SALT ECOLOGY

Fine Scale Intertidal Monitoring of Whareama Estuary

Prepared for

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Cover photo: Intertidal flats in the lower Whareama Estuary, with vehicle tracks and flood scouring evident.

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For the People
Mō ngā tāngata

Fine Scale Intertidal Monitoring of Whareama Estuary

Prepared by

Barrie Forrest,

Leigh Stevens,

and Keryn Roberts

for

Greater Wellington Regional Council

February 2023

barrie@saltecology.co.nz, +64 (0)27 627 4631

www.saltecology.co.nz

For the environment
Mō te taiao

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
BHM	Benthic Health Model
Cd	Cadmium
CMEC	Coastal Marine Ecology Consultants
Cr	Chromium
Cu	Copper
DGV	Default Guideline Value
Epibiota	Animals (epifauna) and seaweeds (macroalgae) visible on the surface on the sediment
ETI	Estuary Trophic Index
Hg	Mercury
GWRC	Greater Wellington Regional Council
NEMP	National Estuary Monitoring Protocol
Ni	Nickel
NIWA	National Institute of Water and Atmospheric Research
Pb	Lead
SACFOR	Epibiota categories of: Super-abundant, Abundant, Common, Frequent, Occasional, Rare
SOE	State of the Environment (monitoring)
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
Zn	Zinc

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BACKGROUND

As part of its State of the Environment programme, Greater Wellington Regional Council (GWRC) undertakes monitoring and assessment of estuaries and other coastal environments in its region. This report describes a 'fine scale' survey of two sites (Site A downstream, Site B further upstream) in Whareama Estuary conducted on 31 March 2022, following methodologies described in New Zealand's National Estuary Monitoring Protocol (NEMP). Findings are compared with previous surveys undertaken in 2008, 2009, 2010 and 2016, the status and long-term trends in estuary health are evaluated, and future monitoring and management needs are discussed.

KEY FINDINGS

The following table presents mean values of sediment indicators relative to established rating criteria of ecological health for New Zealand estuaries (see Glossary for definition of indicators and Fig. 3 (p. 4) for site locations). Key findings with respect to these, and other indicators in the main report, are presented below:

Site	Year	Mud %	aRPD mm	TN mg/kg	TP mg/kg	TOC %	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Pb mg/kg	Hg mg/kg	Ni mg/kg	Zn mg/kg	AMBI na
A	2008	67.8	15	780	417	-	-	0.048	9.2	8.0	6.9	-	9.9	42.7	3.6
	2009	43.2	25	613	363	0.39	-	0.037	9.0	6.9	6.5	-	9.1	38.3	3.6
	2010	23.4	10	< 503	343	0.29	-	0.019	6.7	3.5	4.6	-	6.3	25.7	3.6
	2016	52.6	20	600	400	0.49	-	-	-	-	-	-	-	-	4.1
	2022	58.4	4	450*	333	0.50	3.8	0.047	8.6	9.0	7.5	0.04	9.7	42.3	4.1
B	2008	73.4	28	817	430	-	-	0.050	10.0	8.7	7.7	-	10.3	47.0	3.4
	2009	59.6	27	760	410	0.53	-	0.041	10.3	8.8	7.7	-	10.3	43.7	3.3
	2010	64.9	25	677	363	0.56	-	0.044	9.2	7.4	7.1	-	9.1	40.0	3.6
	2016	89.6	10	900	540	0.73	-	-	-	-	-	-	-	-	4.2
	2022	79.2	15	733	390	0.70	3.3	0.061	9.8	10.9	8.7	0.05	11.7	49.7	4.1

** Sample mean includes values below lab detection limits*

< All values below lab detection limit

Very Good	Good	Fair	Poor

Sediment quality indicators

- Average sedimentation at Site B since 2008 (sedimentation has not been measured at Site A) was 6.8mm/yr, which is more than three-times greater than the national guideline value of 2mm/yr. A small amount of net erosion was recorded between 2016 and 2022, although it is not possible to assess variability in sediment accrual in this period due to a lack of annual monitoring data.
- The sediment at the two monitoring sites has been consistently muddy (generally rated 'poor), and has relatively low oxygenation as indicated by a shallow 'aRPD' depth (especially at Site A).
- Other sediment quality indicators were rated as 'good' or 'very good', with low sediment levels of total organic carbon (%TOC), nutrients (TN, total nitrogen; TP, total phosphorus), and trace metal contaminants.

Epibiota and sediment-dwelling macrofauna

- Surface-dwelling epibiota have been consistently sparse at the two fine scale sites, likely reflecting the river-dominated nature of the location. No macroalgae or seagrass has been recorded within the sites in any surveys, although a small area of seagrass is present upstream of Site B.

- Sediment core sampling revealed a species-poor assemblage of mainly hardy sediment-dwelling macrofauna. In total 33 species (or higher taxonomic groups) were recorded over the five surveys. Macrofaunal richness and organism abundances were notably lower in the two most recent surveys (2016 & 2022) relative to earlier years.
- Declines in species richness and abundances were associated with increases in sediment mud content. However, changes in overall community composition were not strongly linked to any of the sediment quality indicators, although there was a weak-moderate association with sediment oxygenation.
- Scores for the biotic index AMBI were indicative of moderately degraded conditions.

Overall, Whareama Estuary appears to be a relatively harsh environment for sediment biota, and is strongly influenced by Whareama River. River influences include hydrodynamic scouring, pulses of low salinity water during flood events, and high sediment inputs from the catchment. The most recent results suggest a degradation in habitat conditions related to elevated mud inputs (i.e. declines in macrofauna richness and abundance in the two most recent surveys). This finding is consistent with a separate analysis of the data using a National Benthic Health Model, which categorised Whareama Estuary as exhibiting a 'high' or 'very high' level of mud sedimentation impact relative to other estuarine sites in New Zealand. The elevated muds place Whareama among the most degraded of the larger estuaries regularly monitored in the Wellington region. Long term monitoring will help to elucidate whether there is a trend of ongoing degradation attributable to catchment modification.

In terms of the management implications, the main consideration is the scope to mitigate sediment inputs. The catchment is characterised by steep pastoral hill country (57% of catchment area) used mainly for beef and sheep farming, with a further 26% in exotic forestry. Both land uses can be associated with significant sediment run-off, which in the Whareama River catchment is compounded by the highly erodible nature of the soils.

RECOMMENDATIONS

- Continue fine-scale monitoring surveys at intervals of 5-years, as is typical for this method. To track key changes in the estuary in intervening years, annual sediment plate monitoring should be restarted, along with measurement of sediment grain size and oxygenation (aRPD).
- Evaluate the feasibility of reducing muddy sediment inputs, contingent on Whareama Estuary being recommended as a high priority for management as an outcome of a related study being undertaken for GWRC by Stevens and Roberts (2023).

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 monitoring to map 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.

Greater Wellington Regional Council (GWRC) has undertaken monitoring of selected estuaries in the region using the NEMP methods and other approaches (e.g. synoptic surveys, sedimentation monitoring) for over a decade. One of these locations is Whareama Estuary on the region's east coast (Fig. 1), where NEMP fine scale surveys have previously been undertaken in 2008, 2009, 2010 and 2016 (Robertson & Stevens 2016).

Salt Ecology was contracted to carry out a further NEMP fine scale survey, and to remeasure 'sediment plates' that were installed in 2008 to track estuary sedimentation. This report describes the methods and results of the survey (conducted 31 March 2022), compares findings with earlier work in terms of the current status and trends in estuary health, and makes recommendations for future management and monitoring.

Whareama Estuary showing the meeting of turbid river and clearer coastal waters in the lower estuary (top) and turbid waters of mid-estuary (bottom)

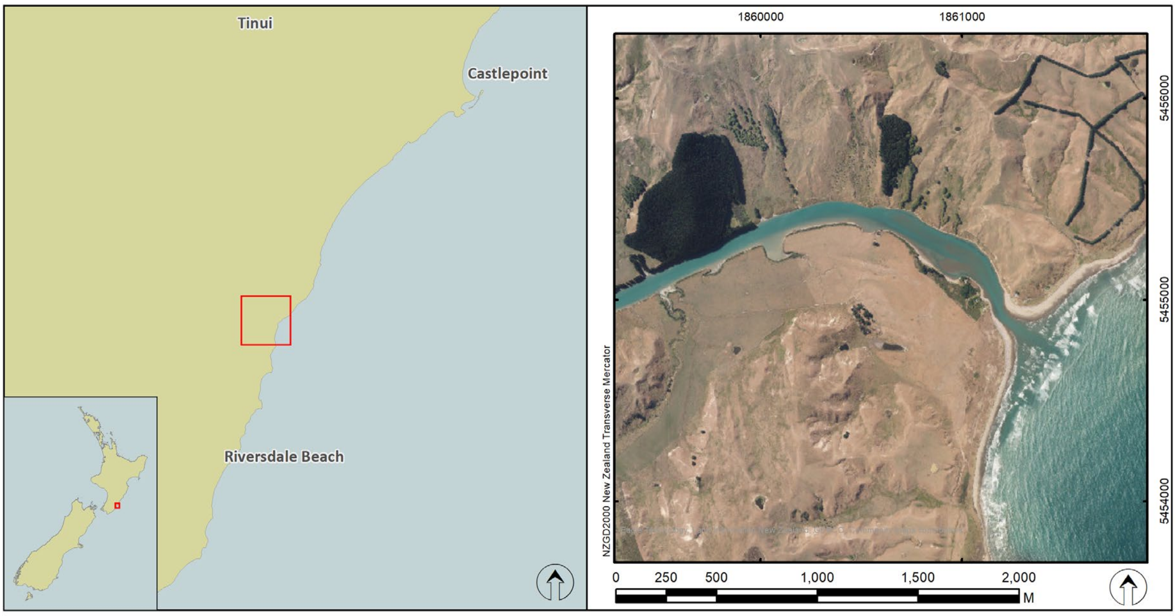


Fig. 1 Location of Whareama Estuary.

2. BACKGROUND TO WHAREAMA ESTUARY

Detailed information on Whareama Estuary described in previous reports (e.g. Robertson & Stevens 2016). The estuary is a moderate-sized (113ha) river dominated system located ~20km south of Castlepoint. It is defined as a shallow, short residence time (<1 day) tidal river estuary (Plew et al. 2018) with small intertidal areas toward the mouth. The estuary entrance is permanently open to the sea (Robertson & Stevens 2007).

While the estuary is river dominated, during periods of low flow (e.g. during summer) salt water is reported to intrude up to 17km upstream from the mouth (Robertson & Stevens 2007). However, a recent survey (Stevens & Roberts 2023) detected seawater only 7km upstream, hence the actual extent of intrusion is uncertain. Under low flow conditions the estuary is commonly stratified, with fresh surface water overlying denser (heavier) seawater. During prolonged periods of low flow (e.g. in summer), seawater can become trapped (e.g. in pools), which creates the potential for oxygen to become depleted in bottom waters, nutrients to be released from the sediment (e.g. phosphorus release in the absence of oxygen), and phytoplankton blooms to develop if conditions (e.g. temperature and light availability) are suitable. In previous surveys moderate macroalgal growth and high phytoplankton (i.e. green colour of water column) have been observed at times (Robertson & Stevens 2016). However, frequent periods of flushing (i.e. high river flows) have likely prevented these problems from persisting (Robertson & Stevens 2016).

The catchment is highly modified from its historic indigenous forest cover, and comprises 57% high producing grassland and 26% exotic forestry (Fig. 2). The catchment is steep and susceptible to erosion, which is reflected in the estuary with high sediment muddiness and low water clarity due to suspended solids (Robertson & Stevens 2007). Bank erosion and grazing along the estuary margin are also common. Because most of the immediate estuary margin is steep and dominated by grassland and/or gorse there is limited available habitat for salt marsh. Only small areas of rushland have been observed on the lower estuary margin and around small river inputs with intertidal areas. A small area of seagrass has been observed in the mid-estuary, growing in very soft sandy muds. Despite the muddy, turbid conditions, shellfish appear abundant in the estuary, with mussels growing on hard rock substrate and cockles observed in soft-sediment areas (see photos).

Cattle grazing to the estuary margin

Land slip on steep estuary margin after heavy rainfall, and turbid water column

Exotic forestry on steep estuary margin

Seagrass in the mid estuary

Cockles in very soft sandy muds

Previous fine scale surveys at two sites in the lower estuary have highlighted that the intertidal sediments have a high mud content, low levels of organic enrichment, moderate to poor sediment oxygenation and a mud tolerant macrofauna community (Robertson & Stevens 2016). The muddiness reflects the highly erodible catchment soils. At fine scale Site B, where sedimentation monitoring has been undertaken since 2008, steady sediment accumulation has been measured. While muddy sediment inputs are therefore clearly an issue, the estuary nonetheless supports a range of habitats and retains both high ecological and human use values.

Mussels growing on rocky substrate

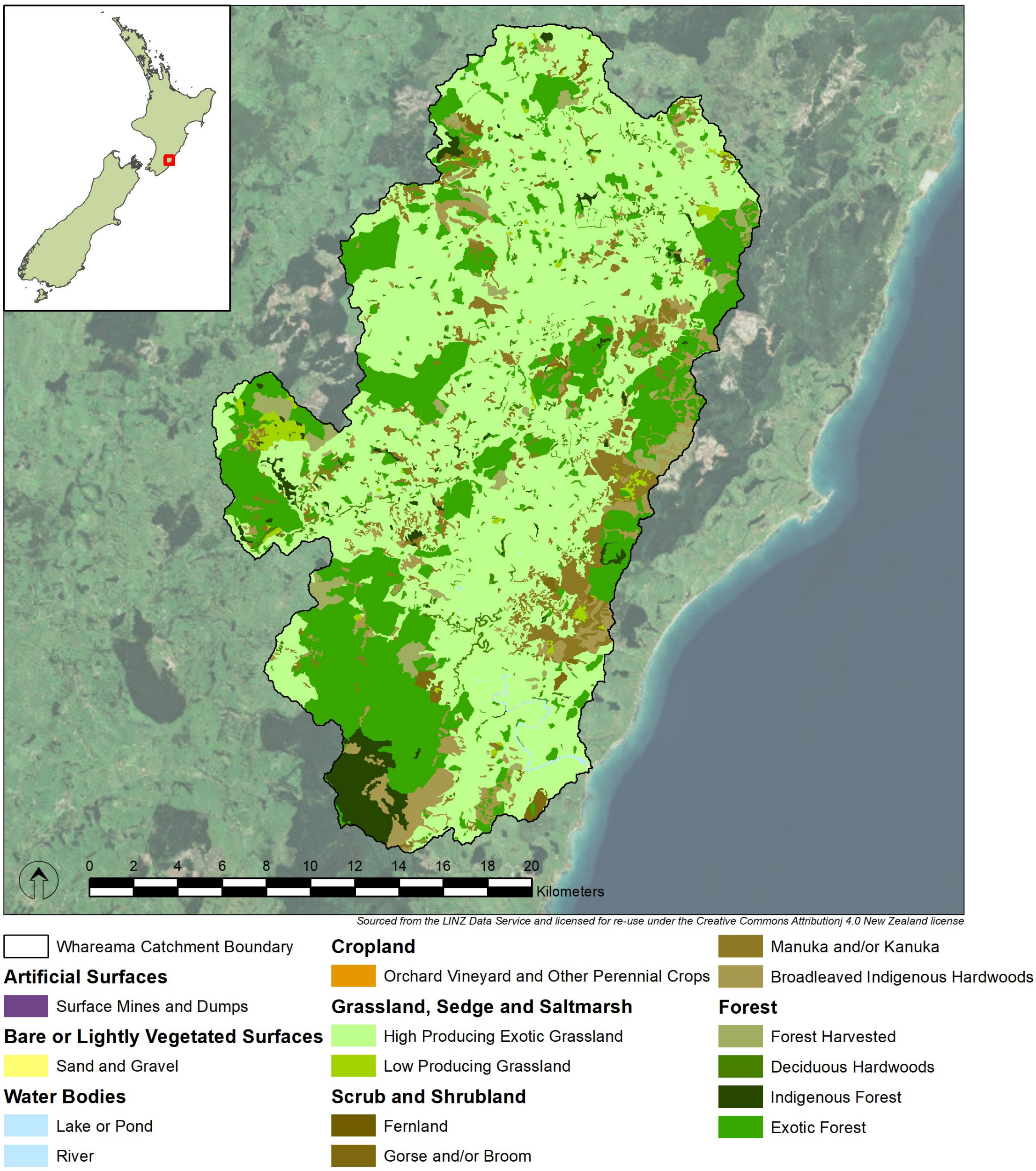


Fig. 2 Whareama Estuary and surrounding catchment land use classifications - (LCDB5 2017/18 database).

3. FINE SCALE METHODS

3.1 OVERVIEW OF SEDIMENT PLATE AND FINE SCALE SITES

Fine scale monitoring was recommended following the a Wairarapa coastline risk assessment conducted by Robertson and Stevens (2007). Two unvegetated fine scale sites were established in January 2008. Site A was located on the well flushed intertidal flats in the lower estuary and Site B was located in a muddy deposition zone further upstream. Due to the limited intertidal area Site A is 15m x 60m and Site B is 20m x 60m, rather than the 30m x 60m site dimensions recommended in the NEMP. Site GPS positions are provided in Appendix 1.

'Sediment plates' (buried concrete pavers) for monitoring of sedimentation were installed at Site B at the time of the 2008 survey (Fig. 3). Plates were not installed at Site A as that site is prone to flood scouring and not suitable for the method used. The location of sediment plates at Site B not only provides information on patterns of sediment accretion and erosion, but also aids interpretation of physical and biological changes at the site. A schematic of the layout and sampling approach for fine scale monitoring is provided in Fig. 3, with methods detailed below.

Site A, Whareama Estuary looking toward estuary entrance

Site B, Whareama Estuary looking upstream

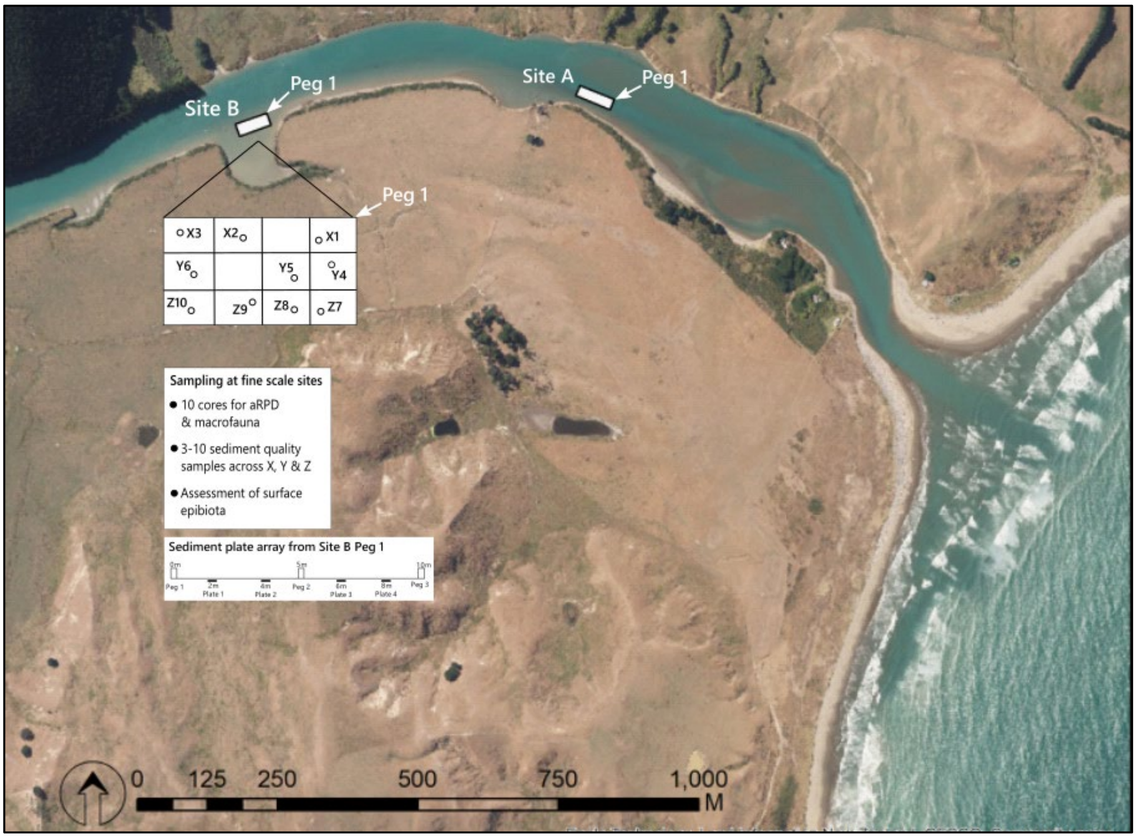


Fig. 3 Location of Whareama sites A and B, and schematic of fine scale and sediment plate sampling.

3.2 SEDIMENT PLATES

In 2008, four concrete 'plates' (pavers, 19cm x 23cm) for sediment plate monitoring were installed at Site B, positioned at 2, 4, 6 and 8m along the downstream site boundary (see Fig. 3). Plates were measured annually from 2008 to 2016, and then again during the 2022 survey. On 31 March 2022, plates were measured using a 2m straight edge placed over each plate position to average out 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.

Measuring sediment plates at Whareama Site B

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 the 10 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 the 10 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 the 10 plots (see notes 1, 2)
Depth of apparent redox potential discontinuity layer (aRPD)	Subjective measure of the enrichment state of sediments according to the visual transition between brown oxygenated surface sediments and deeper grey/black oxygen-depleted 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 10 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 10 plots, sieved to 0.5mm to retain macrofauna
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, sediment quality is assessed in 3 composite samples rather than 10 discrete samples as specified in the NEMP.

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

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

3.3 FINE SCALE SAMPLING AND BENTHIC INDICATORS

Each fine scale site was divided into a 3 x 4 grid of 12 plots. Fine scale sampling for benthic indicators was conducted in 10 of these plots, with Fig. 3 showing the standard numbering sequence for replicate plots used at sampling sites, and the designation of zones X, Y and Z (for compositing sediment samples; see below). A summary of the NEMP benthic indicators, the rationale for their inclusion, and the field sampling methods, is provided in Table 1. Although the general sampling approach closely follows the NEMP, alterations and additions to early NEMP methods have been introduced over the last 10 or more years, including for the Whareama Estuary surveys. For present purposes we have adopted these modifications as indicated in Table 1.

3.3.1 Sediment quality assessment

Three composite sediment samples (each ~250g) were collected from sub-samples (to 20mm depth) pooled across each of plots 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 metals or metalloids (arsenic, As; cadmium, Cd; chromium, Cr; copper, Cu; mercury, Hg; lead, Pb; nickel, Ni; zinc, Zn). Details of laboratory methods and detection limits for trace elements are provided in Appendix 2.

3.3.2 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 was measured after extracting a large sediment core (130mm diameter, 150mm deep, ~2L volume) from each of the 10 plots, placing it on a tray, and splitting it vertically. Representative split cores were also photographed.

3.3.3 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 75% isopropyl alcohol and 25% seawater mixture for later sorting and taxonomic identification by NIWA. The types of animals present in each sample (commonly referred to as 'macrofauna'), 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.

Collecting a sediment core from Site B

Splitting the sediment core to measure aRPD in the sediment

Surface-dwelling epibiota

In addition to macrofaunal core sampling, conspicuous epibiota (macroalgae, and surface-dwelling animals nominally >5mm body size) visible on the sediment surface at each site were semi-quantitatively categorised using the '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 and was used in 2016 and 2022 as an alternative to the quantitative quadrat sampling specified in the NEMP. As quadrat counts (10 x 0.25m2 quadrats) were undertaken in some earlier surveys (2008-2010), these were converted to SACFOR ratings for comparative purposes. Note that the 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

3.4 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. In 2022, field measurements 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.

To assess changes over the surveys, and minimise the risk of data manipulation errors, Excel sheets for the different data types and years were imported into the software R 4.0.5 (R Core Team 2022) 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, averages were calculated using half the detection limit value, according to convention.

For the macrofauna data, an extensive QA process was undertaken to achieve consistency in the naming of species and high taxonomic groups across years. This step was necessary as NIWA undertook the taxonomic identifications in 2022, whereas in previous surveys this component was undertaken by Coastal Marine Ecology Consultants (CMEC). To resolve issues identified:

- All macrofauna names were updated to that accepted by the World Register of Marine Species (WoRMS, www.marinespecies.org/).
- Taxonomic QA was undertaken by CMEC and NIWA on archived samples collected by CMEC since 2008, in part during an Envirolink project (Mills et al. 2021) but also subsequently by CMEC.
- Minor remaining differences between CMEC and NIWA data were addressed by aggregation to a common taxonomic level.

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 or freshwater drift). Macrofaunal univariate response variables were derived from raw data, namely richness and abundance by species and higher taxonomic groupings, and scores for the biotic health index AMBI (Borja et al. 2000).

AMBI scores reflect the proportion of taxa falling into one of five eco-groups (EG) that reflect sensitivity to pollution or disturbance, ranging from relatively sensitive (EG-I) to relatively resilient (EG-V). To meet AMBI criteria, 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 eco-group classifications for New Zealand (e.g. Cawthron EGs used by Berthelsen et al. 2018). Note that AMBI scores were not calculated if macrofaunal cores did not meet operational limits suggested by Borja et al. (2012), in terms of the percentage of unassigned taxa (>20%), or low sample richness (<3 taxa) or abundances (<6 individuals).

Using zone data within each site (zones X, Y and Z; i.e. replicates 1-3, 4-6 and 7-10, respectively, as per Fig. 3), simple Pearson correlation was undertaken to describe associations between pairwise combinations of macrofauna (richness and abundance) and sediment quality variables. Potential predictors of change in macrofauna composition were also investigated, using multivariate analysis procedures in the software Primer v7.0.13 (Clarke et al. 2014). Patterns in similarity as a function of macrofauna composition were visualised using a non-metric multidimensional scaling (nMDS) biplot, based on pairwise Bray-Curtis similarity index scores among samples aggregated within sites. Overlay vectors and/or bubble plots of site-averaged sediment quality and sedimentation variables were used to visualise relationships between multivariate biological patterns and sediment attributes. Using a Bray-Curtis similarity matrix of zone data, a more detailed analysis of macrofauna community-environment relationships was undertaken using the Primer procedure BIOENV. Prior to all multivariate analyses, macrofaunal abundance data were fourth-root transformed to down-weight the influence of the dominant species or higher taxa.

3.5 ASSESSMENT OF ESTUARY CONDITION

To supplement our analysis and interpretation of the data, fine scale survey results across all years 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 'health status' 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 the rating approach are as follows:

Table 3. Condition ratings used nationally to characterise estuarine health for key fine scale indicators. See text for explanation of the origin or derivation of the different metrics.

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

1. General indicator thresholds derived from a New Zealand Estuarine Tropic Index, with adjustments for mud and aRPD as described in the main text.
2. Thresholds derived from the ANZECC Estuary Sedimentation Guideline (Townsend & Lohrer 2015).
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. These were formerly the ANZECC (2000) sediment quality guidelines whose exceedance roughly equates to the occurrence of 'possible' and 'probable' ecological effects, respectively.

- *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 (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 adopted ratings based on the US Coastal and Marine Ecological Classification Standard Catalog of Units (FGDC 2012), rather than the oxidation-reduction potential thresholds in the ETI.
- *ANZG (2018) Sediment Quality Guidelines:* The condition rating categories for trace metals and metalloids are benchmarked to ANZG (2018) sediment quality guidelines as described in Table 4. 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.
- *ANZECC Estuary Sedimentation Guideline*: the condition ratings for sedimentation are benchmarked to the 2mm of sediment accumulation per year above natural deposition rates, proposed by Townsend and Lohrer (2015).

The scoring categories in Table 3 provide a general guide to assist with interpretation of estuary health status. It is major spatio-temporal changes in the health categories that are of most interest, rather than their subjective condition descriptors, i.e. descriptors such as 'poor' health status should be regarded more as a relative rather than absolute rating.

4. KEY FINDINGS

4.1 SEDIMENTATION

Sedimentation at Site B showed a period of steady accrual between 2008 and 2016 (Fig. 4), followed by a small amount of net erosion from 2016 to 2022 represents. Nonetheless, net sediment accrual since over the 14 years since 2008 has been 6.8mm/yr, which is more than three-times greater than the national DGV of 2mm/yr.

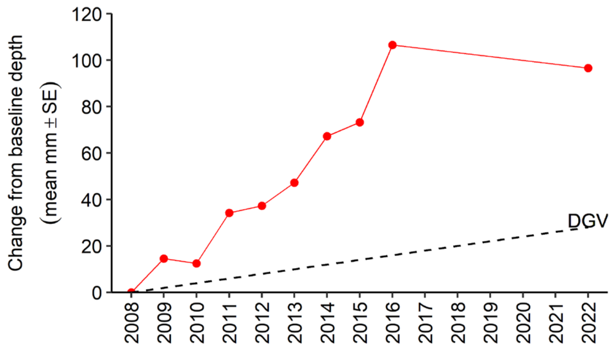


Fig. 4. Mean change (± SE) in sediment depth over buried plates at Site B, since the 2008 baseline. The dashed DGV line represents accrual at the national Default Guideline Value of 2mm/yr.

4.2 SEDIMENT MUD, TOC AND NUTRIENTS

Composite sediment sample data for fine scale sites are provided in Appendix 3, with Fig. 5 showing data for years matching fine scale and intervening sediment plate surveys (from Stevens & Robertson 2016). Sediments are largely mud-dominated, although sandier at Site A in some years. Mean %mud values in 2022 (58% Site A, 79% Site B) were within the previous range recorded, but there is a slight overall trend for an increase in mud content at both sites since 2009/10.

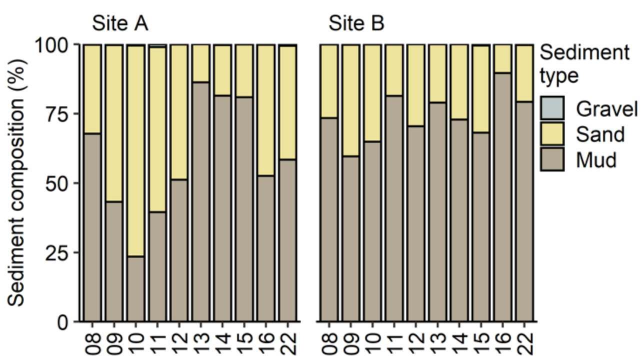


Fig. 5. Percentage composition of mud (<63µm), sand (<2mm to ≥63µm) and gravel (≥2mm) sampled in sediment plate survey years.

To provide a visual impression of sediment quality in fine scale survey years 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. For mud content, site ratings have been 'poor' in all but one survey, reflecting a mud content that exceeds the biologically-relevant threshold of 25%.

Despite the high mud content, levels of sediment organic matter (TOC) and TN have remained quite low at both sites across all years. Accordingly, condition rating scores for these analytes were 'good' or 'very good'. Levels of the nutrient total phosphorus (TP, no rating criteria) have also been relatively low (Appendix 3).

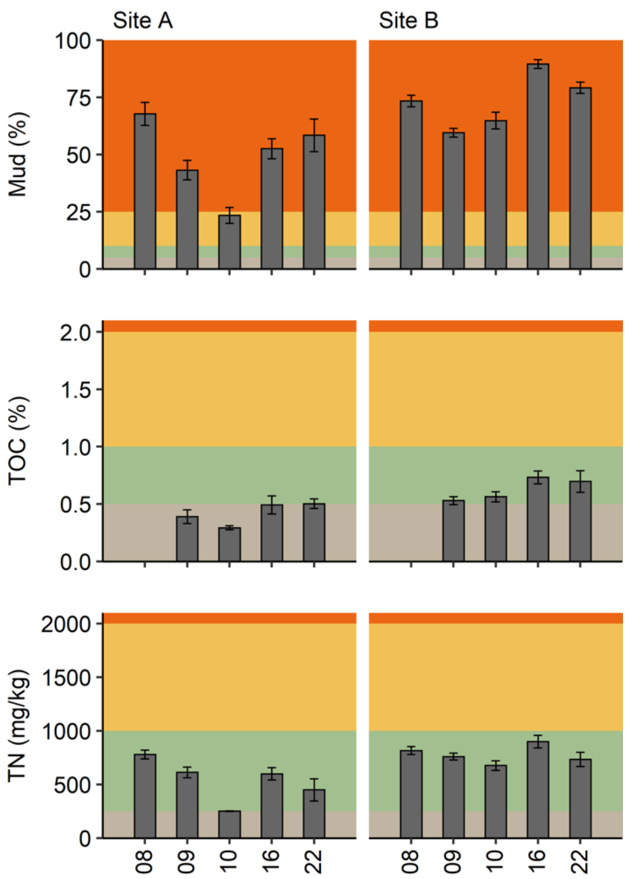


Fig. 6. Sediment mud content (Mud%), total organic carbon (TOC), and total nitrogen (TN) concentrations relative to condition ratings. TOC was derived from ash-free dry weight (AFDW) in 2008 and may be inaccurate so has been excluded. Condition rating key as follows:

Very Good	Good	Fair	Poor

4.3 REDOX STATUS

Mean aRPD values at fine scale sites are compared to condition ratings in Fig. 7. The aRPD has been highly variable across years, but was relatively shallow in 2022, especially at Site A (mean depth ~4mm, rating 'poor'). At Site B in 2022 the aRPD was deeper on average than Site A, but was nonetheless highly variable within the site (Appendix 3), being increasingly shallow from the land side (Zone Z, 20-35mm) towards the estuary channel (Zone X, 5-10mm). A shallow aRPD can be associated with conditions of moderate organic enrichment, but given that %TOC was not concurrently elevated, it is more likely in this instance to be associated with recent mud deposits at Site A. Mud-size particles inhibit flushing and oxygen diffusion into the sediment matrix. However, there are several plausible explanations for the apparent variability in aRPD across years, as follows:

- Sampling the sediment to 20mm may not accurately reflect the influence on aRPD of recently deposited muddy surface sediments
- Bioturbation (e.g. by worms, shellfish, crabs) can lead to mixing of oxic surface sediments with deeper oxygen-reduced sediments, which is apparent in the photos shown in Fig. 8. Hence, the depth of the aRPD is not always well-defined.

There is also inherent subjectivity in aRPD measurement, such that variability across surveys due to interpretation can be expected. However, the same practitioner made the aRPD assessment from 2008 to 2016, when marked variability was recorded. On this basis, it is reasonable to attribute some of the change in aRPD in Fig. 7 to be a true reflection of a change in trophic state over time.

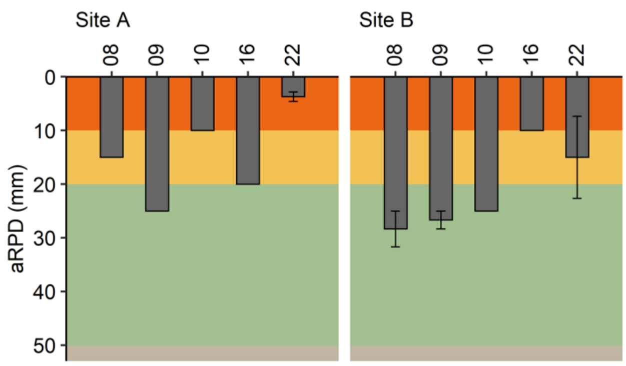


Fig. 7. aRPD depth in sediment and condition ratings. Condition rating key as follows:

Very Good	Good	Fair	Poor

Fig. 8. Example sediment cores from the 2022 survey. The aRPD is visible as the transition from brown surface sediment to deeper grey or black. Considerable mixing of brown surface sediment in deeper core layers is evident, especially at Site A.

4.4 TRACE CONTAMINANTS

Trace metal contaminant levels in relation to condition ratings and ANZG (2018) sediment quality guidelines are plotted in Fig. 9, with raw data and guideline values in Appendix 3. Mean concentrations have consistently been very low, and rated 'very good' except for a single instance where nickel concentrations slightly exceeded half of the DGV for 'possible' ecological effects.

Trace metals are considered an indicator of potential contaminant inputs and, even though more typically elevated in urban environments, can be associated with pastoral land uses due to practices such as fertiliser application (Gaw et al. 2006; Lebrun et al. 2019). The results strongly suggest that there are no significant sources of such contaminants in the Whareama Estuary catchment.

Steep eroding hillside margins in the upper Whareama Estuary

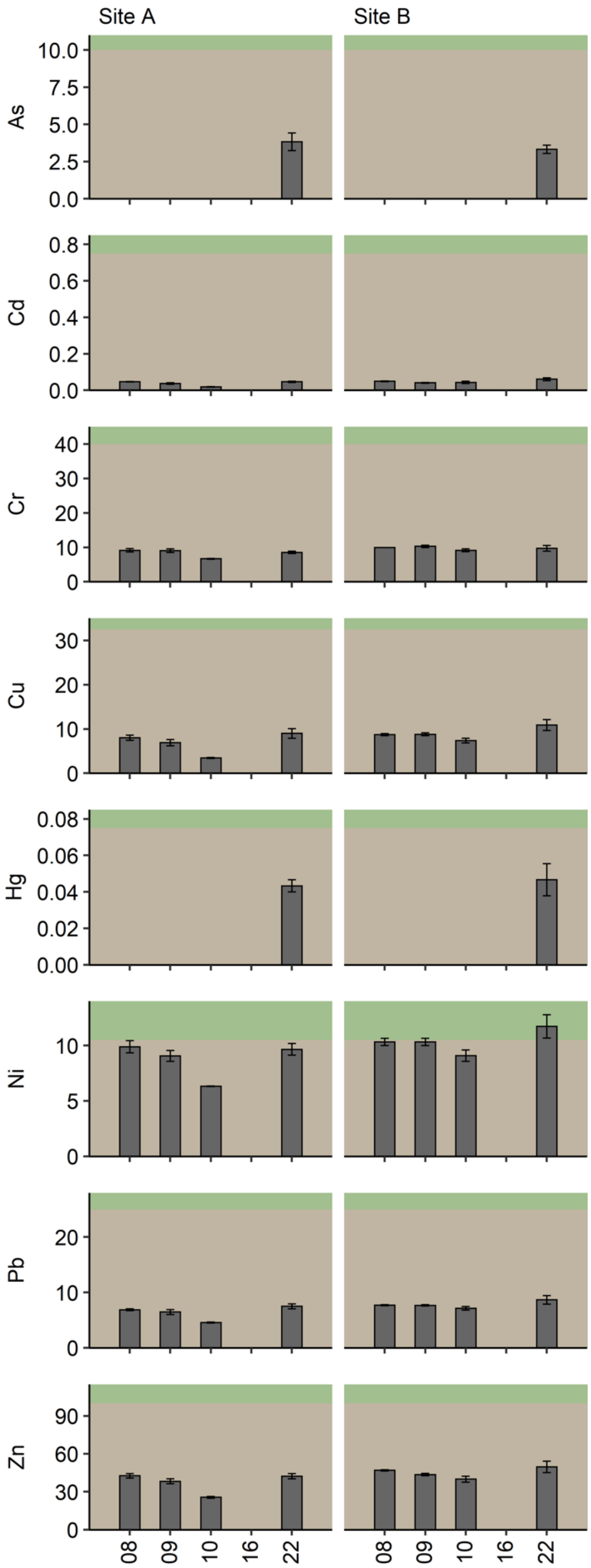


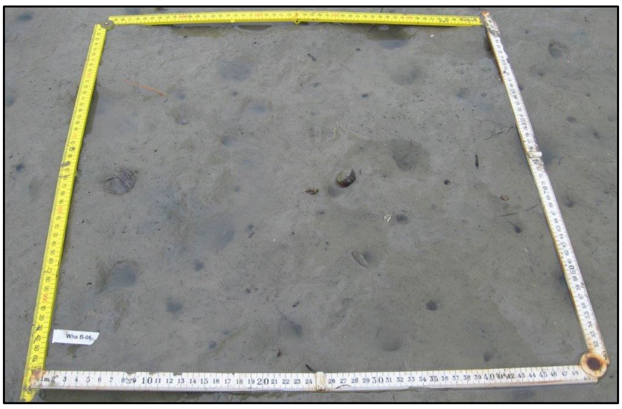
Fig. 9. Plots for trace metals (mean values, mg/kg ± SE). The boundary between grey and green represents half the DGV. Condition rating key as follows:

Very Good	Good	Fair	Poor

4.5 MACROFAUNA

4.5.1 Conspicuous surface epibiota

Epibiota have been consistently sparse at the two fine scale sites, likely reflecting the river-dominated nature of the location. No macroalgae or seagrass have been recorded in any surveys. Mud snails (*Amphibola crenata*) have been consistently recorded at Site B, at densities of 3-10/m^2. Mud whelks (*Cominella glandiformis*) were recorded in 2022 at Site A, but at a very low density (<0.01/m^2), and are also evident in archived photos taken at Site B in 2010.



Epibiota were sparse, consisting of mud snails (*Amphibola crenata*; top) and mud whelks (*Cominella glandiformis*; middle). However, burrows in the sediment surface (bottom) and the presence of cockles provided evidence of the activity of macrofauna within the sediment matrix. Specimen photos provided by NIWA.

4.5.2 Macrofauna cores

Raw macrofaunal data are provided in Appendix 4. In total, 33 species (or higher taxa) have been recorded over the five surveys. Abundances of the most common taxa are provided in Table 4, with descriptions of these in Table 5.

Main groups, richness, abundance and AMBI

The macrofauna is numerically dominated by taxa from three main groups - polychaete worms, bivalves, and decapods (crabs) (Fig. 10) - although 11 taxonomic groups are represented in total.

Mean species richness has been low in most surveys, ranging from ~4-8 taxa/core, with moderate abundances of 29-101 individuals/core (Fig. 11). Mean richness and abundance values were notably less in 2016 and 2022 than in the three surveys conducted over 2008-2010. At both sites there has been a clear abundance decline of the small bivalve *Arthritica* sp. 5 (EG-III) since 2010, and of the hardy polychaete worm *Heteromastus filiformis* (EG-IV) since 2016 (Table 4). The other obvious abundance declines are site-specific, notably a reduction in densities of the EG-I (disturbance-sensitive) polychaete worm *Microspio maori* at Site A in 2016 and 2022.

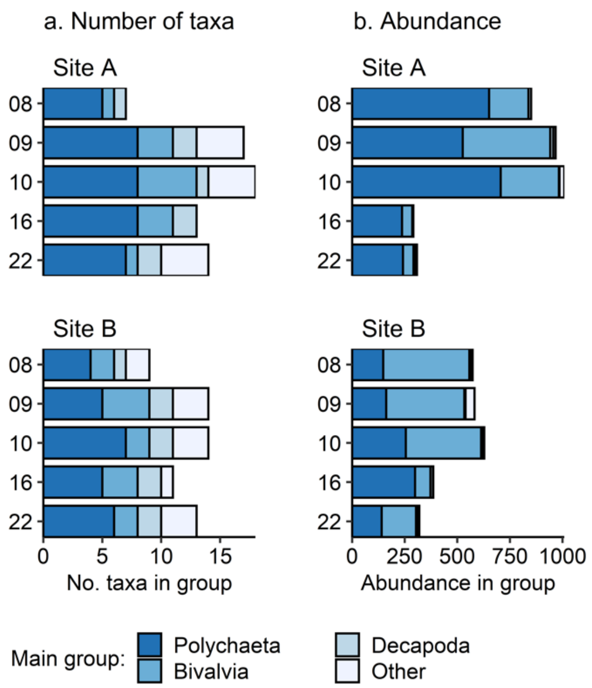


Fig. 10. Data pooled across years showing the contribution of main taxonomic groups to site-level richness and abundance values. Groups contributing ≥1% of site abundance are shown, with those <1% pooled into 'Other'.

Consistent with the decline in richness and abundance, values for the biotic index AMBI increased (indicative of increased degradation) in 2016 and 2022 relative to earlier years (Fig. 12). AMBI scores were mainly rated 'fair', with mean values of 3.3-4.2 indicative of moderate stress on the macrofaunal community. This result reflects that very few EG I taxa were present (Appendix 4), with the macrofauna dominated for the most part by resilient species in EG III to V (Table 4, Fig. 13).

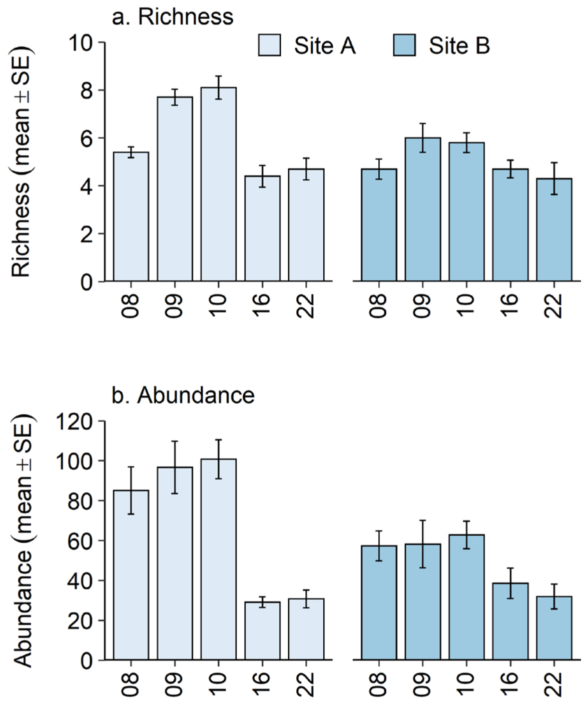


Fig. 11. Patterns (mean ± SE) in taxon richness and abundance per core (cores 0.013m^2, 150mm deep, volume ~2L).

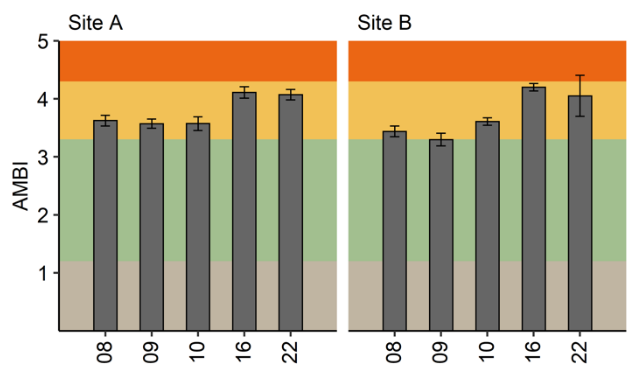


Fig. 12. Patterns (mean ± SE) in AMBI scores compared with condition ratings.

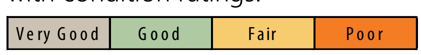


Table 4. Site-aggregated abundance of the most commonly occurring sediment-dwelling macrofauna. Eco-groups (EG) range from sensitive to pollution/disturbance (EG-I) to tolerant (EG-V).

Taxa	EG	A 2008	A 2009	A 2010	A 2016	A 2022	B 2008	B 2009	B 2010	B 2016	B 2022
Bivalves											
Arthritica sp. 5	III	187	410	265	44	50	399	344	347	64	161
Austrovenus stutchburyi	II		5	9	4		10	25	11	8	3
Crabs											
Austrohelice crassa	V				1				2	6	4
Hemiplax hirtipes	III	13	13	3	4	4	9	5	7	6	3
Mysid shrimps											
Mysida	II		8			3		35	1		
Oligochaete worms											
Oligochaeta spp.	V			19					3		3
Polychaete worms											
Boccardia syrtis	II	8	5	2	4						
Capitella spp.	V			15		7					6
Heteromastus filiformis	IV	410	203	117	99	2	6	7	19	36	
Microspio maori	I	95	51	123	1	2			2		1
Nereididae (juv)	na			18	7				8	5	
Nicon aestuariensis	III		10	1	3		3	5	1	1	3
Perinereis vallata	III		9	6	1	13		4	2	3	11
Scolecolepides benhami	IV	134	244	424	121	215	137	142	222	254	117

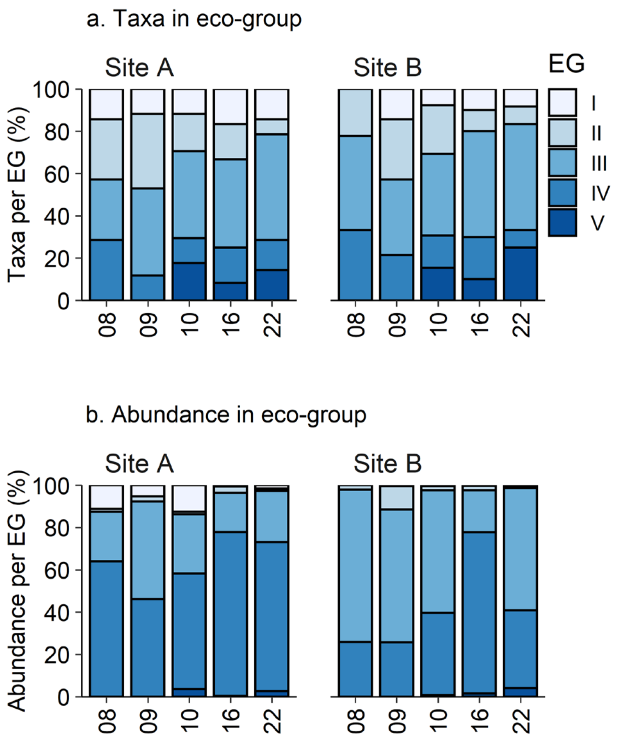


Fig. 13. Site-level data showing the number of taxa and organisms within eco-groups ranging from sensitive to pollution/disturbance (EG-I) to tolerant (EG-V).

Declines in the richness and abundance of macrofauna were correlated with increases in sediment mud content (Pearson r=-0.71 richness, r=-0.46 abundance, p≤0.01) (Fig. 14). Mud content was itself highly positively correlated with %TOC (r=0.92) and TN (r=0.84) concentrations (Appendix 5). This general trend is consistent with known tolerances of the dominant species. For example, abundances of *Microspio maori* (sensitive EG I) at Site A, and its near-absence from Site B, is likely a reflection of its intolerance of high levels of mud in the sediment matrix (Robertson et al. 2015). Conversely, the highest densities of this species occurred at Site A in 2010 when conditions were relatively sandy (see Fig. 5).

Changes in AMBI scores were not significantly associated with mud and TOC, but did show a significant negative correlation with aRPD (r=-0.64). That is, an increase in AMBI scores (suggesting a deteriorating state) was associated with stronger symptoms of reduced oxygenation in the sediment matrix (i.e. the aRPD became shallower and values decreased).

Table 5. Description and eco-group sensitivities of the most commonly occurring sediment-dwelling macrofauna. (EG-I = most sensitive to pollution/disturbance, EG-V = most tolerant). Specimen photos provided by NIWA. Pink colour due to a vital stain.

Main group	Description	Image
Arthritica sp. 5 (Bivalve, EG III)	A small sedentary deposit feeding bivalve that lives buried in the mud. Tolerant of muddy sediments and moderate levels of organic enrichment.	
Austrovenus stutchburyi (Cockle, EG II)	Suspension feeding bivalve, living near the sediment surface. Can improve sediment oxygenation, increasing nutrient fluxes and influence the type of macrofauna present. Sensitive to organic enrichment. Important in diet of certain birds, rays and fish.	
Austrohelice crassa (Crab, EG V)	Endemic, burrowing mud crab. Concentrated in well-drained, compacted sediments above mid-tide level. Highly tolerant of high silt/mud content.	
Hemiplax hirtipes (Crab, EG III)	Deposit feeding stalk-eyed mud crab, endemic to New Zealand. Can be common in wet areas at the mid to low water level. Makes extensive burrows in the mud. Specimen in photo is missing some legs.	
Mysid shrimps (EG II)	Likely to be *Tenagomysis*, which is a genus of mysid shrimps in the family Mysida. At least nine of the fifteen species known are from New Zealand. Considered relatively sensitive.	
Oligochaete worms (EG V)	Segmented worms in the same group as earthworms. Deposit feeders that are generally considered pollution or disturbance tolerant.	
Polychaete worms (*Capitella* spp., EG V)	Subsurface deposit feeding worm that is highly tolerant of disturbed or harsh conditions. Similar to *Capitella capitata*.	
Polychaete worms (*Heteromastus filiformis*, EG III)	Small capitellid polychaete worm. A sub-surface, deposit-feeder that can thrive under conditions of moderate organic enrichment.	
Polychaete worms (*Microspio maori*, EG I	A small, common, intertidal spionid worm. Can handle moderately enriched situations. Prey item for fish and birds.	
Polychaete worms (Nereididae juveniles)	These juveniles included *Nicon aestuariensis*, which is a deposit feeding omnivorous worm that is tolerant of freshwater.	
Polychaete worms (*Perinereis vallata*, EG III)	An intertidal omnivorous nereid worm, associated with mud/sand sediments. Prey item for fish and birds. Considered sensitive to high sedimentation.	
Polychaete worms (*Scolecolepides benhami*, EG IV)	A relatively hardy, deposit feeding spionid worm that is common in estuaries and coastal areas throughout New Zealand.	

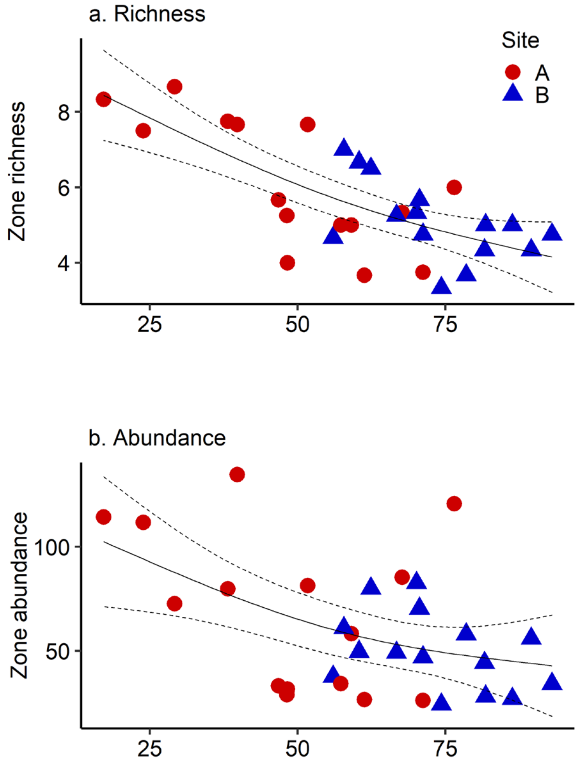


Fig. 14. Relationships between mud content and macrofauna richness and abundances, based on zone-average data. A smoothing line (solid black) is fitted with a 95% confidence interval (dashed).

Macrofauna composition patterns

To explore the differences and similarities among sites and surveys in terms of the macrofauna present and their relative abundances, the nMDS ordination in Fig. 15 places sites of similar composition close to each other in a 2-dimensional plot, with less similar sites being further apart.

Fig. 15a reveals a limited separation of the two sites according to their composition, with each site showing a consistent temporal trend in composition change between 2008 and 2022. Much of the trend reflects changes in taxa abundances such as evident in Table 4. When only the identity of the taxa is considered (irrespective of their abundances), the patterns are weaker, and sites appear more similar (graph not shown).

Irrespective of whether the MDS is based on relative abundance or the identity of the taxa present, the temporal change in composition is more pronounced at Site A than Site B, which is evident in Fig. 15a in the greater spread of Site A survey years. In particular, macrofauna in the 2008 and 2022 surveys at Site A were most dissimilar in composition to a cluster group comprising all other sites/years. Much of this change is determined by the occurrence of species that occurred in very low numbers; often only one or a few specimens were recorded in any one site and survey. As such, the apparent differences may in part be due to chance sampling of the least common taxa.

Based on the Bio-Env analysis, the changes in macrofauna composition were not linked to changes in sediment mud content and TOC (Spearman rank correlation $\rho \leq 0.05$). This result is in contrast to the moderately significant correlation between these variables and richness and abundance patterns, as described above and in Fig. 14. In fact, none of the measured variables were strongly correlated with composition patterns, with the best correlation being a weak-moderate association between macrofauna composition and aRPD ($\rho = 0.41$). The latter is illustrated by the bubble plot in Fig. 14b in which the circle size is scaled to aRPD depth; the shallowest depth of the aRPD (i.e. most oxygen depleted) that occurred at Site A in 2022 is illustrated, for which the macrofaunal was the most distinct from other sites. As noted above, this result may simply reflect reduced oxygen penetration into the sediment due to a surface mud layer, as none of the macrofaunal characteristics of Site A in 2022 are consistent with an enrichment effect. For example, among the taxa sampled, oligochaete worms and capitellid polychaetes (*Capitella* spp. and *Heteromastus filiformis*) can become very abundant in enriched conditions, but that pattern was not evident at Site A in 2022.

Conceivably the moderate correlation with aRPD does not reflect a causal association in terms of an effect on macrofauna. It appears more likely that the subtle changes in macrofaunal composition are determined by factors other than the measured sediment quality variables. The potential for chance sampling of organisms at low density, as noted above, may be a partial explanation. It is also likely that the river-dominated nature of the estuary system means the fine scale sites are subject to other important influences, such as salinity fluctuations or physical effects of river scouring or deposition during flood conditions. For example, parts of Site A had the appearance of being recently scoured at the time of the 2022 survey, with shell debris having accumulated in places, which is consistent with flood flows around 25 March (see Section 5.1).

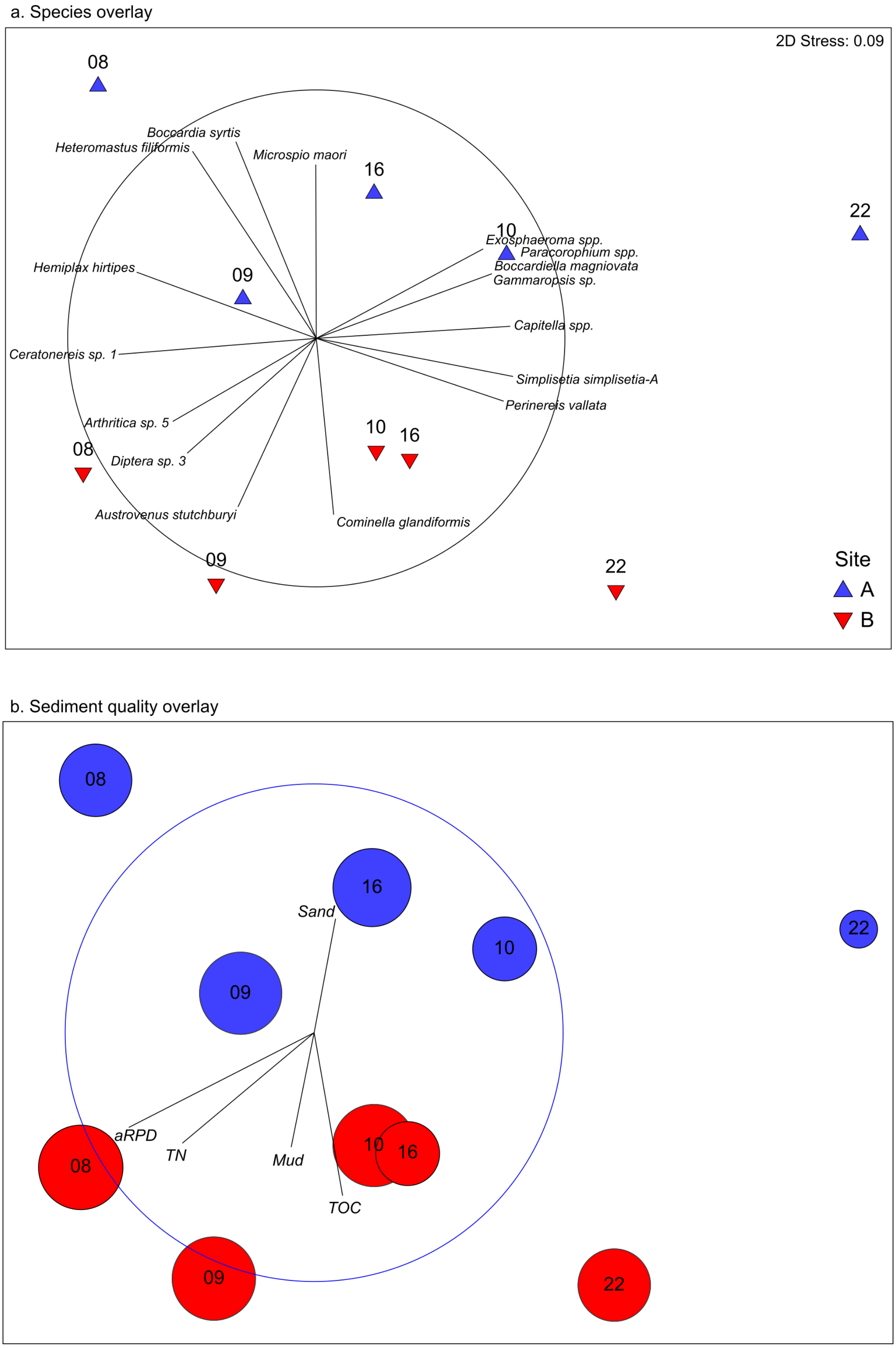


Fig. 15. Non-metric MDS ordination of macrofaunal data.

Sites are placed such that closer ones are more similar than distant ones in terms of macrofaunal composition. A 'stress' value of 0.09 for the nMDS indicates that a 2-dimensional plot provides a reasonable representation of differences. The plot shows a top-bottom separation of sites and a left-right temporal shift. Surveys within Site B were ~70% similar in terms of the Bray-Curtis macrofaunal index, with Site A samples being more variable. 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 (redox conditions), which was the only sediment quality variable that was moderately correlated with macrofaunal composition differences. See text.

5. SYNTHESIS AND RECOMMENDATIONS

5.1 SYNTHESIS OF KEY FINDINGS

This report has described the findings of five intertidal surveys (between 2008 and 2022) of Whareama Estuary, largely following the fine scale survey methods described in New Zealand's NEMP. A summary of mean values of key physical and biological indicators in relation to ecological condition ratings is provided in Table 6. In overview, Table 6 highlights the low concentrations of trace metal contaminants, and trophic state variables (TOC, TN, TP). The Table also illustrates the degraded nature of the estuary due to the high mud content of intertidal sediments, an aRPD depth that is at times shallow (indicating a moderate reduction in sediment oxygenation), and scores for the biotic index AMBI that are indicative of moderately degraded conditions. In these respects, Whareama is degraded relative to the other larger estuaries regularly monitored in the Wellington region (Fig. 16).

The high mud content of Whareama Estuary sediments reflects the dominant catchment land uses (farming and pine forestry) and erodible nature of the soils (see Section 2). As well as generating muddy sediments, agricultural land use 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 forn contaminant adsorption. However, in the case of Whareama Estuary, the analysis of trace elements provided no evidence of any significant contaminant sources in the catchment, with concentrations of all analytes being very low relative to ANZG (2018) sediment quality guideline values.

The moderate AMBI scores reflect that Whareama Estuary is characterised by a dominant suite of macrofauna taxa (EG III to V) that are tolerant of harsh environmental conditions. However, AMBI scores increased in 2016 and 2022 relative to earlier surveys (indicative of increased degradation), with concurrent declines in taxa richness and abundance to the lowest levels yet measured. The overall declines in macrofauna richness and abundance were associated with an increase in sediment mud content. However, compositional changes in the macrofauna community were not clearly or strongly related to mud nor any of the other measured sediment quality variables. Mud (along with trophic state indicators such as TOC) are recognised as key drivers of macrofaunal response in estuarine sediments in New Zealand (Cummings et al. 2003; Robertson et al. 2015; Berthelsen et al. 2018; Clark et al. 2020; Clark et al. 2021).

Table 6. Summary of condition scores of ecological health based on mean values of key indicators for fine scale survey years (rating criteria not established for TP). See Glossary for definition of indicators and Fig. 3 (p. 4) for site locations.

Site	Year	Mud %	aRPD mm	TN mg/kg	TP mg/kg	TOC %	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Pb mg/kg	Hg mg/kg	Ni mg/kg	Zn mg/kg	AMBI na
A	2008	67.8	15	780	417	-	-	0.048	9.2	8.0	6.9	-	9.9	42.7	3.6
	2009	43.2	25	613	363	0.39	-	0.037	9.0	6.9	6.5	-	9.1	38.3	3.6
	2010	23.4	10	< 503	343	0.29	-	0.019	6.7	3.5	4.6	-	6.3	25.7	3.6
	2016	52.6	20	600	400	0.49	-	-	-	-	-	-	-	-	4.1
	2022	58.4	4	450*	333	0.50	3.8	0.047	8.6	9.0	7.5	0.04	9.7	42.3	4.1
B	2008	73.4	28	817	430	-	-	0.050	10.0	8.7	7.7	-	10.3	47.0	3.4
	2009	59.6	27	760	410	0.53	-	0.041	10.3	8.8	7.7	-	10.3	43.7	3.3
	2010	64.9	25	677	363	0.56	-	0.044	9.2	7.4	7.1	-	9.1	40.0	3.6
	2016	89.6	10	900	540	0.73	-	-	-	-	-	-	-	-	4.2
	2022	79.2	15	733	390	0.70	3.3	0.061	9.8	10.9	8.7	0.05	11.7	49.7	4.1

** Sample mean includes values below lab detection limits*

< All values below lab detection limit

Very Good	Good	Fair	Poor

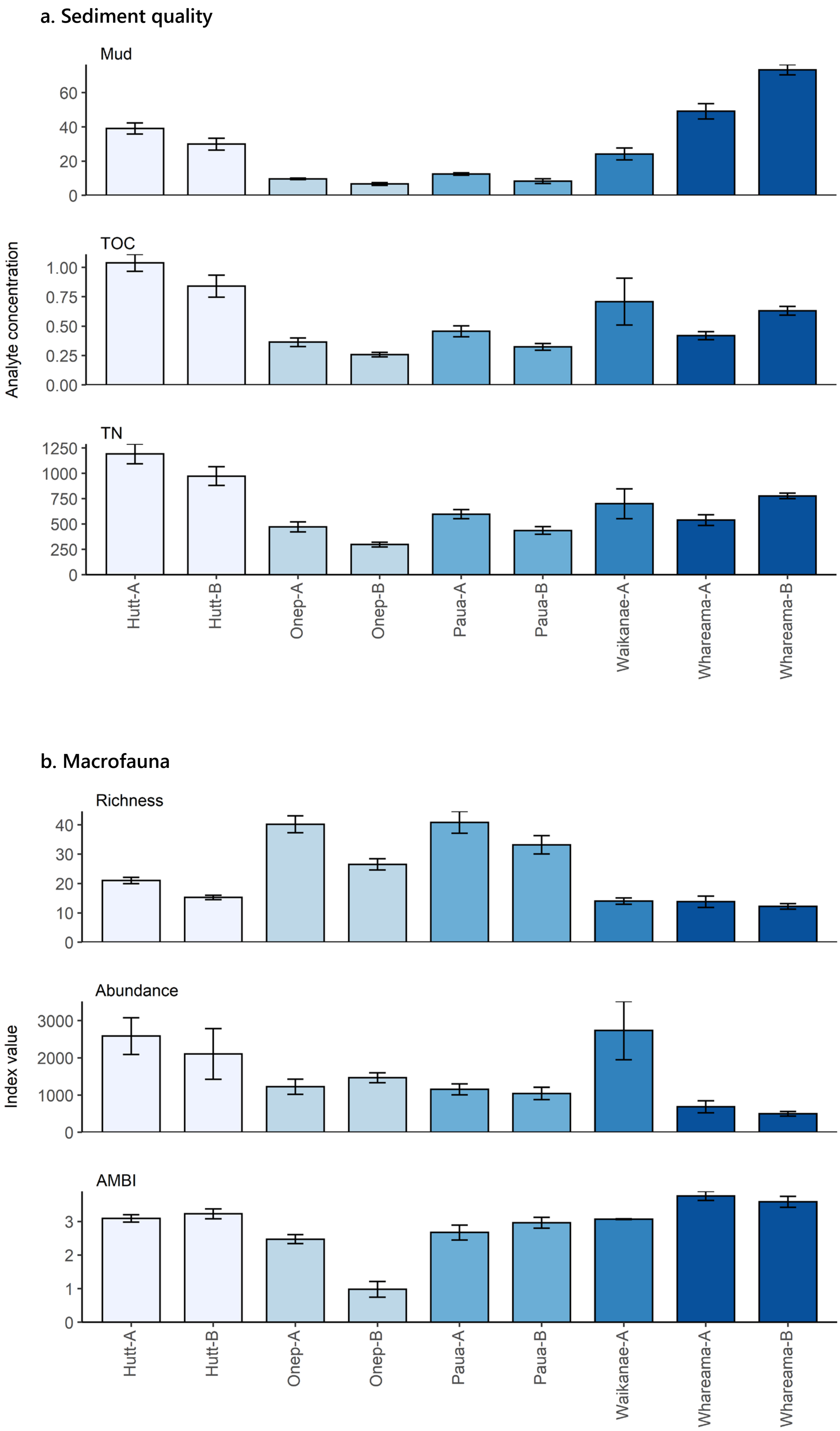


Fig. 16. Broad patterns in key sediment quality and macrofauna indicators, comparing Whareama Estuary sites with other key estuaries in the Wellington region (mean ± SE for surveys pooled over time within each site). Sediment analyte concentrations for mud and TOC are percentages, and for TN are mg/kg. Note, all estuaries except the Porirua Harbour (Onep and Paua) are river-dominated systems.

It is possible that the absence of a consistent or strong macrofauna-mud relationship may reflect that the NEMP method requires only surface mud (20mm depth) to be collected, which may not represent the sediment across the 150mm depth of the macrofauna core. In addition, as the sediments have been mud-dominated since monitoring began (except for Site A in 2010), the hardy taxa that are present are already those that that are tolerant of turbid waters and muddy conditions (Robertson et al. 2015). Accordingly, the variation in mud content across the range typically recorded in Whareama Estuary may not have a significant influence.

It also needs to be recognised that the harsh physical conditions typically associated with river-dominated estuaries may have a significant effect on the composition of sediment-dwelling organisms. Relevant in this respect is that a particularly significant flood event preceded the 31 March 2022 survey, and may have had an influence on survey findings (Fig. 17). Physical scouring and a pulse of low salinity water during flood flow, a highly variable background tidal salinity regime (Stevens & Roberts 2023), as well as variable sediment deposition and erosion events that also relate to catchment rainfall and river flows, are all likely to be important ecological drivers in Whareama Estuary. The influence of such factors may in fact override the measurable effects of changes in the monitored sediment quality variables. In other tidal river estuaries that we monitor using the NEMP protocol, it is common to see dramatic changes in macrofauna richness, abundance and composition between surveys (e.g. Forrest et al. 2020; Forrest et al. 2021, 2022), reflecting that the community is in constant flux between disturbance and recovery. On this basis, it is possible that the apparent trends suggesting a recent degradation in habitat conditions (e.g. declines in macrofauna richness and abundance, increase in AMBI scores) in Whareama Estuary is part of the range of 'natural' conditions experienced in this system. Further fine scale monitoring would be required to evaluate whether there is a trend of ongoing degradation. It would also be of value to reinstate regular (e.g. annual) sedimentation monitoring. Based on the trend from 2008 to 2016, high rates of sediment accrual can clearly occur in the estuary. However, the absence of sediment plate measurements in the years between 2016 and 2022 means there is no recent sedimentation history; the apparent sediment erosion between 2016 and 2022 may have been due in part to the flood event just before the survey.

At the request of GWRC, the results of the fine scale monitoring have been briefly assessed below in the context of the findings of a separate study in which the fine scale data were analysed using a National Benthic Health Model (BHM). The BHM has been recently developed as a tool to provide a nationally standardised measure of the relative impact of muddy sediments (Mud BHM) and trace metal contamination (Metals BHM; based on copper, lead and zinc concentrations) on macrofaunal communities in New Zealand estuaries (Clark et al. 2020). For a given site and survey, the method provides a score of estuary health on a six-point scale relative to other New Zealand estuaries. In the case of the Metals BHM, scores are also benchmarked to sediment quality guidelines that are stricter than ANZG (2018) DGVs referred to in the present report. BHM

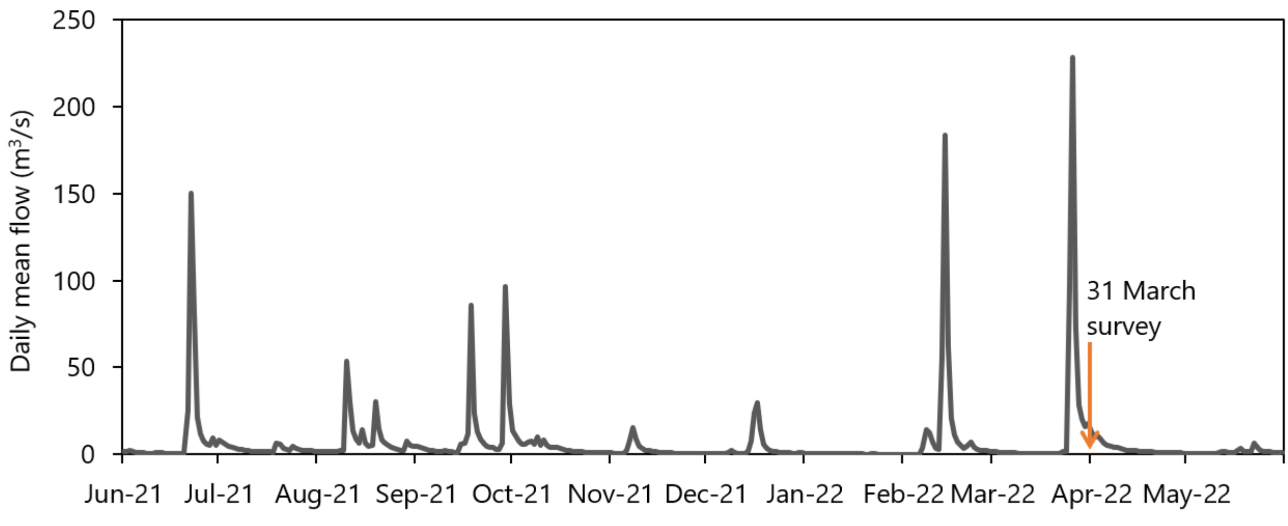


Fig. 17. Whareama River (daily mean) flows at Waiteko station approximately 15km upstream of the estuary mouth. A significant flood event peaked six days prior to the survey on 25 March.

scores for GWRC estuaries were recently provided to GWRC by Cawthron Institute as part of a separate analysis, with a summary in Appendix 6.

For Whareama Estuary, Mud BHM results indicate that the sites fall within a band of impact of either 'high' (score 4 to <5) or 'very high' (score ≥5) relative to other estuarine sites the Wellington region (Fig. 18) or elsewhere in New Zealand (Appendix 6). These results do not relate strongly to the %mud values for the Whareama sites, with considerable variability in Mud BHM values across the range of sediment %mud values measured, and only a slight increase in BHM in response to increasing mud (Fig. 18). The absence of a strong relationship between BHM scores and mud across the values measured at Whareama Estuary sites is consistent with other analyses described above (i.e. Bio-Env), which did not show a strong association between mud content and macrofaunal community composition.

In terms of Metals BHM results, most of the scores fell in a 'low' to 'moderate' impact category relative to other estuaries in New Zealand. Interpretation of impacts is further aided by a rating scheme of 'absolute' impact boundaries (see Appendix 6), in which Metals BHM values <3.6 are rated 'good' and values of 3.6 to < 4.8 are rated fair. For Whareama Estuary, Metals BHM absolute scores were 'good' in all cases except for Site A in 2009 (score 4.1). These results are consistent with the very low copper lead and zinc concentrations in the sediment (see Fig. 9). However, as for Mud BHM, Metals BHM scores also varied widely across a small range in metal concentration (note that the single 'metal concentration' variable used in the BHM was derived by aggregating copper, lead and zinc concentrations using Principal Component Analysis).

Overall, the BHM provides a useful means of placing the relative health of Whareama Estuary fine scale sites in context to other estuaries in the Wellington region and nationally. From a monitoring perspective in Wellington SOE estuaries specifically, the BHM appears to have limited utility as a tool for tracking temporal changes in estuary health, due to the following:

- Within each estuary or site, there is considerable variability of BHM scores across the measured range of mud or metal values.
- The trend of an increasing BHM score (i.e. degrading condition) with increasing sediment mud content evident for Wellington estuaries collectively in Fig. 18 (also in Appendix 6 for estuaries nationally), is not mirrored within each Wellington estuary site; BHM scores do not significantly increase across the range of mud values measured in each Wellington estuary (Fig. 18).
- Together, these limitations suggest that the BHM will be relatively insensitive to changes in mud and metals in Wellington estuaries. Even in Whareama Estuary (see Fig. 16) where there was a particularly wide range in the mean sediment mud content(~23-90%), there was a trend for only a slight increase in BHM with increasing mud. It is important, therefore, that undue weight is not placed on small temporal changes in BHM scores; Clark et al. (2020, Supplementary Material C) recommended that BHM score changes of ≤ ± 1 should be considered within the range of natural variation.

In terms of Whareama Estuary specifically, the BHM results further reinforce that there are other, potentially more important, drivers of macrofaunal change than mud or metals.

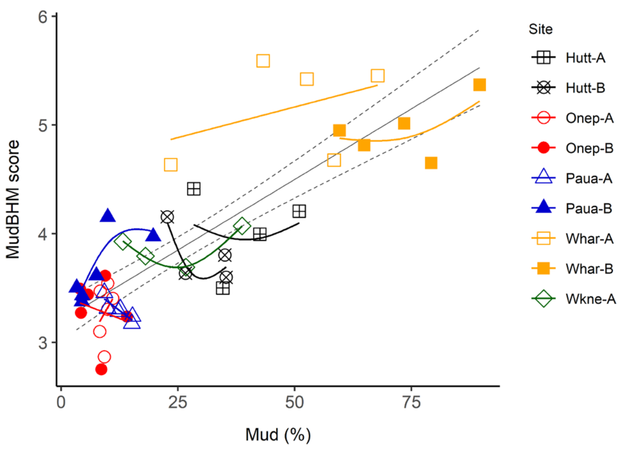


Fig. 18. Relationship between average sediment mud content and Mud BHM scores for GWRC estuaries, showing Sites A and B in Whareama (orange). Smoothing lines that allow for non-linear responses are fitted to the overall data (solid grey) with 95% confidence interval (dashed grey), and for individual estuaries.

Although mud is not clearly implicated as a major driver of change in macrofaunal community composition at the two fine scale sites, Fig. 14 showed that increased mud is associated with a reduction in macrofaunal richness and organism abundances. Mud also has a range of other impacts on estuary biota (e.g. seagrass, birds, fish), and is symptomatic of a strong catchment influence. It would therefore be of value to consider the scope to mitigate inputs. As noted in Section 2, the catchment is characterised by steep pastoral hill country (57% of catchment area) used mainly for beef and sheep farming, with a further 26% in exotic forestry. Ongoing sediment run-off from pastoral land in New Zealand has been estimated at close to 1T/ha/yr (Donovan 2022), with exotic forestry having the potential to release large pulses of sediment during harvest and for a few years after (e.g. Gibbs & Woodward 2018). Sediment run-off in the Whareama River catchment is compounded by the highly erodible nature of the soils. GWRC (in conjunction with the Ministry for Primary Industries) targets erosion prone areas in Wairarapa catchments considered the most in need of management, as part of a Wellington Regional Erosion Control Initiative (WRECI; started in 2009). However, as we understand it, there are no specific measures in place for the Whareama River catchment. Salt Ecology is currently preparing a report for GWRC that includes a synoptic survey of 25 estuaries along the Wairarapa coast (Stevens & Roberts 2023), which will identify the priority to manage Whareama Estuary relative to the other systems.

5.2 RECOMMENDATIONS

- Continue fine-scale monitoring surveys at intervals of 5-years, as is typical for this method. To track key changes in the estuary in intervening years, annual sediment plate monitoring should be restarted, along with measurement of sediment grain size and oxygenation (aRPD).
- Evaluate the feasibility of reducing muddy sediment inputs, contingent on Whareama Estuary being recommended as a high priority for management as an outcome of a related study being undertaken for GWRC by Stevens and Roberts (2023).

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APPENDIX 1. COORDINATES OF FINE SCALE SITES (CORNERS)

Estuary	Site	Label	NZTM_East	NZTM_North
Whareama	Whar-A	A_C1	1860646	5455355
Whareama	Whar-A	A_C2	1860652	5455366
Whareama	Whar-A	A_C3	1860711	5455342
Whareama	Whar-A	A_C4	1860702	5455329
Whareama	Whar-B	B_C1	1860093	5455325
Whareama	Whar-B	B_C2	1860038	5455301
Whareama	Whar-B	B_C3	1860045	5455279
Whareama	Whar-B	B_C4	1860100	5455306

APPENDIX 2. RJ HILL ANALYTICAL METHODS

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 QUALITY RAW DATA ALL YEARS

Values based on composite samples within each zone except for aRPD in 2022 for which the zone range is shown.

Site	Year	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	2008	X	<0.1	23.5	76.5	-	860	420	15	-	0.049	10	9.2	-	11	7.2	46
		Y	0.5	31.8	67.7	-	720	400	15	-	0.044	8.3	7.4	-	9.3	6.7	41
		Z	<0.1	40.9	59.1	-	760	430	15	-	0.05	9.2	7.5	-	9.4	6.7	41
	2009	X	<0.1	48.3	51.7	0.51	710	390	25	-	0.045	10	8.3	-	10	7.3	42
		Y	0.1	60.1	39.8	0.34	590	340	25	-	0.035	8.9	6.7	-	8.9	6.4	38
		Z	0.8	61	38.2	0.32	540	360	25	-	0.032	8.2	5.8	-	8.3	5.7	35
	2010	X	1	81.8	17.2	0.33	<500	330	10	-	0.02	6.7	3.4	-	6.3	4.4	25
		Y	0.1	70.7	29.2	0.27	<500	350	10	-	0.021	6.9	3.7	-	6.4	4.7	27
		Z	0.3	75.8	23.9	0.28	<510	350	10	-	0.017	6.5	3.3	-	6.3	4.6	25
	2016	X	0.3	51.5	48.3	0.41	600	380	20	-	-	-	-	-	-	-	-
		Y	<0.1	38.7	61.3	0.65	700	420	20	-	-	-	-	-	-	-	-
		Z	0.3	51.5	48.2	0.42	500	400	20	-	-	-	-	-	-	-	-
	2022	X	1	41.7	57.3	0.53	600	340	1-5	3.1	0.048	8.5	8	0.04	9.6	7.2	42
		Y	0.6	52.5	46.8	0.42	<500	320	1-3	3.4	0.041	8	7.9	0.04	8.8	6.9	39
		Z	<0.1	28.8	71.2	0.56	500	340	1-4	5	0.052	9.2	11.2	0.05	10.6	8.4	46
B	2008	X	<0.1	29.4	70.6	-	890	460	25	-	0.053	10	9.2	-	11	7.9	48
		Y	0.3	21.3	78.5	-	770	420	35	-	0.045	9.9	8.5	-	10	7.6	46
		Z	<0.1	28.8	71.2	-	790	410	25	-	0.051	10	8.5	-	10	7.6	47
	2009	X	<0.1	39.6	60.4	0.53	750	410	25	-	0.039	10	8.8	-	10	7.5	44
		Y	<0.1	43.9	56	0.47	710	410	30	-	0.04	10	8.3	-	10	7.6	42
		Z	0.3	37.3	62.4	0.59	820	410	25	-	0.045	11	9.4	-	11	7.9	45
	2010	X	<0.1	42.1	57.8	0.5	590	360	25	-	0.032	8.5	6.5	-	8.2	6.6	36
		Y	<0.1	29.9	70.1	0.65	730	390	25	-	0.054	10	8.4	-	10	7.7	44
		Z	<0.1	33.3	66.7	0.54	710	340	25	-	0.045	9	7.3	-	9.1	7.1	40
	2016	X	<0.1	13.7	86.3	0.65	800	500	10	-	-	-	-	-	-	-	-
		Y	<0.1	10.5	89.5	0.71	900	550	10	-	-	-	-	-	-	-	-
		Z	<0.1	7	93	0.84	1000	570	10	-	-	-	-	-	-	-	-
	2022	X	<0.1	25.7	74.3	0.52	600	330	5-10	2.8	0.046	8.2	8.5	0.03	9.7	7.1	41
		Y	0.1	18.3	81.6	0.84	800	450	10-20	3.7	0.074	11	12.6	0.05	13.2	9.6	56
		Z	0.7	17.5	81.8	0.73	800	390	20-35	3.5	0.063	10.1	11.6	0.06	12.3	9.3	52
									DGV	20	1.5	80	65	0.15	21	50	200
									GV-high	70	10	370	270	1	52	220	410

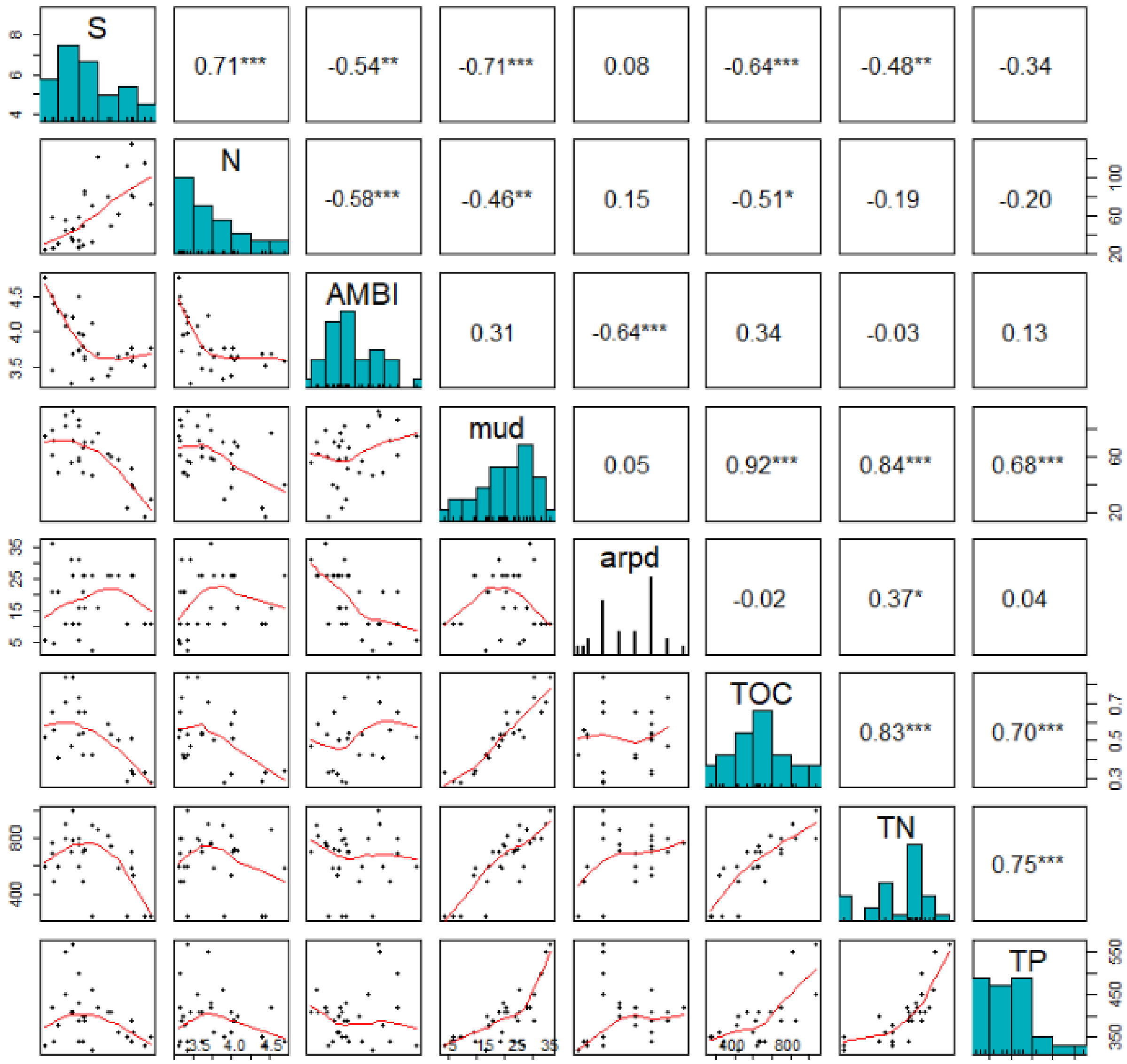
APPENDIX 4. MACROFAUNA CORE SUMMARY DATA ALL YEARS.

Cores 130mm diameter to 150mm deep, 0.013m^2 sample area, ~2L core volume. Data summed across cores within site and survey.

Main group	Taxa	Habitat	EG	08A	08B	09A	09B	10A	10B	16A	16B	22A	22B
Amphipoda	Gammaropsis sp.	Infauna	I									3	
Amphipoda	Paracorophium spp.	Infauna	III					1				1	
Arachnida	Acari	Epibiota	NA										1
Bivalvia	Arthritica sp. 5	Infauna	III	187	399	410	344	265	347	44	64	50	161
Bivalvia	Austrovenus stutchburyi	Infauna	II		10	5	25	9	11	4	8		3
Bivalvia	Cyclomactra tristis	Infauna	I			1	1	1		1	1		
Bivalvia	Macomona liliana	Infauna	II				1						
Bivalvia	Mytilidae sp. 1	Epibiota	III					1					
Bivalvia	Paphies australis	Infauna	II					1					
Copepoda	Copepoda sp. 2	Infauna	II			1							
Decapoda	Austrohelice crassa	Infauna	V						2	1	6		4
Decapoda	Halicarcinus whitei	Infauna	III			1						4	
Decapoda	Hemiplax hirtipes	Infauna	III	13	9	13	5	3	7	4	6	4	3
Decapoda	Palaemon affinis	Infauna	I				1						
Diptera	Diptera sp. 3	Larva	IV		5		1						
Gastropoda	Amphibola crenata	Epibiota	III		2	1							
Gastropoda	Cominella glandiformis	Epibiota	III			1	7	1	2		2		4
Isopoda	Exosphaeroma spp.	Infauna	II					1				1	
Mysidacea	Mysida	Infauna	II			8	35		1			3	
Oligochaeta	Oligochaeta spp.	Infauna	V					19	3				3
Polychaeta	Boccardia syrtis	Infauna	II	8		5		2		4			
Polychaeta	Boccardiella magniovata	Infauna	III									1	
Polychaeta	Capitella spp.	Infauna	V					15				7	6
Polychaeta	Ceratonereis sp. 1	Infauna	II	4	2	2	4		1				
Polychaeta	Glycera spp.	Infauna	II			2							
Polychaeta	Heteromastus filiformis	Infauna	IV	410	6	203	7	117	19	99	36	2	
Polychaeta	Microspio maori	Infauna	I	95		51		123	2	1		2	1
Polychaeta	Nereididae (juv)	Infauna (juv)	NA					18	8	7	5		
Polychaeta	Nicon aestuariensis	Infauna	III		3	10	5	1	1	3	1		3
Polychaeta	Perinereis vallata	Infauna	III			9	4	6	2	1	3	13	11
Polychaeta	Prionospio aucklandica	Infauna	III							1			
Polychaeta	Scolecolepides benhami	Infauna	IV	134	137	244	142	424	222	121	254	215	117
Polychaeta	Simplisetia simplisetia-A	Infauna	III									2	2

APPENDIX 5. ASSOCIATIONS BETWEEN MACROFAUNA AND SEDIMENT QUALITY

A. Macrofauna richness (S) and abundance (N) associations with key sediment variables based on Spearman rank correlation. Trace metals not included due to absence of data for 2016, the very low concentrations recorded, and the high correlation with %mud and %TOC.



SALT ECOLOGY

B. Macrofauna composition associations (Spearman rank correlation) with key sediment variables based on multivariate Bio-Env procedure in Primer v7.0.13. Trace metals not included for reasons described in A.

All sites	Whar-A	Whar-B
0.405 aRPD	0.437 aRPD	0.357 aRPD
0.130 TN	0.201 TOC	0.123 sand
0.075 sand	0.106 TP	0.121 mud
0.056 TP	0.042 sand	0.059 TOC
0.050 mud	0.037 mud	0.052 TP
-0.019 TOC	0.009 TN	-0.088 TN

APPENDIX 6. NATIONAL BENTHIC HEALTH MODEL RESULTS

National Benthic Health Model (BHM) results for GWRC estuaries provided by Dana Clark, Cawthron Institute.

For Whareama Estuary, no sediment metals data were available in 2016, so the fit of calculated Metals BHM scores could not be assessed in that year.

Table 1. Descriptive names and boundaries for Benthic Health Model (BHM) score categories.

BHM Group	Level of impact relative to other estuarine sites in New Zealand*	BHM score
1	Very low	1.0 to < 2.0
2	Low	2.0 to < 3.0
3	Moderate	3.0 to < 4.0
4	High	4.0 to < 5.0
5	Very high	≥ 5.0

* This is a relative measure of impact rather than an absolute measure of health.

Table 2. Absolute health boundaries for the National Metals Benthic Health Model (BHM).

Absolute health	Metals BHM score
Good	Less than 3.6
Fair	3.6 to < 4.8
Poor	4.8 or greater

Table 3. Raw BHM scores for GWRC estuaries. Whareama sites are designated as 'Whar'.

National Benthic Health Model (BHM) results for GWRC estuaries provided by Dana Clark, Cawthron Institute.

Site	MudBHM	MetalsBHM
Hutt-A-2010	4.2	3.5
Hutt-A-2011	4.0	3.4
Hutt-A-2012	4.4	3.3
Hutt-A-2017	3.5	3.1
Hutt-B-2010	3.6	3.1
Hutt-B-2011	3.8	3.0
Hutt-B-2012	4.2	3.1
Hutt-B-2017	3.6	3.4
Onep-A-2008	3.5	3.5
Onep-A-2009	2.9	3.2
Onep-A-2010	3.3	3.0
Onep-A-2015	3.5	3.5
Onep-A-2020	3.4	2.4
Onep-A-2022	3.1	2.8
Onep-B-2008	3.5	3.8
Onep-B-2009	3.4	3.7
Onep-B-2010	3.6	3.8
Onep-B-2015	3.3	3.2
Onep-B-2020	3.2	4.1
Onep-B-2022	2.8	3.5
Paua-A-2008	3.3	3.6
Paua-A-2009	3.3	3.2
Paua-A-2010	3.2	3.1
Paua-A-2015	3.5	3.4
Paua-A-2020	3.3	2.7
Paua-A-2022	3.2	3.0
Paua-B-2008	3.4	3.6
Paua-B-2009	3.4	3.7
Paua-B-2010	3.6	3.6
Paua-B-2015	3.5	3.0
Paua-B-2020	4.0	3.2
Paua-B-2022	4.2	3.5

Site	MudBHM	MetalsBHM
Waiw-A-2009	3.8	3.5
Waiw-A-2012	3.9	4.1
Waiw-B-2009	4.2	4.3
Waiw-B-2012	4.0	4.4
Whar-A-2008	5.5	3.5
Whar-A-2009	5.6	4.1
Whar-A-2010	4.6	2.9
Whar-A-2016*	5.4	3.1
Whar-A-2022	4.7	3.2
Whar-B-2008	5.0	3.2
Whar-B-2009	4.9	3.2
Whar-B-2010	4.8	2.7
Whar-B-2016*	5.4	3.1
Whar-B-2022	4.7	2.7
Wkne-A-2010**	3.7	3.3
Wkne-A-2011**	3.8	3.9
Wkne-A-2012**	4.1	4.1
Wkne-A-2017**	3.9	4.2

* Unable to test the fit with the Metals BHM but given the good fit in other years, the Metals BHM is considered appropriate for determining the level of metal impact at this site relative to other estuarine sites across New Zealand

** Poor fit with the Metals BHM and unable fit unable to be tested with the Mud BHM - these scores should not be used to determine the level of metal or sediment impact relative to other estuarine sites across New Zealand but can be used to track health at these sites through time

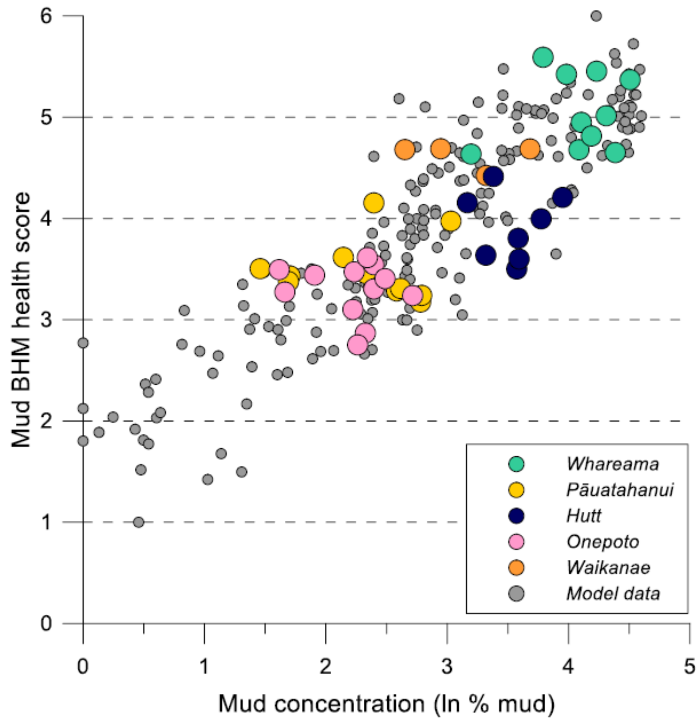


Figure 1. Comparison of Mud Benthic Health Model (BHM) scores from four Wellington estuaries (coloured circles) with those from sites used to develop the model (grey circles). Sediment mud content data were not available for the Waiwhetū sites, so the fit of these sites with the BHM data could not be tested. BHM scores range from 1 (least impacted) to 6 (most impacted) relative to other estuarine sites across New Zealand.

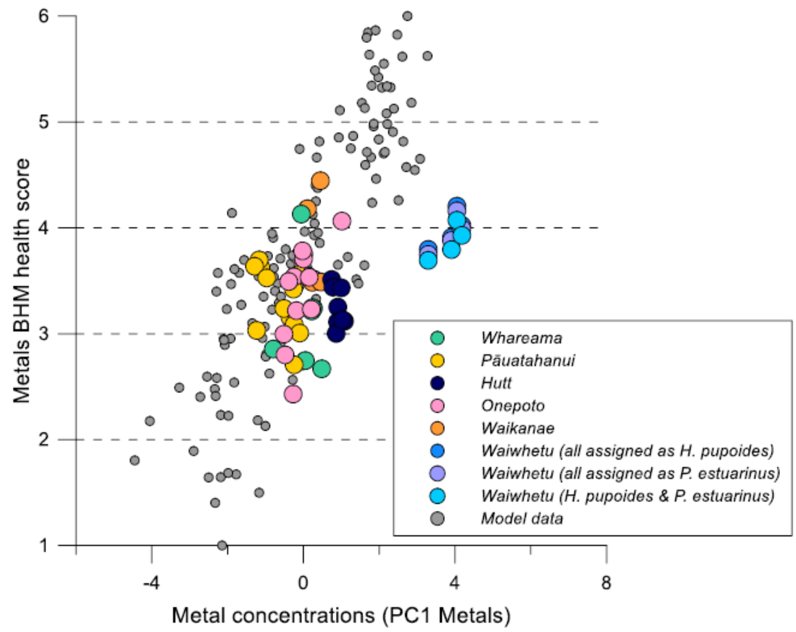


Figure 2. Comparison of Metals Benthic Health Model (BHM) scores from five Wellington estuaries (coloured circles) with those from sites used to develop the model (grey circles). Scores from Waiwhetū Stream estuary were calculated three different ways to assess the effect that differences in taxonomic resolution of *Halopyrgus pupoides* and *Potamopyrgus estuarinus* had on BHM scores. BHM scores range from 1 (least impacted) to 6 (most impacted) relative to other estuarine sites across New Zealand.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