SALT ECOLOGY

Fine Scale Intertidal Monitoring of Pleasant River (Te Hakapupu) Estuary

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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 (for ANZG sediment quality)
ETI	Estuary Trophic Index
Hg	Mercury
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

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SUMMARY

As part of its State of the Environment programme, Otago Regional Council (ORC) monitors the ecological condition of significant estuaries in its region. This report describes the first of three planned annual baseline ecological monitoring and sedimentation surveys in Pleasant River (Te Hakapupu) Estuary, which was conducted in November 2021. The estuary is of particular interest to the local community and ORC due to concerns regarding a deterioration in its condition in recent years. The survey followed the 'fine scale' approach described in New Zealand's National Estuary Monitoring Protocol, with 'sediment plates' installed at the time of the survey to enable future sedimentation monitoring. Monitoring was conducted at two sites, and results assessed against condition rating criteria for estuary health, as per the Table below.

KEY FINDINGS

- Both sites had a moderate to high sediment mud content and showed mild to moderate symptoms of enrichment in terms of three trophic state indicators (aRPD, %TOC and TN in the Table below). These attributes are consistent with catchment run-off, in part reflecting catchment land uses dominated by pasture and exotic forestry.
- An analysis of trace contaminants (mainly trace metals) provided no evidence of any significant anthropogenic contaminant sources in the catchment.
- The estuary has a diverse mix of macrofauna species that is greater than most other estuaries in the Otago region, and stands out as having particularly high organism abundances. The most abundant organisms included some relatively hardy taxa that can thrive in enriched or disturbed conditions, which contributed to moderately-elevated values of the ecological health index AMBI.

Considering the sediment quality and biological assessment collectively, the fine scale survey results suggest that the two monitored sites in Pleasant River Estuary are exhibiting symptoms of mild stress, although have not reached a 'tipping' point whereby multiple indicators are showing signs of degradation. By contrast, the results of the broad scale habitat mapping survey, which was undertaken concurrent with the fine scale assessment, revealed that some areas of the upper estuary, as well as side arms, are exhibiting symptoms of excess nutrient enrichment; i.e. eutrophication. Although not being situated in the worst-affected parts of the estuary, the fine scale sites are representative of the main tidal flats, and are suitable for long-term monitoring.

Summary of estuary condition based on key indicators

Site	Mud	aRPD	TN	TP	TOC	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn	AMBI
	%	mm	mg/kg	mg/kg	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	na
A	38.5	3	900	483	0.69	4.5	0.040	8.7	2.8	3.7	< 0.02	5.1	22.3	3.6
B	41.7	3	450*	440	0.40	4.3	0.039	7.7	2.4	3.2	< 0.02	4.5	23.3	3.5

** Sample mean includes values below lab detection limits*
< All values below lab detection limit

Condition rating key:

Very Good	Good	Fair	Poor

RECOMMENDATIONS

- Complete two additional annual surveys as planned in the summers of 2022/23 and 2023/24. Together with data gathered from changes in sediment plate depth, the work will provide a comprehensive baseline for the long-term monitoring of ecological health in Pleasant River Estuary.
- Compile data summaries after the second survey, but defer the next comprehensive analysis and reporting until completion of the 3-year baseline, at which time the management implications of the survey findings should be considered.

1. INTRODUCTION

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, with key locations being Shag River, Waikouaiti, Kaikorai, Tokomairiro, Blueskin Bay and Catlins estuaries. ORC has recently expanded its SOE monitoring programme and in the summer of 2021/2022 added several other estuaries, one of which was Pleasant River (Te Hakapupu) Estuary in North Otago (Fig. 1). Pleasant River Estuary is of particular interest to the local community and ORC due to concerns regarding a deterioration in its condition in recent years.

In November 2021, Salt Ecology undertook a NEMP broad scale and fine scale survey in Pleasant River Estuary, and installed sediment plates for future sedimentation monitoring. This report describes the methods and results of the fine scale and sediment plate components, with the broad scale work described by Roberts et al. (2022). Results of the present survey are discussed in the context of existing knowledge and historical influences on Pleasant River Estuary and in relation to various criteria for assessing estuary health. The survey is intended as the first of three consecutive annual baseline surveys using the fine scale and sediment plate approach.

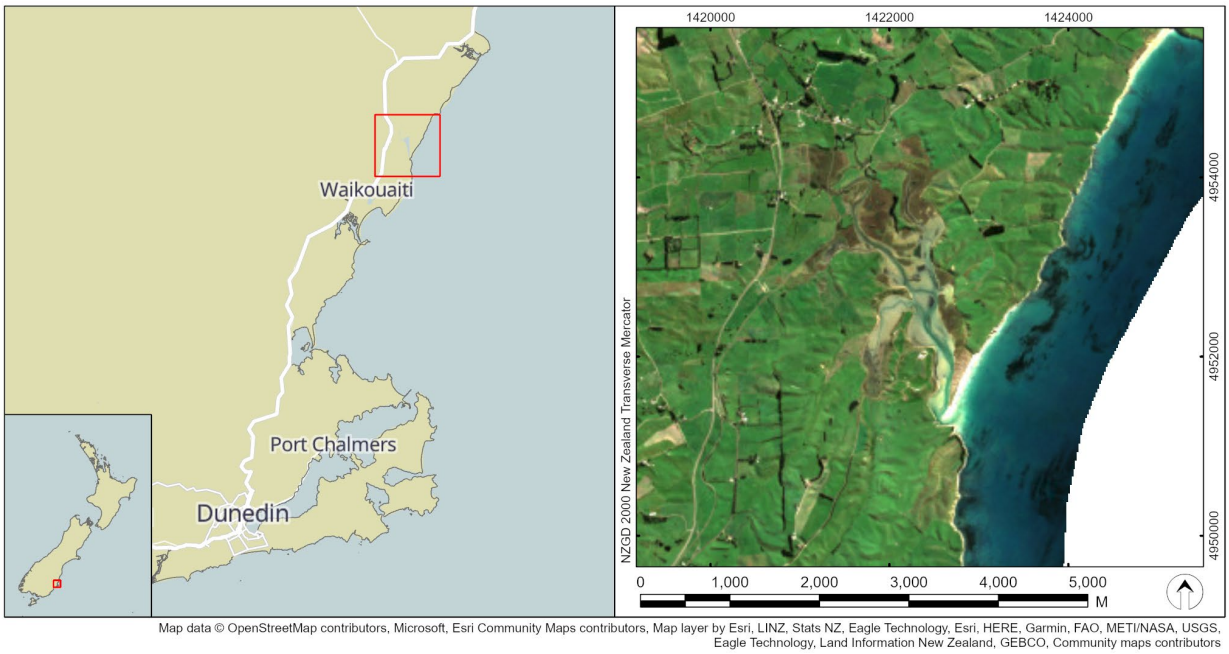


Fig. 1. Location of Pleasant River (Te Hakapupu) Estuary.

2. BACKGROUND TO PLEASANT RIVER ESTUARY

The following background information on Pleasant River Estuary has been adapted from Roberts et al. (2022) and incorporates the findings of the broad scale habitat mapping survey described in that report.

Pleasant River Estuary is a medium sized (216ha) estuarine system, defined as a shallow, intertidally dominated, tidal lagoon type estuary (SIDE). The estuary has a flushing time of ~5 days (Plew et al. 2018); however, whereas, the mid to lower estuary is relatively well-flushed, the narrow channels in the upper estuary are susceptible to stratification and water column nutrient problems. The estuary has the capacity to retain fine sediments and sediment bound nutrients in deposition areas (e.g. side arms) making it moderately susceptible to nutrient enrichment impacts.

The main freshwater inflow to the estuary is Pleasant River, along with several smaller tributaries. Freshwater inputs represent ~30% of the total estuary volume (Plew et al. 2018). The estuary drains almost completely at low tide exposing ~86% of the estuary area (Roberts et al. 2022). The lower estuary is protected from the ocean by a sand spit dominated by marram grass dunes. The catchment area is 12,747ha, comprising ~38.1% intensive pasture, ~23.8% low producing pasture and ~31.1% exotic forest. In total, 37.7% of the catchment is densely vegetated (Fig. 2).

The immediate terrestrial margin of Pleasant River Estuary is dominated by pasture on gently sloping hill country that falls steeply to the estuary (Moore 2015). The bedrock is sedimentary, meaning there is moderate to high susceptibility of overland flow and sediment and particulate phosphorus issues (LandscapeDNA.org).

The broadscale survey highlighted that the estuary is expressing signs of eutrophication (i.e. nutrient enrichment), with nuisance macroalgae and filamentous algae common in the side arms and mid estuary and often associated with muddy sediments and anoxia (i.e. no oxygen). Mud-dominated (>50% mud) sediments were common and comprised 16.7% of the intertidal area, and were generally found in the estuary side arms or within salt marsh habitat where fine sediments tend to accumulate.

Ulva spp. and *Agarophyton* spp. growing in muddy anoxic sediments in the north-west arm

Salt marsh herbfield (mainly glasswort, *Sarcocornia quinqueflora*), is the dominant vegetation type in the estuary (42.8% of the intertidal area) and is recognised as a regionally significant wetland in the Regional Plan: Water for Otago (Roberts et al. 2022). However, historic drainage and reclamation of salt marsh for pasture is a common feature of the estuary, particularly in the side arms (see photos next page). Fencing of herbfield for grazing continues to occur, and flap gates restrict saltwater inundation of salt marsh habitat. A causeway that blocked the entrance of the southern arm to allow for cattle grazing was removed in 2009 to reinstate tidal flushing (Moller & Moller 2012). However, the area of previous salt marsh habitat has not recovered.

Middle section of Pleasant River Estuary

Remnants of the causeway removed in 2009

Salt marsh in the southwest side arm 1958 (top; source Retrolens) and 2019 (bottom; source ORC)

Pleasant River Estuary was traditionally utilised by Māori as an important kāinga mahinga kai (food gathering settlement). A significant archeological site at the estuary mouth has identified early hunting of moa and seals before a transition to kaimoana (seafood). The estuary provides extensive spawning and nursery habitat for marine and freshwater fish species including patiki (flatfish), inanga (whitebait) and tuna (long-finned eel and short-finned eel; Ngāi Tahu Atlas). The establishment of a marine reserve that would extend from Pleasant River Estuary to Stony Creek has been proposed to protect important coastal reef, estuary, and kelp forest habitats (SMPF 2018).

The estuary is a coastal protection area in the Otago Regional Plan: Coast, based on its cultural and ecological values. The estuary is particularly important for waders and waterfowl including godwits, South Island pied oystercatcher, variable oystercatcher, pied stilt, banded dotterel white-faced heron, gulls, shags and ducks (WDC 2004).

The Tūmai Beach Development on the southern margin of the estuary has recently prepared an environmental enhancement plan as part of their consent conditions. The long-term restoration plan aims to integrate ecosystem restoration and sustainable pasture production by planting natives on the terrestrial margin, salt marsh plantings, and through exclusion of stock and reducing vehicle use in the estuary (TBEEG 2021).

While there has been extensive reclamation and modification to the estuary margin, the estuary retains high ecological, cultural and human use values.

Lower estuary flats

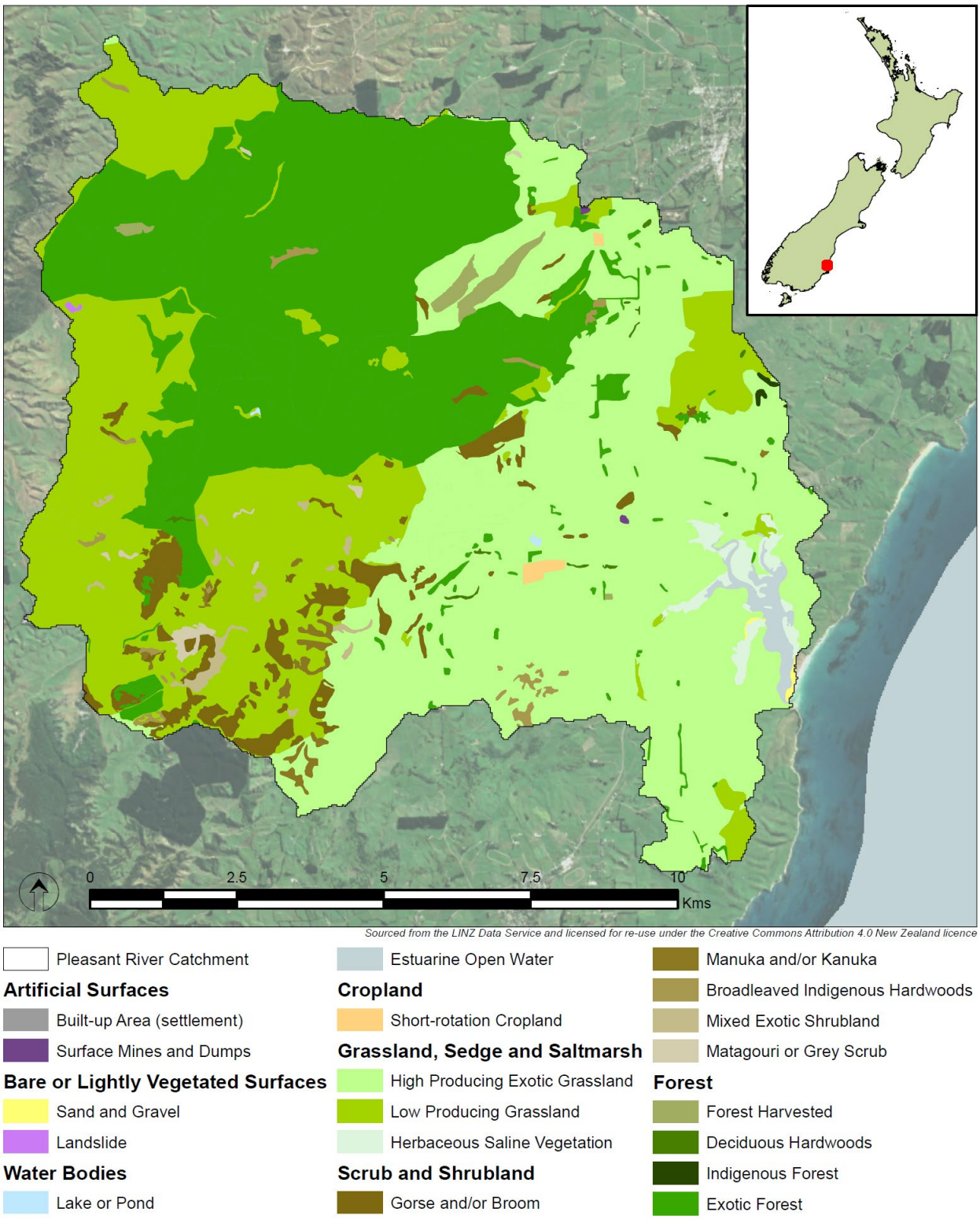


Fig. 2. Pleasant River Estuary and surrounding catchment land use classifications from LCDB5 (2017/18) database.

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 actual tidal elevation is often determined by the location of suitable, stable soft-sediment habitat.

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 (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 PLEASANT RIVER ESTUARY FINE SCALE AND SEDIMENT PLATE SITES

The broad scale survey revealed extensive mud/sand flats across much of Pleasant River Estuary, providing a choice of locations for fine scale sites. The selected placement of the sites was in muddy-sand habitats of the middle and upper estuary (Fig. 3), at approximately mid-tide level.

A schematic of the sampling approach is provided on the site overview map in Fig. 3, with details described below. Site A was positioned on the true right side of Pleasant River in an embayment off the main river channel, with Site B placed in an upper estuary side arm off the true left of the main channel. Each fine scale site was set up as a 30 x 60m rectangle according to NEMP recommendations.

Sediment plates were installed along the upstream 30m margin of each site (Fig. 3). 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. Site set-up, sediment installation and sampling were undertaken on 26 Nov 2021, with the support of the local community. On the day of sampling, the predicted low tide at Pleasant River entrance was 0.66m occurring at ~15:16 (tides.niwa.co.nz), with a lag of ~2 hours observed at the sampling sites.

Overview of fine scale site B, 26 November 2021

3.3 SEDIMENT PLATES

Four concrete 'plates' (pavers, 19cm x 23cm) for sediment plate monitoring were installed at each of the two fine scale sites, positioned at 5, 10, 20 and 25m along the upstream site boundary (see Fig. 3).

Plates were buried between 50-100mm depth in the sediment. After leveling, baseline depths (from the sediment surface to each buried plate) were 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 millimeter.

At each site, a single sediment sample (composited from sub-samples 20mm deep taken next to each plate) was collected and retained for laboratory analysis of grain size, using the methods described for fine scale monitoring (see Section 3.4). As the sediment plate measurements are expected to be undertaken annually, the grain size data can be used to assess any changes in sediment muddiness.

Installing sediment plates at Pleasant River Site B, 26 November 2021

Fig. 3. Location of sites in Pleasant River Estuary, and schematics illustrating fine scale and sediment plate methods.

3.4 FINE SCALE SAMPLING AND BENTHIC INDICATORS

Each fine scale site was divided into a 3 x 3 grid of nine plots (Fig. 3). Fine scale sampling for sediment indicators was conducted in each plot, with Fig. 3 showing the standard numbering sequence for replicates 1-9 at both sites, and the designation of zones X, Y and Z (for compositing sediment samples; Fig. 3). A summary of the benthic indicators, the rationale for their inclusion, and the field sampling methods, is provided in Table 1. Although the baseline sampling approach generally adhered to the NEMP, additions to early NEMP methods that have been introduced in most surveys conducted over the last 10 or more years. For present purposes we adopted these modifications as indicated in Table 1.

3.4.1 Sediment quality assessment

At each fine scale site, three composite sediment samples (each ~250g) were pooled from sub-samples collected (to 20mm depth) across each of zones X, Y and Z (replicates 1-3, 4-6 and 7-9, respectively; see Fig. 3). Samples were stored on ice and sent to RJ Hill Laboratories for analysis of the following constituents: 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 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 in Appendix 2.

3.4.2 Field sediment oxygenation assessment

To assess sediment oxygenation, the apparent redox potential discontinuity (aRPD) depth (Table 1) was measured. The aRPD is a subjective measure of the enrichment state of sediments according to the depth of visible transition between oxygenated surface sediments (typically brown in colour) and deeper less oxygenated sediments (typically dark grey or black in colour). 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 nine 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 by NIWA. 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.

Laying sediment plates and placing pegs at Site B

Collecting sediment cores from Site A

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

NEMP benthic indicators	General rationale	Sampling method
Physical and chemical		
Sediment grain size	Indicates the relative proportion of fine-grained sediments that have accumulated.	1 x surface scrape to 20mm sediment depth, with 3 composited samples taken across 9 plots (see note 1).
Nutrients (nitrogen and phosphorus) and organic matter	Reflects the enrichment status of the estuary and potential for algal blooms and other symptoms of enrichment.	1 x surface scrape to 20mm sediment depth, with 3 composited samples taken across 9 plots (see note 1).
Trace metals (copper, chromium, cadmium, lead, nickel, zinc)	Common toxic contaminants generally associated with human activities.	1 x surface scrape to 20mm sediment depth, with 3 composited samples taken across 9 plots (see notes 1, 2).
Depth of apparent redox potential discontinuity layer (aRPD)	Subjective time-integrated measure of the enrichment state of sediments according to the visual transition between oxygenated surface sediments and deeper deoxygenated black sediments. The aRPD can occur closer to the sediment surface as organic matter loading increases.	1 x 130mm diameter sediment core to 150mm deep for each of 9 plots, split vertically, with depth of aRPD recorded in the field where visible.
Biological		
Macrofauna	The abundance, composition and diversity of macrofauna, especially the infauna living with the sediment, are commonly-used indicators of estuarine health.	1 x 130mm diameter sediment core to 150mm deep (0.013m^2 sample area, 2L core volume) for each of 9 plots, sieved to 0.5mm to retain macrofauna (see note 1).
Epibiota (epifauna)	Abundance, composition and diversity of epifauna are commonly-used indicators of estuarine health.	Abundance score based on ordinal SACFOR scale in Table 2 (see note 3).
Epibiota (macroalgae)	The composition and prevalence of macroalgae are indicators of nutrient enrichment.	Percent cover score based on ordinal SACFOR scale in Table 2 (see note 3).
Epibiota (microalgae)	The composition and prevalence of microalgae are indicators of nutrient enrichment.	Visual assessment of conspicuous growths based on ordinal SACFOR scale in Table 2 (see notes 3, 4).

Notes:

[1] For cost reasons, and to provide a balanced sampling grid, macrofauna was assessed in 9 discrete samples (one per plot) and sediment quality assessed in 3 composite samples, rather than 10 discrete samples as specified in the NEMP.

[2] Arsenic and mercury are not required by NEMP, but were included in the trace element suite.

[3] Assessment of epifauna, macroalgae and microalgae used SACFOR in favour of quadrat sampling outlined in 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 unavailability of expertise nationally, and lack of demonstrated utility of microalgae as a routine indicator.

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.

The Excel sheets were imported into the software R 4.0.5 (R Core Team 2021) 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/).

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 where possible (http://ambi.azti.es), with the most recent eco-group list developed in December 2020.

To reduce the number of taxa with unassigned eco-groups, international data were supplemented with more recent eco-group classifications for New Zealand (e.g. Cawthron EGs used by Berthelsen et al. 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 aggregated within each site and zone (see Fig. 3). The purpose of aggregation was to smooth over the 'noise' associated with a core-level analysis and enable the relationship to patterns in sediment quality variables (which were composited within zones) to be determined.

Prior to the multivariate analysis, macrofaunal abundance data were fourth-root or presence-absence transformed 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. The procedure PERMANOVA was used to test for compositional differences among sites, based on both types of transformed data.

Overlay vectors and bubble plots on the nMDS were used to visualise relationships between multivariate biological patterns and sediment quality data. Additionally, the Primer procedure Bio-Env was used to evaluate the suite of sediment quality variables that best explained the biological ordination pattern.

3.6 ASSESSMENT OF ESTUARY CONDITION

To supplement our analyses and interpretation of the data, results were assessed within the context of various 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 (Robertson et al. 2016a, b), 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):* The ETI 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 described by Robertson et al. (2016b). We adopted those thresholds for present purposes, except: (i) for %mud we adopted the refinement to the ETI thresholds described by Robertson et al. (2016c); and (ii) for aRPD we modified the ETI ratings based on the US Coastal and Marine Ecological Classification Standard Catalog of Units (FGDC 2012).
- *ANZG (2018) sediment quality guidelines*: The condition rating categories for trace contaminants were benchmarked to ANZG (2018) sediment quality guidelines as described in Table 3. The Default Guideline Value (DGV) and Guideline Value-High (GV-high) specified in ANZG are thresholds that can be interpreted as reflecting the potential for 'possible' or 'probable' ecological effects, respectively. Until recently, these thresholds were referred to as ANZECC (2000) Interim Sediment Quality Guideline low (ISQG-low) and Interim Sediment Quality Guideline high (ISQG-high) values, respectively.
- A sedimentation guideline of 2mm of sediment accumulation per year above natural deposition rates, proposed by Townsend and Lohrer (2015), will be relevant to subsequent surveys in Pleasant River Estuary.

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.

Walking to the fine scale site in the mid to lower estuary

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. Note that sediment plates were installed in November 2021, hence the sedimentation rate indicator will be relevant to future surveys.

Indicator	Unit	Very good	Good	Fair	Poor
General indicators [1]					
Sedimentation rate[a]	mm/yr	< 0.5	≥0.5 to < 1	≥1 to < 2	≥ 2
Mud content[b]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD depth[c]	mm	≥ 50	20 to < 50	10 to < 20	< 10
TN[b]	mg/kg	< 250	250 to < 1000	1000 to < 2000	≥ 2000
TOC[b]	%	< 0.5	0.5 to < 1	1 to < 2	≥ 2
AMBI[b]	na	0 to 1.2	> 1.2 to 3.3	> 3.3 to 4.3	≥ 4.3
Trace elements [2]					
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

1. Ratings derived or modified from: [a]Townsend and Lohrer (2015), [b]Robertson et al. (2016) with modification for mud content described in text, [c]FGDC (2012).

2. 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. These were formerly the ANZECC (2000) sediment quality guidelines whose exceedance roughly equates to the occurrence of 'possible' and 'probable' ecological effects, respectively.

Macroalgae (*Agarophyton* spp. and *Ulva* spp.) in Pleasant River Estuary

4. KEY FINDINGS

4.1 GENERAL FEATURES OF FINE SCALE SITES

The selected sites were typical of the intertidal flats across the main estuary. Within each site the sediment textural characteristics were uniform, being sands with a substantial mud component that made conditions soft to walk on. The photos below show the similarity in the general appearance of the two sites, with both having a conspicuous cover of macroalgae, in particular *Agarophyton* spp.

Soft muddy-sand sediments at Site A (top) and Site B (bottom)

4.2 SEDIMENT PLATES

Sediment plate data are provided in Appendix 3. These data provide baseline measurements against which future changes in plate depth can be determined, and annual or longer-term sediment accrual or erosion evaluated.

4.3 SEDIMENT QUALITY

4.3.1 Sediment grain size, TOC and nutrients

Composite sediment sample raw data are tabulated in Appendix 4. Laboratory analyses of sediment grain size confirmed the field observations of muddy-sand sediments at both site with a mean mud content of 38% at Site A and 42% at Site B (Fig. 4).

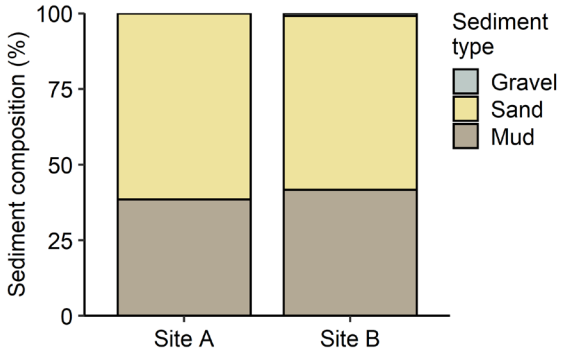


Fig. 4. Mean (n=3) sediment grain size in composite samples. Size fractions are mud (<63µm), sand (≥63µm to <2mm) and gravel (≥2mm).

To provide a visual impression of sediment quality relative to the Table 3 condition ratings, Fig. 5 compares the mean percentage mud, total organic carbon (TOC) and total nitrogen (TN) from composite samples against the rating thresholds. Both sites are rated 'poor' for their mud content, reflecting exceedance of the biologically relevant threshold of 25%.

Levels of organic matter (TOC) and nutrients (TN and TP) were elevated at Site A relative to Site B (Fig. 5, Appendix 4). Condition ratings for TOC and TN were 'good' or 'very good' (TP has no rating criteria), although TN at Site A was approaching the 'fair' threshold of 1,000mg/kg.

4.3.2 Sediment oxygenation

Despite the 'good' rating for two of the trophic state indicators (TOC and TN), the sediment profile showed signs of moderate enrichment (Fig. 6, see also photos in Fig. 7). Mean aRPD values were around 3mm, which is rated as 'poor', with a dark grey/black sediment profile evident.

The shallow aRPD will to a certain extent reflect the moderate mud content of the sediment, which acts as a barrier to oxygenation. Importantly, there were no symptoms of excessive enrichment, which usually manifests as black anoxic sediment near the surface and a strong 'rotten egg' smell of hydrogen sulphide.

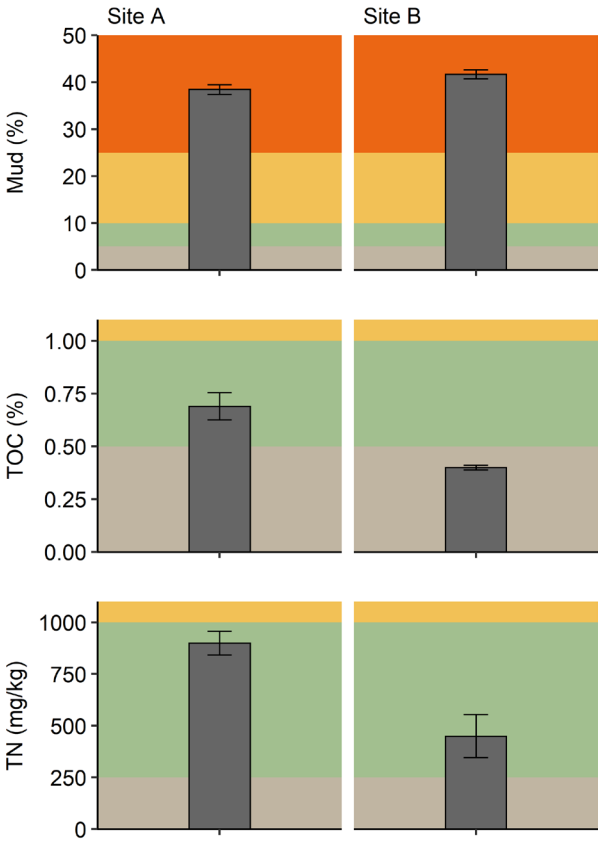


Fig. 5. Mean (±SE, n=3) sediment %mud, total organic carbon, and total nitrogen relative to condition ratings.

Condition rating key:

Very Good	Good	Fair	Poor

Note also, that although the aRPD was shallow on average, there was evidence of brown oxygenated surface sediments being mixed into deeper sediment layers by the action of the burrowing organisms (a process known as 'bioturbation'; see photos in Fig. 7).

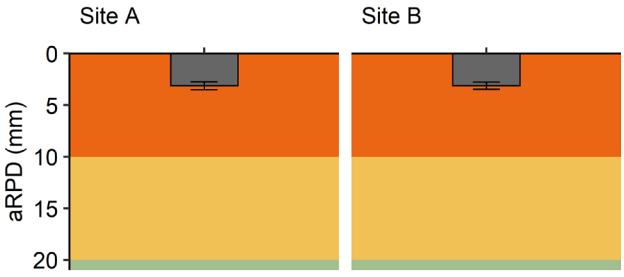


Fig. 7. Mean (±SE, n=3) aRPD relative to condition ratings. Rating key as per Fig. 5.

4.3.3 Trace contaminants

Plots of trace contaminants in relation to condition ratings are provided in Fig. 8 (see also Appendix 4). Trace contaminant levels were very low, and all rated as 'very good', reflecting that the concentrations were less than half of the ANZG (2018) Default Guideline Value (DGV) for 'possible' ecological effects. These results suggest that there are no significant anthropogenic sources of trace contaminants in the catchment.

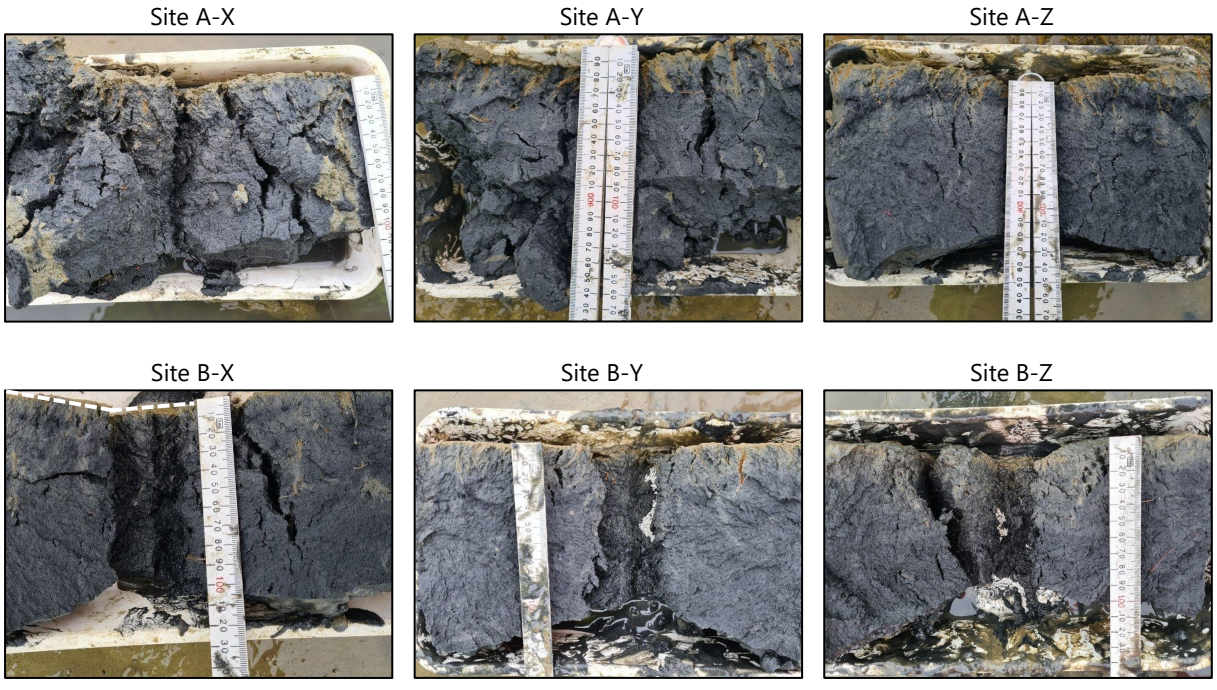


Fig. 6. Example sediment cores from the fine scale sites A and B. To illustrate the approximate depth of the aRPD, a dashed white line is shown on the zone X core from Site B.

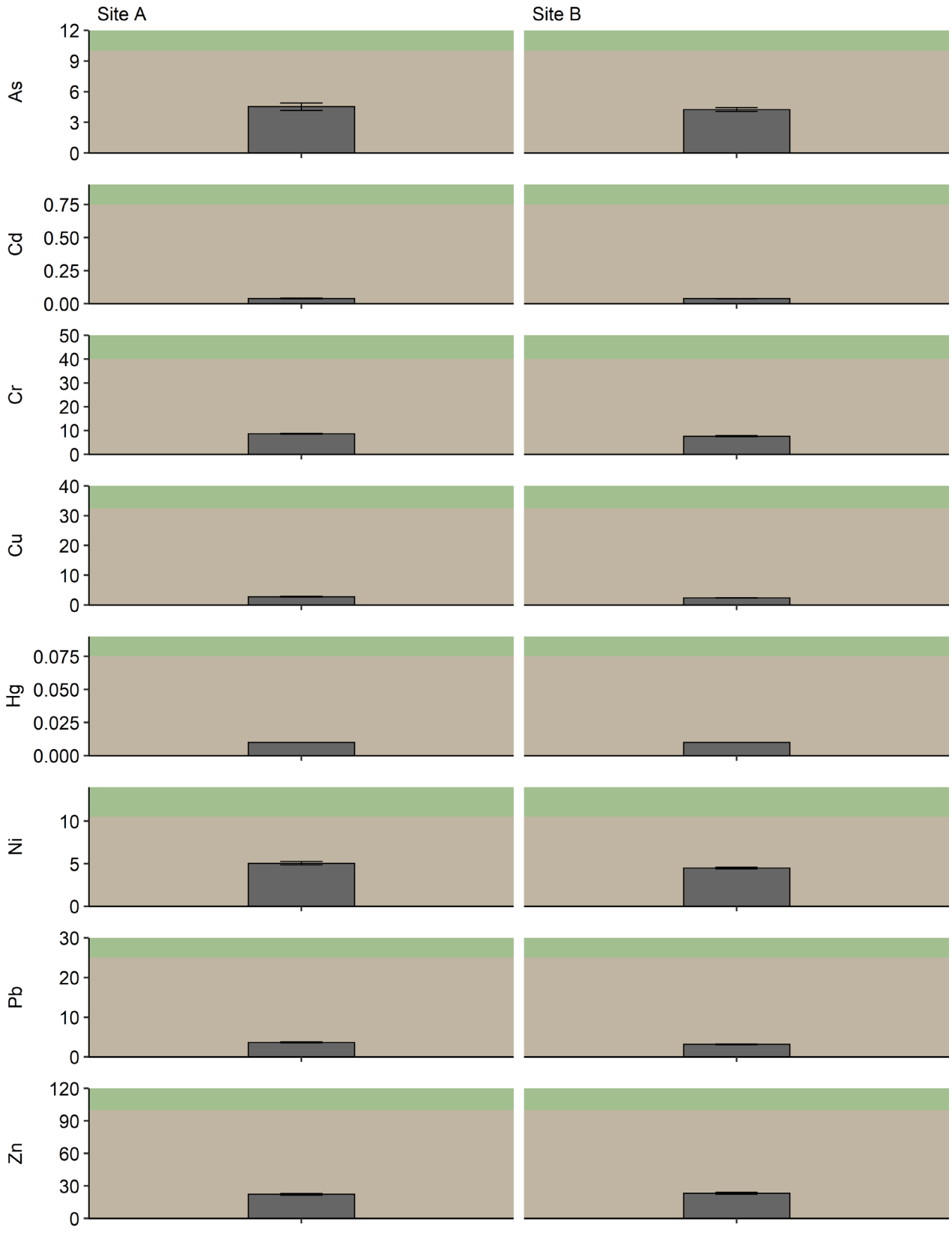


Fig. 8. Mean (±SE, n=3) trace contaminant concentrations relative to condition ratings. The boundary between grey ('very good' condition) and green ('good' condition) corresponds to half of the ANZG (2018) sediment quality Default Guideline Value for 'possible' ecological effects.

Condition rating key:

4.4 MACROFAUNA

4.4.1 Conspicuous surface epibiota

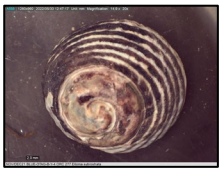
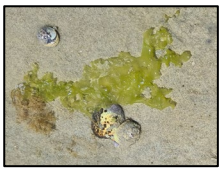
Results from the site-level assessment of surface-dwelling invertebrates and macroalgae are shown in Table 4. Conspicuous at both sites was the mud whelk *Cominella glandiformis*, rated as common, and the mudflat topshell *Diloma subrostratum*. At Site B the horn snail *Zeacumantus subcarinatus* was particularly abundant (~250/m^2), but this species was not observed at Site A.

In terms of macroalgae, the red seaweed *Agarophyton* spp. was common (~15% cover) at Site A, but rated as rare at Site B. Trace amounts of sea lettuce *Ulva* spp. were present at both sites, but not to the extent observed in some other parts of the estuary (Roberts et al. 2022; see also report cover photo).

Clumps of mud whelks *Cominella glandiformis* were common at both sites

The horn snail (aka black spire snail) *Zeacumantus subcarinatus* was abundant at Site B

Table 4. SACFOR scores for epibiota based on the scale in Table 2. Invertebrate specimen photos provided by NIWA.

Species	Common name	Functional description	Image	Site A	Site B
Invertebrates					
Cominella glandiformis	Mud whelk	Carnivore and scavenger		C (21)	C (21)
Diloma subrostratum	Mudflat topshell	Grazer and deposit feeder		F (3)	O (1)
Zeacumantus subcarinatus	Horn snail	Microalgal and seaweed grazer		Absent	A (250)
Macroalgae					
Agarophyton spp.*	Red seaweed	Primary producer		C (15%)	R (0.5%)
Ulva spp.	Green seaweed/ Sea lettuce	Primary producer		R (0.1%)	R (0.05%)

* *Agarophyton* spp. is the revised name for *Gracilaria* spp.

4.4.2 Macrofauna cores

Raw data for sediment-dwelling macrofauna are provided in Appendix 5, and the most commonly-occurring taxa are described in Table 5.

Macrofaunal taxa and abundances

Both sampling sites were species-rich, but Site A in particular. A total of 12 main taxonomic groups was present, with 46 macrofaunal taxa sampled in total. Of these, 41 taxa were present at Site A and 30 at Site B (see Appendix 5). Mean species richness values were 22 taxa at Site A and 16 taxa at Site B. Organism abundances were very high, being 960/core at Site A and less than half that number (435/core) at Site B (Fig. 9b).

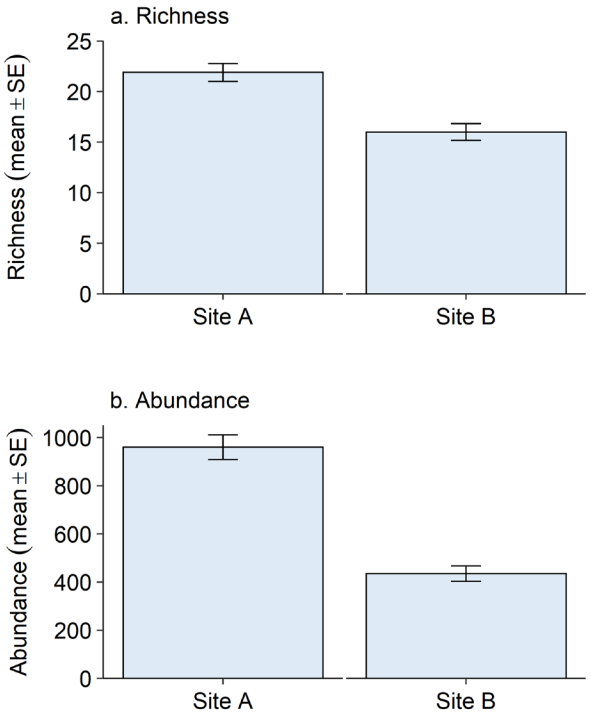


Fig. 9. Mean (± SE, n=10) taxon richness and abundance per core sample.

The representation of organisms in terms of the five AMBI eco-groups is shown in Fig. 10. All EGs were represented across the species mix, but especially EGs II and III. Although the range of hardy taxa (EGs IV and V) was relatively low, those present were quite abundant. As such, mean values of the biological index AMBI were moderately elevated, with an index value at both sites of ~3.5 out of a maximum score of 7 (Fig. 11). This value corresponds to a 'fair' condition rating against the New Zealand ETI criteria (Table 3).

Organism abundances were dominated by various polychaete worms, notably *Capitella* cf. *capitata*, which is a tolerant EG V organism that can thrive in disturbed or enriched environments. Also abundant were nationally cosmopolitan polychaete species that spanned relative hardy to more sensitive EGs, including *Scolecolepides benhami* (EG IV), *Paradoneis lyra* (EG III) and *Boccardia syrtis* (EG II).

Among the sub-dominant non-polychaete taxa were species that are common in estuaries nationally, including the small bivalve *Arthritica* sp. 5 (EG III; referred to in other ORC reports as Arthritica sp. 1 or Arthritica cf bifurca, with the sp. 5 designation being based on the voucher specimens held by NIWA), the small anemone *Edwardsia* sp. (EG II) and the amphipod *Paracalliope novizelandiae* (EG I).

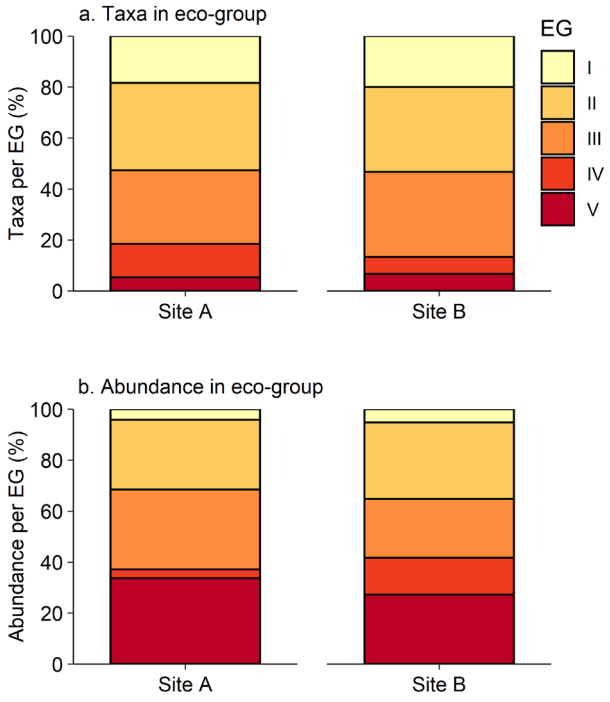


Fig. 10. Site-level data showing the number of taxa and organisms within eco-groups ranging from sensitive (EG-I) to tolerant (EG-V).

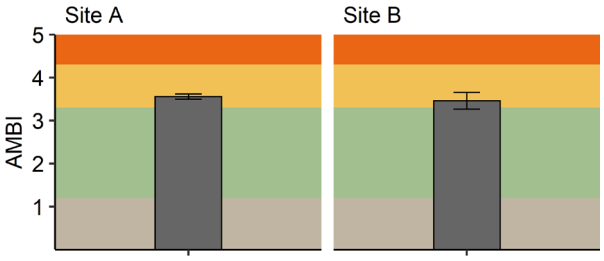
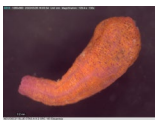
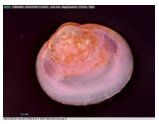
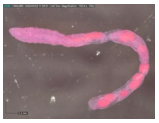


Fig. 11. Mean (± SE, n=10) AMBI scores compared with condition rating criteria.

Condition rating key:

Very Good	Good	Fair	Poor

Table 5. Description and site-aggregated abundances of the most commonly occurring sediment-dwelling macrofauna.

Main group, species & eco-group	Site A	Site B	Description	Image
Amphipoda, *Paracalliope novizelandiae* EG I	156	2	Amphipods are shrimp-like crustaceans. This species is common in New Zealand estuaries. It is considered to be able to tolerate muddy habitats to some extent, despite the EG I designation.	
Anthozoa, *Edwardsia* sp. EG II	73	126	A tiny elongate anemone adapted for burrowing. Fairly common throughout New Zealand. Prefers sandy sediments with low-moderate mud. Considered intolerant of anoxic conditions.	
Bivalvia, *Arthritica* sp. 5 EG III	26	61	A small sedentary deposit feeding bivalve that lives buried in the mud. Tolerant of muddy sediments and moderate levels of organic enrichment.	
Polychaeta, *Boccardia syrtis* EG II	1825	927	A small surface deposit-feeding spionid. Found in a wide range of sand/mud habitats. Lives in flexible tubes constructed of fine sediment grains, and can form dense mats on the sediment surface. Sensitive to organic enrichment.	
Polychaeta, *Capitella* cf. *capitata* EG V	2894	1063	Subsurface deposit feeding worm that is highly tolerant of disturbed or harsh conditions.	
Polychaeta, *Microphthalmus riseri* EG II	324	61	A little-known worm in family Hesionidae, which is a family of phyllodocid 'bristle worms'.	
Polychaeta, *Paradoneis lyra* EG III	2413	778	Common deposit feeding paraonid worm considered to be reasonably tolerant of muddy sediment and organic enrichment.	
Polychaeta, *Prionospio aucklandica* EG III	182	40	A surface deposit-feeding spionid common in harbours and estuaries. Associated mainly with muddy habitats. Considered tolerant to organic enrichment.	
Polychaeta, *Scolecolepides benhami* EG IV	261	564	A spionid, surface deposit feeder that is common in estuaries and coastal areas throughout New Zealand.	
Polychaeta, *Scoloplos cylindrifer* EG I	180	185	Common in estuaries. Long, slender, sand-dwelling unselective deposit feeder. Although designated EG I, can inhabit relatively muddy and organic-rich sediments.	

EG=Eco-Group, ranging from sensitive (EG-I) to tolerant (EG-V) to enrichment and other types of environmental pollution

Multivariate patterns and association with sediment quality variables

The nMDS ordination in Fig. 13 shows zone-aggregated samples of similar composition close to each other in a 2-dimensional plot, with less similar samples being further apart. This plot illustrates that macrofaunal composition among sampling zones within sites was more similar than between the two sites, which is fairly typical in estuarine environments where strong gradients can occur over scales of hundreds of metres.

However, tests based on the PERMANOVA procedure indicated that compositional differences between sites were not significant, irrespective of whether the comparison was based on relative abundance (i.e. fourth-root transformed) data (Pseudo-F=5.65, p= 0.11) or species presence-absence (Pseudo-F=6.03, p=0.003). In fact, SIMPER analysis revealed that, despite spatial separation in the MDS, the compositional similarity between the two sites (measured by the Bray-Curtis index) was quite high (~71%), while within each site the similarity among zones was ~85%.

Hence, the differences in macrofauna composition among the sites are reasonably subtle, and reflect both shifts in dominance (e.g. see Table 5) and differences in the actual species present (see Fig. 13a). There were 16 species or higher taxa at Site A that were not recorded at the relatively species-poor Site B, but only 5 taxa present at Site B that were not recorded at Site A (Appendix 5). Some of these were organisms that occurred in low abundance, for which chance plays a role in determining whether they are detected by core sampling (i.e. they could be present at a site but missed during sampling due to their low abundances). However, some of the differences were attributable to more abundant taxa that were present at one site but not the other, and conceivably represent true differences. For example, the Site B taxa included the gastropod *Zeacumantus subcarinatus*, amphipod *Torridoharpinia hurleyi* and copepods, which were absent at Site A.

Analysis of associations between macrofauna and sediment quality revealed that organic matter (%TOC) and nutrient content (TN) were both highly correlated with composition patterns (Spearman rank correlation, ρ=0.80). By contrast, there was no correlation with the other trophic state variable aRPD (ρ=-0.01), and a poor correlation with sediment mud content (ρ=0.28).

Sediment mud content and organic/nutrient enrichment are 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. 2020; Clark et al. 2021). In the case of Pleasant River Estuary, as the fine scale sites have a similar grain size composition (see Fig. 4), the mild levels of TOC and TN enrichment at Site A relative to Site B appear to be the more important of the factors that influence site macrofaunal differences.

Whelks clumped on the sediment surface

Core sampling at site B

Sand flats in the mid estuary

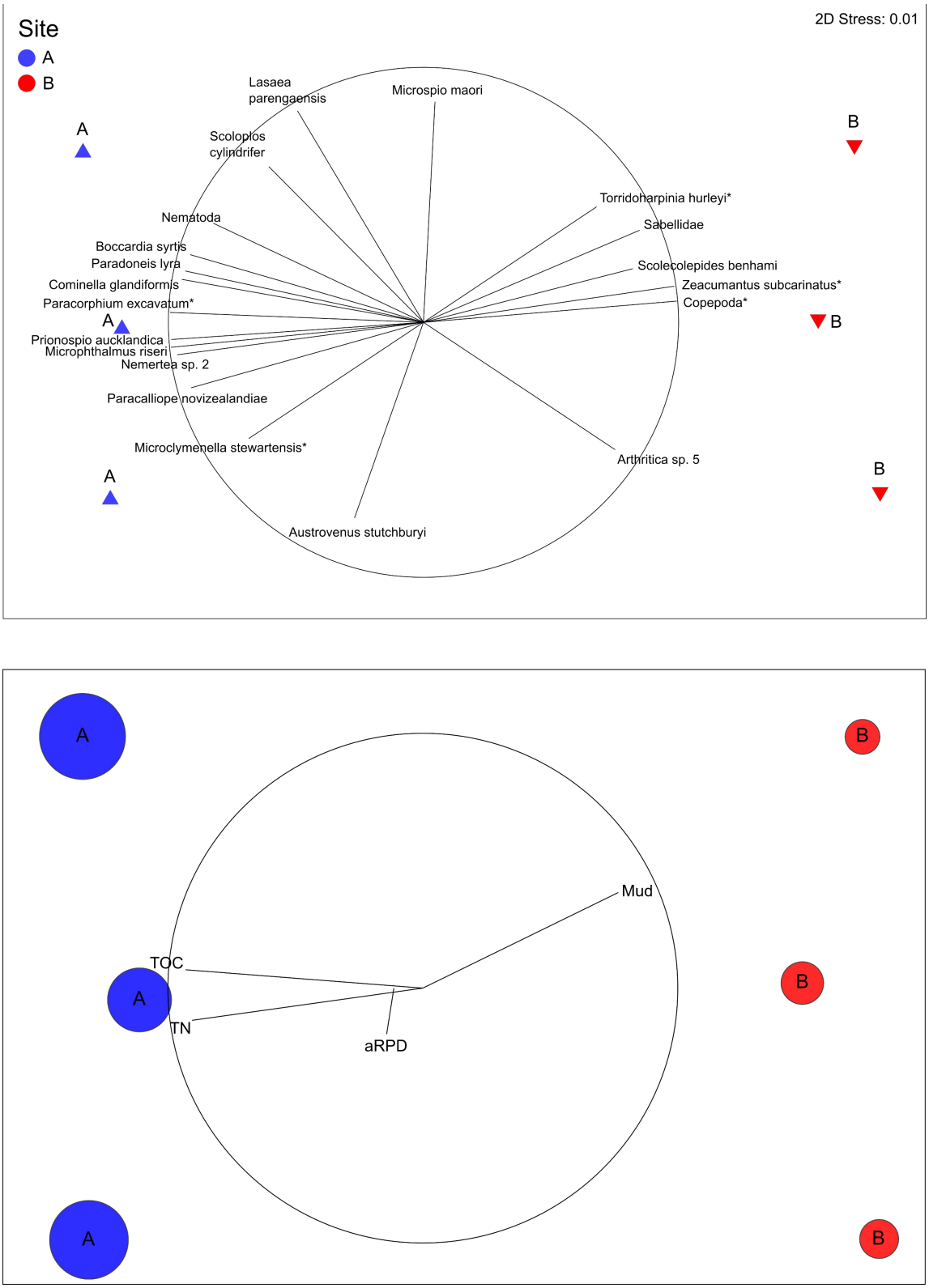


Fig. 12. Non-metric MDS ordination of macrofaunal core samples aggregated within sampling zones at each site.

The three zones at each site are placed such that closer ones are more similar than distant ones in terms of macrofaunal composition. A 'stress' value of near-zero for the nMDS indicates that a 2-dimensional plot provides an accurate representation of differences. Samples aggregated within zone and site were ~85% similar in terms of the Bray-Curtis macrofaunal index, with a between site similarity of ~71%. 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 (an asterisk denotes those present at one site but not the other), and b) key sediment quality variables. Bubble sizes in the bottom pane are scaled to sediment %TOC; TOC and TN were the sediment quality variables most closely correlated with macrofaunal composition differences.

5. SYNTHESIS AND RECOMMENDATIONS

5.1 SYNTHESIS OF KEY FINDINGS

This report has described the findings of an ecological monitoring survey conducted at two sites in Pleasant River Estuary, largely following the fine scale methods described in New Zealand's National Estuary Monitoring Protocol (NEMP), with method extensions described in Table 1. Sediment plates installed at the time of the survey will be monitored in the future to determine sedimentation rates.

A summary of key environmental quality indicators relative to condition ratings (Table 6) highlights that both sites were relatively muddy and showed moderate symptoms of enrichment (i.e. a shallow aRPD). Quantitative indicators of trophic state (%TOC & TN) were elevated at Site A relative to Site B, with nutrient-enrichment levels (i.e. TN) being close to the 'fair' threshold of 1000mg/kg.

Table 6. Summary of scores of estuary condition based on mean values of key indicators, compared to rating criteria in Table 3. Note that TP has no rating criteria.

Metric	Units	A	B
Mud	%	38.5	41.7
aRPD	mm	3	3
TN	mg/kg	900	450*
TP	mg/kg	483	440
TOC	%	0.69	0.40
As	mg/kg	4.5	4.3
Cd	mg/kg	0.040	0.039
Cr	mg/kg	8.7	7.7
Cu	mg/kg	2.8	2.4
Pb	mg/kg	3.7	3.2
Hg	mg/kg	< 0.02	< 0.02
Ni	mg/kg	5.1	4.5
Zn	mg/kg	22.3	23.3
AMBI	na	3.6	3.5

** Sample mean includes values below lab detection limits*

< All values below lab detection limit

The enriched, muddy nature of the estuary sediments is consistent with catchment run-off, in part reflecting the high proportion of land use consisting of pasture and exotic forestry (Fig. 2). A NIWA study currently being undertaken in the estuary is investigating sediment sources in relation to these types of land uses. As well as generating muddy sediments, land uses such as agriculture can lead to soil contamination with trace metals and other pollutants, which are associated with practices such as fertiliser application (Gaw et al. 2006; Lebrun et al. 2019). In turn, muddy sediments can carry a high load of anthropogenic contaminants, due to the surface area they provide for contaminant adsorption. However, in the case of Pleasant River Estuary the analysis of trace elements provided no evidence of any significant contaminant sources in the catchment, with concentrations of all analytes being less than half of the ANZG (2018) sediment quality guideline value associated with the potential for adverse ecological effects.

Looking toward the estuary entrance

Pleasant River channel in the upper estuary

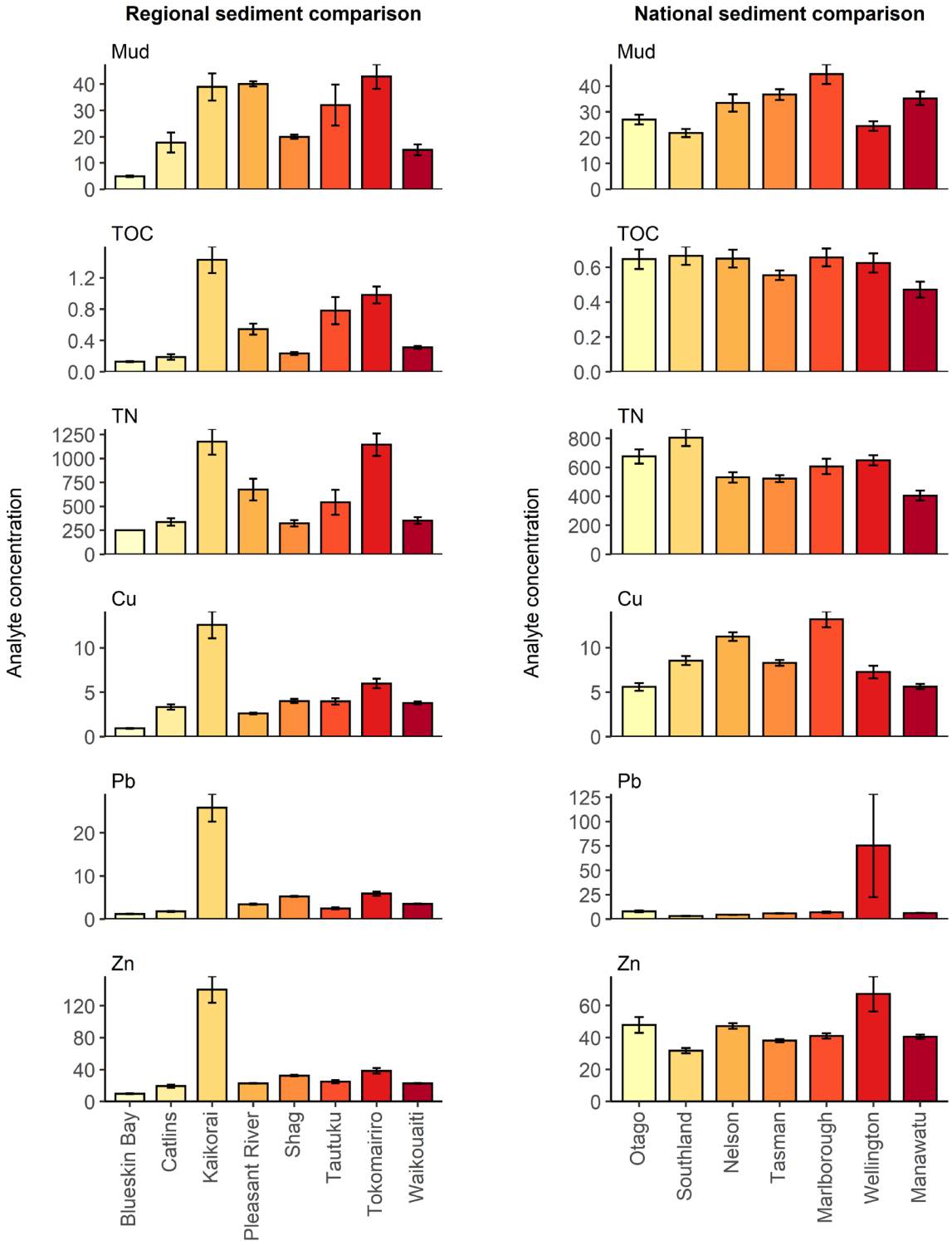


Fig. 13. Broad patterns in key sediment quality indicators, comparing Pleasant River Estuary with other estuaries in the Otago region (mean ± SE for surveys pooled within estuary), and Otago estuaries collectively against other regions of New Zealand (mean ± SE for estuary surveys pooled within region). Analyte concentrations for mud and TOC are percentages, otherwise they are mg/kg.

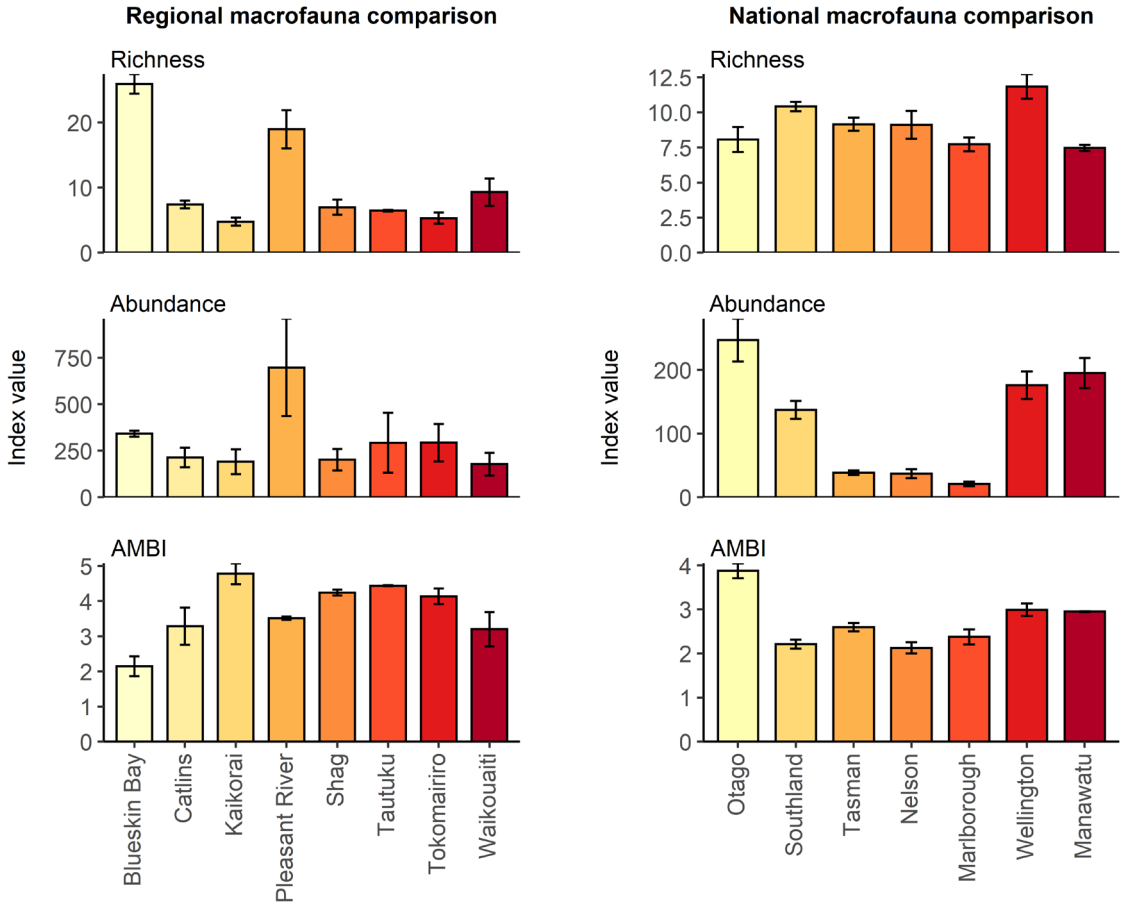


Fig. 14. Broad patterns in key macrofaunal indicators, comparing Pleasant River Estuary with other estuaries in the Otago region (mean ± SE for surveys pooled within estuary), and Otago estuaries collectively against other regions of New Zealand (mean ± SE for estuary surveys pooled within region).

Compared with other estuaries that are monitored as part of ORC's programme, Pleasant River Estuary is relatively muddy, shows intermediate levels of enrichment, and has low levels of key trace contaminants especially when compared against Kaikorai Estuary and its urbanised catchment (Fig. 13). In terms of macrofauna, Pleasant River Estuary had a diverse mix of species that is greater than most other estuaries in the region, and stands out as having particularly high organism abundances (Fig. 14). The abundant organisms included some relatively hardy taxa that can thrive in enriched or disturbed conditions. As such, the AMBI index was elevated outside of a healthy range and rated as 'fair' against ETI criteria (see Table 3), although mean values were within the range evident in other Otago estuaries (Fig. 13).

Considering the sediment quality and biological assessment collectively, the fine scale survey results suggest that the two monitored sites in Pleasant River Estuary are exhibiting symptoms of mild stress, although have not reached a 'tipping' point whereby multiple indicators are showing signs of degradation. By contrast, the results of the broad scale survey revealed that some areas of the upper estuary, as well as side arms, are exhibiting symptoms of excess nutrient enrichment; i.e. eutrophication (Roberts et al. 2022). Although not being situated in the worst-affected parts of the estuary, the fine scale sites are representative of the main tidal flats, and are suitable for long-term monitoring.

5.2 RECOMMENDATIONS

- Complete two additional annual surveys as planned in the summers of 2022/23 and 2023/24. Together with data gathered from changes in sediment plate depth, the work will provide a comprehensive baseline for the long-term monitoring of ecological health in Pleasant River Estuary.
- Compile data summaries after the second survey, but defer the next comprehensive analysis and reporting until completion of the 3-year baseline, at which time the management implications of the survey findings should be considered.

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

FINE SCALE SITES

Estuary	Site	Peg	NZTM_E	NZTM_N
Ples-Otag	A	C1	1422303	4952329
Ples-Otag	A	C2	1422330	4952280
Ples-Otag	A	C3	1422301	4952268
Ples-Otag	A	C4	1422275	4952396
Ples-Otag	B	C1	1422383	4953211
Ples-Otag	B	C2	1422391	4953154
Ples-Otag	B	C3	1422361	4953516
Ples-Otag	B	C4	1422351	4953209

SEDIMENT PLATES

Site	Site	Peg/Plate	NZTM_E	NZTM_N
Ples-Otag	A	Peg1 (C1)	1422303	4952329
Ples-Otag	A	Plate 1	1422297	4952326
Ples-Otag	A	Plate 2	1422293	4952326
Ples-Otag	A	Peg2	1422289	4952324
Ples-Otag	A	Plate 3	1422284	4952322
Ples-Otag	A	Plate 4	1422279	4952319
Ples-Otag	A	Peg3 (C4)	1422275	4952316
Ples-Otag	B	Peg1 (C1)	1422383	4953211
Ples-Otag	B	Plate 1	1422378	4953213
Ples-Otag	B	Plate 2	1422374	4953211
Ples-Otag	B	Peg2	1422369	4953211
Ples-Otag	B	Plate 3	1422364	4953210
Ples-Otag	B	Plate 4	1422359	4953210
Ples-Otag	B	Peg3 (C4)	1422351	4953209

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. SEDIMENT PLATE RAW BASELINE DATA

Date	Site	Sediment Texture	Sediment Type	Mud (%)	Sand (%)	Gravel (%)	aRPD (mm)	Plate	Depth (mm)
26/11/2021	A	soft	MS25_50	42.6	57.4	<0.1	4	p1	54
26/11/2021	A	soft	MS25_50					p2	53
26/11/2021	A	soft	MS25_50					p3	61
26/11/2021	A	soft	MS25_50					p4	50
26/11/2021	B	soft	MS25_50	46.1	51.6	2.3	2	p1	60
26/11/2021	B	soft	MS25_50					p2	55
26/11/2021	B	soft	MS25_50					p3	54
26/11/2021	B	soft	MS25_50					p4	83

* MS25_50 = muddy sand with >25-50% mud

APPENDIX 4. SEDIMENT QUALITY RAW DATA

Value for aRPD show zone mean and range. Data are otherwise based on composite samples in each zone.

Site	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	X	0.2	59.4	40.5	0.79	1000	500	2.7 (2 to 4)	4.8	0.044	9	2.9	<0.02	5.4	3.8	23
	Y	<0.1	62.9	37.1	0.71	900	500	3.7 (2 to 5)	5	0.036	8.8	2.9	<0.02	5.1	3.8	23
	Z	<0.1	62.1	37.8	0.57	800	450	3.0 (2 to 4)	3.8	0.04	8.3	2.6	<0.02	4.7	3.4	21
B	X	0.3	59.9	39.8	0.42	600	460	3.3 (2 to 4)	4.4	0.039	7.6	2.5	<0.02	4.5	3.2	23
	Y	1.6	55.6	42.8	0.38	<500	400	3.3 (2 to 5)	3.9	0.037	7.3	2.3	<0.02	4.3	3	22
	Z	0.5	57.1	42.4	0.4	500	460	2.7 (2 to 3)	4.5	0.041	8.1	2.5	<0.02	4.7	3.3	25
								DGV	20	1.5	80	65	0.15	21	50	200
								GV-high	70	10	370	270	1	52	220	410

APPENDIX 5. MACROFAUNA CORE RAW DATA

Raw data are for 9 replicate cores at each of Sites A and B.

Main group	Taxa	Habitat	EG	A1	A2	A3	A4	A5	A6	A7	A8	A9	B1	B2	B3	B4	B5	B6	B7	B8	B9
Amphipoda	Aoridae	Infauna	I													1					
Amphipoda	Paracalliope novizealandiae	Infauna	I	27	12	21	15	46	19	2	4	10	1								1
Amphipoda	Paracorophium excavatum	Infauna	IV	1		1		1		1		1									
Amphipoda	Parawaldeckia kidderi	Infauna	II	2	3	6	2	3	10	8	6	8						1			
Amphipoda	Proharpinia sp.	Infauna	I					1													
Amphipoda	Protorchestia sp.	Infauna	II							1											
Amphipoda	Torridoharpinia hurleyi	Infauna	I										1			1					
Anthozoa	Edwardsia sp.	Epibiota	II	10	4	6	4	6	8	16	11	8	23	16	20	5	16	20	3	15	8
Bivalvia	Arthritica sp. 5	Infauna	III	6		2	1	7	5	2	2	1	5	9	5	4	3	5	5	15	10
Bivalvia	Austrovenus stutchburyi	Infauna	II						1	1	2									1	1
Bivalvia	Lasaea parengaensis	Infauna	II	6		4			2	3			1		1		3	1			1
Bivalvia	Linucula hartvigiana	Infauna	II	1				2													
Copepoda	Copepoda	Infauna	II												2		5				3
Cumacea	Colurostylis lemurum	Infauna	II	2	1	1						1									
Decapoda	Hemiplax hirtipes	Infauna	III	2																1	1
Gastropoda	Cominella glandiformis	Epibiota	III	1	3		1		2	4				1	1		2		1		1
Gastropoda	Dotidae	Epibiota	NA									2									
Gastropoda	Notoacmea scapha	Epibiota	II				1														
Gastropoda	Potamopyrgus estuarinus	Epibiota	IV				1														
Gastropoda	Zeacumantus subcarinatus	Epibiota	II										8		1	12	4	5	3		4
Nematoda	Nematoda	Infauna	III	6	1			5		2		4	1					1			
Nemertea	Nemertea	Infauna	III		1				1	2		2		3	1	1	2		2		1
Nemertea	Nemertea sp. 2	Infauna	III	1	4	2	3	5	2	3		3	1	1			1		1		
Oligochaeta	Naididae	Infauna	V	2	1		1							1				1			1
Polychaeta	?Orbiniidae	Infauna	NA						1												
Polychaeta	Boccardia proboscidea	Infauna	IV	2	1																
Polychaeta	Boccardia syrtis	Infauna	II	196	222	187	155	240	192	214	195	224	72	80	199	101	121	148	31	72	103
Polychaeta	Capitella cf. capitata	Infauna	V	317	256	400	340	382	314	238	306	341	214	184	55	210	108	113	127	16	36
Polychaeta	Glycera sp.	Infauna	II				1														
Polychaeta	Heteromastus filiformis	Infauna	IV	9	2	2	5	4		3	2	4		1	3		1				
Polychaeta	Macroclymenella stewartensis	Infauna	II				1					1									
Polychaeta	Maldanidae (juv)	Infauna	I		1																
Polychaeta	Microphthalmus riseri	Infauna	II	39	14	54	19	65	25	17	35	56	12	11	5	4	9	2	15	1	2
Polychaeta	Microspio maori	Infauna	I			1											2				
Polychaeta	Naineris naineris-A	Infauna	I		1	1		1			1	1									
Polychaeta	Nereididae (juv)	Infauna (juvenile)	NA		4	2		8	4	5	1	5									
Polychaeta	Paradoneis lyra	Infauna	III	483	378	241	189	147	260	223	90	402	115	80	137	81	64	74	92	84	51
Polychaeta	Perinereis vallata	Infauna	III							2			1								
Polychaeta	Pettiboneia sp.	Infauna	II	6	26	6	3	5	2	3		5	1								1
Polychaeta	Platynereis sp.	Infauna	III	1																	
Polychaeta	Prionospio aucklandica	Infauna	III	23	14	36	23	20	15	14	18	19	7	11	3	1	4	2	6	2	4
Polychaeta	Protocirrineris nuchalis	Infauna	III	1			2	2			4	1		1							
Polychaeta	Sabellidae	Infauna	I	2		2		2	1	1	3	3	3	1	12	2	35	22	2	4	12
Polychaeta	Scolecolepides benhami	Infauna	IV	28	25	31	15	5	22	44	55	36	67	63	46	61	74	51	91	59	52
Polychaeta	Scoloplos cylindrifer	Infauna	I	15	28	32	15	4	15	35	15	21	20	16	16	13	10	14	4	4	8
Tanaidacea	Tanaidacea	Infauna	II															1			


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