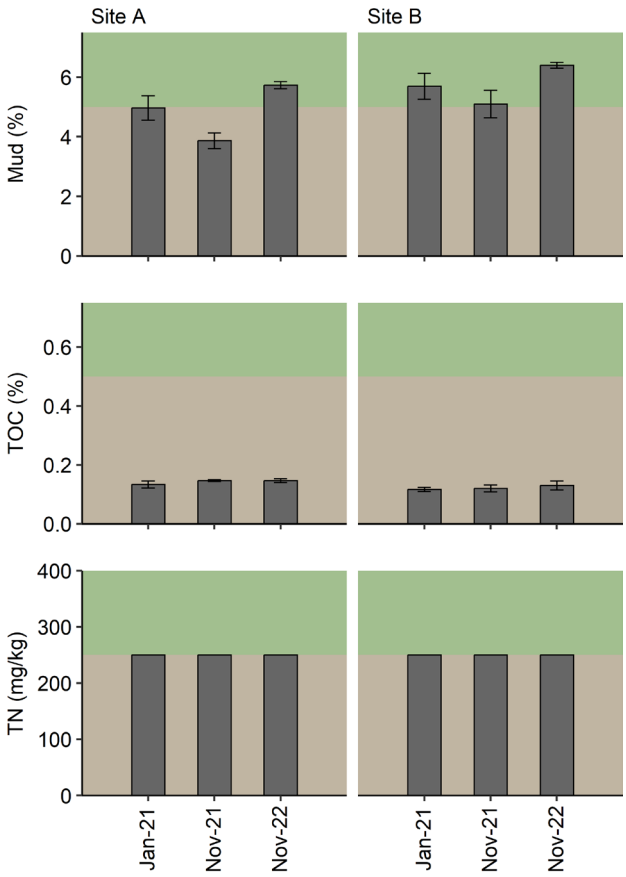

Fig. 6. Mean (±SE, n=3) sediment %mud, total organic carbon (TOC), and total nitrogen (TN) relative to condition ratings. TN values shown as 50% of laboratory detection limit.

4.3.2 Sediment oxygenation

No signs of excessive sediment enrichment were evident in the sediment core profiles at either site – see Fig. 7 and photos in Fig. 8. Baseline aRPD values ranged from ~10-15mm sediment depth at Site A and ~25-30mm at Site B, which correspond to condition ratings of 'fair' and 'good', respectively (Fig. 7).

While small changes in the aRPD depth have been observed over the three-year baseline (e.g., has become deeper at Site B), persistent changes in the aRPD condition bandings are considered more meaningful. This is because aRPD can be highly variable at both the site and core scales, with the aRPD depth horizon at times indistinct, for example due to sediment mixing by invertebrates (e.g., Fig. 8, core A-Z). Also, although measurements were carried out by experienced field staff, there is subjectivity in the aRPD assessment, hence some variability due to interpretation can be expected.

The aRPD nonetheless provides a simple field measure that is useful for capturing gross shifts in sediment oxygenation status. Importantly, neither site provided evidence of black anoxic (and sulphide-smelling) sediments at (or within a few millimetres of) the sediment surface, as would occur under strongly enriched conditions. The absence of excessive enrichment likely reflects that the sandy sediments at both sites are sufficiently coarse-grained to enable water penetration into the sediment matrix, maintaining well-oxygenated conditions.

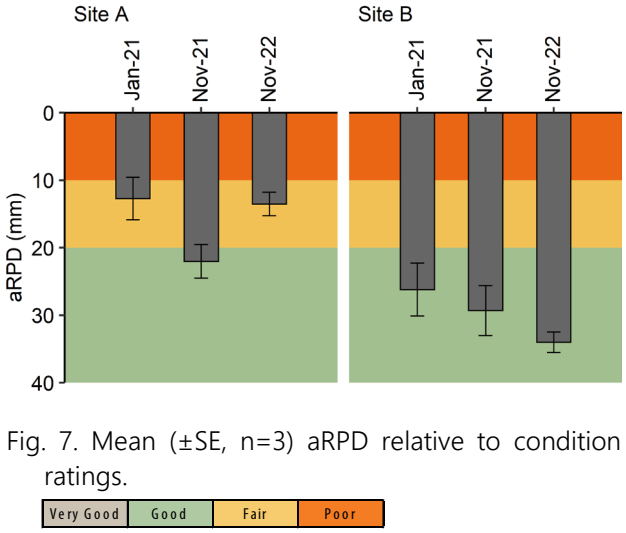

Fig. 7. Mean (±SE, n=3) aRPD relative to condition ratings.

4.3.3 Trace metal contaminants

Plots of trace metal contaminants in relation to condition ratings are provided in Fig. 9 (see also Appendix 5). Contaminant levels were very low, and all rated as 'very good', reflecting that the concentrations were less than half of the ANZG (2018) DGV (Fig. 6). The results in part reflect the sandy nature of the sediments, as sand particles have a reduced capacity for adsorption of trace contaminants than is the case for muddy sediment particles (which have a greater surface area for contaminant adsorption).

Land uses such as agriculture and horticulture can lead to soil contamination with trace metals (and other pollutants) due to practices such as fertiliser application (Gaw et al. 2006; Lebrun et al. 2019). Current results suggest there are no catchment contaminant sources of widespread significance to Blueskin Bay. Due to the absence of extensive urbanisation or industrial development in the catchment (see Fig. 2), there is no reason to expect significant sources of other contaminant types (e.g., biocides, hydrocarbons), hence there would be little benefit in undertaking monitoring of a wider contaminant suite than the NEMP trace metal indicators described here.

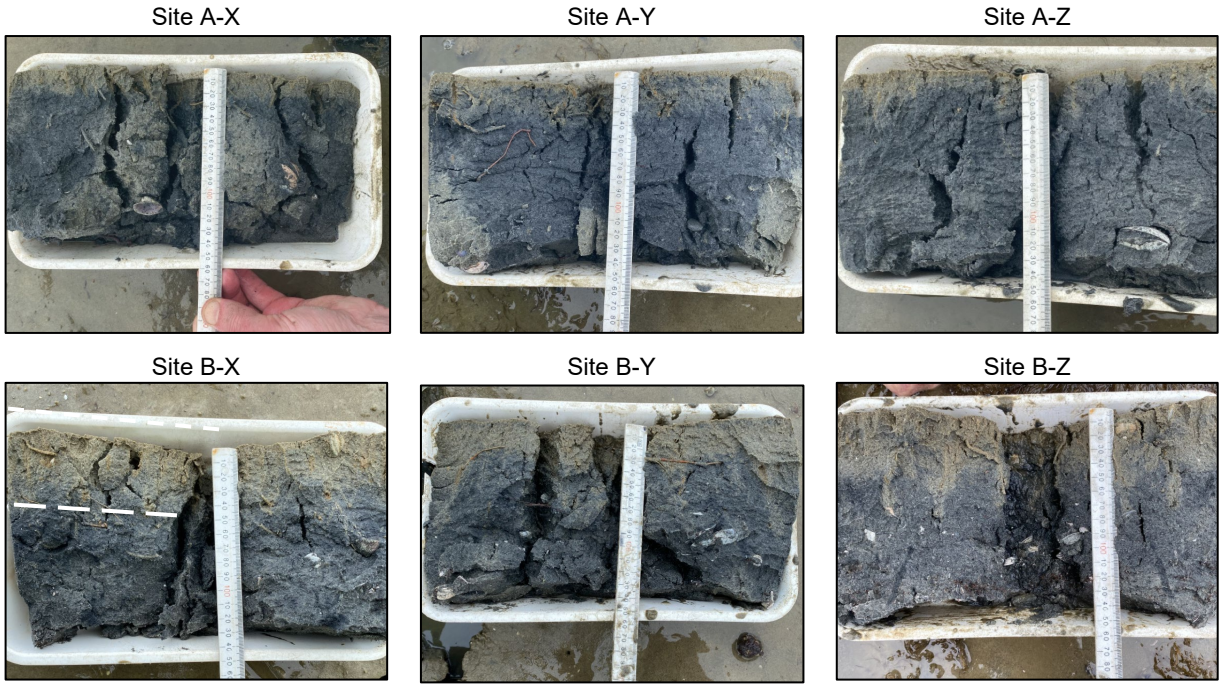

Fig. 8. Example sediment cores from the fine scale sites in November 2022. To illustrate the approximate depth of the aRPD, a dashed white line is shown on the zone X core from Site B.

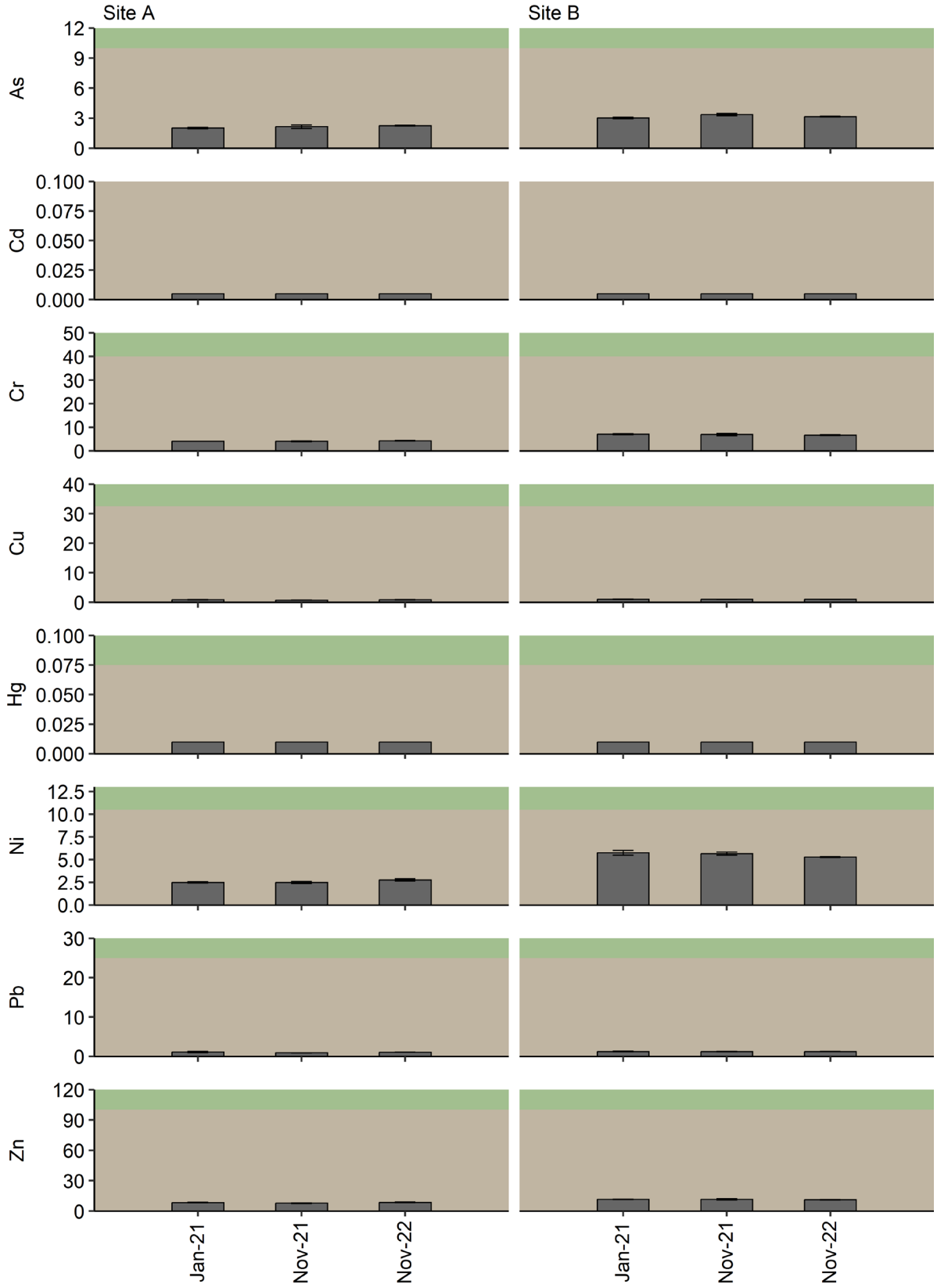

Fig. 9. Mean (±SE, n=3) trace metal concentrations (mg/kg) relative to condition ratings. ANZG (2018) sediment quality DGV's are represented by the boundary between 'good' and 'fair' condition. Note that concentrations of cadmium (Cd) and mercury (Hg) were all less than laboratory detection limits.

4.4 MACROFAUNA

4.4.1 Conspicuous surface epibiota

Results from the site-level assessment of surface-dwelling invertebrates and macroalgae are shown in Table 5. The epibiota in Blueskin Bay was diverse and abundant compared with that described from other estuaries in Otago where NEMP monitoring has been undertaken (e.g., Robertson et al. 2017a, b; Forrest et al. 2022a, b).

Macroalgae were visually conspicuous at both sites during the initial survey, usually attached to shell. At that time, the total algal cover was estimated as 60% at Site A and 35% at Site B, and mainly comprised of sea lettuce *Ulva* spp. and the red seaweed *Agarophyton* spp., which had SACFOR scores of common (C) or abundant (A). Also conspicuous at Site A were various species of filamentous red seaweed (C), of which the most commonly occurring was *Ceramium* spp. Algal cover reduced to 25% at both sites in November 2021, with *Ulva* spp. remaining common across both sites, and filamentous red seaweed common at Site B. The November 2022 survey observed a further reduction in algal species and algal cover, with only *Agarophyton* spp. present and total algae cover estimated as 3% at Site A and 1% at Site B (see photos Section 4.1). Although algal cover across the site was low, *Agarophyton* spp. was present in discrete patches of up to 30% cover at the corner of Site B.

Another species present during the initial survey and conspicuous at Site B but less so at Site A was the brown seaweed *Tinocladia novae-zelandiae*, which is characterised by its spaghetti-like appearance and very slippery texture. Although distributed New Zealand-wide, we have not encountered this species in other New Zealand estuaries, as it is more typically associated with rock and cobble habitats (Nelson 2013). This species was observed as rare (<1% cover) at Site B in the subsequent November 2021 survey, and not present at either site in the most recent survey.

Spaghetti-like *Tinocladia novae-zelandiae* present in January 2021.

Invertebrates observed on the sediment surface consisted mainly of three species of mud snail, with the mud whelk *Cominella glandiformis* occurring frequently (SACFOR 'F') at both sites across surveys, however within the most recent survey the numbers declined at Site A. Mud whelks were typically aggregated in clumps of individuals feeding on prey items. The mudflat topshell *Diloma subrostratum* was common at Site B but less so at Site A (SACFOR rating 'F'), with this difference consistent across survey years. The horn snail *Zeacumantus subcarinatus*, a typical estuarine species generally widespread across the estuary, was recorded at Site B across all survey years and at Site A within the latest survey.

Further species observed at Site A were single records of occasional mud snail *Amphibola crenata*, which though typical of estuarine environments had not previously been observed at this site. While at Site B there were single records of *Ostrea chilensis* (aka Bluff oyster) and cat's eye (*Lunella smaragda*), the latter being a common species of rocky shorelines that is not typically found in estuaries.

Site A with macroalgae estimated to be 60% total cover in January 2021.

A cluster of mud whelks *Cominella glandiformis* at Site B in November 2022.

Table 5. SACFOR scores for epibiota based on the scale in Table 2. Dash = not recorded. Mollusc images courtesy of Andrew Spurgeon (www.mollusca.co.nz).

Species	Functional description	Image	Site A Jan21	Site A Nov21	Site A Nov22	Site B Jan21[1]	Site B Nov21	Site B Nov22
Invertebrates								
Mud whelk *Cominella glandiformis*	Carnivore and scavenger		F	F	O	F	F	F
Mud snail *Amphibola crenata*	Microalgal grazer		-	-	O	-	-	-
Mudflat topshell *Diloma subrostratum*	Grazer and deposit feeder		F	F	F	C	C	C
Flat oyster *Ostrea chilensis*	Filter feeder		-	-	-	R	-	-
Cat's eye *Lunella smaragda*	Grazer		-	-	-	F	-	-
Horn snail *Zeacumantus subcarinatus*	Microalgal and detrital grazer		-	-	F	F	F	C
Macroalgae								
Red seaweed *Agarophyton chilense*[2]	Primary producer		C	F	F	C	R	O
Red filamentous seaweed mainly *Ceramium* spp.	Primary producer		C	F	-	O	C	-
Brown seaweed *Tinocladia novae-zelandiae*	Primary producer		O	-	-	O	R	-
Green seaweed Sea lettuce *Ulva* spp.	Primary producer		A	C	-	C	C	-

1. Additional species observed at Site B in 2021 include flat oyster *Ostrea chilensis* (SACFOR 'R') and the cat's eye snail *Lunella smaragda* (SACFOR 'F').

2. *Agarophyton* spp. is the revised name for *Gracilaria chilensis* and consists of three visually similar species.

4.4.2 Macrofauna cores

Richness, abundance and AMBI

Raw data for sediment-dwelling macrofauna are provided in Appendix 6.

In total across the three baseline surveys, the number of macrofaunal species or higher taxa described was 46-49 taxa at Site A and 49-57 taxa at Site B (Appendix 3, Appendix 6). Table 7 describes the main species and higher taxa that were recorded. Mean species richness ranged from 24 to 27 taxa per core sample, with marginally higher richness at Site B. Richness at both sites remained relatively consistent between years (Fig. 10a). Mean organism abundance was similar between the two sites in each survey. However, abundance increased in November 2021 at both Site A and Site B to mean values of 556/core and 637/core, respectively (Fig. 10b).

Mean values of the biological index AMBI remained relatively consistent at each site and ranged from 1.86-2.18 at Site A and 2.35-2.55 at Site B, corresponding to a condition rating of 'good' (Fig. 11). This result is consistent with the high sediment quality. The low AMBI values reflect a very high prevalence of eco-group II (EG-II) species (Fig. 12), as well as a range of EG-I species. Species in EG-I and EG-II are sensitive species that thrive in relatively healthy and undisturbed conditions (Table 7).

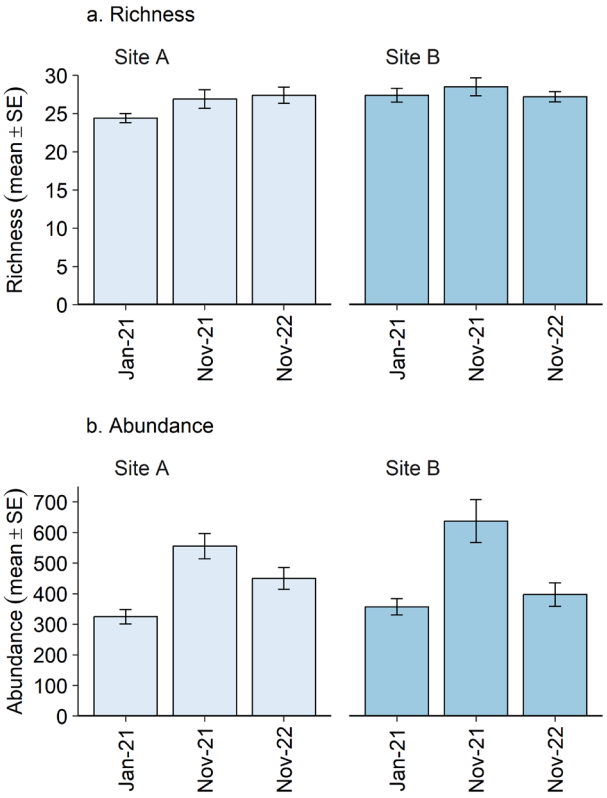

Fig. 10. Mean (±SE, n=10) taxon richness and abundance per core sample.

Table 6. Sediment-dwelling macrofauna taxa that comprised 10% or more of abundances at any one site and year. The table shows abundances pooled across cores within each survey. The taxa shown are based on the aggregated groups shown in Appendix 3. To highlight the differences the SACFOR scheme from Table 2 has been used to colour-code the relative abundances.

Main group	Taxa	Eco-Group	Site A Jan21	Site A Nov21	Site A Nov22	Site B Jan21	Site B Nov21	Site B Nov22
Amphipoda	Lysianassidae	I or II	37	10	5	23	290	3
Amphipoda	*Paracalliope novizealandiae*	I	86	83	110	26	317	90
Bivalvia	*Lasaea parengaensis*	II	580	508	860	67	79	103
Bivalvia	*Nucula nitidula*	I	53	89	101	397	598	481
Oligochaeta	Oligochaeta	V	30	230	100	517	1183	507
Ostracoda	Ostracoda	I	28	22	17	91	221	29
Polychaeta	Boccardia	II or III	93	212	178	20	7	4
Polychaeta	Exogoninae	II	103	490	266	42	275	222
Polychaeta	*Macroclymenella stewartensis*	II	248	764	162	102	280	353
Polychaeta	*Microspio maori*	I	400	165	112	63	1	3
Polychaeta	Syllidae	II	32	5	2	124	12	6
Tanaidacea	Tanaidacea	II	131	404	606	184	472	221
Polychaeta	Paradoneis	III	1099	2166	1510	1523	2074	1446

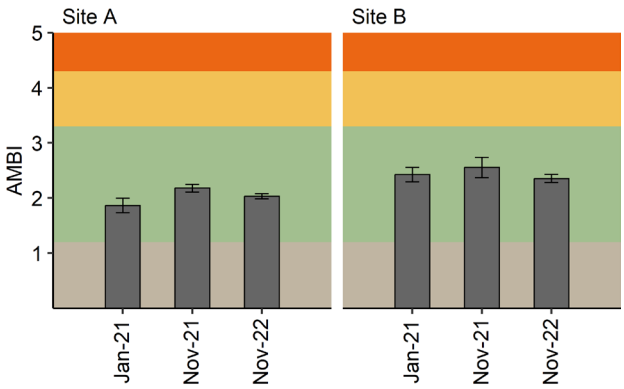

Fig. 11. Mean (±SE, n=10) AMBI scores relative to condition ratings.

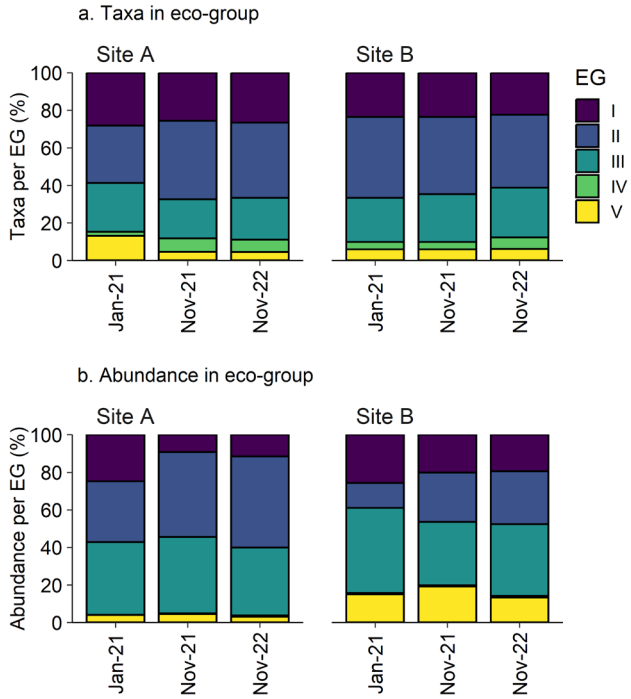

Fig. 12. Site-level data showing the percentage of taxa within eco-groups ranging from sensitive (EG-I) to resilient (EG-V).

Main taxonomic groups and species

The species present represented 19 taxonomic groups, with 7 dominant groups (Fig. 13). Polychaete worms were by far the most species-rich and numerically abundant group. Half of the most abundant taxa were polychaetes, with five of the six dominant polychaetes classified as EG-I or EG-II, as evident in Table 7. At Site A and B, *Paradoneis lyra* were super abundant (SACFOR 'S'), the mean density of *P. lyra* ranged from 109-216/core sample. In all surveys, both sites had relatively high abundances of the 'bamboo' worm *Macroclymenella stewartensis* and the syllid polychaete Exogoninae. The abundance of small spionid worms *Microspio maori* (EG-1) and the Boccardia species *B. syrtis* and *B. accus* (both EG-II) were elevated at Site A.

Bivalves and gastropods (i.e., molluscs) were also reasonably species-rich, with two bivalves being notably abundant. These were the little-known species *Lasaea parengaensis* at Site A, and the nutshell *Nucula nitidula* at Site B (EG-II). Subdominant bivalves included low densities of small cockles (*Austrovenus stutchburyi*) and wedge shells (*Macomona liliana*). The fine scale sites are not representative of the high cockle densities present elsewhere in the estuary where there is commercial harvesting. However, cockle density observed at the sites align with surveys carried out in adjacent areas in Blueskin Bay (Wing et al. 2002).

Other main taxa of interest included the following:

- The shrimp-like Tanaid, *Zeuxoides* sp. is a relatively sensitive EG-I species, which was abundant at both sites across all surveys.
- Oligochaete worms were notably more abundant at Site B and were super abundant in November 2021. Oligochaetes are an EG-V group generally considered pollution or disturbance tolerant and often associated with enriched conditions.
- There were a range of nationally-common amphipods, most dominant being *Paracalliope novizealandiae* (EG-I) and the Lysianassidae group. The latter is the group name used by Cawthron in January 2021, but based on NIWA taxonomy in the two subsequent surveys, is almost certainly *Parawaldeckia kidderi* (EG-II). Similarly, the Phoxocephalidae amphipod group listed by Cawthron was likely to have mainly consisted of *Torridoharpinia hurleyi* (EG-II) as identified by NIWA. This taxon comprised less than 10% of total abundance (hence is not shown in Table 6), but increased across surveys becoming abundant at both sites in November 2022 (Appendix 6).

Epifauna *Amphibola crenata* with encrusting barnacles at Site A in November 2022.

Table 7. Description of the most commonly occurring sediment-dwelling macrofauna.

Main group, species & eco-group (EG)	Description	Image
Amphipoda, EG I or II	Shrimp-like crustaceans dominated by *Paracalliope novizealandiae*, *Torridoharpinia hurleyi and Parawaldeckia kidderi*. Considered to be tolerant of sedimentation and mud, although *T. hurleyi* and *P. kidderi* are regarded as sensitive to enrichment. Probably important prey for birds and small fish.	
Bivalvia, *Lasaea parengaensis* EG II	Small and little-known bivalve, not widely distributed in New Zealand and appears limited to southern areas. Probably a prey item in the diet of birds and fish.	
Bivalvia, *Nucula nitidula* EG I	Small estuarine bivalve mollusc, commonly called a nutshell. Considered to prefer sandy habitats, and sensitive to excess sedimentation. Probably a prey item in the diet of birds and fish.	
Oligochaeta, Oligochaete worm EG V	Segmented worms in the same group as earthworms. Deposit feeders that are generally considered pollution or disturbance tolerant.	
Ostracoda, Ostracod EG I	Class of crustaceans, sometimes known as seed shrimps because of their appearance. They are typically around 1mm in size and the body is encased by two valves, superficially resembling the shell of a clam. Poorly understood group. Considered to be omnivorous scavengers.	
Polychaeta, *Boccardia* spp. EG II or III	Spionid worms comprising common species *Boccardia syrtis* and *B. acus*. Tube-building surface deposit and suspension feeders which can form dense mats on the sediment surface. Found in a wide range of sand/mud habitats however sensitive to excessive sedimentation. Variable tolerance to organic enrichment.	
Polychaeta, Exogoninae EG II	Small syllid polychaete worm. Common but poorly understood group. Considered to be free-burrowing or epifaunal omnivores.	
Polychaeta, *Macroclymenella stewartensis* EG II	A sub-surface, deposit-feeding maldanid 'bamboo' worm that is usually found in tubes of fine sand or mud. This species may have a key role in turn-over of sediment. Tolerant of mud, but optimum range ~10-15%. Intolerant of anoxic conditions.	
Polychaeta, *Microspio maori* EG I	A small common spionid worm considered to be sensitive to muddy sediment but tolerant of organic enrichment, despite EG I classification. Prey items for fish and birds.	
Polychaeta, *Paradoneis lyra* EG III	Common worm considered to be reasonably tolerant of muddy sediment and organic enrichment. Paraonids are considered to be deposit feeders, possibly selectively feeding on microscopic diatoms and protozoans.	
Polychaeta, Syllidae EG II	Free-burrowing or epifaunal predators. Classified as EG II, but there appears to be little known about environmental tolerances.	
Tanaidacea, *Zeuxoides* sp. EG I	Shrimp-like tanaid. Little known species. Tanaids reported to inhabit all sediment types but have a mud optimum <15%.	

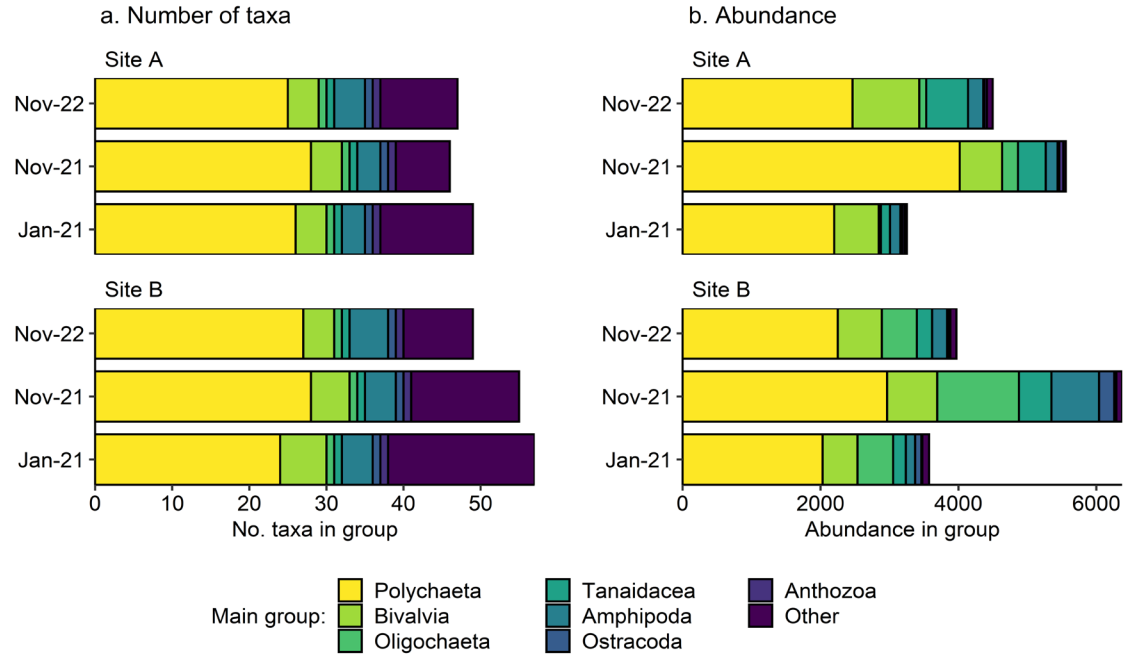

Fig. 13. Pooled data showing the contribution of main taxonomic groups to site-level richness and abundance values.

Multivariate patterns and association with sediment quality variables

To further explore the differences among sites and surveys in terms of the macrofaunal assemblage, the nMDS ordination in Fig. 14 places zone-grouped samples of similar composition close to each other in a 2-dimensional plot, with less similar samples being further apart. This analysis uses species data aggregated (as necessary) to a higher taxonomic level, to enable comparison of years where different taxonomic providers were used (see Methods section and Appendix 3).

Fig. 14a further illustrates the dominant species that characterised each site that were noted above and in Table 7, and also highlights that a range of other sub-dominant taxa characterised each site or discriminated the sites or surveys from each other.

The plot emphasises that, despite being selected to be in superficially similar habitats, the two sites had some fundamental differences in species composition. Part of this difference was driven by species dominance patterns (revealed by Table 6 for the most dominant taxa), such as higher abundance of the bivalve *Lasaea parengaensis* at Site A, and the nutshell *Nucula nitidula* at Site B, but also reflects a subset of species recorded at one site but not the other. Of the 59 aggregated taxa from Site A and 71 from Site B, the two sites had 49 taxa in common. As such, when the nMDS was based on species presence or absence (i.e., relative abundance was not taken into account) the ordination pattern was less distinct than that shown in Fig. 14a due to the many species that were present across both sites.

Although less apparent than compositional shifts between sites, the nMDS plot also displays differences across sites between survey years. In January 2021, the composition of the macrofaunal community differed compared to the subsequent surveys, even after undertaking taxonomic aggregation to account for provider differences. The dissimilarity was primarily driven by abundance changes. For example, compared to January 2021, in the two subsequent surveys there was a marked increase in the abundance of syllid (Exogoninae) polychaetes, terebellid polychaetes, shrimp-like tanaids, and the amphipod *Paracalliope novizealandiae*, with a concomitant decrease in the polychaete *Microspio maori*.

Exploration of the relationship between macrofauna patterns and sediment quality was based on a subset of variables. Trace contaminants were excluded, as any influence on sediment biota was not considered likely given their very low concentrations relative to ANZG (2018) guidelines. The nutrient TP was included as a proxy for total nitrogen (TN) with which it is typically correlated. In other studies, TP has been considered to be a relatively good proxy for catchment-level nutrient and organic enrichment, even though nitrogen rather than phosphorus is regarded as the nutrient that is most important for algal growth in estuaries (Berthelsen et al. 2018). In this instance TN was not quantifiable, as all values were less than the laboratory method detection limit.

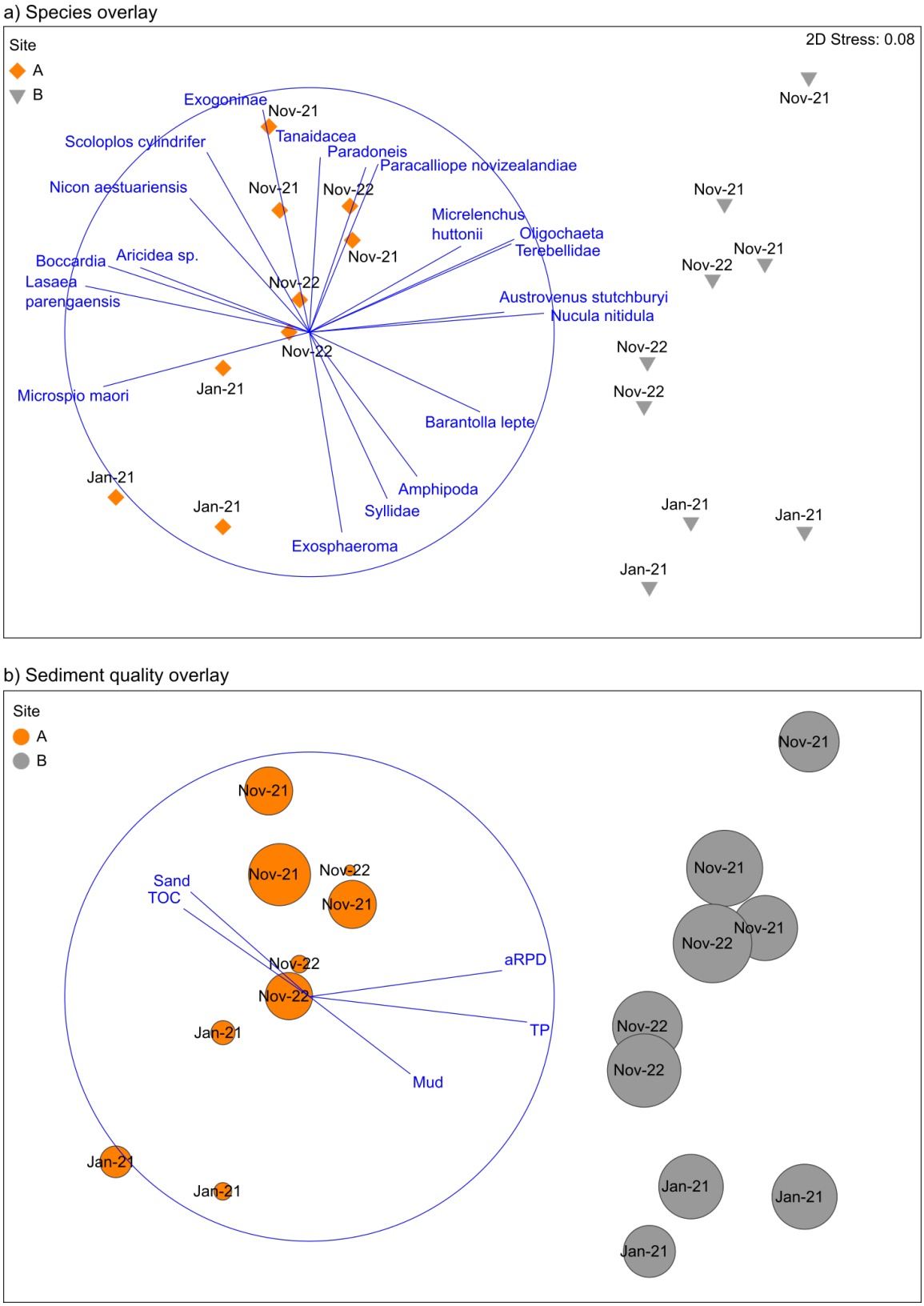

Fig. 14. Non-metric MDS ordination of macrofaunal core samples aggregated by sampling zones for each site and year, showing: a) species associated with site-year, and b) sediment quality variables associated with site-year.

The site-year combinations are placed such that those more similar in macrofaunal composition are nearer to each other than those less similar. A low 'stress' value of 0.08 for the nMDS indicated that a 2-dimensional plot provided an accurate representation of differences. Vector overlays indicate the direction and strength of association (length of line relative to circle) of grouping patterns in terms of: a) the most correlated macrofauna species and b) key sediment quality variables. Bubble sizes in the bottom pane are scaled to sediment aRPD (oxygenation), which (along with TP) was partially correlated with macrofaunal composition differences.

The vector overlays in Fig. 14a, and associated correlation analysis, suggested that the left-to-right separation along the x-axis of the nMDS was partially associated with an increase in TP (Pearson r^2 = 0.89) and a deepening of the aRPD (Pearson r^2 = 0.79). The BIO-ENV analysis of overall relationships between macrofauna and sediment quality similarly revealed that TP best explained spatio-temporal changes (Spearman rank correlation ρ = 0.67), with a marginal correlation increase (ρ = 0.68) when the effect of TP and aRPD were considered together.

However, given that TP (and by extension TN) concentrations were very low, it is doubtful that they would have a causal influence on macrofauna composition. It is, however, plausible that shallower aRPD at Site A has an influence on its macrofauna composition differences with Site B, although Site A is not significantly more enriched than Site B in terms of TOC (see further discussion in Section 5.1).

Although sediment mud content can be among the strongest drivers of macrofaunal composition in New Zealand estuaries (Cummings et al. 2003; Robertson et al. 2015; Berthelsen et al. 2018; Clark et al. 2021), it was unimportant in this instance (BIO-ENV, Spearman ρ=-0.054). This result is a reflection of the mud content at both sites being similar and below the thresholds typically associated with ecological change.

Results overall indicate that none of the measured NEMP sediment quality indicators clearly explain the spatio-temporal changes in the macrofaunal community. Other environmental variables not assessed here may also influence community characteristics. Physical factors could include the duration of tidal inundation at the site (with Site A being slightly higher in the intertidal zone), different levels of exposure to waves and currents, the closer proximity of Site B to catchment freshwater inputs, or differences in sediment stability. Biological processes could also be important, such as spatio-temporal variation in species recruitment patterns (e.g., from planktonic life-stages), or species interactions that occur post-recruitment (e.g. competition, predation).

Blueskin Bay looking over Site B towards the estuary mouth.

5. SYNTHESIS AND RECOMMENDATIONS

5.1 SYNTHESIS OF KEY FINDINGS

This report has described the findings of three baseline ecological monitoring surveys conducted at two sites in Blueskin Bay, largely following the fine scale methods described in New Zealand's National Estuary Monitoring Protocol (NEMP). Sediment plates were monitored alongside the November 2021 and 2022 sampling to determine sedimentation rates.

In Table 8, key physical and biological indicators are compared against the condition rating criteria from Table 3. The survey revealed sand-dominated sediments with very low concentrations of organic carbon, nutrients, and trace contaminants. Accordingly, sediment quality for most variables was rated 'good' or 'very good' (see Table 8).

The 'fair' ratings for aRPD at Site A suggest slightly greater sediment enrichment than at Site B. This result conceivably reflects increased microbial activity in the sediment. Although TOC was only marginally elevated at Site A relative to Site B (see Fig. 6), it is plausible that the greater macroalgal extent observed within some surveys at that site (see Section 4.4.1), nourish the underlying sediment with organic matter and lead to enhanced microbial decomposition relative to Site B. Despite this result, there were no symptoms of excessive enrichment, such as a black, anoxic and sulphide-smelling sediments.

The macroalgal coverage was elevated in 2021, especially at Site A (~60% cover) but was low in the two subsequent surveys. Furthermore, although opportunistic species such as *Agarophyton* spp. were present, the macroalgae were attached to shell and other hard surfaces rather than entrained within the sediment as is characteristic of nuisance macroalgal problems (e.g., Stevens et al. 2020; Roberts et al. 2021).

As nutrient loads to Blueskin Bay are about 10% of the threshold at which nuisance macroalgae problems are predicted to occur in intertidally-dominated estuaries (Robertson et al. 2017c), the observed occurrence of the macroalgal beds is unlikely to be enrichment-related. Rather, the beds are likely maintained by the plentiful stable shell habitat for algal attachment, high water clarity, and the very flat profile of the sites, which enables water to be retained after the tide has receded.

The high sediment quality at the fine scale sites was reflected in the diverse and abundant macrofauna present. The macrofaunal patterns were correlated with the shallower aRPD at Site A, suggestive of a greater level of enrichment at Site A. However, as noted above, other indicators of enrichment were not elevated at Site A, nor did the composition of the macrofauna reflect the type of community typical present under enriched conditions (e.g., a community dominated by hardy species).

Future monitoring surveys will help to determine whether the site differences described in this three-year baseline remain consistent, and inform a management response if degradation were to occur. Despite the site differences, compared to other estuaries in the Otago region, Blueskin Bay stands out as clearly having the greatest macrofaunal richness and some of the highest abundances (Fig. 15). In other regional estuaries, high macrofaunal abundances tend to be a symptom of a degraded environment, where hardier disturbance-tolerant species proliferate in what are otherwise typically species-poor assemblages (e.g., Forrest et al. 2020b, a).

Table 8. Summary of scores of estuary condition based on values of key indicators, compared to rating criteria in Table 3. AMBI values are zone averages.

Site	Survey	Sed rate (mm/yr)	Mud (%)	aRPD (mm)	TN	TP	TOC (%)	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn	AMBI na
A	Jan-21	-	5.0	13	<500	177	0.13	2.0	<0.01	4.1	0.9	1.1	<0.02	2.5	8.4	1.9
	Nov-21	-5.4	3.9	22	<500	181	0.15	2.2	<0.01	4.1	0.8	0.9	<0.02	2.5	7.8	2.2
	Nov-22	2.0	5.7	14	<500	160	0.15	2.3	<0.01	4.4	0.9	1.1	<0.02	2.8	8.7	2.0
B	Jan-21	-	5.7	26	<500	260	0.12	3.0	<0.01	7.1	1.1	1.3	<0.02	5.8	11.7	2.4
	Nov-21	-1.6	5.1	29	<500	270	0.12	3.4	<0.01	7.0	1.0	1.3	<0.02	5.7	11.6	2.6
	Nov-22	5.6	6.4	34	<500	213	0.13	3.2	<0.01	6.8	1.0	1.3	<0.02	5.3	11.2	2.4

< All values below lab detection limit. Units are mg/kg except where noted. See Glossary for abbreviations and Table 3 for condition rating thresholds.

Very Good	Good	Fair	Poor

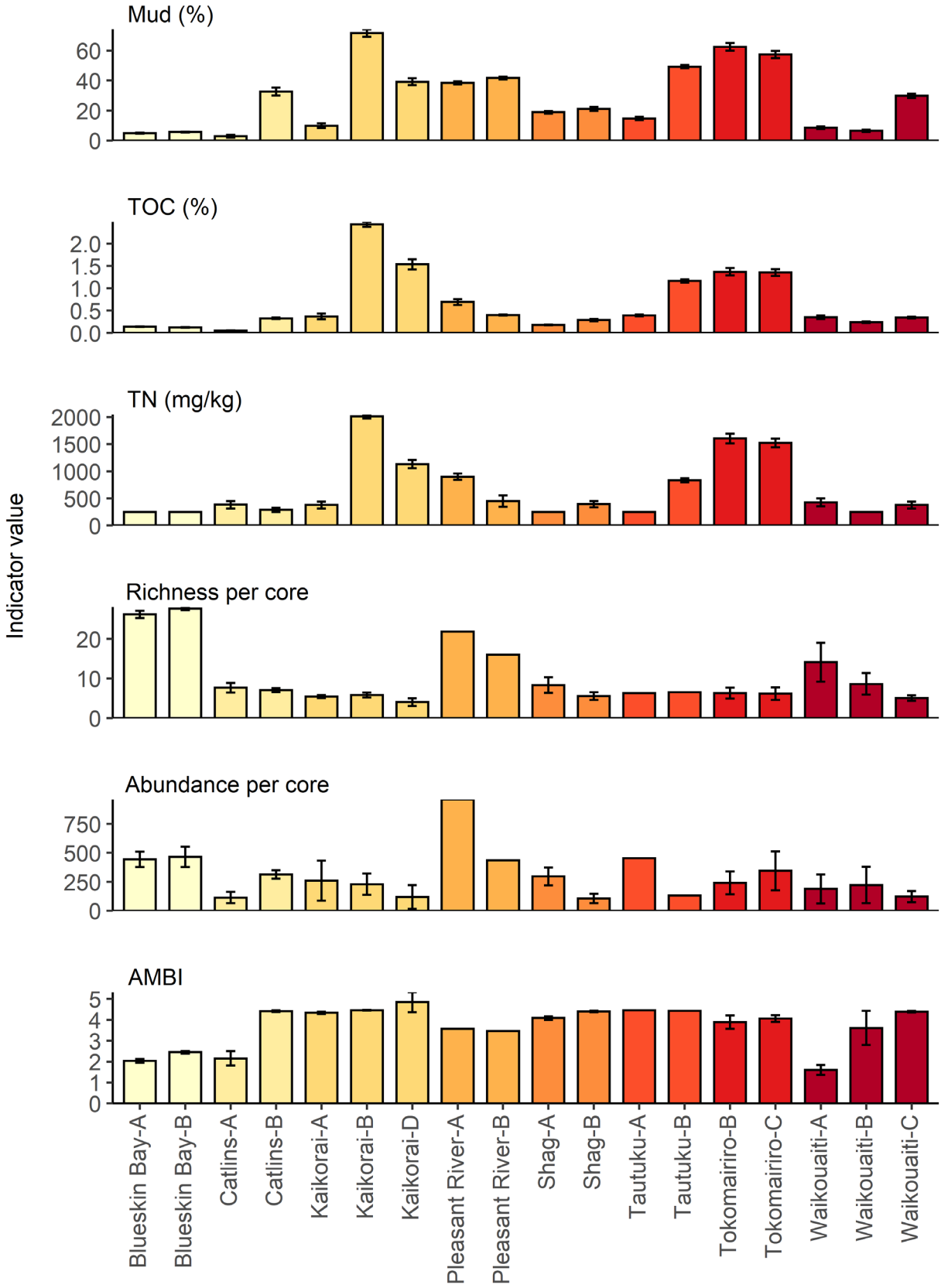

Fig. 15. Sediment parameters and macrofauna indices summary (mean ±SE) based on NEMP monitoring in Otago estuaries over the last decade. For illustrative purposes, site-level data are averaged across multiple surveys in each estuary.

By contrast, the species-rich assemblage in Blueskin Bay are dominated by a variety of taxa, with both sites characterised by a range of organisms considered to be sensitive to habitat disturbance.

Overall, the main tidal flats of Blueskin Bay are in a healthy condition, especially relative to other Otago estuaries that have been monitored to date. This situation has persisted in Blueskin Bay despite historic modification of estuary margins, loss of salt marsh, and catchment land-use changes that have increased the threat from muddy sediment inputs (Roberts et al. 2021). Future threats should be managed so that the current healthy state of the estuary is maintained.

5.2 MANAGEMENT AND MONITORING CONSIDERATIONS

5.2.1 Catchment management implications

One of the most significant catchment-related threats to Blueskin Bay is the potential for increased sediment inputs. The 2018 catchment data shown in Fig. 2 reveal that ~51% of the Blueskin Bay catchment is in land-uses that are known to generate a high fine-sediment run-off to waterways, namely pastoral farming and exotic plantation forestry. The latter can be a particularly significant source of muddy sediment during forest harvest and for a few years after, when it can contribute a disproportionately high sediment load per catchment hectare (e.g. Gibbs & Woodward 2018).

At present, catchment modelling data presented in Roberts et al. (2021) show a low ratio (1.3) of current to estimated natural sedimentation, and predict an annual sedimentation rate for Blueskin Bay of 0.5mm/yr, which is less than the guideline value for New Zealand estuaries of 2mm/yr (Townsend & Lohrer 2015). However, satellite imagery identifies large areas of plantation forest clear-felled in 2019, which is not captured in the current land use mapping nor predicted sedimentation calculations. Nonetheless, sedimentation pressures appear to be low at present, which is consistent with the sand-dominated, healthy state of the estuary's intertidal flats. A longer time-series of sediment plate monitoring will help to elucidate whether site-specific sedimentation rates match the catchment model predictions for the estuary overall.

As well as harvesting of existing exotic forest, long term increases in sediment load to the Blueskin Bay catchment could arise due to forestry expansion, reflecting the recent national trend of conversion of farmland to plantation forestry in response to the high-value of pine forests for carbon sequestration. Pastoral land use intensification (e.g., increased stock densities, intensive winter grazing) could also result in increased sediment loads (Donovan 2022). Whether load increases translate to increase muddy sediment deposition on the intertidal flats of Blueskin Bay is uncertain However, the estuary is estimated to have a 98% sediment trapping efficiency (i.e., of catchment sediment retained in the estuary), suggesting that the potential exists for significant sedimentation, an increase in the extent of muddy habitat, and associated adverse ecological effects (e.g., loss of sensitive macrofauna).

Given the above factors, it is timely for ORC to further consider potential changes in catchment land use that could lead to fine-sediment load increases, and work with landowners to mitigate potential adverse effects. Understanding future forest harvest schedules, and opportunities to mitigate harvest-related sediment inputs, will be a key component of this assessment.

5.2.2 Fine scale monitoring considerations

ORC's intended SOE monitoring for Blueskin Bay consists of annual sediment plate monitoring, broad scale habitat mapping (at intervals of ~5 years), and continued fine scale monitoring. Following the 'baseline' established by the three consecutive annual fine scale surveys described in the present report, the NEMP recommends long-term monitoring at intervals of 5-yearly at a minimum. Given that the baseline is now completed, it is timely to consider whether the NEMP fine scale approach is fit-for-purpose.

Recent guidance produced by NIWA (Hewitt 2021) recommends fine scale monitoring is conducted twice a year as a minimum, with a time series of approximately 15 years needed for trend detection. This monitoring frequency for ORC is constrained by budgets and other monitoring priorities. In the case of Blueskin Bay, sediment pate monitoring, coupled with sediment sampling, will at least help to establish an annual time-series of sedimentation and grain size changes. Site visits and photographs taken during annual sediment plate monitoring also provide a qualitative means of keeping track of any obvious changes in estuary condition. As such, conducting intensive fine scale surveys every five years is a reasonable way forward, with more frequent monitoring justifiable only if there are significant physical changes in the estuary (e.g., obvious mud deposition on the tidal flats) over shorter time scales.

For future monitoring purposes, the current fine scale sites, methods and indicators are all appropriate, even though the present approach is not as comprehensive as described by the original NEMP (see Table 1 and

associated footnotes). For example, sediment quality analyses are based on three composite samples rather than 10 discrete samples recommended by the NEMP. This compositing approach reduces cost to ORC, and is entirely adequate given low analyte concentrations and low within-site variability.

In terms of macrofauna, Hewitt (2021) recommended collection of 12 macrofauna cores per estuary site, noting that reducing sampling effort (or monitoring frequency from the recommended twice per year) would affect the robustness of monitoring programmes. The relative cost of the macrofaunal component of ORC's fine scale monitoring (currently 10 cores per site) is high, being around 65% of the total survey budget (excluding analysis and reporting). In order to better understand site-specific macrofauna sampling needs for Blueskin Bay, a separate analysis is summarised in Appendix 7, which evaluated the effect of different levels of macrofauna core replication on the ability to detect changes in estuary condition. That analysis suggests that replication could be reduced to nine of macrofauna cores, without any substantive loss of ability to detect long term changes. Sampling nine cores per site is consistent with the baseline fine scale survey approaches established for ORC's Pleasant River and Tautuku Estuary monitoring programmes.

6. RECOMMENDATIONS

On the basis of the findings and discussion in this report, and in view of the recommendations that arose from the broad scale survey in 2021, additional recommendations for Blueskin Bay are as follows:

- Evaluate likely future sediment sources to the estuary, and investigate options for a reduction of inputs.
- Continue annual sediment plate monitoring, with concurrent sampling of sediments for grain size analysis to track changes in sediment mud content.
- Undertake fine scale monitoring at a minimum of five yearly intervals, based on the current approach, except for a reduction in macrofauna sampling effort to nine cores per site.
- Given that ORC has now undertaken ecological assessments of the main estuaries in Otago, it would be timely to also consider management and monitoring in Blueskin Bay alongside the priorities for other estuaries regionally.

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APPENDIX 1. GPS COORDINATES AND FOR FINE SCALE SITES (CORNERS) AND SEDIMENT PLATES

FINE SCALE SITE A

Peg	NZTM East	NZTM North
1	1411507	4933343
2	1411565	4933333
3	1411560	4933303
4	1411500	4933313

FINE SCALE SITE B

Peg	NZTM East	NZTM North
1	1411184	4932115
2	1411242	4932132
3	1411252	4932104
4	1411193	4932088

SEDIMENT PLATES SITE A

Plate	NZTM East	NZTM North	Distance from fine scale site peg 1 (m)
1	1411506	4933338	5
2	1411505	4933333	10
3	1411503	4933324	20
4	1411501	4933318	25

SEDIMENT PLATES SITE B

Plate	NZTM East	NZTM North	Distance from fine scale site peg 1 (m)
1	1411187	4932112	5
2	1411188	4932107	10
3	1411191	4932096	20
4	1411192	4932092	25

APPENDIX 2. RJ HILL ANALYTICAL METHODS FOR SEDIMENTS

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request. Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Sediment			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Individual Tests			
Environmental Solids Sample Drying*	Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%.	-	1-6
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation May contain a residual moisture content of 2-5%.	-	1-6
Dry Matter for Grainsize samples (sieved as received)*	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-6
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	1-6
Total Recoverable Phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt	1-6
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-6
Total Organic Carbon*	Acid pretreatment to remove carbonates present followed by Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-6
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg	Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level.	0.010 - 0.8 mg/kg dry wt	1-6
3 Grain Sizes Profile as received			
Fraction >/= 2 mm*	Wet sieving with dispersant, as received, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-6
Fraction < 2 mm, >/= 63 µm*	Wet sieving using dispersant, as received, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-6
Fraction < 63 µm*	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-6

APPENDIX 3. TAXONOMIC AGGREGATION

Taxonomic aggregation undertaken to enable multivariate compositional comparison across the three baseline surveys. Caw = Cawthron Institute (January 2021), NIWA = National Institute of Water and Atmospheric Research (November 2021 and 2022).

Main group	Caw Jan-2021	NIWA Nov-2021	NIWA Nov-2022	Raw taxa name	Aggregation name
Amphipoda	Yes	-	-	Amphipoda	Amphipoda
Amphipoda	Yes	-	-	*Lysianassidae*	*Lysianassidae*
Amphipoda	Yes	Yes	Yes	*Paracalliope novizealandiae*	*Paracalliope novizealandiae*
Amphipoda	-	-	Yes	*Paracorophium excavatum*	*Paracorophium excavatum*
Amphipoda	-	Yes	Yes	*Parawaldeckia kidderi*	*Lysianassidae*
Amphipoda	Yes	-	-	*Phoxocephalidae*	*Phoxocephalidae*
Amphipoda	-	Yes	Yes	*Proharpinia* sp.	*Phoxocephalidae*
Amphipoda	-	Yes	Yes	*Torridoharpinia hurleyi*	*Phoxocephalidae*
Anthozoa	Yes	-	-	Anthozoa	Anthozoa
Anthozoa	-	Yes	Yes	*Edwardsia* sp.	Anthozoa
Bivalvia	Yes	Yes	-	*Arthritica* sp. 5	*Arthritica* sp. 5
Bivalvia	Yes	Yes	Yes	*Austrovenus stutchburyi*	*Austrovenus stutchburyi*
Bivalvia	Yes	Yes	Yes	*Lasaea parengaensis*	*Lasaea parengaensis*
Bivalvia	Yes	Yes	Yes	*Macomona liliana*	*Macomona liliana*
Bivalvia	Yes	Yes	Yes	*Nucula nitidula*	*Nucula nitidula*
Bivalvia	Yes	-	-	*Offadesma angasi*	*Offadesma angasi*
Chironomidae	-	-	Yes	*Chironomidae*	*Chironomidae*
Cirripedia	-	Yes	-	*Austrominius modestus*	*Austrominius modestus*
Copepoda	Yes	Yes	Yes	Copepoda	Copepoda
Cumacea	Yes	Yes	Yes	*Colurostylis lemurum*	*Colurostylis lemurum*
Decapoda	Yes	-	-	*Austrohelice crassa*	*Austrohelice crassa*
Decapoda	Yes	-	-	Brachyura (juv.)	Brachyura (juv)
Decapoda	Yes	-	-	*Halicarcinus* sp. (juv)	*Halicarcinus*
Decapoda	-	Yes	-	*Halicarcinus varius*	*Halicarcinus*
Decapoda	Yes	Yes	Yes	*Halicarcinus whitei*	*Halicarcinus*
Decapoda	Yes	Yes	Yes	*Hemiplax hirtipes*	*Hemiplax hirtipes*
Gastropoda	Yes	-	-	*Austrolittorina cincta*	*Austrolittorina cincta*
Gastropoda	Yes	Yes	Yes	*Cominella glandiformis*	*Cominella glandiformis*
Gastropoda	Yes	-	-	*Diloma* sp.	*Diloma*
Gastropoda	Yes	Yes	-	*Diloma subrostratum*	*Diloma*
Gastropoda	Yes	-	-	Gastropoda unid. (juv)	Gastropoda unid. (juv)
Gastropoda	Yes	Yes	-	*Micrelenchus huttonii*	*Micrelenchus huttonii*
Gastropoda	Yes	Yes	Yes	*Neoguraleus* sp.	*Neoguraleus* sp.
Gastropoda	-	Yes	-	*Notoacmea scapha*	*Notoacmea*
Gastropoda	Yes	-	-	*Notoacmea* sp.	*Notoacmea*
Gastropoda	Yes	-	-	*Retusa striata*	*Retusa striata*
Gastropoda	Yes	-	-	*Turbonilla* sp.	*Turbonilla* sp.
Gastropoda	Yes	Yes	Yes	*Zeacumantus subcarinatus*	*Zeacumantus subcarinatus*

Main group	Caw Jan-2021	NIWA Nov-2021	NIWA Nov-2022	Raw taxa name	Aggregation name
Isopoda	Yes	-	-	*Exosphaeroma obtusum*	*Exosphaeroma*
Isopoda	Yes	-	-	Exosphaeroma sp.	*Exosphaeroma*
Isopoda	-	Yes	-	*Isocladus* sp.	*Isocladus* sp.
Mysidacea	-	-	Yes	Mysida	Mysida
Nematoda	Yes	Yes	Yes	Nematoda	Nematoda
Nemertea	Yes	Yes	Yes	Nemertea	Nemertea
Nemertea	Yes	-	-	Nemertea sp. 1	Nemertea
Nemertea	Yes	-	-	Nemertea sp. 2	Nemertea
Oligochaeta	-	Yes	Yes	*Naididae*	Oligochaeta
Oligochaeta	Yes	-	-	Oligochaeta	Oligochaeta
Ostracoda	Yes	Yes	Yes	Ostracoda	Ostracoda
Phoronida	-	-	Yes	Phoronida	Phoronida
Polychaeta	-	Yes	-	?*Leodamas* sp.	?*Leodamas* sp.
Polychaeta	-	Yes	Yes	?*Thelepus* sp.	Terebellidae
Polychaeta	Yes	Yes	Yes	*Aglaophamus macroura*	*Aglaophamus macroura*
Polychaeta	Yes	-	-	*Ampharetidae*	*Ampharetidae*
Polychaeta	Yes	Yes	Yes	*Aonides trifida*	*Aonides trifida*
Polychaeta	Yes	Yes	Yes	*Aricidea* sp.	*Aricidea* sp.
Polychaeta	-	Yes	Yes	*Armandia maculata*	*Armandia maculata*
Polychaeta	Yes	Yes	Yes	*Barantolla lepte*	*Barantolla lepte*
Polychaeta	-	Yes	Yes	*Boccardia acus*	*Boccardia*
Polychaeta	Yes	-	-	*Boccardia* spp.	*Boccardia*
Polychaeta	-	Yes	Yes	*Boccardia syrtis*	*Boccardia*
Polychaeta	-	Yes	Yes	*Capitella cf. capitata*	*Capitella*
Polychaeta	Yes	-	-	*Capitella* sp.	*Capitella*
Polychaeta	Yes	Yes	Yes	*Disconatis accolus*	*Disconatis accolus*
Polychaeta	Yes	-	-	*Dorvilleidae*	*Dorvilleidae*
Polychaeta	Yes	-	-	*Exogoninae*	*Exogoninae*
Polychaeta	-	Yes	Yes	*Exogoninae* sp. 1	*Exogoninae*
Polychaeta	-	Yes	Yes	*Exogoninae* spp.	*Exogoninae*
Polychaeta	-	Yes	Yes	*Glycera* sp.	*Glycera* sp.
Polychaeta	-	Yes	-	*Goniadidae*	*Goniadidae*
Polychaeta	Yes	-	Yes	*Hemipodia simplex*	*Hemipodia simplex*
Polychaeta	Yes	-	-	*Hesionidae*	*Hesionidae*
Polychaeta	Yes	Yes	Yes	*Heteromastus filiformis*	*Heteromastus filiformis*
Polychaeta	-	-	Yes	*Levinsenia gracilis*	*Levinsenia gracilis*
Polychaeta	Yes	Yes	Yes	*Macroclymenella stewartensis*	*Macroclymenella stewartensis*
Polychaeta	-	-	Yes	*Magelona dakini*	*Magelona dakini*
Polychaeta	Yes	Yes	Yes	*Microspio maori*	*Microspio maori*
Polychaeta	-	Yes	Yes	*Naineris naineris-A*	*Naineris*
Polychaeta	Yes	-	-	*Naineris* sp.	*Naineris*
Polychaeta	Yes	Yes	-	*Nereididae* (juv)	*Nereididae* (juv)
Polychaeta	Yes	Yes	Yes	*Nicon aestuariensis*	*Nicon aestuariensis*
Polychaeta	Yes	Yes	Yes	*Orbinia papillosa*	*Orbinia papillosa*
Polychaeta	-	Yes	Yes	*Owenia petersenae*	*Owenia petersenae*
Polychaeta	-	Yes	Yes	*Paradoneis lyra*	*Paradoneis*
Polychaeta	Yes	-	-	*Paradoneis* sp.	*Paradoneis*

Main group	Caw Jan-2021	NIWA Nov-2021	NIWA Nov-2022	Raw taxa name	Aggregation name
Polychaeta	Yes	-	-	*Perinereis* sp.	*Perinereis* sp.
Polychaeta	-	Yes	-	*Pettiboneia* sp.	*Dorvilleidae*
Polychaeta	Yes	Yes	Yes	*Platynereis* sp.	*Platynereis* sp.
Polychaeta	Yes	-	-	Polychaete larvae	Polychaete larvae
Polychaeta	Yes	Yes	Yes	*Prionospio aucklandica*	*Prionospio*
Polychaeta	Yes	-	-	*Prionospio* sp.	*Prionospio*
Polychaeta	-	Yes	Yes	*Protocirrineris nuchalis*	*Protocirrineris nuchalis*
Polychaeta	-	Yes	-	*Sabellidae*	*Sabellidae*
Polychaeta	Yes	Yes	Yes	*Scolecolepides benhami*	*Scolecolepides benhami*
Polychaeta	-	-	Yes	*Scolelepis* sp. A	*Scolelepis* sp. A
Polychaeta	Yes	Yes	Yes	*Scoloplos cylindrifer*	*Scoloplos cylindrifer*
Polychaeta	Yes	Yes	Yes	*Sphaerodoridae*	*Sphaerodoridae*
Polychaeta	Yes	-	-	*Sphaerosyllis* sp.	*Syllidae*
Polychaeta	-	Yes	-	*Spio readi*	*Spio readi*
Polychaeta	Yes	-	-	*Spionidae*	*Spionidae*
Polychaeta	Yes	-	-	*Syllidae*	*Syllidae*
Polychaeta	-	Yes	Yes	*Syllinae*	*Syllidae*
Polychaeta	Yes	-	-	*Terebellidae*	*Terebellidae*
Porifera	Yes	-	-	Porifera	Porifera
Tanaidacea	-	Yes	Yes	Tanaidacea	Tanaidacea
Tanaidacea	Yes	-	-	*Zeuxoides* sp.	Tanaidacea

APPENDIX 4. SEDIMENT PLATE RAW DATA

		Depth to plate (mm)							
Date	Site	Plate 1	Plate 2	Plate 3	Plate 4	Mud (%)	Sand (%)	Gravel (%)	aRPD (mm)
2021-01-15	A	44	60	42	47	5	94.5	0.6	45
2021-11-27	A	43	55	38	38	4	96	<0.1	20
2022-11-28	A	45	57	39	40	6	94	<0.1	15
2021-01-15	B	50	60	44	46	5.7	93.2	1.1	35
2021-11-27	B	49	65	38	43	6.6	93.3	0.1	30
2022-11-28	B	53	68	44	51	6.9	92.7	0.4	30

APPENDIX 5. SEDIMENT QUALITY RAW DATA

Values based on a composite sample within each of X1-3, Y4-6, Z7-10, except for aRPD for which the mean and range is shown for 10 replicates.

Site	Survey	Zone	Gravel	Sand	Mud	TOC	TN	TP	aRPD	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
			%	%	%	%	mg/kg	mg/kg	mm	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
A	Jan-21	X	<0.1	94.4	5.6	0.11	<500	179	11.3 (6-25)	1.9	<0.010	4.1	0.9	<0.02	2.6	0.94	9
		Y	1.6	93.3	5.1	0.15	<500	172	14.3 (8-30)	2.1	<0.010	4.2	1	<0.02	2.5	1.44	9
		Z	<0.1	95.8	4.2	0.14	<500	179	12.5 (5-20)	2.1	<0.010	4.1	0.8	<0.02	2.4	1	8
	Nov-21	X	<0.1	95.6	4.4	0.14	<500	176	20.0 (15-30)	2.5	<0.010	4.3	0.8	<0.02	2.5	0.96	8
		Y	<0.1	96.4	3.6	0.15	<500	185	26.7 (20-40)	2.1	<0.010	4.4	0.8	<0.02	2.7	0.99	8
		Z	1.7	94.7	3.6	0.15	<500	181	20.0 (15-25)	1.9	<0.010	3.7	0.7	<0.02	2.3	0.88	7
	Nov-22	X	0.4	93.8	5.8	0.16	<500	160	19.7 (18-23)	2.2	<0.010	4.5	1	<0.02	2.9	1.11	9
		Y	<0.1	94.1	5.9	0.14	<500	170	11.3 (6-13)	2.3	<0.010	4.5	0.9	<0.02	2.9	1.11	9
		Z	<0.1	94.4	5.5	0.14	<500	149	10.5 (9-12)	2.3	<0.010	4.1	0.8	<0.02	2.5	1.03	8
B	Jan-21	X	1.4	93.5	5	0.11	<500	250	21.7 (10-35)	2.9	<0.010	6.9	1	<0.02	5.8	1.22	11
		Y	1.6	92.8	5.6	0.11	<500	260	28.3 (10-45)	3	<0.010	7	1	<0.02	5.3	1.21	12
		Z	0.2	93.4	6.5	0.13	<500	270	28.0 (12-35)	3.2	<0.010	7.5	1.2	<0.02	6.2	1.41	12
	Nov-21	X	0.4	95.3	4.3	0.14	<500	280	35.0 (30-45)	3.2	<0.010	6.3	1	<0.02	5.4	1.17	11
		Y	0.1	94.8	5.1	0.1	<500	260	28.3 (20-35)	3.3	<0.010	6.8	1	<0.02	5.6	1.26	11
		Z	1	93.1	5.9	0.12	<500	270	25.8 (25-40)	3.6	<0.010	7.9	1.1	<0.02	6	1.36	13
	Nov-22	X	0.1	93.4	6.5	0.12	<500	210	31.0 (28-35)	3.2	<0.010	6.9	1.1	<0.02	5.3	1.29	12
		Y	1.1	92.4	6.5	0.11	<500	210	33.3 (27-38)	3.1	<0.010	6.4	1	<0.02	5.2	1.22	11
		Z	1.2	92.7	6.2	0.16	<500	220	36.8 (32-42)	3.2	<0.010	7	1	<0.02	5.4	1.28	11
									DGV	20	1.5	80	65	0.15	21	50	200
									GV-high	70	10	370	270	1	52	220	410

APPENDIX 6. MACROFAUNA RAW DATA SUMMED ACROSS CORES

Cores 130mm diameter to 150mm deep, 0.013m^2 sample area, ~2L core volume. EG = AMBI Eco-group. EGs may differ to that listed in the 2021 report due to updates to the international EG database. Species richness, abundance and AMBI values were based on the species list below. However, for multivariate analyses of community composition, taxonomic differences between the 2021 survey (Cawthron taxonomy) and subsequent surveys (NIWA taxonomy) were resolved by aggregating the list below into the higher-level taxa described in Appendix 3.

Main group	Taxa	Habitat	EG	Jan21 A	Jan21 B	Nov21 A	Nov21 B	Nov22 A	Nov22 B
Amphipoda	Amphipoda	Infauna	II		8				
Amphipoda	*Lysianassidae*	Infauna	I	37	23				
Amphipoda	*Paracalliope novizealandiae*	Infauna	I	86	26	83	317	110	90
Amphipoda	*Paracorophium excavatum*	Infauna	IV					2	6
Amphipoda	*Parawaldeckia kidderi*	Infauna	II			10	290	5	3
Amphipoda	*Phoxocephalidae*	Infauna	I	27	79				
Amphipoda	*Proharpinia* sp.	Infauna	I				2		17
Amphipoda	*Torridoharpinia hurleyi*	Infauna	I			78	81	103	103
Anthozoa	Anthozoa	Epibiota	II	34	14				
Anthozoa	*Edwardsia* sp.	Epibiota	II			61	31	36	16
Bivalvia	*Arthritica* sp. 5	Infauna	III		1		3		
Bivalvia	*Austrovenus stutchburyi*	Infauna	II	6	29	13	41	3	51
Bivalvia	*Lasaea parengaensis*	Infauna	II	580	67	508	79	860	103
Bivalvia	*Macomona liliana*	Infauna	II	7	11	4	6	5	4
Bivalvia	*Nucula nitidula*	Infauna	I	53	397	89	598	101	481
Bivalvia	*Offadesma angasi*	Infauna	II		1				
Chironomidae	*Chironomidae*	Infauna	III						1
Cirripedia	*Austrominius modestus*	Epibiota	II				1		
Copepoda	Copepoda	Infauna	II		1	2		4	1
Cumacea	*Colurostylis lemurum*	Infauna	II		16	1	1	6	18
Decapoda	*Austrohelice crassa*	Infauna	V	1					
Decapoda	Brachyura (juv.)	Infauna	-	1					
Decapoda	*Halicarcinus* sp. (juv)	Infauna	III	1					
Decapoda	*Halicarcinus* varius	Infauna	III				1		
Decapoda	*Halicarcinus whitei*	Infauna	III	5	6	2	6	6	11
Decapoda	*Hemiplax hirtipes*	Infauna	III	2			2	2	1
Gastropoda	*Austrolittorina cincta*	Epibiota	II		1				
Gastropoda	*Cominella glandiformis*	Epibiota	III	2	4	3	7	1	8
Gastropoda	*Diloma* sp.	Epibiota	II		1				
Gastropoda	*Diloma subrostratum*	Epibiota	II		1		1		
Gastropoda	Gastropoda unid. (juv)	Epibiota	-		2				
Gastropoda	*Micrelenchus huttonii*	Epibiota	-		3		20		
Gastropoda	*Neoguraleus* sp.	Epibiota	-		1	1	2	2	
Gastropoda	*Notoacmea scapha*	Epibiota	II				13		
Gastropoda	*Notoacmea* sp.	Epibiota	II	1	1				
Gastropoda	*Retusa striata*	Epibiota	II		1				
Gastropoda	*Turbonilla* sp.	Epibiota	I		2				
Gastropoda	*Zeacumantus subcarinatus*	Epibiota	II		2		6		6
Isopoda	*Exosphaeroma obtusum*	Infauna	V	2					
Isopoda	*Exosphaeroma* sp.	Infauna	V	1	8				
Isopoda	*Isocladus* sp.	Infauna	I				1		
Mysidacea	Mysida	Infauna	II					2	
Nematoda	Nematoda	Infauna	III	11	38	4	3	41	28
Nemertea	Nemertea	Infauna	III		3	23	19	18	16
Nemertea	Nemertea sp. 1	Infauna	III	1					
Nemertea	Nemertea sp. 2	Infauna	III	4	5				
Oligochaeta	*Naididae*	Infauna	V			230	1183	100	507
Oligochaeta	Oligochaeta	Infauna	V	30	517				
Ostracoda	Ostracoda	Infauna	I	28	91	22	221	17	29
Phoronida	Phoronida	Infauna	II					2	

Main group	Taxa	Habitat	EG	Jan21 A	Jan21 B	Nov21 A	Nov21 B	Nov22 A	Nov22 B
Polychaeta	?*Leodamas* sp.	Infauna	III			7			
Polychaeta	?*Thelepus* sp.	Infauna	II			5	121	25	82
Polychaeta	*Aglaophamus macroura*	Infauna	II	23	6	19	5	18	26
Polychaeta	*Ampharetidae*	Infauna	II	3					
Polychaeta	*Aonides trifida*	Infauna	I	22	44	19	35	14	32
Polychaeta	*Aricidea* sp.	Infauna	I	3		6		7	2
Polychaeta	*Armandia maculata*	Infauna	III				3		1
Polychaeta	*Barantolla lepte*	Infauna	V	4	7		5		17
Polychaeta	*Boccardia acus*	Infauna	IV			7			2
Polychaeta	*Boccardia* spp.	Infauna	III	93	20				
Polychaeta	*Boccardia syrtis*	Infauna	II			205	7	178	2
Polychaeta	*Capitella cf. capitata*	Infauna	V			17	22	40	3
Polychaeta	*Capitella* sp.	Infauna	V	88					
Polychaeta	*Disconatis accolus*	Infauna	I		2		1	1	
Polychaeta	*Dorvilleidae*	Infauna	II	2	6				
Polychaeta	*Exogoninae*	Infauna	II	103	42				
Polychaeta	*Exogoninae* sp. 1	Infauna	II			330	33	227	34
Polychaeta	*Exogoninae* spp.	Infauna	II			160	242	39	188
Polychaeta	*Glycera* sp.	Infauna	II			2	2		2
Polychaeta	*Goniadidae*	Infauna	II			2			
Polychaeta	*Hemipodia simplex*	Infauna	II		1				1
Polychaeta	*Hesionidae*	Infauna	I	2	1				
Polychaeta	*Heteromastus filiformis*	Infauna	IV	6	15	14	45	25	23
Polychaeta	*Levinsenia gracilis*	Infauna	III					3	
Polychaeta	*Macroclymenella stewartensis*	Infauna	II	248	102	764	280	162	353
Polychaeta	*Magelona dakini*	Infauna	I					1	
Polychaeta	*Microspio maori*	Infauna	I	400	63	165	1	112	3
Polychaeta	*Naineris naineris-A*	Infauna	I			7	8	16	11
Polychaeta	*Naineris* sp.	Infauna	I	2	5				
Polychaeta	*Nereididae* (juvenile)	Infauna	-	5	3	3	12		
Polychaeta	*Nicon aestuariensis*	Infauna	III	9	2	15	8	8	4
Polychaeta	*Orbinia papillosa*	Infauna	I	5		1	1	3	1
Polychaeta	*Owenia petersenae*	Infauna	II				4	3	1
Polychaeta	*Paradoneis lyra*	Infauna	III			2166	2074	1510	1446
Polychaeta	*Paradoneis* sp.	Infauna	III	1099	1523				
Polychaeta	*Perinereis* sp.	Infauna	III		2				
Polychaeta	*Pettiboneia* sp.	Infauna	II			6	16		
Polychaeta	*Platynereis* sp.	Infauna	III	4		9		9	1
Polychaeta	Polychaete larvae	Larva	-		1				
Polychaeta	*Prionospio aucklandica*	Infauna	III	22	10	29	8	22	2
Polychaeta	*Prionospio* sp.	Infauna	II	6	12				
Polychaeta	*Protocirrineris nuchalis*	Infauna	III				1		1
Polychaeta	*Sabellidae*	Infauna	I			10			
Polychaeta	*Scolecolepides benhami*	Infauna	IV		11	3	1	2	
Polychaeta	*Scolelepis* sp. A	Infauna	III						1
Polychaeta	*Scoloplos cylindrifer*	Infauna	I	11		36	17	36	5
Polychaeta	*Sphaerodoridae*	Infauna	-	4		7	1	1	
Polychaeta	*Sphaerosyllis* sp.	Infauna	II	1					
Polychaeta	*Spio readi*	NA	III				1		
Polychaeta	*Spionidae*	Infauna	III		1				
Polychaeta	*Syllidae*	Infauna	II	31	124				
Polychaeta	*Syllinae*	Infauna	II			5	12	2	6
Polychaeta	*Terebellidae*	Infauna	II	3	26				
Porifera	Porifera	Epibiota	-		1				
Tanaidacea	Tanaidacea	Infauna	II			404	472	606	221
Tanaidacea	*Zeuxoides* sp.	Infauna	I	131	184				

APPENDIX 7. MACROFAUNA SAMPLING OPTIMISATION

SUMMARY

The current NEMP protocol specifying 10 macrofauna cores per site may not be optimal for statistical testing, and complete characterisation of the species pool. However, given the cost of macrofauna sample processing, and in light of the three-year dataset that has been developed for Blueskin Bay, reducing sampling to 9 cores would have a minor effect on ability to detect change and have the benefit of reduced taxonomy costs. Collection of 9 cores would also cater for a simplified 3x3 field sampling grid, compared with the present situation in which cores are taken from 10 random plots out of 12 available (i.e. reflecting a 3x4 grid).

A7.1. BACKGROUND

The National Estuarine Monitoring Protocol (NEMP) recommended collecting 10 macrofauna core samples per site (reps) based on an analysis of a national dataset in 2002 (Robertson et al. 2002). This average sampling effort appeared to have been biased upwards by sediment chemistry indicators, with the recommended number of reps specifically for species richness (S) reported as 7-8, and for abundance (N) 8-9. NIWA have released a recent guidance document recommending collection of 12 reps twice yearly for macrofaunal sampling (Hewitt 2021), based on long term work in Manukau Harbour.

The purpose of the analysis below is to assess macrofauna sampling requirements for Blueskin Bay given that a three-year 'baseline' has now been established. The analysis considers macrofauna sampling sufficiency using the following approaches:

- The NEMP approach, which was based on the coefficient of variation (CV) in univariate responses as a function of increasing sampling effort, using pooled estuary reps.
- An approach based on power analysis that reflects previous NIWA work (Hewitt et al. 1993; Hewitt 2021) and considers the levels of minimum detectable change in three univariate responses analysed in the report (S, N, AMBI).
- An approach based on species detection, which considers the percentage of the 'true' estimated pool of species that is captured by different levels of sampling effort. This approach is particularly relevant to multivariate analysis, for which knowledge of species detection provides insight into whether assessed differences in ecological communities among sites or times are true differences or are potentially biased by under-sampling of less common species.

There are additional more recent and sophisticated approaches that could be explored, including change detection in trends, multivariate approaches, and multilevel occupancy modelling, but going to this level of analysis would justify a standalone technical report and was beyond present scope.

A7.2 DESCRIPTION OF NEMP APPROACH

The NEMP approach was to model the coefficient of variation (CV) as a function of increasing reps, using pooled estuary reps, then determine a cost-benefit-point (CBP) whereby further increases in sample size yielded insubstantial returns (Robertson et al. 2002). The CBPs were used to assess levels of detectable change, sometimes referred to as statistical power. CV is the sample standard deviation divided by the sample mean, and a relative measure that could be compared across sites, estuaries, or even indicators. However, the value of using this statistic for determining optimal sample size lies solely in the sample estimate of standard deviation, where increasing reps should decrease this measure of variation, given certain assumptions and bias corrections.

An improvement in the NEMP approach would be to consider standard error (SE), which is standard deviation divided by the square root of sample size. This was the approach taken by Hewitt et al. (1993) to optimize the trade-off between accuracy and cost for species abundance monitoring in Manukau Harbour. Fig. A7.1 plots the change in SE of the 3 univariates responses (S, N, AMBI) in relation to sampling effort, with power curve extrapolations used to estimate SE beyond the number of actual samples taken. The graphs show the diminishing returns arising from sampling beyond the current effort of 10 reps. Of course, the specific responses are site and time dependent, which is smoothed over by averaging across surveys in Fig. A7.1.

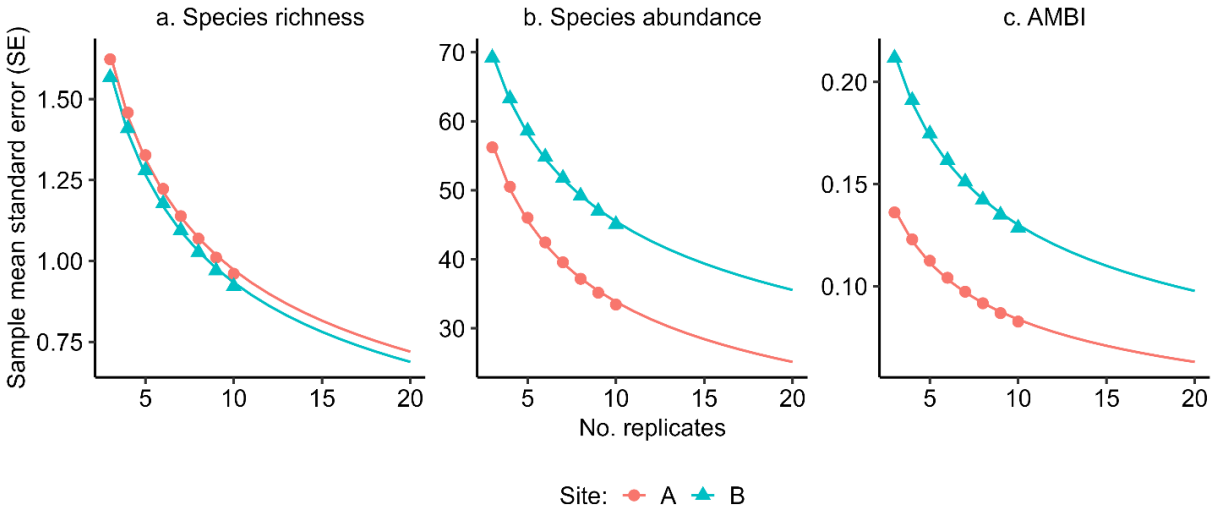

Figure A7.1. The standard error (SE) for the mean univariate response at each site in Blueskin Bay, averaged across three surveys, are plotted against differing numbers of replicates. The markers show the SE of sample means for observed data, and the lines are power curve extrapolations to indicate how uncertainty in sample mean estimates would continue to decrease as sample sizes increase. Note the differing scale of the y-axis, where SEs for species abundance (b) are much higher than that of species richness (a) and AMBI (c).

A7.3 POWER ANALYSIS OF UNIVARIATE RESPONSES

Power analysis considers the minimum change in a statistic that a certain statistical test could detect given differing data variance and sampling effort. This section defines minimum detectable change as the difference in sample means required for paired t-tests to suggest a non-zero change at each site from year to year, with type I and II error rates thresholds of 0.05 and 0.20 (Champely 2020). Fig. A7.2 shows these minimum detectable changes as the +/- percentage change for each of the 3 macrofauna response variables as a function of sampling effort, averaged across the three surveys.

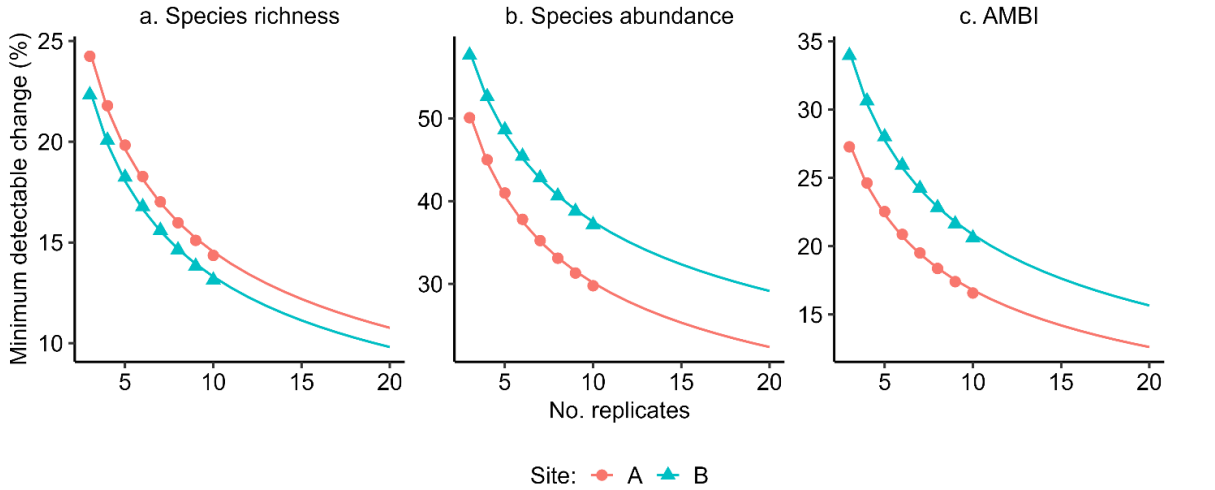

Figure A7.2. The minimum detectable change (%) for the mean univariate response at each site, averaged across three surveys, are plotted against differing numbers of replicates. The markers show the detectable change as a % of sample means for observed data and the lines are power curve extrapolations to indicate how statistical tests could detect smaller changes in these sample means as sample sizes increase.

Fig A7.1 and Fig A7.2 conform with basic statistics; as more replicates are obtained, the uncertainty in univariate macrofauna sample means decrease and our ability to detect change increases. However, the difference between increasing sample effort to 12 reps (as recommended by NIWA twice yearly for seasonality and change in trend detection, Hewitt 2021) versus decreasing effort to 9 reps appears relatively small. Table A7.1. confirms this, with the minimum detectable changes between the current survey (November 2022) sample means and future surveys, suggesting that collecting 12 reps would allow detection of changes about 1-2% smaller than what we could currently detect, while reducing to 9 reps would mean changes detected would be at most 1% larger than at present. These differences in statistical power between 9, 10, and 12 reps are relatively small when considering the large differences in taxonomic processing costs for the increased sampling effort.

Table A7.1. Minimum +/- changes we could detect in future surveys when compared to the November 2022 survey, using paired paired t-tests for change in sample means (alpha=0.05). The second header row indicates the number of reps required to detect the respective change, and the column highlighted in gold is the detectable change under the current NEMP recommendation of 10 reps.

Indicator	Site	Nov-2022	Future +/- minimum detectable change (% in brackets)						
		10	5	6	7	8	9	10	12
S	A	27.4	5.8 (21%)	5.4 (20%)	5.0 (18%)	4.7 (17%)	4.5 (16%)	4.3 (16%)	3.9 (14%)
	B	27.2	3.7 (14%)	3.4 (13%)	3.2 (12%)	3.0 (11%)	2.9 (10%)	2.7 (10%)	2.5 (9%)
N	A	450	190 (42%)	177 (39%)	166 (37%)	157 (35%)	150 (33%)	143 (32%)	133 (30%)
	B	397	193 (49%)	182 (46%)	173 (43%)	165 (42%)	159 (40%)	153 (39%)	144 (36%)
AMBI	A	2.03	0.24 (12%)	0.22 (11%)	0.21 (10%)	0.20 (10%)	0.19 (9%)	0.18 (9%)	0.17 (8%)
	B	2.36	0.39 (17%)	0.36 (15%)	0.34 (14%)	0.32 (14%)	0.31 (13%)	0.29 (12%)	0.27 (12%)

A7.4 SPECIES-ACCUMULATION CURVES

The final approach considered was extrapolation of species-accumulation curves, which is a permutation-based approach that describes the cumulative number of species detected with an increase in sampling effort. Typically, such curves approach an asymptote, reflecting diminishing returns as sampling effort increases. Various techniques can be used to model the number of total species number where this asymptote is reached, which is the estimate of 'true' total species richness. This approach enables a CBP to be chosen based on the desired percentage of the estimated true total richness to be captured by a sampling programme. Achieving 100% species detection is unlikely to be practically attainable, due to the chance sampling of uncommon/rare species.

For present purposes, several total species richness estimators were used and compared, with the Chao1 estimator from the iNEXT R package chosen as the most appropriate (Chao et al. 2014; Hsieh et al. 2020; R Core Team 2023). Table A7.2 and Fig A7.3 suggest that the current NEMP protocol of 10 reps captures about 94% and 83.6% of the estimated total species present at Site A and B respectively. Reducing sampling effort to 9 reps would on average mean identifying one less species, while increasing to 12 reps would potentially detect 1-2 more species.

Table A7.2. The number of species detected at each site-year using different numbers of reps. Richness estimates for 5-9 reps are based on averages of all possible subsample combinations, while estimates for 12 reps are extrapolations towards the Chao1 estimator of total richness (Chao et al. 2014; Hsieh et al. 2020; R Core Team 2023). Green cells highlight the number of reps required to stay within one species of the observed richness each year (gold cells).

Site	Year	5	6	7	8	9	10	12
A	Jan-21	41.9 (76%)	43.9 (79%)	45.5 (82%)	46.8 (85%)	48.0 (87%)	49.0 (88%)	50.6 (91%)
	Nov-21	42.2 (91%)	43.6 (94%)	44.5 (96%)	45.2 (97%)	45.7 (98%)	46.0 (99%)	46.3 (~100%)
	Nov-22	42.1 (85%)	43.5 (88%)	44.7 (91%)	45.6 (93%)	46.4 (94%)	47.0 (95%)	47.9 (97%)
B	Jan-21	46.9 (66%)	49.4 (69%)	51.6 (72%)	53.6 (75%)	55.4 (78%)	57.0 (80%)	59.7 (84%)
	Nov-21	46.6 (71%)	48.7 (74%)	50.6 (77%)	52.2 (79%)	53.7 (82%)	55.0 (84%)	57.2 (87%)
	Nov-22	42.2 (75%)	44.0 (78%)	45.6 (81%)	46.9 (83%)	48.0 (85%)	49.0 (87%)	50.7 (90%)

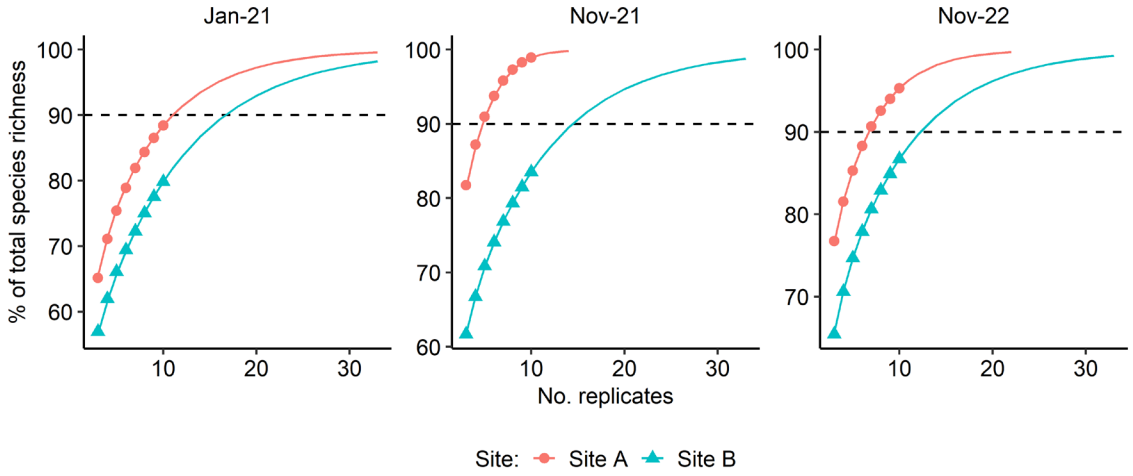

Figure A7.3. Percentage of total estimated richness at each site plotted against the number of replicates. Subplots correspond to sampling years. The points on the graph show % of total richness calculated from observed data and the lines are extrapolations towards the estimated 100% richness using the iNEXT package in R (Hsieh et al. 2020, R Core Team 2023). The dashed horizontal line indicates an estimated 90% of species detected.

Fig. A7.3 shows that returns in species detection with increasing sampling effort do not diminish as predictably as they do for SE (Fig. A7.1) and minimum detectable % change (Fig. A7.2). Furthermore. there are clear site differences suggesting that to capture true species richness (the curve asymptote) would take a greater sampling effort at Site B than Site A. At the Site B the current sampling effort captures <90% of the predicted species. The differences between these species detection results and those of the more traditional statistical approaches above highlight the value in comparing multiple measures of sampling efficacy when determining a CBP.

A7.5 REFERENCES FOR APPENDIX

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