SALT ECOLOGY

Fine Scale Intertidal Monitoring of Tautuku Estuary

Prepared for

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For the People
Mō ngā tāngata

Fine Scale Intertidal Monitoring of Tautuku Estuary

Prepared by

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for

Otago Regional Council

June 2022

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GLOSSARY

AMBI	AZTI Marine Biotic Index
ANZECC	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000)
ANZG	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018)
aRPD	Apparent Redox Potential Discontinuity
As	Arsenic
Cd	Cadmium
Cr	Chromium
Cu	Copper
DGV	Default Guideline Value
ETI	Estuary Trophic Index
Hg	Mercury
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 (SOE) programme, Otago Regional Council 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 Tautuku Estuary, conducted in November 2021. Tautuku Estuary is of special interest as a 'reference' estuary, as it is in an undeveloped catchment that is dominated by indigenous forest. The survey largely followed the 'fine scale' approach described in New Zealand's National Estuary Monitoring Protocol (NEMP), 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

- Sediment quality analyses revealed very low contaminant concentrations for most variables, consistent with the unmodified nature of the catchment. Sediments at one of the two sampling sites had a high mud content, which reflects its location in a depositional environment. There were no symptoms of eutrophication, such as a black, anoxic and sulphide-smelling sediment, and no excessive surface growths of opportunistic macroalgae.
- The diversity and abundance of surface epibiota and sediment-dwelling macrofauna were quite low at the sampling sites, which mirrored the situation for the estuary overall. The macrofauna comprised a resilient suite of species that are typical of estuarine habitats in strongly river-dominated environments (e.g. due to effects of low salinity water and hydrodynamic scouring).
- For most of the indicators measured, Tautuku Estuary is within the range of values recorded at other estuaries in the Otago region, and is most similar to other river-dominated locations, in particular the Shag, Waikouaiti and Tokomairiro estuary systems.

Overall, the fine scale survey, together with observations made across the wider estuary during broad scale habitat mapping, showed that the main unvegetated tidal flats (i.e. outside the areas of extensive salt marsh) of Tautuku Estuary are in a healthy condition, but are naturally impoverished in terms of the biota present. Whereas river flow is likely to be the main driver of estuary condition in the middle reaches where the fine scale sites are positioned, further towards the entrance the presence of mobile sand habitat appears to limit the establishment of a diverse and abundant macrofauna community, and is one of several natural processes that is likely to prevent the establishment of seagrass.

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 surveys will provide a comprehensive baseline for the long-term monitoring of ecological health in Tautuku Estuary. Although the unvegetated estuary flats are quite species-poor, Tautuku nonetheless provides an example of a reference estuary against which long-term changes in other, more modified, river-dominated estuaries within the region can be evaluated.

Summary of estuary condition based on key indicators

Site	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	14.8	45	< 500	367	0.39	7.6	0.012	7.7	3.1	2.0	< 0.02	5.0	20.6	4.5
B	49.2	27	833	427	1.17	6.0	0.020	9.4	4.8	3.0	< 0.02	6.4	29.3	4.4

< All values below lab detection limit

Condition rating key:

Very Good	Good	Fair	Poor

1. INTRODUCTION

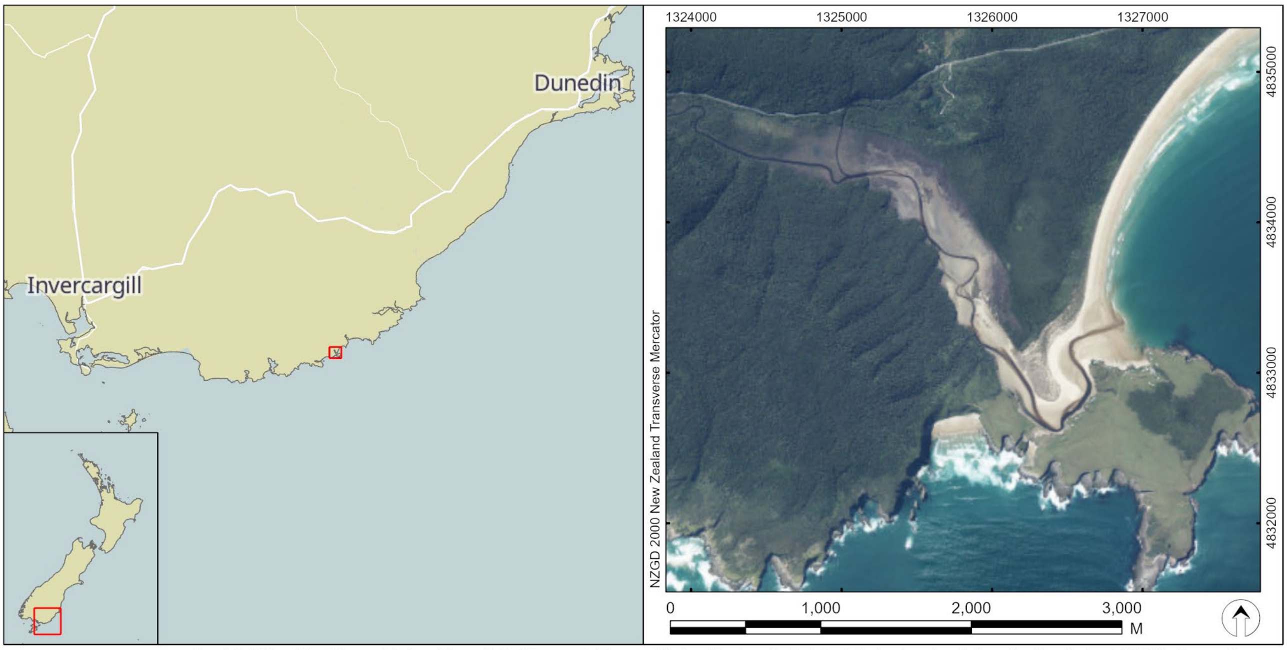
Estuary monitoring is undertaken by most councils in New Zealand as part of their State of the Environment (SOE) programmes. The most widely-used monitoring framework is that outlined in New Zealand's National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002). The NEMP is intended to provide 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 using these methods has been undertaken for several years, with key locations being Shag River, Waikouaiti, Kaikorai, Tokomairiro, Blueskin Bay and Catlins estuaries. ORC has recently expanded its SOE programme and in November 2021 added several other estuaries, one of which was the relatively unmodified Tautuku Estuary in the Catlins area of South Otago, ~140km from Dunedin (Fig. 1). In November 2021, Salt Ecology undertook a NEMP broad scale and fine scale survey in Tautuku 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 Tautuku Estuary and in relation to various criteria for assessing estuary health. The survey is intended as the first of three consecutive annual baseline surveys of Tautuku Estuary using the fine scale and sediment plate approach.



Map data © OpenStreetMap contributors, Microsoft, Esri Community Maps contributors, Map layer by Esri, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors, Esri, HERE, Garmin, FAO, NOAA, USGS

Fig. 1. Location of Tautuku Estuary.

2. BACKGROUND TO TAUTUKU ESTUARY

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

Tautuku Estuary is a medium sized (94ha) system defined as a shallow, intertidally dominated (~86%), tidal lagoon type estuary (SIDE). Tautuku was traditionally an important kāinga mahinga kai (food gathering settlement) for Māori. Archaeological sites on the Tautuku Peninsula have identified bones of moa, smaller birds, seals and fish (Hamel 2001). Two large blocks of land on the southern margin extending to the peninsula were set aside as Māori freehold land under the Native Land Court in 1868 and under the South Island Landless Native Act in 1906 (Ngāi Tahu Atlas). The land remains under the management of trustees with majority of it remaining in native bush cover.

From 1839 to 1846, a whaling station was located on Tautuku Peninsula (Hamel 2001; Prickett 2002) and later a port that was used for fishing, flax, and the timber industry. Sawmills near Tautuku processed rimu, maitai, miro, totara and kahikatea from 1901 through to 1950, with most of the logging occurring on the northern side of the estuary and in other parts of the catchment (see photo). It is unclear how much of the Tautuku catchment itself was actually logged or otherwise disturbed historically; however, our impression from available imagery is that the area was quite small. In the 1920's eight fishing boats were operating out of Tautuku and MacLennan, however they concluded by the 1930's because of 'silting up' in the rivers (Tyrrell 2016).

Historic location of sawmills close to the estuary margin

The present-day estuary drains a catchment of 6,186ha that is 97.9% densely vegetated, comprising 91.5% indigenous forest, 3.3% manuka and/or kanuka, and herbaceous freshwater (1.2%) and saline (1.1%) vegetation (Table 1; Fig. 2). Areas that have been previously modified are now regenerating indigenous forest, except for the Tautuku Peninsula where grassland dominates, and a small number of dwellings are present. The intact transition from native forest to wetland and estuarine salt marsh is uncommon in Otago and New Zealand. As such the wetlands and salt marsh are classified as regionally significant in the ORC Regional Plan: Water. The catchment is largely protected within the Catlins Conservation Park, Lenz Historic Reserve and Māori freehold land.

View up-river toward the indigenous forest catchment

The main freshwater inflow to the estuary is Tautuku River which starts in the Maclennan Ranges (Kā Pukemāeroero) in the Catlins and meanders through a native bush catchment for almost its entire length. Overall, the Tautuku River and smaller freshwater inputs represent ~30% of the total estuary volume (Plew et al. 2018). Water quality and ecological values in Tautuku River are classified as 'excellent' (Ozanne 2011). The river and estuary support a number of diadromous fish species (i.e. fish that migrate between fresh and salt water) including redfin bully, longfin and shortfin eel (tuna), whitebait (inanga) and lamprey (kanakana).

The broad scale survey report shows that 86% of the 94ha estuary area is intertidal. Intertidal sediments are sandy across most of the mid and lower estuary. Despite the relatively unmodified nature of the catchment, mud-dominated (≥50% mud content) sediments are common (~26% of the total intertidal area), particularly within salt marsh in the upper estuary and in deposition zones in the mid estuary. Nuisance macroalgal problems were not widespread; only a small, localised patch of macroalgae (*Agarophyton* spp.) was present in the mid estuary, associated with muddy sediments.

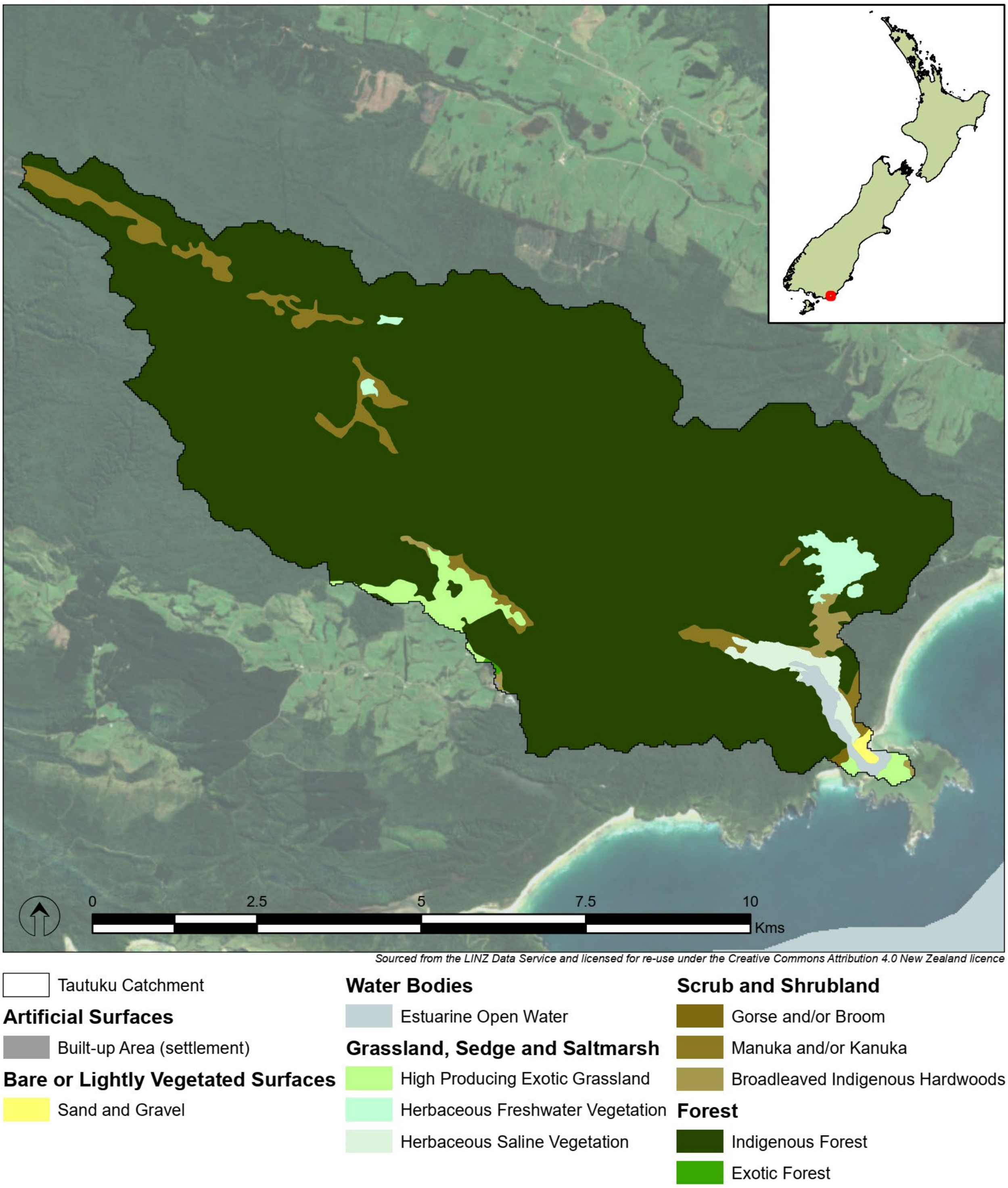
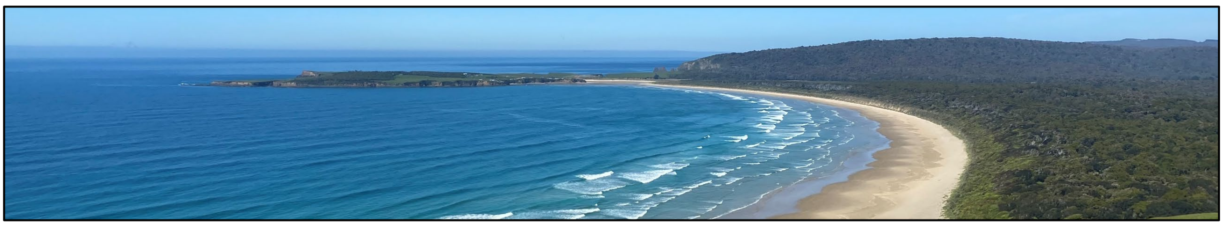


Fig. 2. Tautuku Estuary and surrounding catchment land use classifications from LCDB5 (2017/18) database.



Tautuku Bay looking toward the estuary entrance at the end of the beach surrounded by indigenous forest

Opportunistic macroalgae *Agarophyton* spp. in muddy upper estuary habitats

The most conspicuous vegetated habitats are extensive saltmarsh areas, which comprise ~43% of the estuary intertidal area, and consist mainly of rushland that is dominated by *Apodasmia similis* (jointed wirerush). No high value seagrass (*Zostera muelleri*) habitat was recorded during the broad scale survey, which is likely a reflection of natural limiting factors (e.g. substrate mobility, light limitation of tannin rich waters) discussed by Roberts et al. (2022).

Salt marsh habitat in the mid estuary

In 2016, a marine protected area with fishery restrictions was proposed for the Tautuku Estuary to protect black and yellow belly flounder (pātiki) and other wildlife (e.g. migratory birds such as spoonbills, pied oyster catchers and stilts; SEMPF, 2016). The estuary is also an important habitat for fernbird (mātātā) a threatened (nationally vulnerable) wetland bird on the South Island.

Overall, Tautuku estuary represents an example of a reference estuary surrounded by indigenous forest, wetland and salt marsh. Moore (2015) described the saltmarsh and estuarine communities as 'pristine' from an ecological perspective. Because the estuary retains very high ecological, cultural, and social values it is classified as a coastal protection area in the Otago Regional Plan: Coast.

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 TAUTUKU ESTUARY FINE SCALE AND SEDIMENT PLATE SITES

The broad scale survey revealed extensive sand flats across much of Tautuku Estuary. However, an appraisal of these areas indicated that the sediments were relatively mobile and contained a very low diversity and abundance of biota. As such, the placement of the fine scale sites was constrained to the muddier habitats of the mid estuary near the viewing platform (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 left side of Tautuku River ~400m downstream of the viewing platform, with Site B placed opposite the platform on the true right of the river. 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 (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 30 Nov and 1 Dec 2021. On the days of sampling, predicted low tides at Tautuku entrance were 0.4-0.5m occurring at ~0600 and 1800 (tides.niwa.co.nz), with a lag of ~2-3 hours observed at the sampling sites.

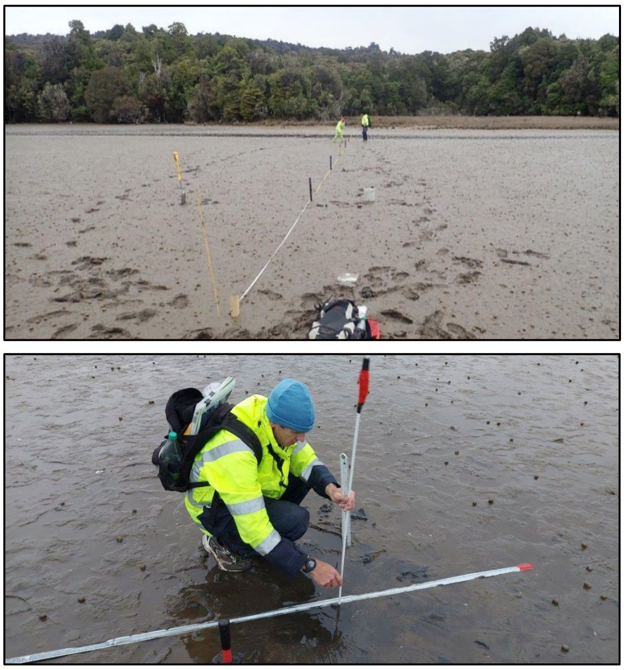
3.3 SEDIMENT PLATES

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 ~50-100mm deep 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.

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



Installing sediment plates at Site A (top) and measuring sediment plate depths (bottom)

3.4 FINE SCALE SAMPLING AND BENTHIC INDICATORS

Each fine scale site was divided into a 3 x 3 grid of nine plots (see Fig. 3). Fine scale sampling for sediment indicators was conducted in each plot, with Fig. 3 showing the standard numbering sequence for replicates at both sites, and the designation of zones X, Y and Z (for compositing sediment samples; 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, alterations and additions to early NEMP methods 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 provided 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 depth 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.

Measuring aRPD of a sediment core

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.

Collecting sediment cores for macrofauna and aRPD assessment

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 macrofauna 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 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


A mud snail (*Amphibola crenata*), Site A

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 as appropriate (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 (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 either fourth-root or presence-absence transformed to down-weight the influence on the ordination pattern of the dominant organisms. 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 and zones, 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 Tautuku 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.

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. (2016b) 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.

Rinsing macrofauna samples in the subtidal channel near the viewing platform

4. KEY FINDINGS

4.1 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.

4.2 SEDIMENT QUALITY

4.2.1 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 sand-dominated sediments at Site A (mean 14.8%) and relatively muddy sediments at Site B (mean 49.2% mud; Fig. 4).

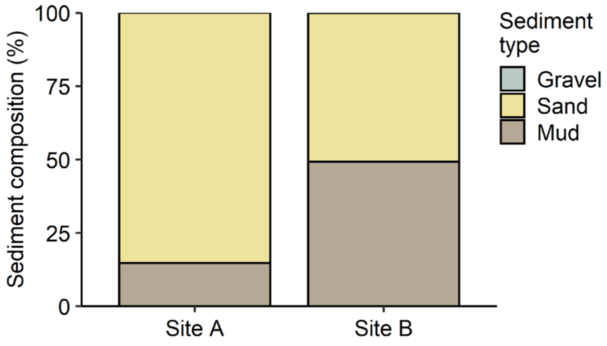


Fig. 4. Mean (n=3) sediment grain size in composite samples. Size fractions are mud (<63µm), sand (≥63µm to <2mm) and gravel (≥2mm).

To provide a visual impression of sediment quality relative to the Table 3 condition ratings, Fig. 5 compares the mean percentage mud content, total organic carbon (TOC) and total nitrogen (TN) from composite samples against the rating thresholds. Site B is rated 'poor' for mud, reflecting exceedance of the biologically relevant threshold of 25%. Elevated levels of TOC and TN at Site B relative to Site A reflect this higher mud content, although ratings were 'fair' and 'good' respectively. Levels of the nutrient total phosphorus (TP) were also elevated at Site B relative to Site A, although values at neither site were especially high, with a maximum of 440mg/kg (Appendix 4).

4.2.2 Sediment oxygenation

No signs of excessive sediment enrichment were evident in the sediment core profiles at either site (Fig. 6, see also photos in Fig. 7). Baseline aRPD values ranged from 40-55mm at Site A and 20-35mm at Site B, which in both cases correspond to a condition rating of 'good' (Fig. 6). The deeper aRPD at Site A reflects the relatively sandy sediments, which enable deeper oxygen penetration. However, the aRPD was at times indistinct, for example due to sediment mixing by invertebrates (e.g. Fig. 7, Site B-X).

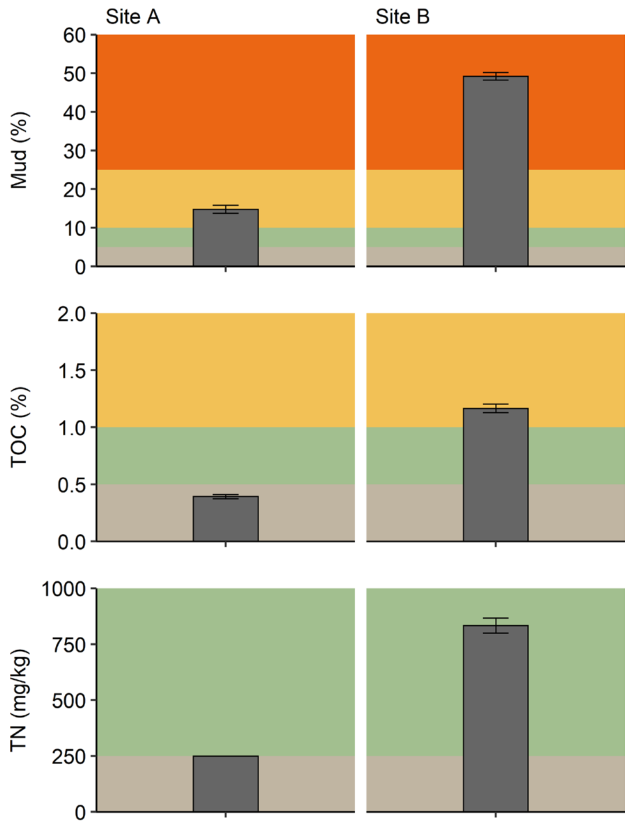


Fig. 5. Mean (±SE, n=3) sediment %mud, total organic carbon, and total nitrogen relative to condition ratings.

Condition rating key:

Very Good	Good	Fair	Poor

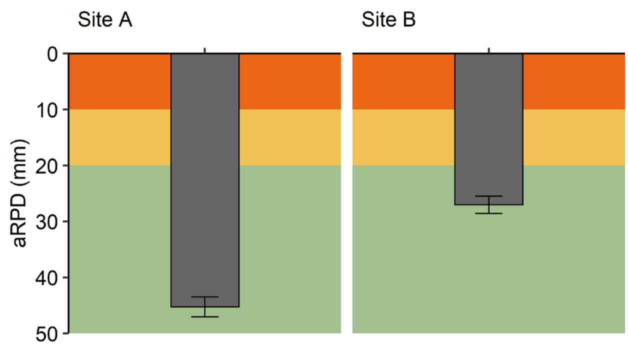


Fig. 6. Mean (±SE, n=3) aRPD relative to condition ratings. Rating key as per Fig. 5.

4.2.3 Trace contaminants

Plots of trace contaminants in relation to condition ratings are provided in Fig. 8 (see also Appendix 4). 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.

Extracted sediment core

Firm, sand-dominated sediments at Site A

Soft and relatively muddy sediments at Site B

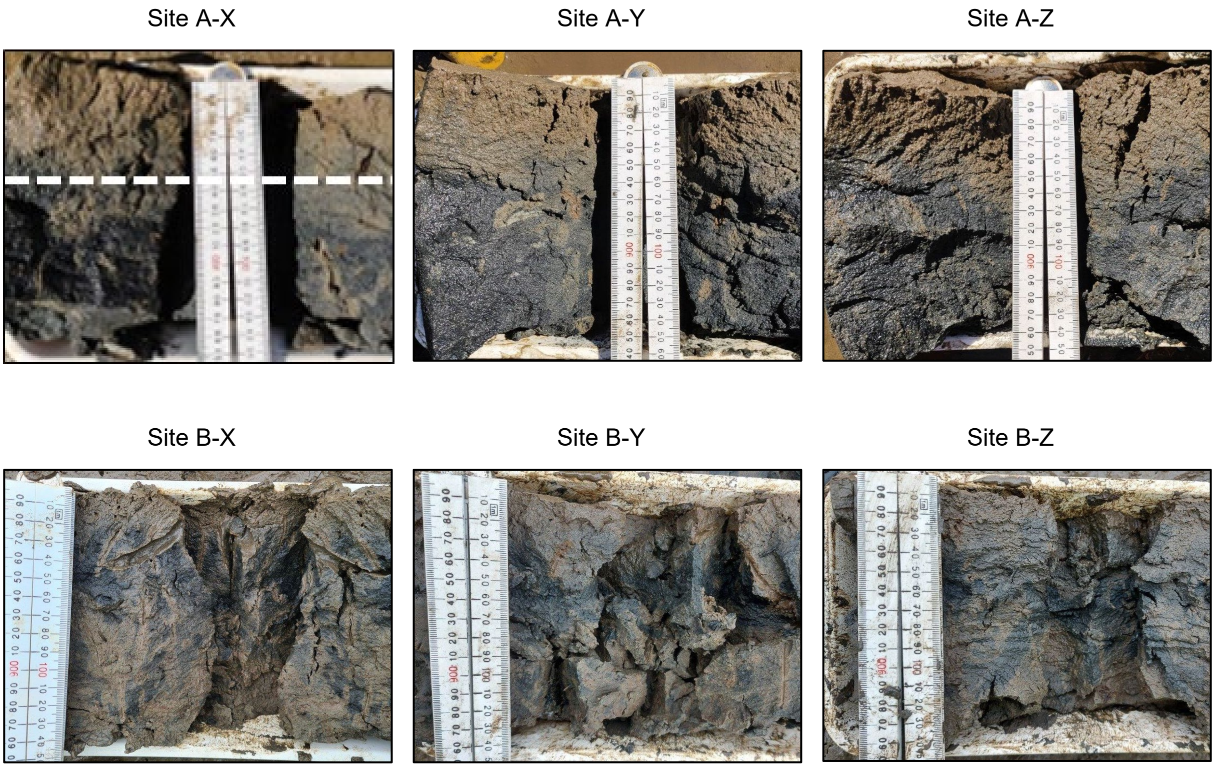


Fig. 7. Example sediment cores from the fine scale sites A and B. To illustrate the approximate depth of the aRPD, a dashed white line is shown on the zone X core from Site A.

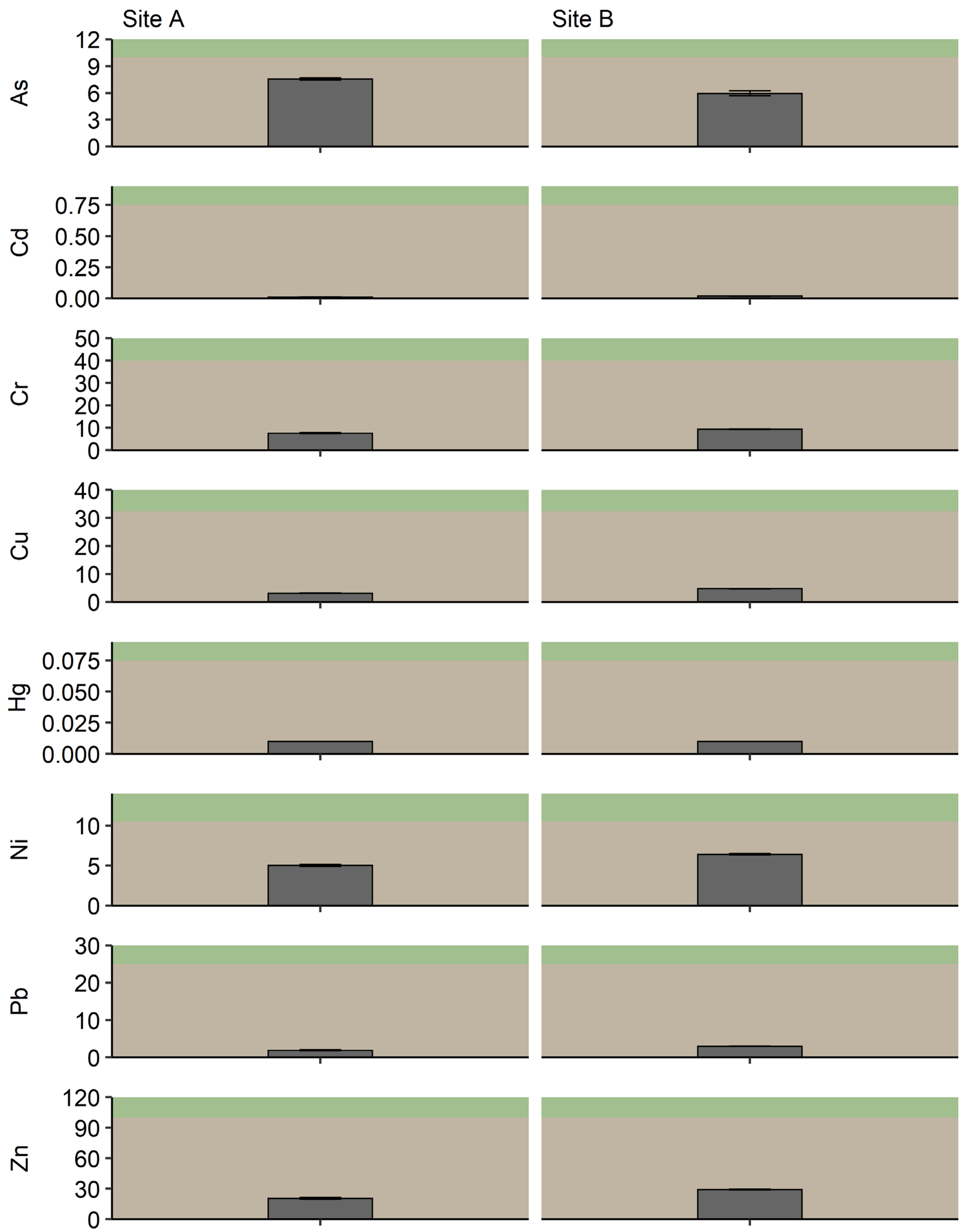


Fig. 8. Mean (±SE, n=3) trace contaminant concentrations relative to condition ratings. The boundary between grey ('very good' condition) and green ('good' condition) corresponds to half of the ANZG (2018) sediment quality Default Guideline Value for 'possible' ecological effects.

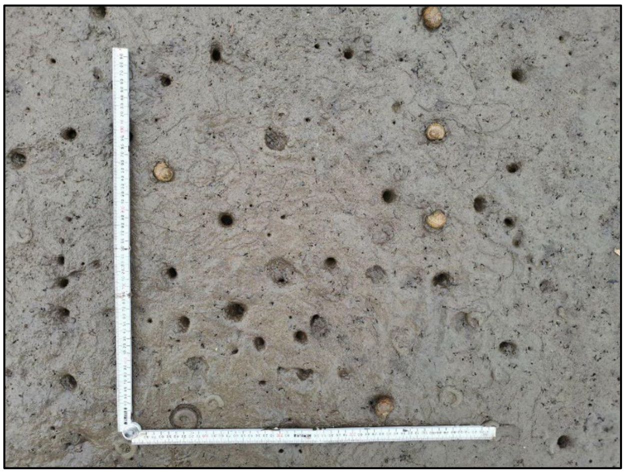
Condition rating key:

Very Good	Good	Fair	Poor

4.3 MACROFAUNA

4.3.1 Conspicuous surface epibiota

Results from the site-level assessment of surface-dwelling invertebrates and macroalgae are shown in Table 4. The epibiota at the two Tautuku Estuary sites was sparse. Macroalgae were absent, and only two invertebrate species were recorded. Most conspicuous were mud snails (*Amphibola crenata*), with occasional mud whelks (*Cominella glandiformis*) also present. This situation mirrored the wider estuary, as very little epibiota were observed during the broad scale survey.



Mud snails were conspicuous at both sites, and rated as common at Site B. Numerous holes reflect burrowing by mud crabs and amphipods.

4.3.2 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-poor. A total of eight main taxonomic groups was present, with only 20 macrofaunal taxa sampled in total. Of these 20 taxa, 15 were present at Site A and 14 at Site B (see Appendix 5). Mean species richness was very low, being ~6-7 taxa per core sample (Fig. 9a). By contrast, mean organism abundances were quite high, and considerably higher at Site A (453/core) than Site B (132/core) (Fig. 9b).

The representation of organisms in terms of the five AMBI EGs is shown in Fig. 10. Although all EGs were represented across the species mix, their abundances were dominated by EG IV (i.e. tolerant) organisms, with sub-dominant taxa spanning EG III to V. Accordingly, mean values of the biological index AMBI were quite high at both sites - index values of ~4.5 out of a maximum score of 7 correspond to a 'poor' rating against the New Zealand ETI criteria (Fig. 11).

By far the most abundant organism was *Paracorophium* sp. As described in Table 5, this species belongs to a group of opportunistic tube-dwelling, burrowing amphipods that can occur in high densities in mud and sand habitats, often in estuaries subjected to disturbance and freshwater influence.

Table 4. SACFOR scores for epibiota based on the scale in Table 2. Specimen photos provided by NIWA. Dash = not recorded.

Species	Common name	Functional description	Image	Site A	Site B
Amphibola crenata	Mud snail	Detritus and deposit feeder		F (6-9/m^2)	C (11-28/m^2)
Cominella glandiformis	Mud whelk	Carnivore and scavenger		O (0.1/m^2)	-

Table 5. Description and site-aggregated abundances of the most commonly occurring sediment-dwelling macrofauna. Specimen photos provided by NIWA. Pink colour due to a vital stain.

Main group, species & eco-group	Site A	Site B	Description	Image
Amphipoda, *Paracorophium* sp. EG IV	3912	978	Shrimp-like corophioid amphipods are opportunistic tube-dwelling, burrowing species that can be abundant in mud and sand habitats, often in estuaries subjected to disturbance and low salinity water.	
Bivalvia, *Arthritica sp. 5* EG III	84	78	A small sedentary deposit feeding bivalve that lives buried in the mud. Tolerant of muddy sediments and moderate levels of organic enrichment.	
Decapoda, *Austrohelice crassa* EG-V	0	8	Endemic, burrowing mud crab. Concentrated in well-drained, compacted sediments above mid-tide level. Highly tolerant of high silt/mud content.	
Oligochaeta, Oligochaeta spp. EG V	10	7	Segmented worms in the same group as earthworms. Deposit feeders that are generally considered pollution or disturbance tolerant.	
Polychaeta, *Capitella* cf. capitata EG V	4	30	Subsurface deposit feeding worm that is highly tolerant of disturbed or harsh conditions.	
Polychaeta, *Nicon aestuariensis* EG III	3	14	Deposit feeding omnivorous worm that is tolerant of freshwater.	
Polychaeta, *Scolecolepides benhami* EG IV	42	56	A spionid, surface deposit feeder. It is rarely absent in sandy/mud estuaries.	

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

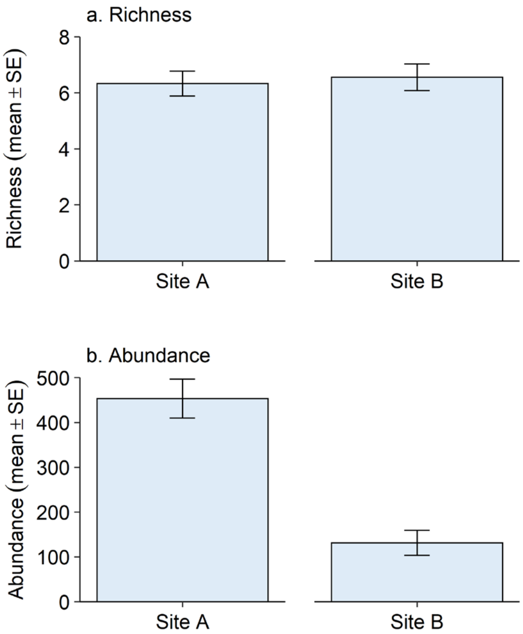


Fig. 9. Mean (± SE, n=10) taxon richness and abundance per core sample.

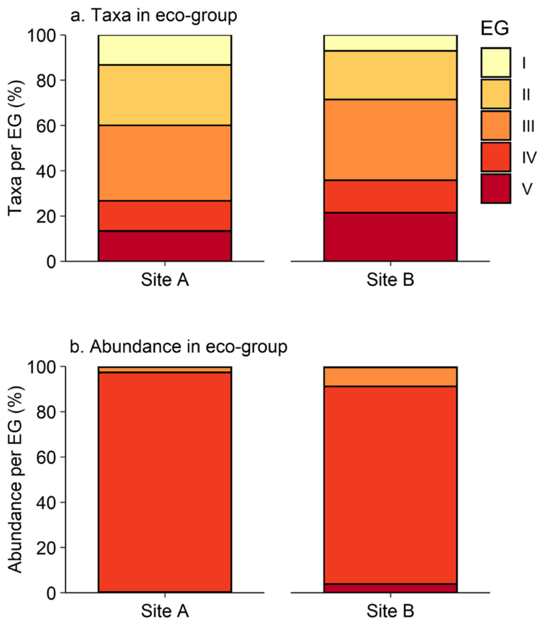


Fig. 10. Site-level data showing the number of taxa and abundance of organisms within eco-groups ranging from sensitive (EG-I) to tolerant (EG-V).

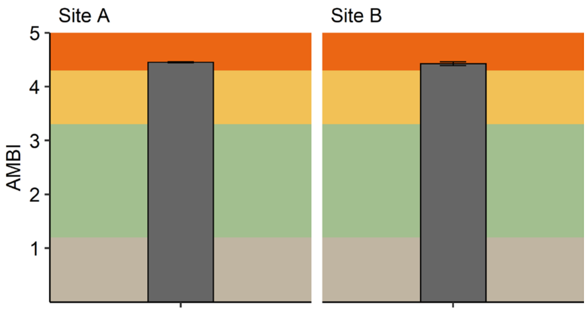


Fig. 11. Mean (± SE, n=10) AMBI scores compared with condition rating criteria.

Condition rating key:

Very Good	Good	Fair	Poor

Abundances of other organisms were low in comparison to *Paracorophium* sp., but two additional species that were nonetheless reasonably numerous were the deposit-feeding polychaete worm *Scolecolepides benhami* and the small bivalve *Arthritica* sp. 5. Note that the latter species is the same as that referred to in other ORC reports as *Arthritica* sp. 1 or *Arthritica* cf *bifurca*; the sp. 5 designation is based on the voucher specimens held by NIWA. Other hardy species present included mud crabs (*Austrohelice crassa*)., oligochaete and capitellid worms, and the freshwater-tolerant worm *Nicon aestuariensis*.

The overall mix of hardy and/or freshwater-tolerant species suggests that despite being relatively pristine in terms of anthropogenic influences, the Tautuku Estuary fine scale sites are subject to natural stressors. Most important is likely to be the influence of the Tautuku River, which reflects the mid estuary location of the sites and relatively confined nature of the tidal flats in that area. Elsewhere in the Otago region, species of *Paracorophium* are particularly abundant in freshwater-dominated habitats in the Tokomairiro, Waikouaiti and Kaikorai estuaries (e.g. Forrest et al. 2020a, b).

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.

Significance tests based on the PERMANOVA procedure indicated significant compositional differences between sites in the case of both relative abundance (i.e. fourth-root transformed) data (Pseudo-F=8.28, p= 0.002) and presence-absence data (Pseudo-F=6.03, p=0.003). Hence, the compositional differences reflect both shifts in dominance and small differences in the actual species present. For example, there were 5 species or higher taxa present at Site A that were not recorded at Site B, and 4 at Site B not recorded at Site A (Appendix 5). However, 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) .

Nonetheless, it is likely that the compositional differences between the two sites are to some extent related to their environmental differences. Analysis of association between macrofaunal composition and sediment quality revealed that mud content was highly correlated with composition patterns (Spearman rank correlation, ρ=0.71), and was itself closely correlated (ρ ≥ 0.95) with the three trophic state variables: aRPD, TOC and TN. This result is consistent with various studies showing that sediment mud content and 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). Fig. 13b illustrates the relatively greater mud content of the sediment at Site B as described above. Note that trace metal concentrations were also highly correlated with sediment mud content, but causal influences on sediment biota were not considered likely given their very low concentrations relative to ANZG (2018) guidelines.

Mud snails (*Amphibola crenata*) and native bush catchment

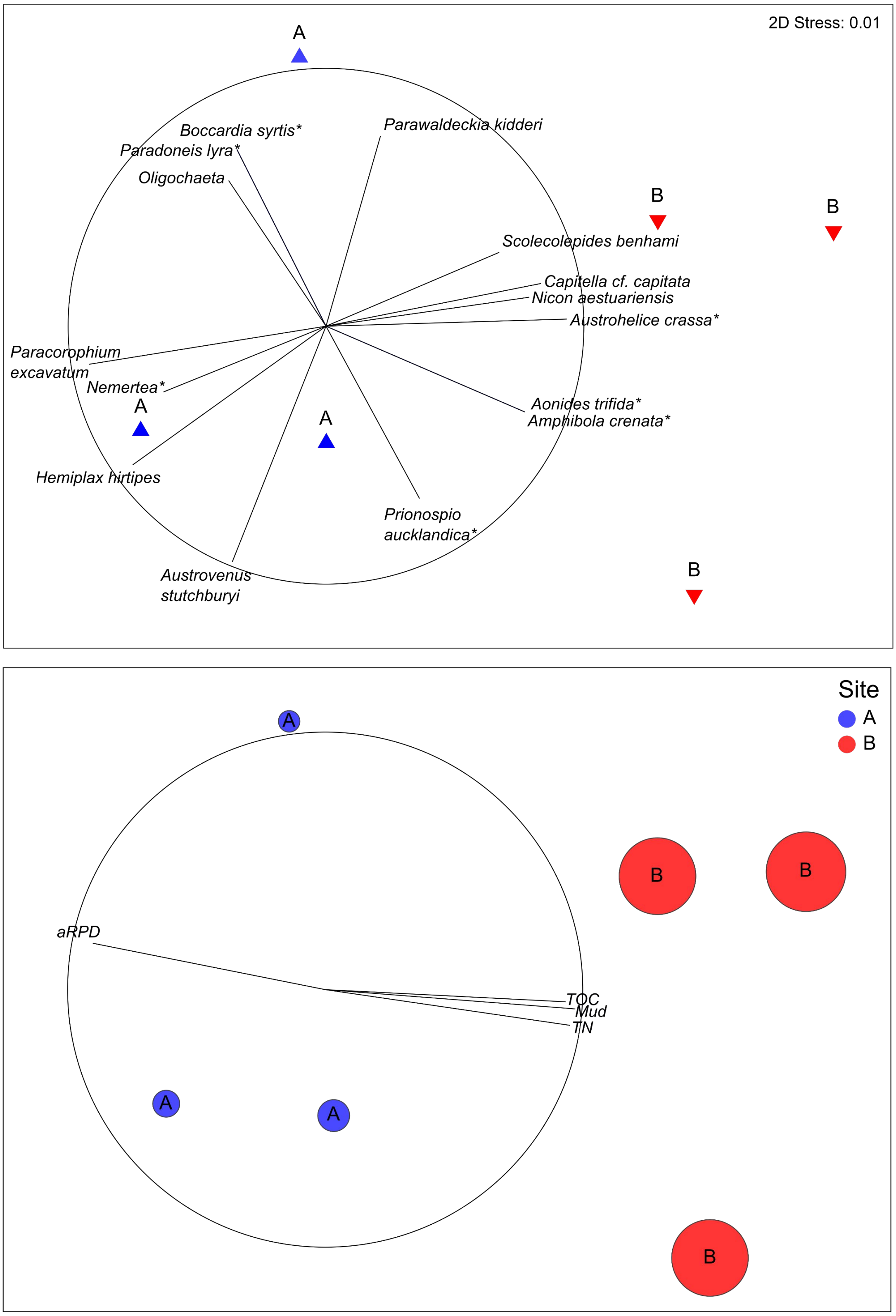


Fig. 12. Non-metric MDS ordination of macrofaunal core samples aggregated within sampling zones at each site.

The three zones at each site are placed such that closer ones are more similar than distant ones in terms of macrofaunal composition. The low 'stress' value indicates that a 2-dimensional plot provides an accurate representation of differences. Samples aggregated within zone and site were ~78% similar, as measured by the Bray-Curtis index, with a between site similarity of ~65%. 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 mud content, which was the sediment quality variable 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 Tautuku Estuary, largely following the fine scale methods described in New Zealand's National Estuary Monitoring Protocol (NEMP) with method extensions as described above in Table 1. Sediment plates installed at the time of the survey will be monitored in the future to determine annual sedimentation rates.

Tautuku Estuary is regarded as a potential 'reference' estuary against which anthropogenic influences in other regional or national estuaries can be benchmarked. The largely unmodified nature of the estuary was highlighted by the broad scale survey, although that survey also highlighted some atypical and unexpected ecological features, such as the absence of seagrass *Zostera muelleri*, and near-absence of epibiota such as macroalgae and invertebrates. This situation was attributed to factors such as tannin-stained water (limiting light for seagrass photosynthesis), reduced available intertidal habitat because of an extensive salt marsh, and the mobility of the substrates in the mid and lower estuary.

Substrate mobility, and field observations of an impoverished infauna in the mid-lower estuary (see Appendix 8 in Roberts et al. 2022), meant the choice of suitable locations for establishing the fine scale survey sites was limited to a relatively narrow zone in the mid estuary where mud/sand tidal flats were present. Further upstream, tidal flats were largely absent, with the Tautuku River channel meandering through extensive areas of salt marsh.

In many respects the fine scale survey results illustrate the healthy, unmodified nature of the estuary, with Table 6 summarising the key physical and biological indicators against the condition rating criteria in Table 3. Ratings of 'good' or 'very good' in Table 6 highlights the very low concentrations of sediment contaminants, and the absence of symptoms of excessive nutrient or organic enrichment (indicated by aRPD). There were no superficial eutrophication symptoms such as black, anoxic and sulphide-smelling sediments, and no excessive surface growths of opportunistic macroalgae, such as can occur in degraded estuaries.

This situation was contrasted by soft, muddy sediments at Site B, which reflects natural depositional processes typical of depositional zones in estuary environments. The estimated flushing time for the estuary is ~4 days (Plew et al. 2018), meaning that the estuary has some capacity to retain fine sediments and sediment bound nutrients in deposition areas (see Roberts et al. 2022).

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	Site A	Site B
Mud	%	14.8	49.2
aRPD	mm	45	27
TN	mg/kg	< 500	833
TP	mg/kg	367	427
TOC	%	0.39	1.17
As	mg/kg	7.6	6.0
Cd	mg/kg	0.012	0.020
Cr	mg/kg	7.7	9.4
Cu	mg/kg	3.1	4.8
Pb	mg/kg	2.0	3.0
Hg	mg/kg	< 0.02	< 0.02
Ni	mg/kg	5.0	6.4
Zn	mg/kg	20.6	29.3
AMBI	na	4.5	4.4

< All values below lab detection limit

Condition rating key:

Very Good	Good	Fair	Poor

In addition to mud deposition (but unrelated), the macrofaunal assemblage was relatively impoverished and comprised a tolerant and resilient suite of species. As noted above, the species present are typical of estuarine habitats in strongly river-dominated environments (e.g. due to effects of low salinity water and hydrodynamic scouring). Nonetheless, for most of the indicators measured, Tautuku Estuary is within the range of values recorded at other estuaries in ORC's SOE programme (Fig. 14).

Biologically the macrofauna at Tautuku is more similar to other regional estuaries where river flows have a strong influence (especially Shag, Waikouaiti and Tokomairiro). These systems are subject to muddy sediment deposition, and are affected by influences from low salinity water and physical stress during flood events. Under these conditions, only the most resilient species can persist. By contrast, the estuaries with the most extensive stable tidal flats (i.e. Blueskin Bay and Pleasant River) are the most species-rich, and the urbanised systems such as Kaikorai Estuary are the most contaminated.

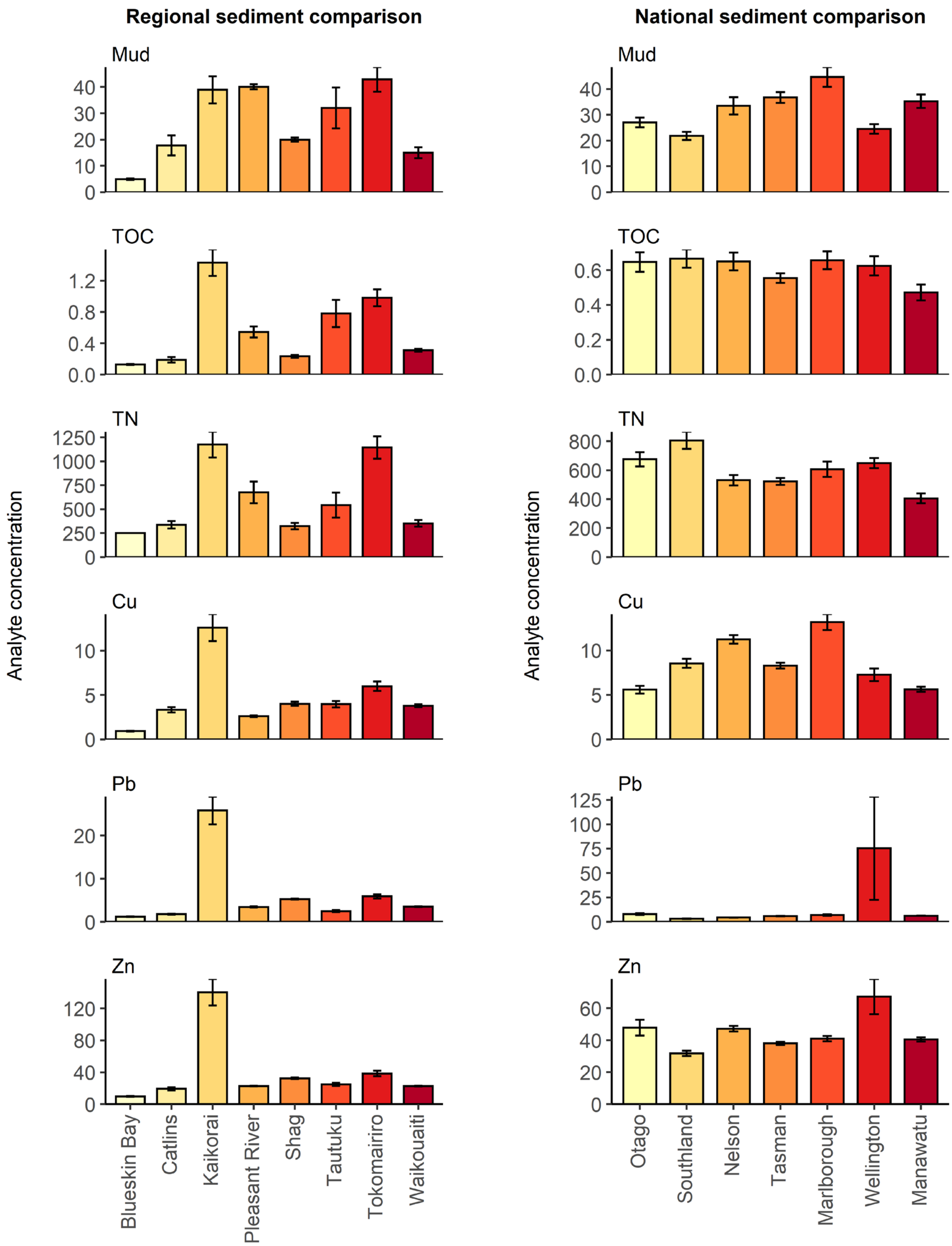


Fig. 13. Broad patterns in key sediment quality indicators, comparing Tautuku Estuary with other estuaries in the Otago region (mean ± SE for surveys pooled within estuary), and Otago estuaries collectively against other regions of New Zealand (mean ± SE for estuary surveys pooled within region). Analyte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

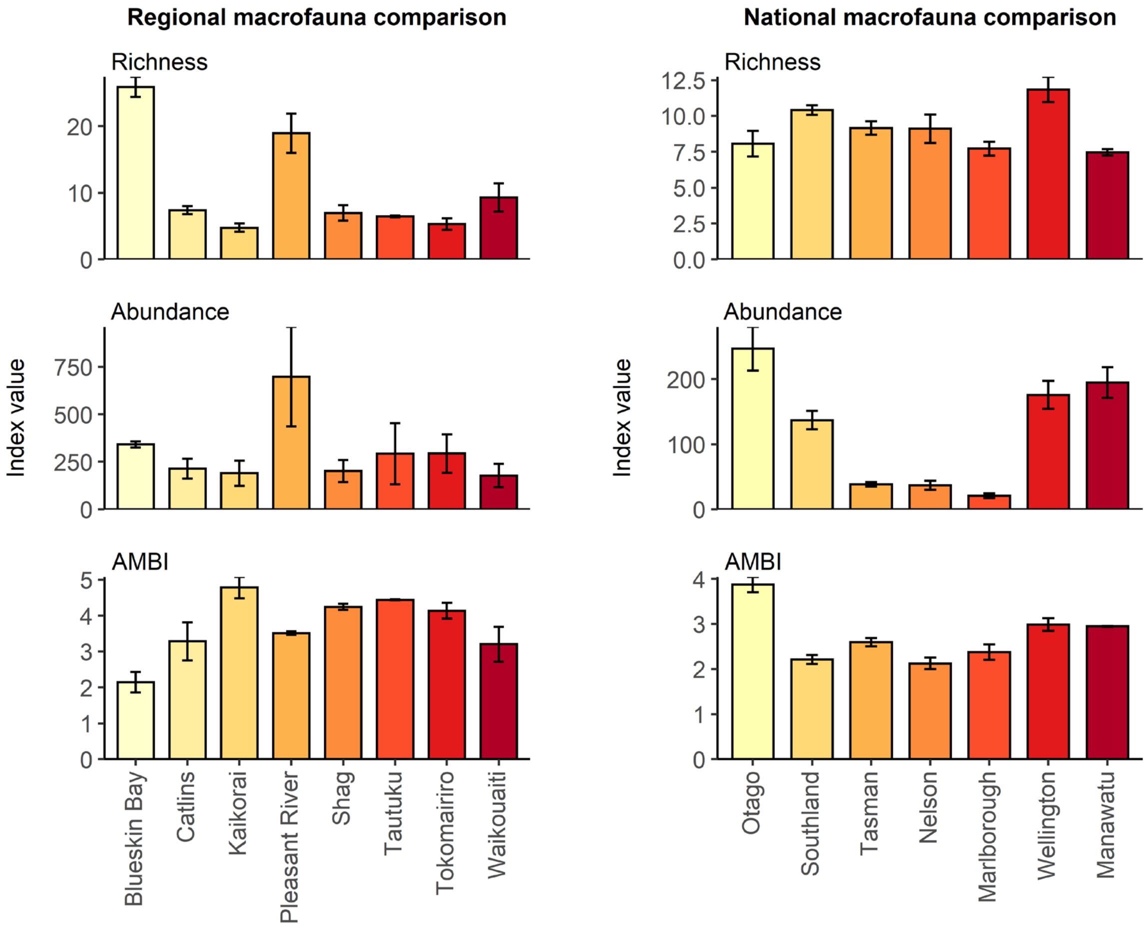


Fig. 14. Broad patterns in key macrofaunal indicators, comparing Tautuku Estuary with other estuaries in the Otago region (mean ± SE for surveys pooled within estuary), and Otago estuaries collectively against other regions of New Zealand (mean ± SE for estuary surveys pooled within region).

Overall, the fine scale survey, together with observations made across the wider estuary during broad scale habitat mapping, showed that the main unvegetated tidal flats (i.e. outside the areas of extensive salt marsh) of Tautuku Estuary are in a healthy condition, but are naturally impoverished in terms of the biota present. Whereas river flow is likely to be the main driver of estuary condition in the upper reaches where the fine scale sites are positioned, further towards the entrance the presence of mobile sand habitats appears to limit the establishment of a diverse and abundant macrofauna community, and is one of several natural processes that is thought to prevent the establishment of seagrass.

5.2 RECOMMENDATIONS

It is recommended that the two additional surveys planned for 2023 and 2024 are completed. Together with data gathered from changes in sediment plate depth, the surveys will provide a comprehensive baseline for the long-term monitoring of ecological health in Tautuku Estuary. Although the unvegetated estuary flats are quite species poor, Tautuku Estuary nonetheless provides an example of a reference estuary against which long-term changes in other more modified river-dominated estuaries in Otago can be evaluated.

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

FINE SCALE SITES

Site	Site	Peg	NZTM_E	NZTM_N
Taut-Otag	A	C1	1325720	4834016
Taut-Otag	A	C2	1325756	4833966
Taut-Otag	A	C3	1325730	4833948
Taut-Otag	A	C4	1325695	4833998
Taut-Otag	B	C1	1325425	4834155
Taut-Otag	B	C2	1325456	4834103
Taut-Otag	B	C3	1325431	4834088
Taut-Otag	B	C4	1325400	4834139

SEDIMENT PLATES

Site	Site	Peg/Plate	NZTM_E	NZTM_N
Taut-Otag	A	Peg1 (C1)	1325720	4834016
Taut-Otag	A	Plate 1	1325715	4834012
Taut-Otag	A	Plate 2	1325711	4834010
Taut-Otag	A	Peg2	1325707	4834008
Taut-Otag	A	Plate 3	1325702	4834005
Taut-Otag	A	Plate 4	1325699	4834001
Taut-Otag	A	Peg3 (C4)	1325695	4833998
Taut-Otag	B	Peg1 (C1)	1325425	4834155
Taut-Otag	B	Plate 1	1325421	4834152
Taut-Otag	B	Plate 2	1325417	4834149
Taut-Otag	B	Peg2	1325413	4834147
Taut-Otag	B	Plate 3	1325409	4834144
Taut-Otag	B	Plate 4	1325405	4834141
Taut-Otag	B	Peg3 (C4)	1325400	4834139

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 DATA

Date	Site	Sediment Texture	Sediment Type*	Mud (%)	Sand (%)	Gravel (%)	aRPD (mm)	Plate	Baseline Depth (mm)
1/12/2021	A	firm	MS10_25	16.1	83.9	<0.1	50	p1	95
1/12/2021	A	firm	MS10_25					p2	80
1/12/2021	A	firm	MS10_25					p3	78
1/12/2021	A	firm	MS10_25					p4	75
1/12/2021	B	soft	SM50_90	53.5	46.4	0.1	20	p1	60
1/12/2021	B	soft	SM50_90					p2	67
1/12/2021	B	soft	SM50_90					p3	63
1/12/2021	B	soft	SM50_90					p4	85

* MS10_25 = muddy sand with 10-25% mud, MS25_50 = muddy sand with >25-50% mud, SM50_90 = sandy mud sand with >50-90% mud.

APPENDIX 4. SEDIMENT QUALITY RAW DATA

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

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	2022	X	<0.1	87.1	13	0.37	<500	360	48.3 (40 to 55)	7.4	0.014	7.3	3.0	<0.02	4.8	1.8	19
		Y	<0.1	85.3	14.7	0.43	<500	380	40.7 (40 to 42)	7.8	0.011	7.9	3.2	<0.02	5.1	2.1	22
		Z	<0.1	83.4	16.6	0.38	<500	360	46.7 (45 to 50)	7.5	0.011	7.8	3.2	<0.02	5.2	1.9	21
B	2022	X	<0.1	51.7	48.2	1.13	900	440	26.7 (20 to 30)	6.4	0.018	9.7	4.9	<0.02	6.6	3.1	30
		Y	0.1	48.7	51.2	1.13	800	430	24.3 (23 to 25)	6.0	0.020	9.3	4.7	<0.02	6.3	3.0	29
		Z	<0.1	51.7	48.3	1.24	800	410	30.0 (25 to 35)	5.5	0.022	9.3	4.8	<0.02	6.4	2.9	29
									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	Paracalliope novizealandiae	Infauna	I		1							3									
Amphipoda	Paracorophium excavatum	Infauna	IV	297	248	317	423	592	482	554	395	604	107	27	218	46	57	229	88	42	164
Amphipoda	Parawaldeckia kidderi	Infauna	II	1														1			
Bivalvia	Arthritica sp. 5	Infauna	III	20	7	5	6	6	14	6	14	6	12	5	18	4	4	11	1	11	12
Bivalvia	Austrovenus stutchburyi	Infauna	II				1			1	1				2						
Decapoda	Austrohelice crassa	Infauna	V										1				3		2	2	
Decapoda	Hemiplax hirtipes	Infauna	III	1			1	2	1	3	1	1			2						
Gastropoda	Amphibola crenata	Epibiota	III										1					1			
Nemertea	Nemertea	Infauna	III						1												
Oligochaeta	Oligochaeta	Infauna	V	2			1	2	2	2		1				2	1		3	1	
Polychaeta	Aonides trifida	Infauna	I										1				1				
Polychaeta	Boccardia syrtis	Infauna	II		1																
Polychaeta	Capitella cf. capitata	Infauna	V		1						3		4		1	1	6	1	6	6	5
Polychaeta	Exogoninae spp.	Infauna	II													1					
Polychaeta	Nicon aestuariensis	Infauna	III	1		1					1		1	1	5		1	2	2		2
Polychaeta	Paradoneis lyra	Infauna	III	1	1																
Polychaeta	Prionospio aucklandica	Infauna	III												3						
Polychaeta	Sabellidae	Infauna	I		1																
Polychaeta	Scolecolepides benhami	Infauna	IV	2	5	7	6	5	5	3	5	4	6	5	4	6	7	10	3	5	10
Tanaidacea	Tanaidacea	Infauna	II							2											


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