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Fine Scale Intertidal Monitoring of Tokomairiro Estuary

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GLOSSARY

AMBI	AZTI Marine Biotic Index
ANZECC	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000)
ANZG	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018)
aRPD	Apparent Redox Potential Discontinuity
As	Arsenic
Cd	Cadmium
Cr	Chromium
Cu	Copper
DGV	Default Guideline Value
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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BACKGROUND

As part of its State of Environment programme, Otago Regional Council (ORC) monitors the ecological condition of significant estuaries in its region. Survey methods are based on the 'fine scale' methodology described in New Zealand's National Estuary Monitoring Protocol (NEMP), supplemented by assessment of sedimentation patterns with a 'sediment plate' method that is widely used in New Zealand estuaries. This report describes the methods and results of baseline surveys undertaken over the last three years (summer 2018, 2019 and 2020). Findings are compared with a similar investigation undertaken in 2009, the status and trends in estuary health are evaluated (see table at end of Executive Summary), and future monitoring needs are discussed.

KEY FINDINGS

The sites range from well-flushed mobile intertidal sands at Site A in the lower estuary, to mud-dominated sediments at Sites B and C in the mid and upper estuary. Key findings with respect to the fine scale indicators are as follows:

- Sedimentation: Sedimentation has been variable across the sites, with both erosion and accretion events evident over the previous three years. Whereas in the first year of monitoring at Site A there has been net erosion, the net sediment accretion relative to baseline has been 7mm or more in the last year at Sites B and C, which greatly exceeds a provisional 2mm/yr national guideline value. To varying degrees these results likely reflect a combination of local sediment redistribution (at Site A) and/or catchment-derived sediment deposition (Sites B and C). A longer time series of sediment plate monitoring will be required to elucidate long-term patterns in sedimentation rates.
- Sediment quality and trophic state: The table below highlights that trace metal concentrations at all sites were very low, suggesting there are no appreciable sources of chemical contaminants in the immediate catchment. Sediment quality overall was relatively good at Site A, with all indicators except AMBI rated as 'good' or 'very good'. At Site A this result reflects the relatively well-flushed sandy sediments at the site. By contrast, at Sites B and C sediment mud and enrichment or trophic state indicators were typically rated as 'fair' or 'poor', reflecting their elevated levels. For example, nutrient and TOC levels at Sites B and C were moderately high and the apparent redox potential discontinuity (aRPD) was shallow, reflecting poor oxygen diffusion coupled with microbial breakdown processes in the organically enriched sediments.
- Macrofauna: Visible epibiota (surface-dwelling animals and seaweeds) were few, and the macrofauna sampled from cores were species-poor. Nonetheless, core samples at all sites had very high organism abundances, which were mainly attributable to a tube-building and disturbance-tolerant amphipod, as well as a few subdominant species that differed among sites. Aside from site-to-site variation in the most common species, macrofaunal composition among sites (especially B and C) was reasonably similar. At Site A there was more pronounced year-to-year variation than at sites B and C.

An analysis of relationships between macrofauna and sediment quality variables revealed that some of the differences in core samples among sites and over time could be explained by their sediment mud content and aRPD depth. However, additional factors that are likely have a major biological influence are a dynamic hydrological environment and highly variable salinity regime, caused by variation in Tokomairiro River flows as well as tidal outflow restrictions at Toko Mouth where the estuary enters the sea. The mouth was being reopened at the time of the 2020 survey after a period of ~10 days compete blockage in which the water had 'backed up' and salinity was presumably relatively very low.

Overall, despite the estuary being muddy and moderately enriched at Sites B and C, there have been no substantive long-term changes that would indicate a deteriorating situation. Furthermore, the type of macrofauna species present, as well as their richness and abundance, are similar to other estuaries in ORC's NEMP programme, especially the river-dominated systems. In addition to an assessment of monitoring

findings, the report discusses some of the considerations for ongoing monitoring, which are reflected in the recommendations below.

RECOMMENDATIONS

1. Monitoring frequency and locations: Ongoing sedimentation ('sediment plate') monitoring should be continued annually, but it is sufficient to undertake fine scale sampling less frequently (e.g. every 5 years). Current sites B and C are adequate for monitoring purposes. Although they are not species-rich, they have a sufficient range of taxa to enable any ecologically significant environmental changes to be detected. Further sediment plate monitoring will help to determine whether Site A is sufficiently stable to be of value for long-term monitoring purposes.

2. Methods and indicators: In terms of the NEMP fine scale methodology and indicators, ORP measurements should be discontinued, as this indicator does not reliably reflect the trophic state of the sediment.

3. Optimising future monitoring: We recommend ORC develop a macrofaunal reference collection, to foster consistent and reliable taxonomic identification and data comparability across surveys. Sampling effort in future surveys requires further discussion but it is suggested that collection of nine macrofauna core samples per site will be adequate to capture ongoing changes.

4. Investigations of estuary state: It is suggested that ORC consider the possible causes of the currently degraded state in parts of mid-upper Tokomairiro Estuary (e.g. salinity and dissolved oxygen monitoring, source tracking of fine sediments), and identify any remedial actions that could be undertaken to improve condition. As part of such an assessment, the feasibility of improving estuary condition by maintaining flow through the outlet channel should be considered.

Summary of condition scores of ecological health based on mean values of key indicators (rating criteria not established for TP)

Site	Year	Mud %	TOC[1] %	TN mg/kg	TP mg/kg	aRPD mm	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg	AMBI na
A	2009	11.3	0.48	610	350	-	3.3	< 0.100	4.2	2.5	-	3.4	2.9	16.0	2.1
	2018	9.9	0.17	< 500	340	50	3.0	0.007*	3.1	1.9	< 0.02	2.8	2.1	10.9	5.3
	2019	9.0	0.22	367*	353	68	3.2	0.009*	3.7	2.2	< 0.02	3.2	2.3	13.3	2.3
	2020	11.1	0.31	333*	403	53	4.2	0.016	4.7	3.1	< 0.02	4.2	2.9	18.7	4.5
B	2009	43.8	0.89	930	410	-	4.1	< 0.100	8.9	5.3	-	6.8	5.5	37.0	1.8
	2018	64.6	1.55	1700	833	10	10.1	0.046	11.9	8.3	0.08	9.7	7.6	47.7	3.8
	2019	68.4	1.28	1667	643	5	6.9	0.050	12.6	7.5	0.03	8.5	7.5	50.7	4.3
	2020	60.6	1.44	1667	617	4	7.6	0.048	12.3	9.2	0.03	10.4	7.9	54.3	3.6
C	2018	56.3	1.49	1533	787	10	9.2	0.044	12.8	8.7	0.03	9.8	8.3	53.3	3.3
	2019	57.6	1.10	1300	590	4	6.2	0.039	12.7	6.4	0.03	7.3	7.5	49.0	4.4
	2020	58.2	1.47	1733	687	5	7.8	0.038	12.6	8.0	0.03	9.1	8.0	57.0	4.1

[1] *TOC in 2009 calculated from % ash free dry weight (AFDW) as TOC = 0.4xAFDW + 0.0025xAFDW2 (Robertson et al. 2002).*

** Sample mean includes values below lab detection limits*

< All values below lab detection limit

Condition rating key: Very Good | Good | Fair | Poor

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 provide a valuable basis for establishing 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.

One of the key additional methods that has been put in place after the NEMP being developed is 'sediment plate' monitoring. This component involves assessment (typically annually) 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.

Monitoring of selected estuaries in the Otago region has been undertaken using the above methods for several years, with a current focus on five locations. From north to south these are Shag River, Waikouaiti, Kaikorai, Tokomairiro and Catlins estuaries. The present report summarises the results of NEMP monitoring conducted in Tokomairiro Estuary (Fig. 1). In 2017, Otago Regional Council (ORC) initiated a series of three consecutive annual fine scale intertidal surveys that were intended to collectively provide a comprehensive 'baseline' against which future changes could be assessed. The first of these was conducted in the summer of 2017/18, alongside broad-scale habitat mapping (Robertson & Robertson 2018; Stevens 2018). ORC contracted Salt Ecology to conduct the second and third baseline surveys, which were undertaken in the summer of 2018/19 and 2019/20, respectively.

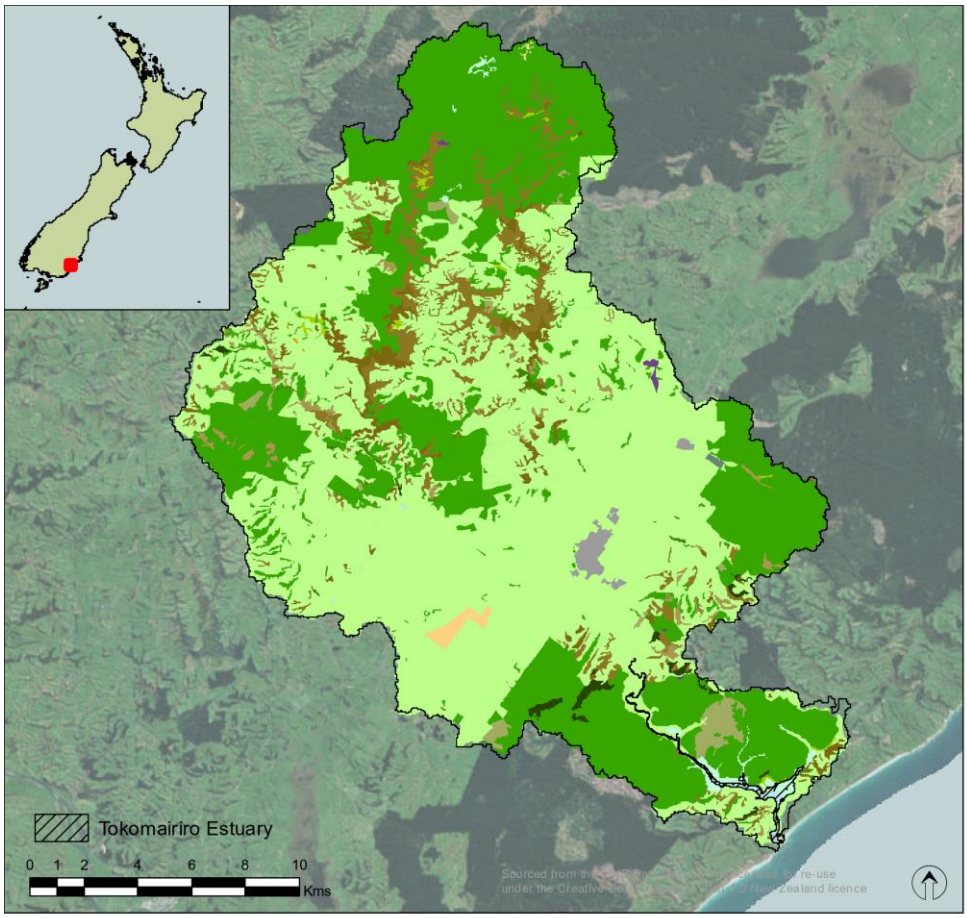
The following report describes the methods and results of all three surveys, and compares key findings with a 2009 synoptic survey (Stewart & Bywater 2009). The current status and long-term trends in estuary health are discussed, and recommendations made for future monitoring.

Fig. 1. Location of Tokomairiro Estuary.

2. BACKGROUND TO TOKOMAIRIRO ESTUARY

Background information on Tokomairiro Estuary described in Stevens (2018) is repeated here, with elaboration on the ecological state of the estuary based on the first fine scale survey (Robertson & Robertson 2018) and earlier 2009 assessment (Stewart & Bywater 2009).

The Tokomairiro Estuary is an elongated moderate-sized (150ha) tidal river estuary on the Otago south coast, ~16km southeast of Milton (Fig. 2). Prior to European settlement, parts of the Tokomairiro Plain were a wetland complex, although northern and eastern portions of the plain were dry grasslands. Subsequently, swampy parts of the plain were drained to allow for pasture development, and to further facilitate farming on the heavy peat soils, tile-mole drains were installed and are used extensively in the catchment. Hence, Tokomairiro Estuary once included large areas of estuary or flood plain that have subsequently been developed for farming.



Tokomairiro Catchment LCDB5 (2018)

Artificial Surfaces
- Built-up Area (settlement)
- Surface Mines and Dumps
- Transport Infrastructure
- Urban Parkland/Open Space

Bare or Lightly Vegetated Surfaces
- Sand and Gravel
- Landslide
- Alpine Grass/Herbfield
- Gravel and Rock
- Permanent Snow and Ice

Water Bodies
- Lake or Pond
- River
- Estuarine Open Water

Cropland
- Short-rotation Cropland
- Orchard Vineyard and Other Perennial Crops

Grassland, Sedge and Saltmarsh
- High Producing Exotic Grassland
- Low Producing Grassland
- Tall Tussock Grassland
- Depleted Grassland
- Herbaceous Freshwater Vegetation
- Herbaceous Saline Vegetation
- Flaxland

Scrub and Shrubland
- Fernland
- Gorse and/or Broom
- Manuka and/or Kanuka
- Broadleaved Indigenous Hardwoods
- Sub Alpine Shrubland
- Mixed Exotic Shrubland
- Matagouri or Grey Scrub

Forest
- Forest - Harvested
- Deciduous Hardwoods
- Indigenous Forest
- Exotic Forest

Fig. 2. Tokomairiro Estuary (hatched) and surrounding catchment land use classifications from LCDB5 database. The town of Milton is represented by the main grey shaded area.

The estuary has a catchment of 398km^2. The catchment is dominated by high- and low-producing grasslands on the Tokomairiro Plain and much of the surrounding hill country (Fig. 2). There are also substantial areas of exotic forest, and several small areas of native bush. Sheep, beef and dairying comprise the main catchment land use types, although since the late 1990s there has been a shift from sheep and beef farming to intensive dairy farming on the Tokomairiro Plain. The Milton Wastewater Treatment Plant discharges into the main stem of the Tokomairiro River at the confluence of the East and West Branches.

The Tokomairiro River is the main freshwater inflow to the estuary, with a mean flow of ~3.7m^3/s. The estuary discharges to the Pacific Ocean via a broad embayment at Toko Mouth. The mouth often has a constricted tidal flow and infrequently closes completely. The estuary itself extends ~12.5km up the valley from the mouth.

Historical monitoring of Tokomairiro River has shown that water quality is degraded, particularly in its lower reaches. The main channel of the upper-mid estuary can be poorly flushed at times, and the presence of deeper sections in the upper estuary can trap dense saline water under a surface layer of more buoyant freshwater, making the estuary susceptible to phytoplankton blooms. This situation is likely exacerbated by the presence of nutrients at levels exceeding eutrophication thresholds (Robertson & Robertson 2018).

In addition to water quality issues, previous assessments of sediment quality have described the estuary as being in a 'moderate' (i.e. moderately degraded) ecological state. Excessively muddy and enriched sediments have been described in mid-upper estuary areas, which likely in part reflects the flow restriction at Toko Mouth. Despite this situation, significant nuisance macroalgal growths have not been reported in previous surveys.

Despite the state of the estuary, ecologically, habitat diversity is moderate. Although large areas of the natural vegetated margin and saltmarsh have been lost through historical drainage and reclamation for grazing, saltmarsh remains a significant feature of the estuary (38% of area), and includes extensive areas of rushland, shrubland and herbfield. However, seagrass appears to be scarce, comprising <2ha of the intertidal area.

The Tokomairiro Swamp, located in the middle estuary, is listed as a 'Significant Wetland' by ORC, with a lot of shallow ponds in addition to tidal habitat. The extensive tidal flats provide excellent habitat for estuarine and freshwater fish and birds. Birds include very high numbers of pied stilt, and waterfowl species including the mallard, grey duck, New Zealand shoveller, grey teal, black swan, royal spoonbill, white faced heron, marsh crake and South Island fernbird. Fish include brown trout, whitebait/inanga, koaro, common smelt, eel, lamprey, common bully, redfinned bully, mullet, three species of flounder, and blue moki.

3. FINE SCALE METHODS

3.1 OVERVIEW OF NEMP APPROACH

The broad scale survey methodology provides a basis for selection of sites for fine scale monitoring. Broad scale surveys involve describing and mapping estuaries according to the dominant habitat features (substrate and vegetation) present. This procedure combines the use of aerial photography, detailed ground truthing, and digital mapping using Geographic Information System (GIS) technology. Once a baseline map has been constructed, changes in the position, size, or type of dominant habitats can be monitored by repeating the mapping exercise.

After an estuary has been classified according to its main habitats and their condition, representative habitats can be selected and targeted for fine scale monitoring. The NEMP advocates monitoring soft sediment (sand/mud) habitat in the mid to low tidal range of priority estuaries, although seagrass habitats or areas with high enrichment conditions are sometimes included.

The environmental characteristics assessed in fine scale surveys incorporate a suite of common benthic indicators, including biological attributes (e.g. macrofauna) and physico-chemical characteristics (e.g. sediment mud content, trace metals, nutrients).

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 above. These additional components are included in the present report.

3.2 TOKOMAIRIRO FINE SCALE AND SEDIMENT PLATE SITE INFORMATION

The history of NEMP sampling in Tokomairiro Estuary is provided in Table 1.

Three fine scale sites A-C (Fig. 3) were established in largely unvegetated mud/sand habitats in summer 2017/18 (on 16 December 2017), with resampling by Salt Ecology conducted on 23 February 2019 and 20 December 2019. These surveys are hereafter referred to as 2018, 2019 and 2020, respectively.

Present sites A and B correspond approximately to two sites (Sites 2 and 1, respectively) that were sampled by Stewart and Bywater (2009). Whereas Site B overlaps, Site A is across a channel from the original site, which has now been scoured out. Site C, further up the estuary channel, was established for the first time when the 2018 survey was undertaken. Each of sites A-C have sediment plates installed either along the upstream or downstream margin. This co-location of plates, in addition to providing information on patterns of sediment accretion and erosion, aids interpretation of physical and biological changes at the fine scale sites.

Table 1. Fine scale survey and sediment plate sampling information summarised from the detail in Appendix 1 and from separate information provided to ORC.

Site	Fine scale survey year[1]	Size (m)	Sediment plates		Notes
			Position	Installation	
A	2018, 2019, 2020	30 x 40	Upstream edge of FS site	No pegs and plates found in 2019, so site was reinstated at that time.	New site pegged in 2019 corresponding to reported position of site sampled in 2018. Adjacent to 'Site 2' (R2 on Fig. 3) sampled by Stewart and Bywater (2009), which had been washed away.
B	2018, 2019, 2020	15 x 20	Upstream edge of FS site	3 plates 2018, extra plate 2019	Overlaps 'Site 1' (R1 on Fig. 3) sampled by Stewart and Bywater (2009)
C	2018, 2019, 2020	15 x 40	Downstream edge of FS site	3 plates 2018, extra plate 2019	New site established in 2018 (Robertson & Robertson 2018)

[1] *Fine scale survey and sediment plate installation dates as follows: 2018 (16 Dec 2017), 2019 (23 Feb 2019), 2020 (20 Dec 2019)*

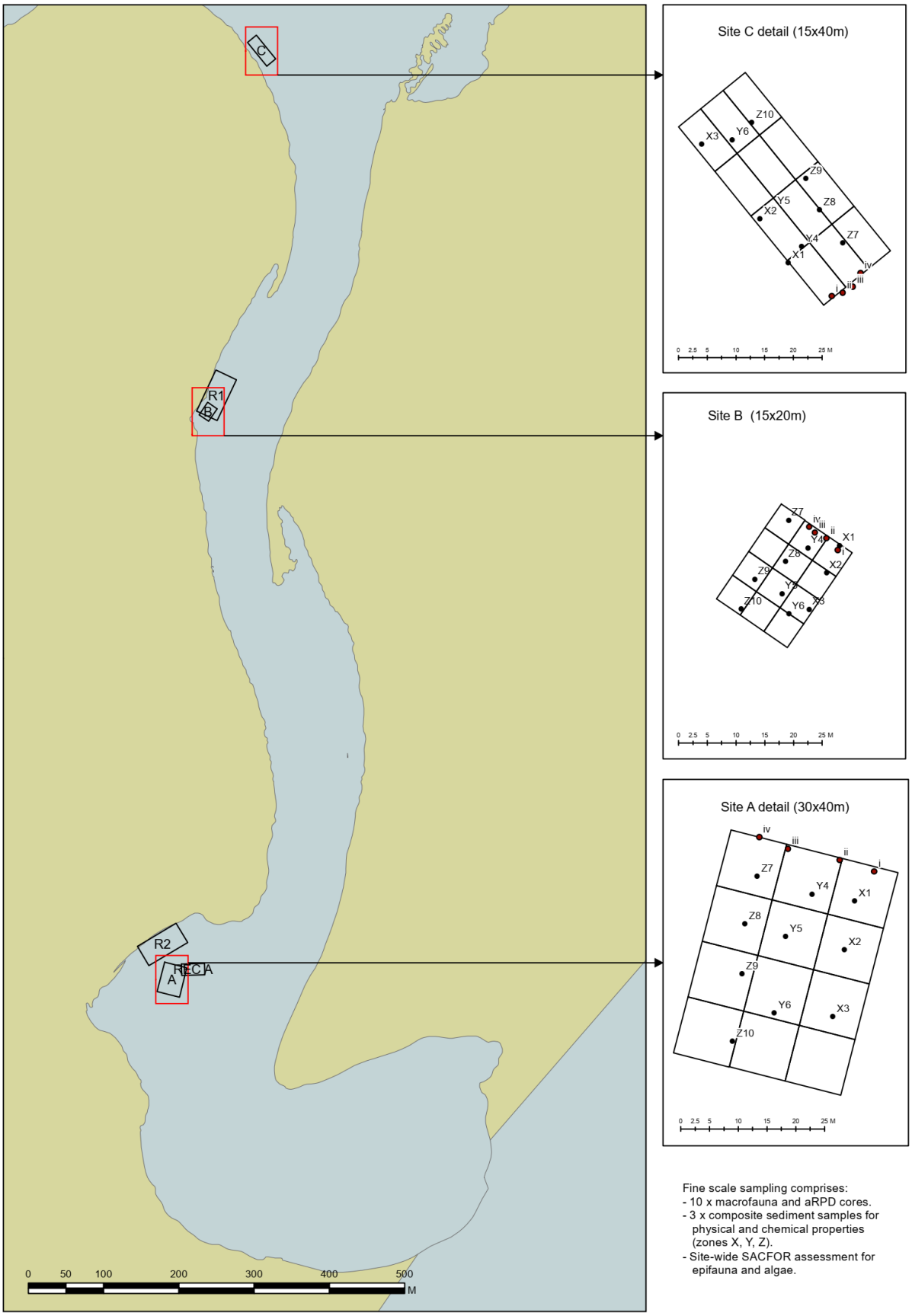


Fig. 3. Locations of sites A-C in Tokomairiro Estuary, and schematic illustrating fine scale monitoring and sediment plate methods (see also Appendix 1). R = sites sampled by Ryder Consulting in 2009 (Stewart & Bywater 2009).

Due to difficulties in relocating the site boundaries and sediment plates at the time of the first Salt Ecology survey in 2019, a separate document has been produced for ORC that provides details of fine scale site orientations and sediment plate locations. As a reference to aid future surveys, this information (including GPS positions) is summarised in Appendix 1. A schematic of the layout and sampling approach for fine scale and sediment plate monitoring is provided in Fig. 3, with methods detailed below.

Site A looking downstream

Site B looking upstream

Site C looking upstream

3.3 SEDIMENT PLATES AND SAMPLING

Concrete pavers (19 x 23cm) for sediment plate assessment were installed at Tokomairiro Estuary Sites A-C during the 2018 fine scale survey on 16 December 2017.

At the time of the 2019 survey pegs and sediment plates at Site A could not be relocated. As such, this site, including four sediment plates, was reinstated at the time of sampling. In addition, Sites B and C were missing their fourth sediment plate at the time of the 2019 survey, and an extra plate was installed at the time of the 2020 survey.

Sediment depths over each buried plate (from the sediment surface to the top of each plate) were measured at the time of plate installation, and at the time of each subsequent survey. Measurements were made by placing a 2.5m straight edge over each plate position (to average out any small-scale irregularities in surface topography), and the depth to each plate was measured (to the nearest mm) in triplicate by vertically inserting a measuring probe into the sediment.

3.4 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 sediment 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 benthic indicators, the rationale for their inclusion, and the field sampling methods, is provided in Table 2. Although the general sampling approach closely follows the NEMP, a recent review undertaken for Marlborough District Council (Forrest & Stevens 2019a) highlighted that 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 have adopted these modifications as indicated in Table 2.

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). 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

Table 2. Summary of NEMP fine scale benthic indicators, rationale for their use, field sampling method, and any differences with NEMP implemented in Tokomairiro Estuary surveys.

NEMP benthic indicators	General rationale	Sampling method and changes from NEMP where relevant
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
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
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. Arsenic and mercury also added in this study
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 (150mm deep) for each of 10 plots, split vertically, with depth of aRPD recorded in the field where visible
Oxidation redox potential (ORP) profiles	Quantitative instantaneous measure of redox state over a core depth profile, as a complement to aRPD. In theory, ORP values should sharply decline at a depth in the sediment that corresponds to the aRPD.	Not part of NEMP. 1 x 120mm diameter sediment core (150mm deep) for each of 3 plots, with ORP measured across core depth profile using field meter
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 (150mm deep) for each of 10 plots, sieved to 0.5mm to retain macrofauna
Epibiota	Abundance, composition and diversity of epifauna are commonly-used indicators of estuarine health	Abundance score based on ordinal SACFOR scale in favour of NEMP quadrat sampling. Quadrat sampling subject to considerable within-site variation for epibiota with clumped or patchy distributions.
Macroalgae	The composition and prevalence of macroalgae are indicators of nutrient enrichment	Percent cover score based on ordinal SACFOR scale in favour of NEMP quadrat sampling (see above comments for epibiota)
Microalgae	The composition and prevalence of microalgae are indicators of nutrient enrichment. The utility of microalgae as a robust or useful routine indicator is yet to be demonstrated.	Visual assessment of conspicuous growths as part of SACFOR. Composition requires specialist taxonomic expertise and is not typically undertaken in NEMP studies.

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 are provided in Appendix 2.

The apparent redox potential discontinuity (aRPD) depth (Table 2) 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).

In 2018 aRPD depth was measured to the nearest centimetre in 3 cores. In 2019 and 2020 it was measured to the nearest millimetre after extracting a large sediment core (130mm diameter, 150mm deep) from each of the 10 plots, placing it on a tray, and splitting it vertically. Representative split cores (1X, 4Y and 7Z) were also photographed.

Collection of sediment cores at Tokomairiro Site A

Although not part of the NEMP, the measurement of oxidation reduction potential (ORP; see Table 2) is increasingly being evaluated for use in council monitoring. To provide sufficient data to enable comparison against results from the visual assessment of the aRPD depth, in each of three plots (1X, 4Y and 7Z), a sediment core (120mm diameter, 150mm deep) was taken using a Perspex corer, and ORP was measured at five sediment depths (10, 30, 50, 70 and 100mm). ORP measurements were made using a YSI Pro10 ORP meter and YSI 1002 ORP (redox) sensor. The sensor probe was inserted horizontally into holes pre-drilled at the designated depth in the Perspex corer and, after allowing the probe to stabilise at each depth for a consistent 1-minute interval, ORP (mV) was measured.

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 by Salt Ecology staff and taxonomic identification by Gary Stephenson, Coastal Marine Ecology Consultants (CMEC).

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. As a QA/QC cross-check on the macrofaunal identifications made in 2020, a single additional large core was collected from sampling plot Y5 (see Fig. 3) at each site and extracted macrofauna were sent to NIWA for taxonomic identification.

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 3. These ratings represent a scoring scheme simplified from established monitoring methods (MNCR 1990; Blyth-Skyrme et al. 2008). Note that the rating categories differ slightly to that described in the 2018 report, but the scores are unaffected.

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

Table 3. SACFOR ratings for assessing site-scale abundance, and percent cover of epibiota and macroalgae, 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

The SACFOR method is intended to characterise the most conspicuous epibiota that are readily apparent to the naked eye (typically organisms exceeding 5mm in size).

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. In 2019 and 2020, 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.

To assess changes over the two surveys, and minimise the risk of data manipulation errors, Excel sheets for the different data types and two years were imported into the software R 3.6.0 (R Core Team 2019) 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.

Before macrofaunal analyses, data were screened to remove species that were not a true part of the macrofaunal assemblage; these were planktonic life-stages and non-marine organisms (e.g. terrestrial beetles). In addition, to enable comparisons across surveys, cross-checks were made to ensure consistent naming of species and higher taxa.

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 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). However, to reduce the number of taxa with unassigned eco-groups, international data were supplemented with more recent eco-group classifications for New Zealand described by Berthelsen et al. (2018), which drew on prior New Zealand studies (Keeley et al. 2012; Robertson et al. 2015).

We also drew on recent work that assigned specific eco-group sensitivities to amphipods of known genus (Robertson et al. 2016c; Robertson 2018), but defaulted to the eco-group designation used in the Berthelsen et al. (2018) study for unclassified species (e.g. Amphipod sp. 1). 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 similarity as a function of macrofauna composition and abundance were assessed using a non-metric multidimensional scaling (nMDS) ordination biplot, based on pairwise Bray-Curtis similarity index scores among samples aggregated within each of zones X, Y and Z (i.e.

aggregation of replicates 1-3, 4-6 and 7-10, respectively, as per 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 to be determined (i.e. as the sediment samples were composites for each corresponding zone).

Following the nMDS, the similarity percentages procedure (SIMPER) was used to explore the main species or higher taxa that characterised the ordination cluster groups or discriminated groups from each other. Overlay vectors and/or bubble plots were used to visualise relationships between multivariate biological patterns and sediment quality variables, with site differences in sediment quality also explored using Principal Components Analysis.

3.6 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 4.

Most of the condition ratings in Table 4 were derived from those described in a New Zealand Estuary Trophic Index (Robertson et al. 2016b, a), which includes purpose-developed criteria for eutrophication, and also draws on wider national and international environmental quality guidelines.

Key elements of the rating 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 (Robertson et al. 2016a). 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). Note that we did not use the ORP thresholds in the ETI as they are provisional and have been recognised as requiring further development.

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.

In addition, for assessing and managing sediment effects, two guidelines are available at a national level.

- Townsend and Lohrer (2015) propose a Default Guideline Value (DGV) of 2mm of sediment accumulation per year above the natural (native forest) sedimentation rate. If the latter is unknown, the default assumption is that it is zero. They emphasise that the DGV should be refined by further development of relationships between annual sedimentation rate and the health/condition of estuaries.
- The ETI recommends using the ratio of estimated current to natural (pre-human) sedimentation rates, with increasing values considered to be associated with increasing ecological stress (Robertson et al. 2016a).

Note that the scoring categories described above and in Table 4. should be regarded only as a general guide to assist with interpretation of estuary health status. Accordingly, 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. For present purposes, our assessment of the multi-year data against the rating thresholds is based on site-level mean values for the different parameters.

Table 4. Condition ratings used 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]					
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 [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. General indicator thresholds derived from a New Zealand Estuarine Tropic Index, with adjustments for mud and aRPD as described in the main text.

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.

4. KEY FINDINGS

4.1 General features of fine scale sites

The sampling sites are each quite different in terms of their key habitat features. Site A is the most downstream and is located on an 'island' between the Tokomairiro River and a secondary channel. It is characterised by relatively firm sand that drains fully at low tide. Sites B and C are soft and muddy (e.g. we typically sank to above our ankles) and did not drain fully at low tide during the 2019 and 2020 surveys. At the time of the 2020 survey, the water level had been especially high due to the Toko Mouth having been closed for ~10 days prior to our visit. A digger was used to clear the entrance to the sea (see photo) with the mouth re-opened two days before the estuary was sampled.

No seagrass was present at any of the sites, consistent with previous surveys. The most noticeable feature of Site B, especially in 2020, was extensive green macroalgae (*Ulva* spp.) across parts of the site, which appeared to be mainly drift material (see photo below).

A digger was opening the Toko Mouth at the time of the 2020 survey. It had been fully closed prior for a period of ~10 days.

Green macroalgal mats were extensive at Site B in 2020

4.2 Sediment plates

Sediment plate raw data are provided in Appendix 3. The summary in Fig. 4 shows a small amount of erosion (mean ~5mm) at Site A in the short (<12 month) period of plate deployment there. Site B experienced net accrual of ~16mm relative to the 2018 baseline. Site C had an initial ~5mm period of erosion between 2018 and 2019, but ~2mm of net sediment accretion in 2020 (i.e. representing ~7mm of accretion between February and December 2019. The erosion at Site A is consistent with the movement of sandy sediments at that site due to hydrological factors, whereas the net deposition at Site B and C further upstream is consistent with their muddy sediment characteristics.

4.3 Sediment grain size, TOC and nutrients

Composite sediment sample raw data are tabulated in Appendix 4. Laboratory analyses of particle grain size (Fig. 5) revealed that the sand fraction was dominant at Site A (mean mud <11% over the three surveys). Sediments at Site B and C were mud-dominated, being around 65% and 57%, respectively, each year. These results are largely consistent with the expected hydrological conditions at each site, with Site A being generally well-flushed (except during Toko Mouth closure), such that the accumulation of fine muddy sediment is reduced.

To provide a visual impression of sediment quality relative to the Table 4 condition ratings, Fig. 6 compares the mean percentage mud, total organic carbon (TOC) and total nitrogen (TN) from composite samples against the rating thresholds. Except for Site A whose percentage mud rating was 'good', all other sites were rated as 'poor' in all years due to their sediment mud contents exceeding 25%.

As concentrations of TOC and TN were very closely correlated with sediment mud (Pearson r = 0.93 and 0.96, respectively), their condition rating patterns were correspondingly similar across sites and years, i.e. except for Site A (which was rated 'good' or 'very good') TOC and TN levels were rated as 'fair' or 'poor' in all surveys. Total phosphorus (TP) does not have a rating criterion, but values were also moderately correlated (Pearson r = 0.83) with mud content, hence also greatest at Sites B and C in all years (Appendix 4).

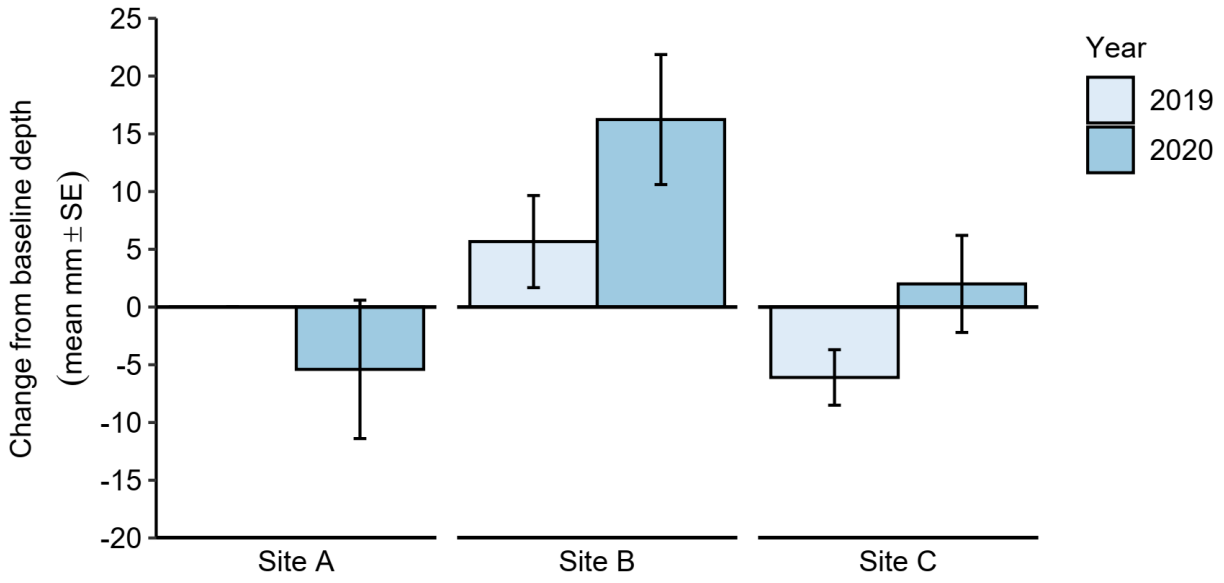


Fig. 4. Mean change (± SE) in sediment depth over buried plates relative to the 2018 baseline.

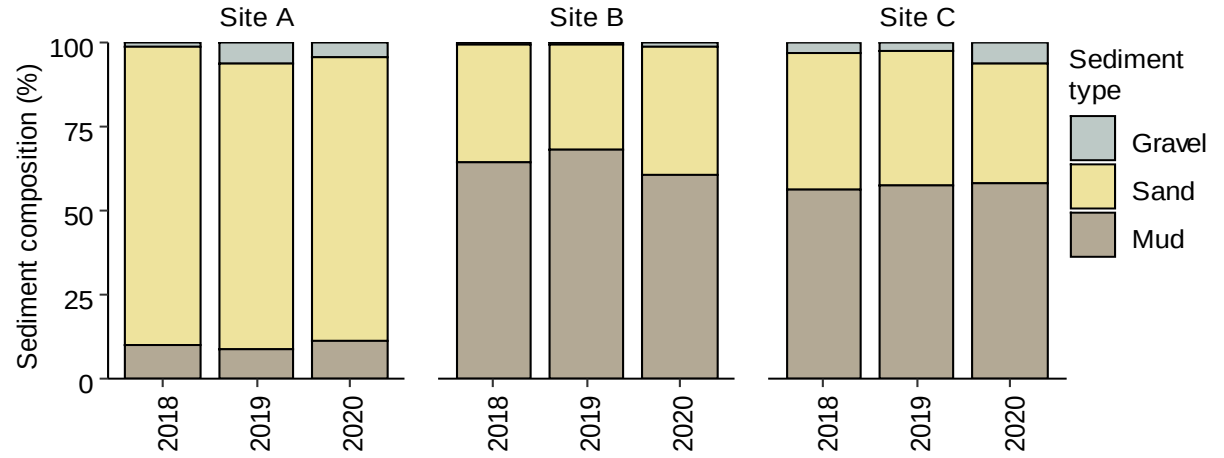


Fig. 5. Sediment particle grain size analysis, showing site-averaged percentage composition of mud (<63µm), sand (<2mm to ≥63µm) and gravel (≥2mm).

4.4 Redox status

The depth to the apparent Redox Potential Discontinuity (aRPD) transition was deepest at Site A (~50-70mm on average), giving a condition rating of 'very good' (Fig. 7). At Sites B and C, the aRPD was ≤10mm, resulting in a condition rating of 'poor' in all survey years. The aRPD patterns reflect the sediment mud, TOC and nutrient patterns described above. The deep aRPD horizon at Site A is consistent with the porous sandy sediments at that site, which enable much greater oxygenation of the sediment matrix than occurs in enriched muddy sediments. This result is evident from core photographs, which show a shallow layer of brown oxic mud overlying oxygen-reduced black-coloured sediment at Sites B and C (Fig. 8). By contrast, Site A has a relatively deep layer of brown sand overlying a less oxygenated grey layer. A judgement was made to call this transition zone the aRPD for monitoring purposes, whereas truly anoxic black sediments were at least 210mm deep (sometimes as deep as 400mm).

It is apparent from Fig. 8 that the aRPD is not always well-defined, even in relatively muddy sediments.

Factors such as bioturbation (e.g. by worms, shellfish, crabs) can lead to mixing of oxic surface sediments with deeper oxygen-reduced sediments, as illustrated by some of the photographs. Furthermore, as there is inherent subjectivity in aRPD measurement, variability across surveys due to interpretation can therefore be expected. As such, it is only gross differences in aRPD that are meaningful.

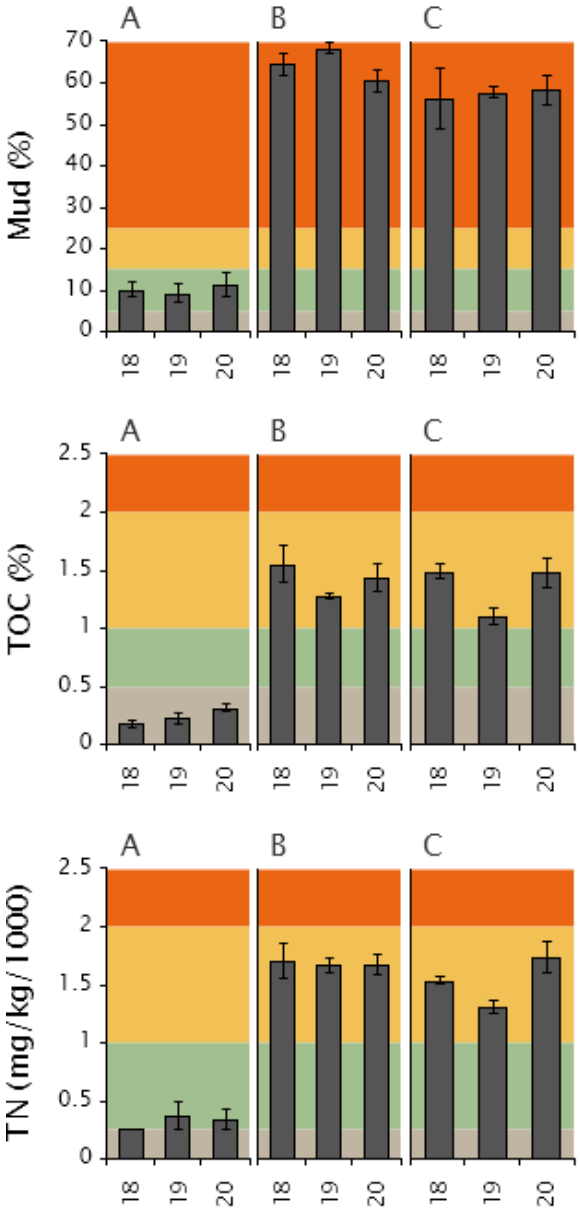


Fig. 6. Sediment mud content, total organic carbon, and total nitrogen concentrations relative to condition ratings.

Condition rating key:

Very Good	Good	Fair	Poor

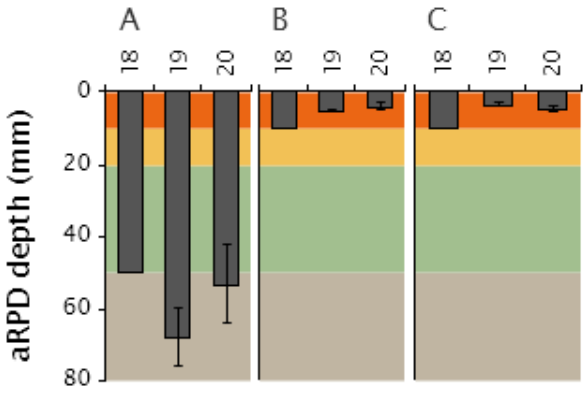


Fig. 7. aRPD depths and condition ratings. Rating colour key as per Fig. 6.

Vertical oxidation reduction potential (ORP) profiles in the sediment are shown in Fig. 9 for 2020 (data for other years in Appendix 4). The data generally show that ORP values in the muddy enriched sediments at Sites B and C are far lower (negative) than at Site A. However, of more interest is not the absolute ORP values, which can change according to sediment mineralogy and other factors, but the occurrence of a marked change in ORP values from relatively positive to negative across a small change in sediment depth. This point reflects the transition from oxic to reduced sediments and should correspond with the visual aRPD transition. The transition cannot be determined by ORP at Sites B and C as the measurement resolution was coarse relative to the shallow aRPD depth. At Site A, there was no clear ORP change at the aRPD horizon.

In general, Fig. 9 and Appendix 4 do not show any trends in ORP values that are useful from a monitoring perspective. Many ORP profiles are counter-intuitive in that values become increasingly positive with depth. In some cases there are abrupt changes in ORP that do not correspond to the recorded aRPD. Marked core-to-core variability and inconsistency between aRPD and ORP has been described in published studies that have compared these methods (Forrest & Creese 2006; Gerwing et al. 2013), as well as in many of our recent NEMP surveys (e.g. Forrest & Stevens 2019c; Forrest & Stevens 2019b, 2020). To some extent these results likely reflect the occurrence of oxic zones throughout the core profile, such as caused by the mixing of surface and deeper sediments by bioturbation as noted above. In such instances, it is a matter of chance whether the ORP probe encounters these areas when it is inserted into the sediment core.

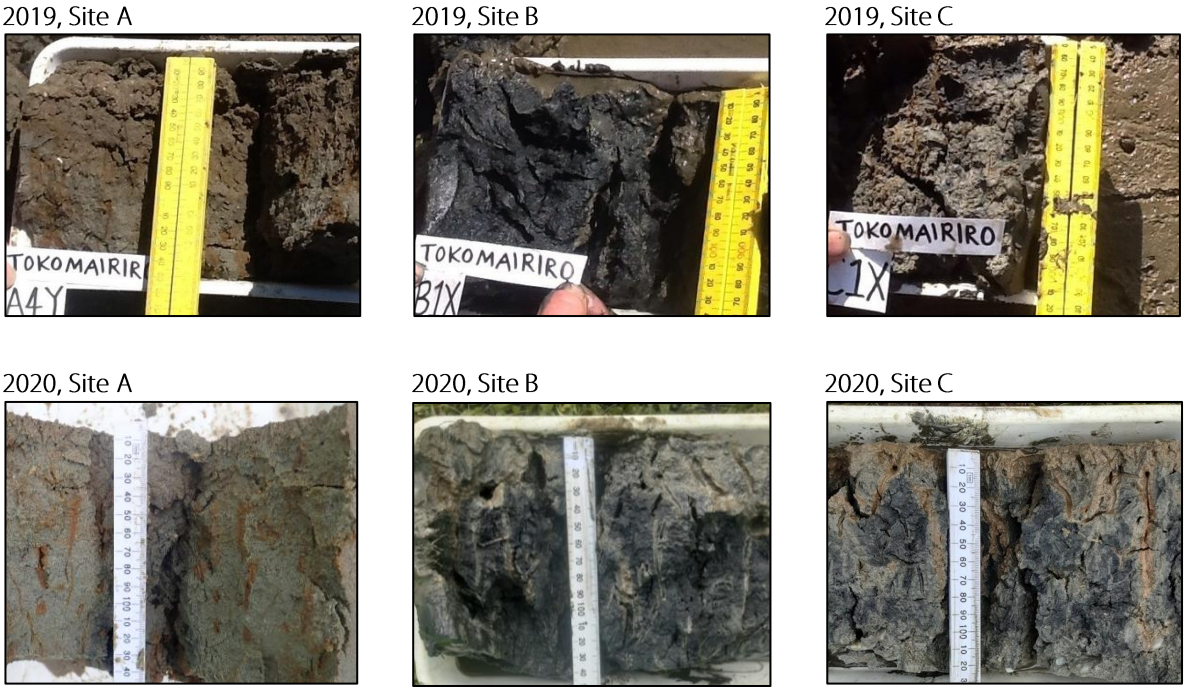


Fig. 8. Example sediment cores from three fine scale sites for the 2019 and 2020 surveys.

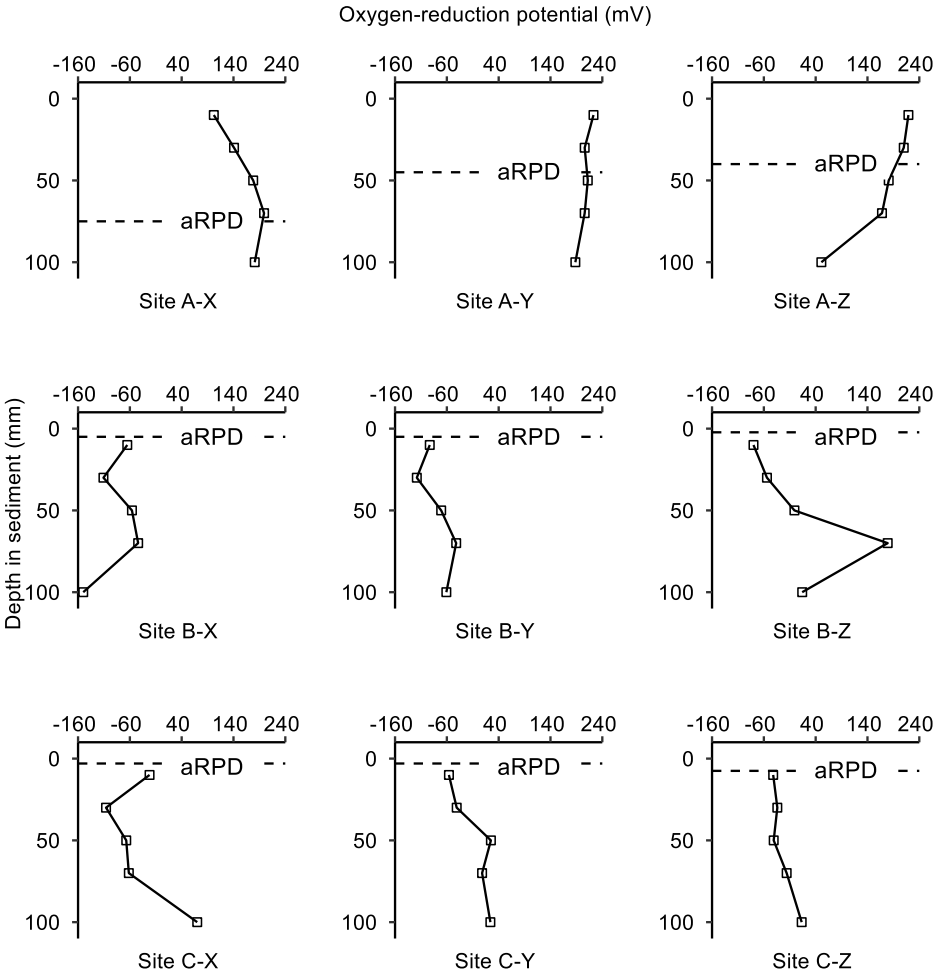


Fig. 9. Example of oxidation-reduction potential (ORP) profiles for three cores (X, Y, Z) taken from each site in 2020, showing associated aRPD depth for that core.

There are also other difficulties in measuring ORP that arise under field conditions. For example, if ORP core holes become part-flooded, the infiltration of ambient water will influence ORP readings. For this reason, cores subject to flooding are typically placed on a tray. In such instances, especially in sandy sediments, the core can become too dry for a reliable ORP reading (i.e. there is insufficient sediment pore water around the ORP probe). These methodological issues undermine the utility of this method, at least for routine field monitoring purposes.

4.5 Trace contaminants

Trace metal contaminant levels in relation to condition ratings and ANZG (2018) sediment quality guidelines are plotted in Fig. 10, with raw data and guideline values in Appendix 4. Mean concentrations have been well below DGV levels over the three surveys. Concentrations have all been within the 'very good' rating bracket, except for 2018 Site B, where arsenic (As) and mercury (Hg) were rated 'good' due to mean values slightly exceeding half of the DGV (see Table 4 footnote).

The higher metal concentrations at Sites B and C relative to A are related to sediment grain size, with muddy sediments providing a greater surface area for contaminant adsorption that sandy sediments. Overall, the results do not indicate contaminant levels of any ecological concern.

4.6 Macrofauna

4.6.1 Conspicuous surface epibiota

Epibiota were absent at Site A in all years. Mud snails (*Amphibola crenata*) were frequent or common at Sites B and C in 2018 and 2019, but were rated as rare in 2020 (Table 5.). However, the 2020 assessment was particularly difficult due to the need to sample while submerged in water (i.e. reflecting water backup due to the period of Toko Mouth closure). A green filamentous macroalga provisionally referred to as *Ulva* spp. was rated as abundant at Site B in 2020, forming mats of up to 50% cover although as noted above this appeared to consist mainly of drift.

4.6.2 Macrofauna cores

Richness, abundance and AMBI

Raw macrofaunal data are provided in Appendix 5. The QA/QC cores taken at each site and assessed by NIWA in 2020 were comparable in species richness, abundance and composition, with reasons for any differences outlined in Appendix 6.

For the main dataset (i.e. excluding QA/QC cores), the three surveys show the macrofaunal assemblages to be relatively impoverished. In total only 31 species or higher taxa have been recorded in the estuary over the three survey years, with background information on the most common of these provided in Table 6. Although mean species richness is low (2-9 species/core), it has steadily increased at all three sites, with mean richness in 2020 being 2-3 times greater than that recorded in 2018 (Fig. 11a).

Despite the low richness values, organism abundances per core were very high in 2020 and to a lesser extent in 2019 at Sites B and C. Abundances in 2019 were very low at Site A, and in 2018 were very low at all sites. In fact in 2018, four of the 10 macrofaunal cores at Site A were recorded as azoic (i.e. contained no macrofauna).

The high spatio-temporal variability in abundances largely reflected changing densities of the tube-dwelling amphipod *Paracorophium excavatum* (Table 6). This species was particularly abundant in 2020, reaching a mean density of >800 individuals per core at Site A, whereas it was near absent from that site the year prior.

Table 5. SACFOR scores for epibiota over the three surveys, based on the scale in Table 3.

Site	Year	*Amphibola crenata* (#/m2)	*Ulva* spp. (% cover)
A	2018	absent	absent
	2019	absent	absent
	2020	absent	absent
B	2018	C	O*
	2019	C	O
	2020	R	A
C	2018	F	O*
	2019	C	R
	2020	R	R

* 2018 report refers to macroalgae cover <5%

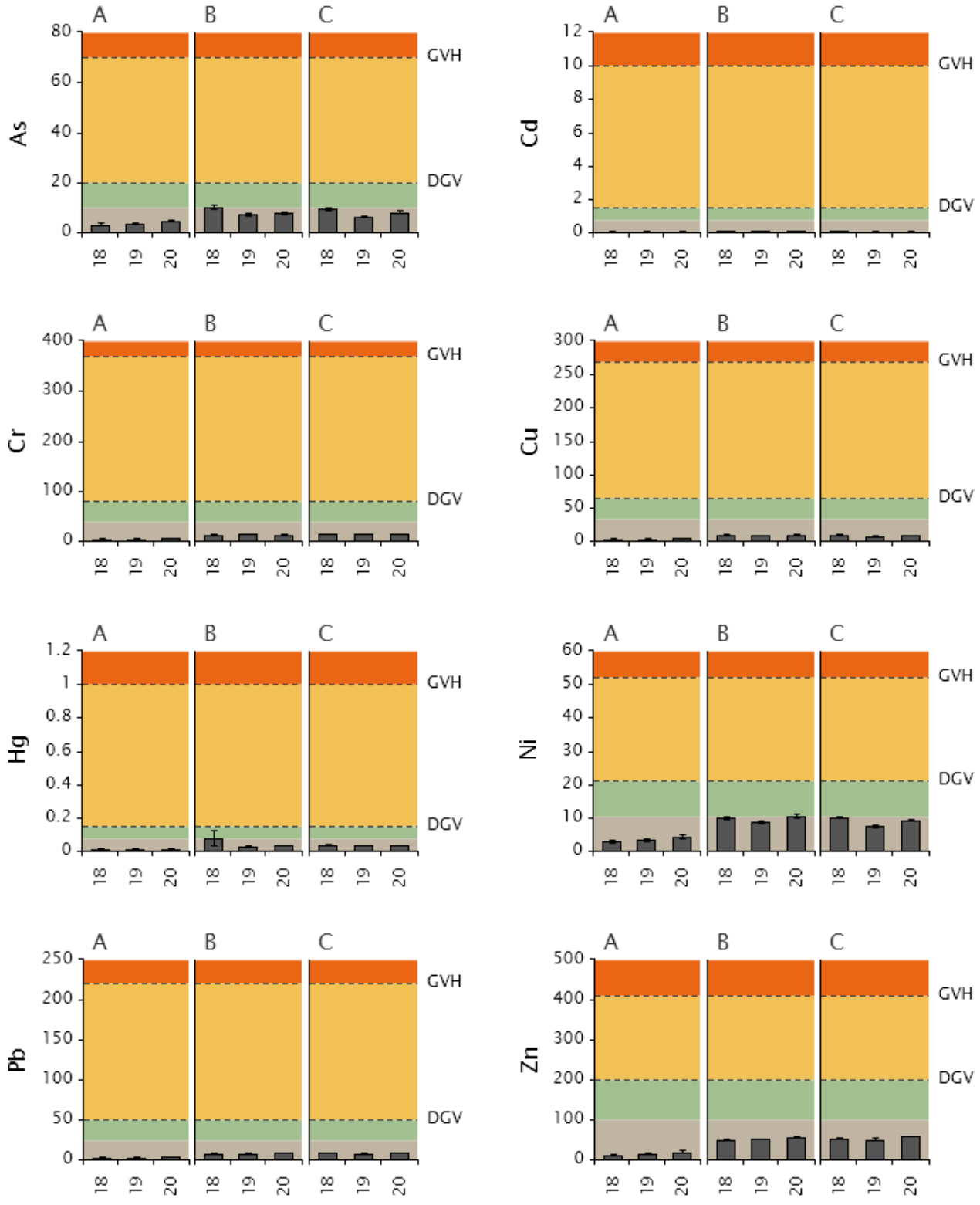


Fig. 10. Condition rating plots for trace metals (site means ± SE). ANZG (2018) sediment quality guideline thresholds are indicated as Default Guideline Value (DVG) and Guideline Value-high (GVH). Note that concentrations of certain analytes are barely visible on the rating scale.

Condition rating key:

Very Good	Good	Fair	Poor

Table 6. Description of the sediment-dwelling species that were consistently the most abundant at one or more sites. Site abundances shown are pooled across the three surveys.

Main group & taxon	Site A	Site B	Site C	Description	Image
Amphipods (Amphipoda sp. 1)	3	824	480	Amphipods are shrimp-like crustaceans. Based on QA/QC cores, this species is likely to be *Paracalliope novizealandiae*.	
Amphipods (*Paracorophium excavatum*)	8513	5503	8973	Shrimp-like corophioid amphipods are opportunistic tube-dwelling species that can occur in high densities in mud and sand habitats, often in estuaries subjected to disturbance and low salinity water.	
Polychaete worms (*Perinereis vallata*)	81	150	300	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*)	124	368	246	A spionid, surface deposit feeder. It is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark.	

The subdominant species differed slightly among sites, with another amphipod (Amphipoda sp. 1, likely to be *Paracalliope novizealandiae*) reasonably abundant at Sites B and C. Also common at all sites were the spionid worm *Scolecolepides benhami* and the nereid worm *Perinereis vallata*.

Mean AMBI scores at Sites B and C fell in the 'fair' band, with values around 3-4 indicative of a moderately disturbed environment (Fig. 12). The range of scores in this band, and the small core-to-core variance, reflects the strong influence on AMBI values of the numerically dominant *Paracorophium excavatum*. This is an eco-group (EG) IV species considered to be resilient to disturbance and/or pollution.

AMBI values were the most variable across years at Site A, and fell outside the range evident at the other sites. In 2018 and 2020, AMBI values were in the 'poor' rating category, reflecting a relative dominance by EG-IV species, namely *Scolecolepides benhami* in 2018 and *Paracorophium excavatum* in 2020. By contrast these disturbance-tolerant species were uncommon a Site A in 2019. Instead, although abundances were low overall, the most common species present was the polychaete *Perinereis vallata*, an EG-II species considered sensitive to high sedimentation.

Main taxonomic groups

General patterns in the composition of the main taxonomic groups across sites are shown in Fig.13. In total across the three surveys, the species present represented 14 main taxa. Amphipods and polychaete worms were consistently the most well-represented groups in terms of both richness and abundance.

The main bivalve present at low densities was the small sediment-dwelling *Arthritica* sp. 1 (cf *A. bifurca*) at all sites, with occasional pipi (*Paphies australis*) at Site A and cockles (*Austrovenus stutchburyi*) at Sites B and C. The occurrence and density of taxa within the different minor groups was highly variable among sites and surveys. Note that the abundances in Fig. 13b are log10-transformed so that the less common groups display.

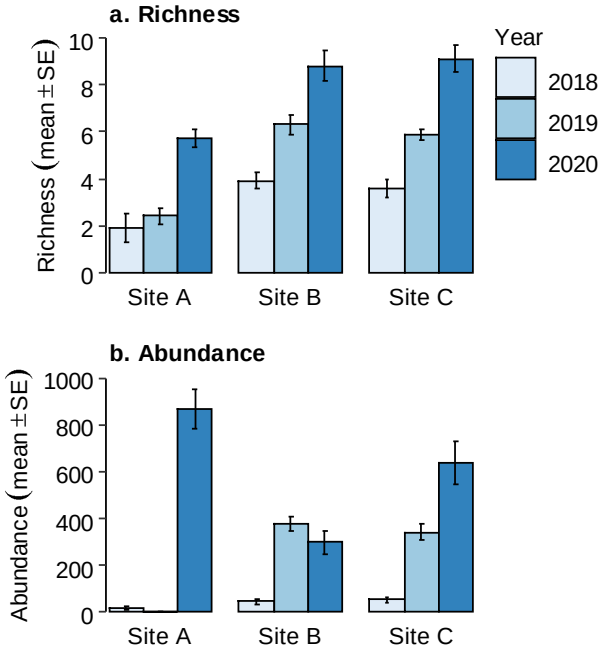


Fig. 11. Patterns (mean ± SE) in taxon richness and abundance per core. Abundances at Site A in 2019 were too low to be visible on graph.

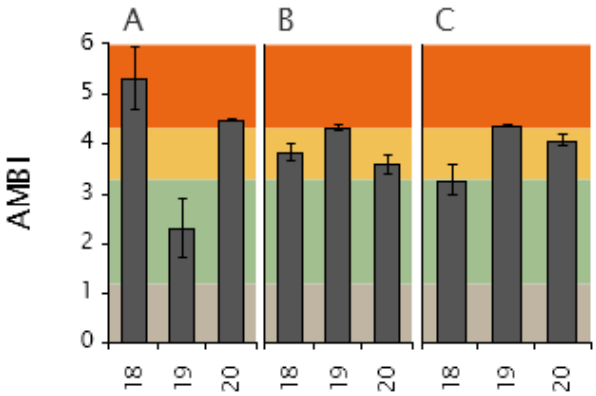


Fig. 12. Patterns (mean ± SE) in AMBI scores compared with condition rating criteria.

Condition rating key:

Very Good	Good	Fair	Poor

Multivariate patterns and association with sediment quality variables

In order to further explore the differences and similarities among sites and surveys in terms of the macrofaunal assemblage, the species-level nMDS ordination in Fig. 14 places zone-aggregated samples of similar composition close to each other in a 2-dimensional biplot, with less similar samples being further apart.

The analysis reveals a relatively similar assemblage across all years at Sites B and C, which collectively had a within-group similarity (Bray-Curtis index) of ~62%. This main group was characterised by the most common species described above and in Table 6. Within this group, survey years were slightly different to each other in assemblage composition, but within each year the two sites were quite similar.

Site A strongly separated from the main Site B and C group, with survey years at Site A differing in terms of macrofaunal composition and dominance. Some of the lesser species were influential in discriminating samples or sample groups from each other, such as the occurrence of occasional Nemertea (ribbon worms) at Site A in 2018 and Diptera (shore fly larvae) in 2019.

Despite these more subtle differences among samples or groups, much of the segregation evident in Fig. 14a is driven by shifts in the relative abundances of the dominant species discussed above. Of interest, is that when the analysis was conducted on presence/absence data (i.e. relative abundances were not accounted for, only the frequency of occurrence in samples), there is a less pronounced separation in the ordination plot (not shown) than evident in Fig. 14a but much of the overall pattern of differences is maintained.

Hence, aside from some of the strong dominance shifts, the differences in species occurrences among sample groups are fairly subtle, and typically reflect variation in sampling of a range of uncommon taxa that were present at very low densities (e.g. 1-2 individuals per core in a small subset of cores). It is important to recognise that for these minor species whose abundances are very low, there is a strong element of chance as to whether (or to what extent) they are detected by core sampling. As such, their apparent presence and absence from sites may not be an accurate reflection of true differences in the macrofaunal assemblages, and their influence needs to be interpreted with caution.

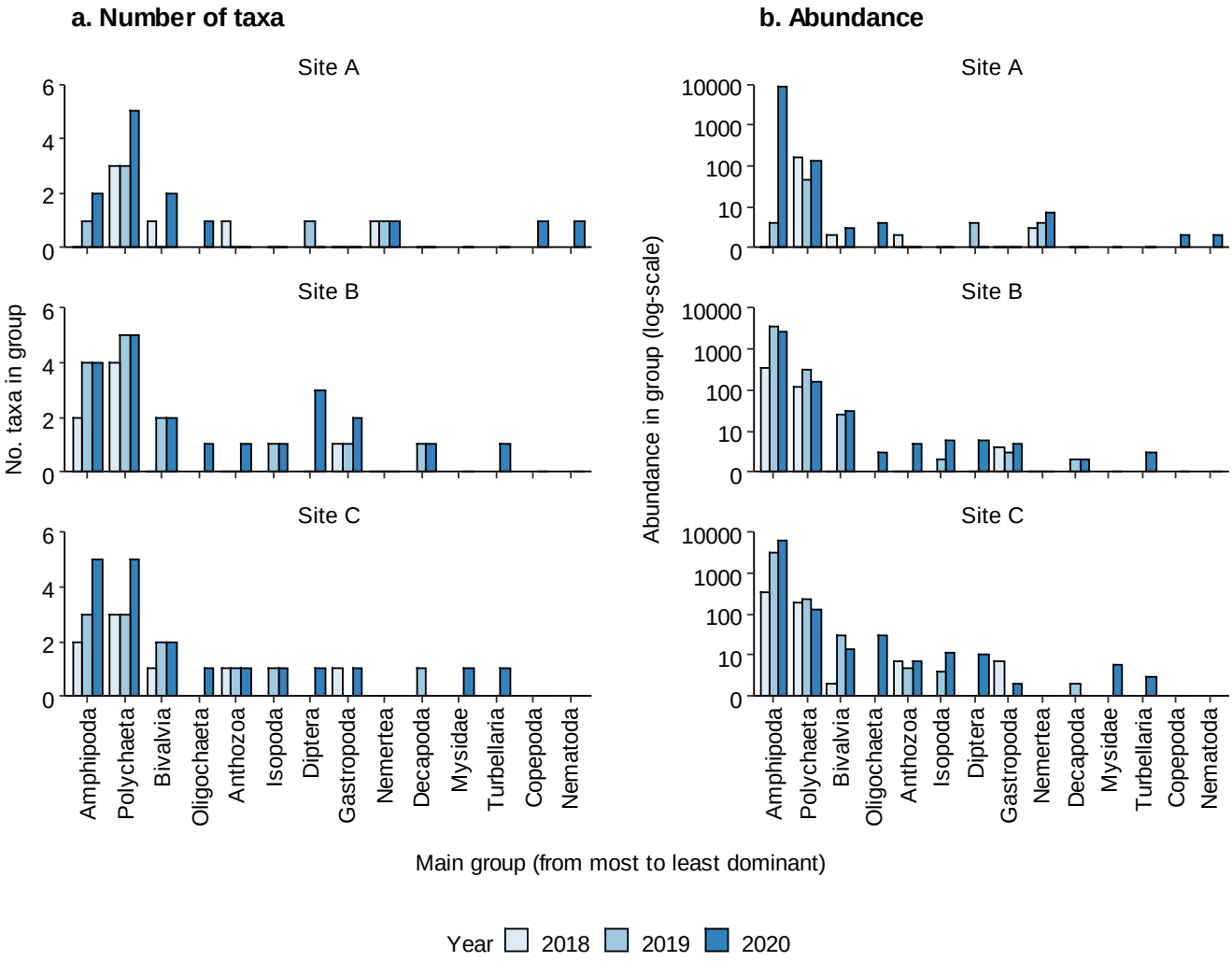


Fig. 13. Data pooled across years showing the contribution of main taxonomic groups to site-level richness and abundance values. For abundance data, log10-transformed values are shown so that the less dominant groups are revealed.

An analysis of patterns among sites in sediment quality variables, and of relationships between macrofauna and sediment quality, suggested that sediment grain size and aRPD were the most influential of the variables measured.

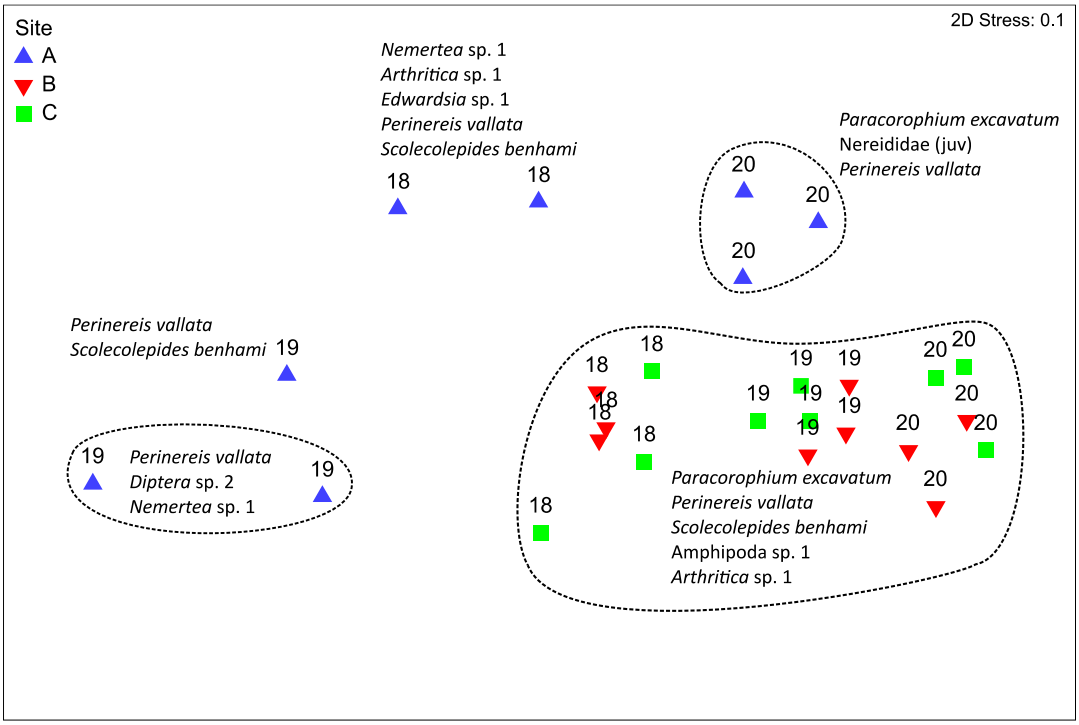
Based on log10-transformed data, sediment mud content was moderately correlated with the macrofaunal differences among sites (Spearman rank correlation coefficient ρ=0.50). This is reflected in the scaling of circle size in Fig. 14b to mud content, highlighting the greater mud component of samples from Sites B and C compared with Site A.

The left-right (and to some extent top-bottom) sample separation in the ordination in Fig. 14b was explained by the deeper aRPD at Site A (Pearson r = 0.70) and greater mud at B and C (Pearson r = 0.61).

As sediment mud content was highly inter-correlated with sediment nutrients (TN, Pearson r = 0.91), organic content (TOC, Pearson r = 0.95) and metals (Pearson r = 0.99 for an aggregated 'metals' variable derived from PCA), it is not possible to categorically say that it is the most important variable in terms of driving macrofaunal differences.

Furthermore, there are clearly also unmeasured factors that are likely to be important, illustrated for example by the separation of Site A samples in Fig. 14 despite this site consisting of sandy sediments with a low mud content and relatively deep aRPD in all years.

a. Species groups



b. Sediment quality overlay

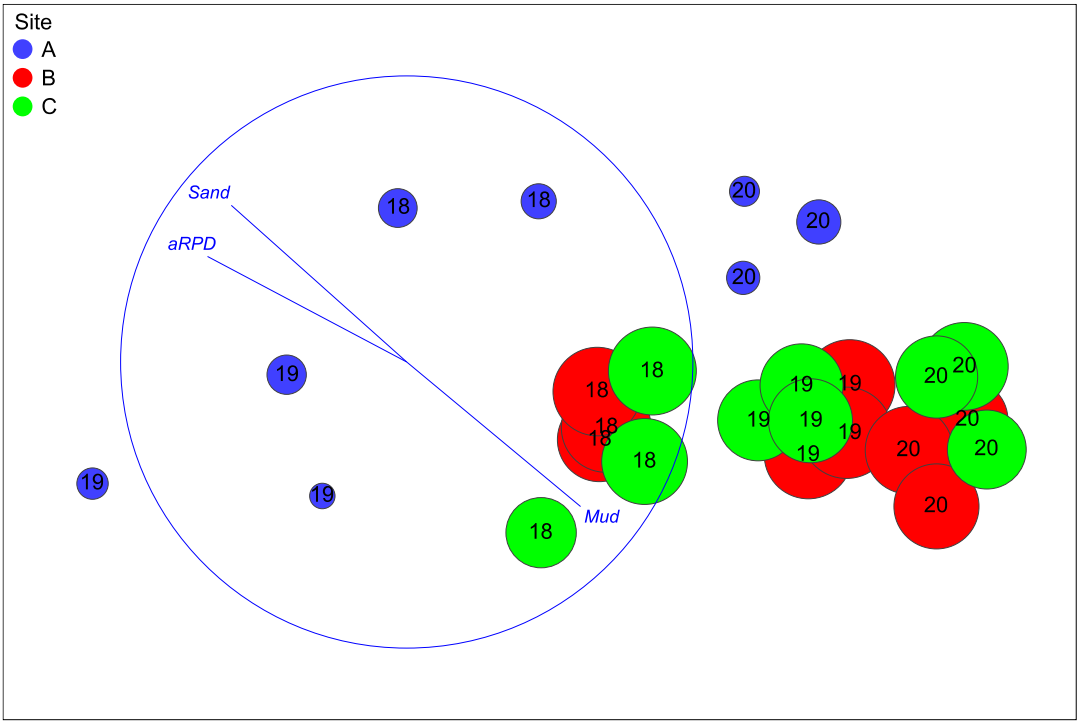


Fig. 14. Non-metric MDS ordination of macrofaunal core samples aggregated with each of zones X, Y and Z (see Fig. 3), resulting in triplicate representation of each year-site combination. One of the zones in 2018 contained no macrofauna, hence does not display on the ordination.

The two panels are as follows: Top: ellipses enclose macrofaunal samples clustering at ≥62% Bray-Curtis similarity, with taxa identified (in order of group dominance) that together comprise >80% of transformed group abundances. Bottom: Circle sizes are scaled to sediment mud content, and vectors represent the direction and relative strength of association (vector length) between the biological ordination pattern and the most highly correlated sediment quality variables.

5. SYNTHESIS AND RECOMMENDATIONS

5.1 Synthesis of key findings

This report has described the findings of three surveys of Tokomairiro Estuary, largely following the fine scale survey methods described in New Zealand's National Estuary Monitoring Protocol (NEMP). A summary of mean values of key physical and biological indicators in relation to ecological condition ratings is provided in Table 7, including comparison with data from the 2009 sampling at or near present Sites A and B (Stewart & Bywater 2009).

Sedimentation has been variable across the sites, with both erosion and accretion events evident over the previous three years. The net sedimentation over two years at Site B equates to ~8mm/yr, which is consistent with the 7mm accretion at Site C between the 2019 and 2020 surveys. These values are well over the provisional 2mm/yr guideline value (above natural background) of Townsend and Lohrer (2015). It is unclear whether these results reflect the sedimentation of catchment-derived material or the local movement of sediment due to hydrological factors as was suggested above for Site A, i.e. variable erosion and accretion patterns suggests a reasonably dynamic hydrological environment. The potential for catchment-derived sedimentation and associated effects can be inferred from the ratio of current to natural sedimentation rate estimated from the NIWA sediment load estimator (Hicks et al. 2019). The estimated ratio of 2.7 (assuming 50% attenuation from wetlands under natural state) falls into Band C of the ETI rating. The ETI describes Band C as roughly equating to moderate' stress on aquatic life with potential loss of sensitive species (Robertson et al. 2016a). A longer time series of sediment plate monitoring will be required to elucidate net sedimentation rates in Tokomairiro Estuary.

Table 7 highlights that sediment quality was relatively good at Site A, with all indicators except AMBI (see below) rated as 'good' or 'very good', reflecting the relatively well-flushed sandy sediments at this site. By contrast, Sites B and C were typically rated as 'fair' or 'poor' reflecting their elevated levels of sediment mud and of various enrichment and trophic state indicators. For example, nutrient and TOC levels were moderately high and the aRPD was shallow, reflecting poor oxygen diffusion coupled with microbial breakdown processes in the organically enriched sediments.

The absence of biologically significant trace metal concentrations, even in the muddy sediment at Sites B and C, suggest there are no appreciable sources of

Table 7. Synthesis of data for Tokomairiro fine scale sites summarising condition scores of ecological health, based on mean values of key indicators and criteria and ratings in Table 4. Rating criteria not established for TP. Note that positions of Sites A and B in 2009 do not correspond exactly to the latest three surveys but are included for comparative purposes.

Site	Year	Mud %	TOC[1] %	TN mg/kg	TP mg/kg	aRPD mm	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg	AMBI na
A	2009	11.3	0.48	610	350	-	3.3	< 0.100	4.2	2.5	-	3.4	2.9	16.0	2.1
	2018	9.9	0.17	< 500	340	50	3.0	0.007*	3.1	1.9	< 0.02	2.8	2.1	10.9	5.3
	2019	9.0	0.22	367*	353	68	3.2	0.009*	3.7	2.2	< 0.02	3.2	2.3	13.3	2.3
	2020	11.1	0.31	333*	403	53	4.2	0.016	4.7	3.1	< 0.02	4.2	2.9	18.7	4.5
B	2009	43.8	0.89	930	410	-	4.1	< 0.100	8.9	5.3	-	6.8	5.5	37.0	1.8
	2018	64.6	1.55	1700	833	10	10.1	0.046	11.9	8.3	0.08	9.7	7.6	47.7	3.8
	2019	68.4	1.28	1667	643	5	6.9	0.050	12.6	7.5	0.03	8.5	7.5	50.7	4.3
	2020	60.6	1.44	1667	617	4	7.6	0.048	12.3	9.2	0.03	10.4	7.9	54.3	3.6
C	2018	56.3	1.49	1533	787	10	9.2	0.044	12.8	8.7	0.03	9.8	8.3	53.3	3.3
	2019	57.6	1.10	1300	590	4	6.2	0.039	12.7	6.4	0.03	7.3	7.5	49.0	4.4
	2020	58.2	1.47	1733	687	5	7.8	0.038	12.6	8.0	0.03	9.1	8.0	57.0	4.1

[1] *TOC in 2009 calculated from % ash free dry weight (AFDW) as TOC = 0.4xAFDW + 0.0025xAFDW2 (Robertson et al. 2002).*

** Sample mean includes values below lab detection limits*

< All values below lab detection limit

Condition rating key: Very Good | Good | Fair | Poor

chemical contaminants in the catchment. Any likely upstream sources, such as urban runoff from Milton or inputs from the Milton Wastewater Treatment Plant are clearly too distant to have a discernible influence on the estuary. Similarly, despite evidence that agriculture and horticultural land use can lead to soil contamination with trace metals, for example due to 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 predominantly agricultural catchment of the estuary. It is possible that other types of trace contaminants could be present (e.g. agricultural biocides), but such an assessment is not part of the NEMP focus.

Despite the degraded sediment quality of Sites B and C, there have been no substantive changes over the last three surveys, nor relative to sampling conducted in 2009 (see Table 7), that would indicate a directional decline. Although *Ulva* spp. was prevalent at Site B for the first time, it appears to have been mainly detached material that had originated from elsewhere in the estuary.

Similarly, although the macrofaunal monitoring suggests an estuary that is under moderate stress, macrofaunal responses have been highly variable over time, with no obvious directional change of concern. Macrofauna species richness increased markedly over the latest the surveys, and in 2020 was similar to that described in 2009 (Fig. 15). On the other hand, Fig. 15 shows that macrofaunal abundances were low historically, but were particularly high in 2019 and/or 2020. AMBI values have generally been in the 'fair' or 'poor' rating band, but are also highly variable, especially at Site A where macrofaunal composition was also the most temporally variable.

The spatio-temporal changes in macrofaunal community composition showed a moderate correlation with sediment grain size and aRPD (and correlated trophic state indicators). Organic enrichment and sediment grain size composition are recognised as strongly influencing macrofaunal composition in estuarine and coastal environments (Pearson & Rosenberg 1978; Cummings et al. 2003; Thrush et al. 2004; Robertson et al. 2015; Ellis et al. 2017). Nonetheless, some of the year-to-year variation in the macrofaunal assemblage appears to be unrelated to the measured sediment quality variables, highlighting that other processes are important.

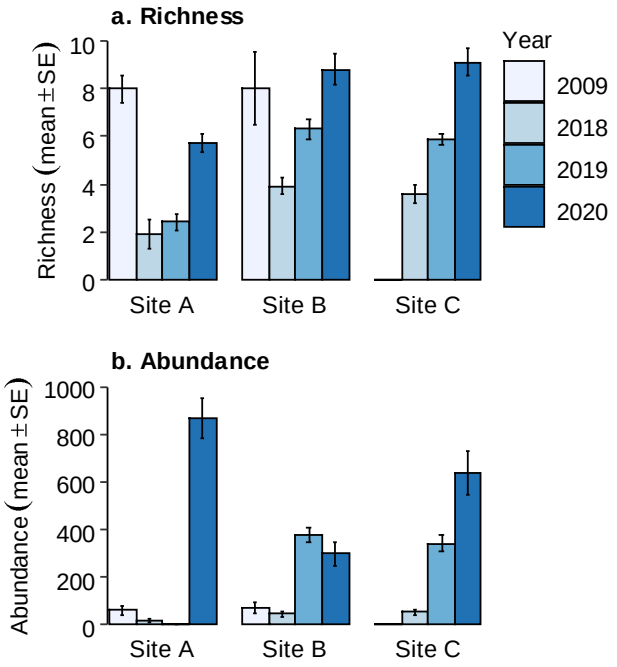


Fig. 15. Data for Tokomairiro fine scale sites on richness and abundance per core. Note that positions of Sites A and B in 2009 do not correspond directly to the latest three surveys (Site C was not sampled in 2009).

The nature of the macrofaunal community, and the pronounced variability in some of the response measures, is consistent with a highly dynamic disturbance regime. The likely contributing factors include physical disturbance from fluctuations in Tokomairiro River flows (e.g. flood-related disturbance) and/or associated variability in the salinity regime, due to both river inflows and flow restriction out of the estuary. The long-term history of closure events at the estuary outlet is unknown, but would likely strongly affect the resident biota due not only to extended periods of low salinity but also due to concomitant hydrodynamic changes that would be expected. The dramatic population increase of *Paracorophium excavatum* (especially in 2020) coincides with estuary outlet restriction and closure at Toko Mouth in the weeks prior to the survey, under which very low salinity conditions presumably developed. *Paracorophium excavatum* is common in high-disturbance river-dominated estuaries subject to variable and/or low salinity conditions, with a reported wide salinity tolerance of ~5-30psu (Wong 1999).

As well as the above, additional factors are likely to be important at Site A. Compared with Site B and C, this site appears to be in a relatively dynamic environment in which sediments are probably mobile and unstable. This situation is suggested by the low sediment mud content (reflecting strong flushing), the loss of the site markers installed in 2018 (which likely reflects erosion), and the erosion measured between 2019 and 2020. These factors would create a harsh physical environment, reflected biologically in the absence of epibiota, a generally species-poor macrofaunal assemblages (in which 4 of 10 cores collected in 2018 were azoic), and marked temporal variation in species assemblage composition such as evident in Fig. 14.

To some extent, the apparent variability in the macrofaunal assemblage among sites and over time will also reflect random sampling variation. As many of the species recorded occur at very low abundances and in very few cores, there is an element of chance as to whether they are sampled in a given survey. Despite the variability evident, the type of species present in Tokomairiro Estuary, as well as the richness and abundance of species are overall similar to other estuaries in ORC's NEMP programme, as evident from the high-level comparison in Fig. 16..

5.2 Key considerations for future monitoring

As the latest survey completes the planned 3-year baseline, it is important to consider the specific needs for future monitoring.

Continuing annual sediment plate monitoring (with associated monitoring of sediment grain size) is worthwhile, as this method provides a simple and informative way of building up a useful time series of data that supports interpretation of ecological condition and long-term change.

Given the absence of any obvious decline in sediment quality and ecological condition over recent years, there is little benefit in continuing annual NEMP fine scale monitoring. Nonetheless, it would be desirable to continue to track long term changes in sediment quality and ecological condition by monitoring at intervals of ~5 years. It may be of greater immediate value to ORC to consider more targeted investigations of some of the current potential drivers of ecological health in the estuary and the extent to which overall condition might be improved. Sediment quality monitoring highlights moderately degraded conditions in the mid-upper estuary due to elevated mud and sediment enrichment. This finding is consistent with synoptic water quality sampling conducted in 2018 (Robertson & Robertson 2018), which revealed eutrophication symptoms in saline bottom waters of the upper estuary and lower Tokomairiro River. As such, investigation of 'upstream' sources and mitigation options may be worthwhile. Simultaneously, overall estuary worth would likely be improved by maintaining flow via the outlet channel, if feasible.

For future applications of the NEMP fine scale method itself, it is important to consider whether the sites and methods are fit for purpose. The current sites are not ideal in that they are not species-rich. However, Sites B and C have a sufficient range of taxa to enable any ecologically significant environmental changes to be detected. Site A is more problematic in that it appears subject to sediment movement and physical disturbance, with so much temporal 'noise' that it would be difficult to ascribe ongoing changes to anthropogenic influences. Ongoing sediment plate monitoring will help to elucidate the longer-term utility of this site.

In terms of the NEMP fine scale methodology and indicators, it is suggested that ORP measurement is discontinued (ORP was not part of the original NEMP but is a provisional indicator in the ETI). This indicator does not reliably reflect the trophic state of the sediment in Tokomairiro Estuary, and undertaking such measurements greatly adds to field time and cost. Visual assessment of aRPD, while itself imperfect, provides a suitable ancillary indicator of gross change in trophic status, especially in muddy sediments. The same recommendation was made in a recent report on Kaikorai Estuary (Forrest et al. 2020).

An additional component to the 2020 survey was a comparison of the laboratory providers undertaking macrofaunal taxonomy. The results were not detailed in the report above, but an assessment of the outcomes is included in Appendix 6. It is reassuring from the assessment that the taxonomic providers (CMEC for the fine scale surveys, NIWA for QA/QC) described assemblages that were similar in richness and abundance, with any apparent discrepancies in composition explained by sample size, taxonomic resolution effort, and subtle naming differences. In order to have complete confidence in the consistency of the taxonomic providers, it would be

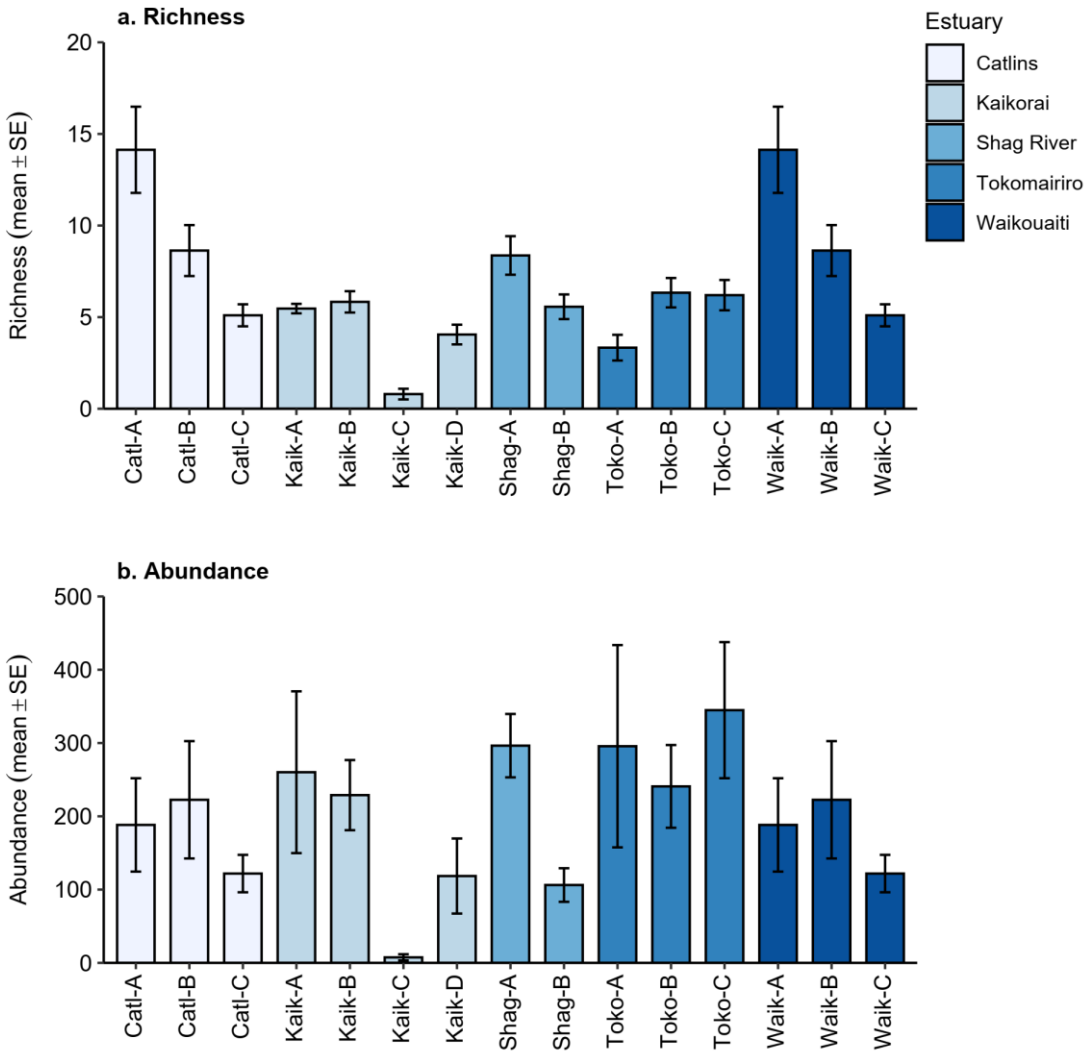


Fig. 16. Macrofauna richness and abundance summary (mean ±SE) for estuaries in the Otago region. For illustrative purposes, fine scale site data are averaged across multiple survey years in each location.

necessary for voucher specimens to be compared. This depth of assessment was beyond the present scope but would be a useful subsequent step.

Relating to the previous, it would be of considerable value to develop a macrofaunal reference collection for Tokomairiro Estuary, to foster reliable and consistent identifications for future surveys. It is recognised nationally that inter-provider differences are a significant source of macrofauna survey data mismatch, and undermine the ability to compare datasets except after aggregation to higher taxa with the associated loss of valuable information (e.g. Berthelsen et al. 2018). A reference collection for Tokomairiro Estuary would therefore provide a valuable resource for future surveys.

One of the further considerations for future monitoring is whether current sampling effort adequately captures information about the fine scale indicators. To address this question across all indicators would be a separate report in itself and require a range of methods to be considered, such as in the original NEMP study. For present purposes, we have assessed sampling adequacy for macrofauna, based on an analysis of species richness and dominance in relation to current sampling effort (i.e. 10 cores per site as specified in the NEMP). Results, detailed in Appendix 6, revealed that characterisation of dominant site macrofauna can often be achieved with far fewer cores. In fact, due to the dominance of species like *Paracorophium excavatum*, even one will generally capture the taxa that represent at least 90%

of site abundance. However, to sample 90% of the species present (irrespective of their abundance) requires at least 8 cores and in some instances >10. As a compromise, it is suggested that sampling effort could be reduced to nine cores in future surveys. Reducing sampling effort to this level will maintain comparability with existing Tokomairiro data, and with other estuaries in the NEMP programme. It would also have the benefits of providing a balanced sampling design (consisting of a 3 x 3 sampling plot) and reduced costs.

5.3 Recommendations

Based on the results of the monitoring and the preceding discussion, the following is recommended:

1. Monitoring frequency and locations: Ongoing sediment plate monitoring should be continued annually, but fine scale sampling can be undertaken less frequently (e.g. every 5 years). Current sites B and C are adequate for monitoring purposes. Although they are not species-rich, they have a sufficient range of taxa to enable any ecologically significant environmental changes to be detected. Further sediment plate monitoring will help to determine whether Site A is sufficiently stable to be of value for long-term monitoring.

2. Methods and indicators: In terms of NEMP methodology and indicators, ORP measurements should be discontinued, as this indicator does not reliably reflect the trophic state of the sediment.

3. Optimising future monitoring: We recommend ORC develop a macrofaunal reference collection, to foster consistent and reliable taxonomic identification and data comparability across surveys. Sampling effort in future surveys requires further discussion but is suggested that the collection of nine macrofauna core samples per site will be adequate.

4. Investigations of estuary state: It is suggested that ORC consider the possible causes of the currently degraded state in parts of mid-upper Tokomairiro Estuary (e.g. salinity and dissolved oxygen monitoring, source tracking of fine sediments), and identify any feasible remedial actions that could be undertaken to improve condition. As part of such an assessment, the feasibility of improving estuary condition by maintaining flow through the outlet channel should be considered.

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APPENDICES

Appendix 1. GPS coordinates of fine scale sites (corners) and sediment plates, and history of sampling

Due to a potentially confusing history of sampling conducted in Otago estuaries, after the first Salt Ecology survey in 2019, an unpublished report was compiled for ORC that included the details of the sampling sites, history of sampling, and locations of sediment plates for Tokomairiro. A summary of this information is provided below.

Tokomairiro Estuary has three existing sites (A-C) of different dimensions and orientations, with sediment plates at each spaced at inconsistent distances and locations relative to site boundaries. Sites established in December 2017 do not replicate sites established by Ryder Consulting (Stewart et al. 2009). Site A had been moved to a current-swept island in the mid-channel of the lower estuary and Site B had been moved to a narrow intertidal flat adjacent to a stream/drain outlet (~100m downstream from a more suitable stable intertidal flat).

At the time of the 2019 survey, no sediment plates were found at Site A, and it was found that only 3 of 4 reported plates appeared to have been installed at each of Sites B and C. Information on the sites as sampled in 2019 and 2020 is provided below, with GPS positions of site corners and sediment plates as per the following Tables and Figures.

SITE A: Pegs and sediment plates reported as installed in 2018 could not be found, hence new site boundaries for a 30x40m site were pegged out in 2019, corresponding to the assumed location of the previous site. Four sediment plates were installed along the upstream margin of the new site (see Fig A.1.1).

SITE B: Narrow 15x20m site, encompassing the entire available low tide margin, located next to a farm drain/culvert. Sediment plates are installed along upstream margin (see Fig A.1.1). The single sediment plate missing in 2019 was installed in 2020.

SITE C: Narrow site with atypical dimensions of ~8.4 x 43m. Sediment plates are installed along the downstream margin, but in an atypical layout (3 plates spaced at uneven intervals from origin, with labelling order reversed; see Fig A1.1). The single sediment plate missing in 2019 was installed in 2020.

Position of Tokomairiro fine scale site corners

Estuary	Site	Site Corners	NZTM EAST	NZTM NORTH	Data Source	Source Peg No
Tokomairiro	A	C1	1371999	4877697	Salt	1
Tokomairiro	A	C2	1371991	4877657	Salt	2
Tokomairiro	A	C3	1371962	4877666	Salt	3
Tokomairiro	A	C4	1371972	4877705	Salt	4
Tokomairiro	A_RET	C1	1372024	4877704	REC	4
Tokomairiro	A_RET	C2	1372024	4877688	REC	3
Tokomairiro	A_RET	C3	1371993	4877688	REC	2
Tokomairiro	A_RET	C4	1371992	4877703	REC	1
Tokomairiro	B	C1	1372039	4878440	REC	1
Tokomairiro	B	C2	1372031	4878425	REC	2
Tokomairiro	B	C3	1372016	4878434	REC	3
Tokomairiro	B	C4	1372026	4878446	REC	4
Tokomairiro	C	C1	1372082	4878933	REC	3
Tokomairiro	C	C2	1372112	4878900	REC	4
Tokomairiro	C	C3	1372106	4878895	REC	1
Tokomairiro	C	C4	1372078	4878929	REC	2

RET indicates site retired

Position of Tokomairiro sediment plates

Estuary	Site	Plate	NZTM East	NZTM North	Distance (m)
Tokomairiro	A	1	1371995	4877698	5
Tokomairiro	A	2	1371989	4877700	10
Tokomairiro	A	3	1371980	4877702	20
Tokomairiro	A	4	1371975	4877704	25
Tokomairiro	B	1	1372037	4878441	2
Tokomairiro	B	2	1372035	4878443	4
Tokomairiro	B	3	1372033	4878444	6
Tokomairiro	B	4	1372032	4878445	8
Tokomairiro	C	1	1372107	4878897	2
Tokomairiro	C	2	1372109	4878898	4
Tokomairiro	C	3	1372111	4878899	6
Tokomairiro	C	4	1372112	4878901	8

Note: plate 4 coordinates provided for sites B and C but no plates were present.
Site C distances are reported spacings. Actual distances are 1) 2.05, 2) 3.25, 3) 5.30, 4) plate missing.

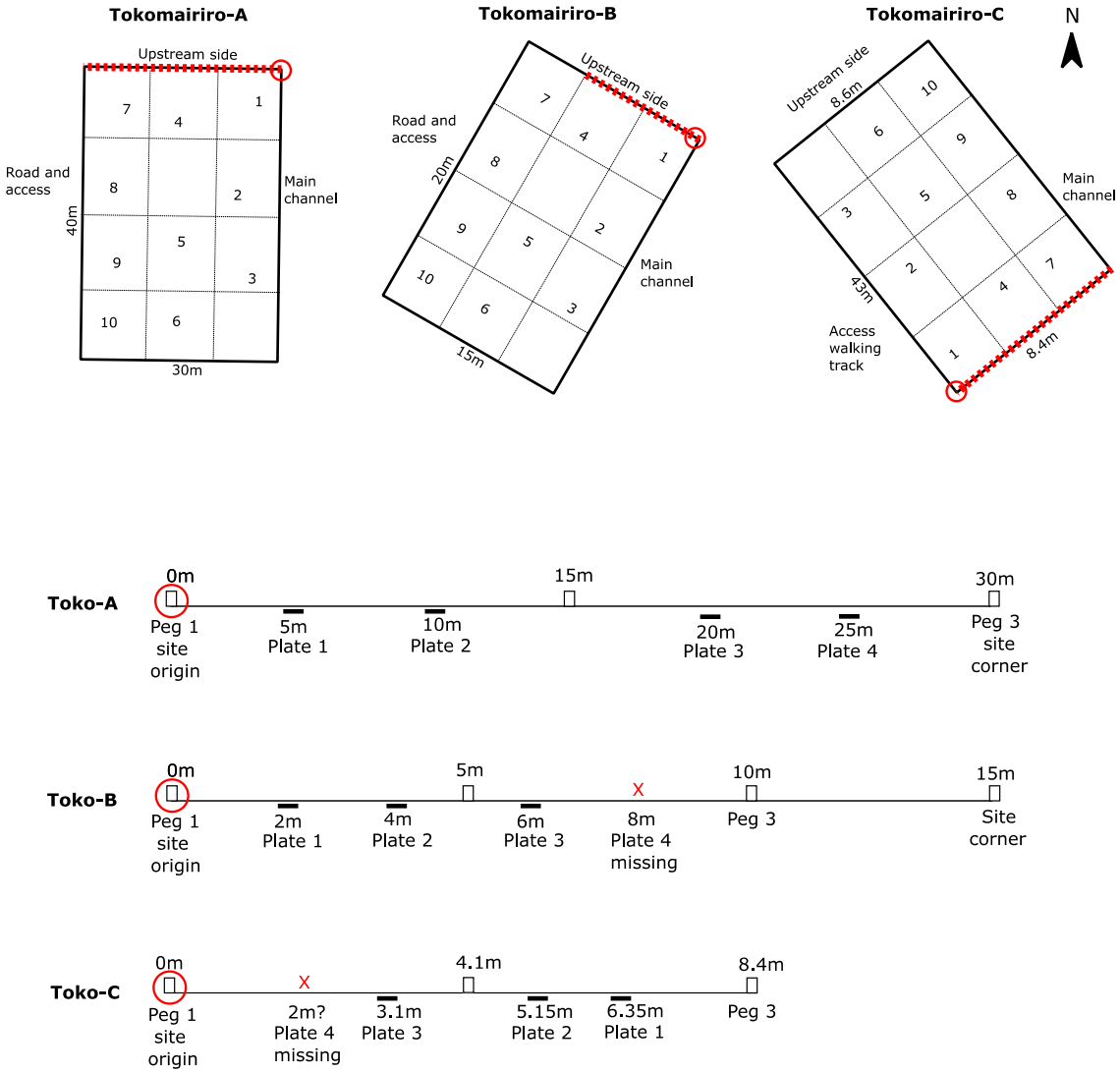


Fig. A1.1 Layout of Tokomairiro fine scale sites in 2019. Sediment plates missing from Sites B and C in 2019 were installed in 2020. A full set of four plates was installed at Site A in 2019. Red hatched line represents plate alignment, with plate 1 closest to origin (red circle).

Appendix 2. RJ Hill analytical methods

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%.	-	1-9
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%.	-	1-9
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	1-9
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	1-9
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	1-9
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-9
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	1-9
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 - 0.4 mg/kg dry wt	1-9
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	1-9
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	1-9
Fraction < 63 µm*	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-9

Appendix 3. Sediment plate raw data

The baseline depth was measured at the time of plate installation.

Date	Year	Site	Plate	Depth (mm)	Baseline depth (mm)	Days since last	Annual adjustment	Annualised change (mm)	Change from baseline (mm)
23/02/2019	2019	A	p1	76	76	NA	NA	NA	0
20/12/2019	2020	A	p1	57	76	300	0.8	-22.3	-18.3
23/02/2019	2019	A	p2	85	85	NA	NA	NA	0
20/12/2019	2020	A	p2	96	85	300	0.8	13	10.7
23/02/2019	2019	A	p3	99	99	NA	NA	NA	0
20/12/2019	2020	A	p3	91	99	300	0.8	-8.9	-7.3
23/02/2019	2019	A	p4	74	74	NA	NA	NA	0
20/12/2019	2020	A	p4	68	74	300	0.8	-8.1	-6.7
16/12/2017	2018	B	p1	65	65	NA	NA	NA	0
23/02/2019	2019	B	p1	75	65	434	1.2	8.4	10
20/12/2019	2020	B	p1	79	65	300	0.8	4.5	13.7
16/12/2017	2018	B	p2	85	85	NA	NA	NA	0
23/02/2019	2019	B	p2	83	85	434	1.2	-2	-2.3
20/12/2019	2020	B	p2	93	85	300	0.8	12.6	8
16/12/2017	2018	B	p3	73	73	NA	NA	NA	0
23/02/2019	2019	B	p3	82	73	434	1.2	7.8	9.3
20/12/2019	2020	B	p3	100	73	300	0.8	21.5	27
16/12/2017	2018	B	p4	87	87	NA	NA	NA	0
20/12/2019	2020	B	p4	49	87	734	2	-19.1	-38.3
16/12/2017	2018	C	p1	70	70	NA	NA	NA	0
23/02/2019	2019	C	p1	61	70	434	1.2	-7.3	-8.7
20/12/2019	2020	C	p1	64	70	300	0.8	2.8	-6.3
16/12/2017	2018	C	p2	75	75	NA	NA	NA	0
23/02/2019	2019	C	p2	67	75	434	1.2	-7	-8.3
20/12/2019	2020	C	p2	80	75	300	0.8	16.2	5
16/12/2017	2018	C	p3	50	50	NA	NA	NA	0
23/02/2019	2019	C	p3	49	50	434	1.2	-1.1	-1.3
20/12/2019	2020	C	p3	57	50	300	0.8	10.5	7.3
16/12/2017	2108	C	p4	76	76	NA	NA	NA	0
20/12/2019	2020	C	p4	47	76	734	2	-14.6	-29.3

Appendix 4. Sediment quality raw data

For aRPD, the range of values is based on 10 measurements per site, otherwise n = 3.

Year	Site	Zone	Gravel	Sand	Mud	TOC	TN	TP	aRPD	ORP10	ORP30	ORP50	ORP70	ORP100	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
			%	%	%	%	mg/kg	mg/kg	mm	mV	mV	mV	mV	mV	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
2018	A	X	0.6	89.0	10.4	0.20	<500	320	50	-53	-163	-	56	117	2.90	<0.010	3.20	1.90	<0.02	2.70	2.10	10
		Y	2.3	91.2	6.5	0.10	<500	260	50	-23	-78	-	-34	76	2.40	<0.010	2.40	1.60	<0.02	2.20	1.75	9
		Z	0.7	86.5	12.7	0.21	<500	440	50	-46	-44	-	31	-23	3.60	0.011	3.70	2.30	<0.02	3.50	2.40	13
	B	X	1.1	39.5	59.4	1.24	1400	740	10	-224	-155	-	-356	-396	8.70	0.042	10.90	7.50	0.17	9.10	7.00	44
		Y	0.4	31.5	68.1	1.62	1800	840	10	-218	-237	-	-346	-381	10.60	0.046	12.30	8.80	0.03	10.20	7.80	49
		Z	0.2	33.6	66.2	1.78	1900	920	10	-117	-241	-	-321	-371	10.90	0.051	12.40	8.70	0.03	9.90	8.00	50
	C	X	3.6	54.7	41.7	1.60	1600	840	10	-210	-189	-	-245	-310	9.90	0.045	12.70	8.80	0.03	10.00	8.60	54
		Y	2.8	35.0	62.2	1.46	1500	730	10	-206	-175	-	-267	-332	8.00	0.044	12.60	8.50	0.04	9.50	8.00	51
		Z	2.7	32.3	65.1	1.40	1500	790	10	-188	-167	-	-206	-311	9.80	0.044	13.10	8.70	0.03	10.00	8.40	55
2019	A	X	9.1	85.4	5.5	0.16	<500	240	85 to 90	186	184	199	221	232	2.60	<0.010	2.90	1.80	<0.02	2.70	1.86	11
		Y	7.6	84.1	8.3	0.18	<500	290	80 to 90	199	201	204	195	220	3.10	0.010	3.40	2.00	<0.02	2.80	2.10	12
		Z	1.2	85.7	13.1	0.31	600	530	30 to 50	186	181	188	193	198	4.00	0.013	4.70	2.70	<0.02	4.10	2.80	17
	B	X	0.3	34.0	65.7	1.24	1800	660	5 to 7	-136	-100	-172	-135	-220	7.90	0.048	12.90	7.60	0.03	9.10	7.50	52
		Y	0.3	30.4	69.3	1.32	1600	710	5 to 6	-38	-190	-202	-228	-161	7.20	0.053	12.60	7.60	0.03	8.50	7.60	51
		Z	1.2	28.6	70.3	1.28	1600	560	2 to 7	-60	-131	-188	-186	-208	5.70	0.049	12.20	7.20	0.02	7.90	7.50	49
	C	X	3.7	41.1	55.2	0.98	1200	580	2 to 3	-113	-119	-108	-111	-95	5.70	0.035	11.20	5.60	0.03	6.30	7.20	43
		Y	1.2	40.8	58.1	1.10	1300	610	3 to 5	-121	-135	-117	-55	-202	6.20	0.037	12.90	6.30	0.03	7.40	7.40	49
		Z	1.7	38.8	59.5	1.21	1400	580	2 to 7	-86	-144	-99	-111	-100	6.70	0.044	14.00	7.30	0.03	8.10	8.00	55
2020	A	X	5.7	86.7	7.6	0.25	<500	350	75	102	141	178	199	181	4.00	0.015	3.90	2.50	<0.02	3.50	2.40	16
		Y	6.5	84.2	9.3	0.30	<500	390	45	223	206	212	206	188	3.80	0.015	4.30	2.90	<0.02	3.90	2.70	17
		Z	0.6	82.8	16.5	0.38	500	470	40	219	210	181	168	51	4.90	0.018	5.80	4.00	<0.02	5.20	3.50	23
	B	X	0.4	44.0	55.6	1.67	1800	680	2 to 8	-65	-111	-56	-44	-150	8.30	0.050	13.10	10.00	0.03	11.40	8.20	56
		Y	0.5	34.5	65.0	1.38	1700	640	10 to 3	-93	-118	-71	-42	-61	8.00	0.046	12.70	9.60	0.03	10.70	8.30	56
		Z	1.9	37.0	61.1	1.27	1500	530	1 to 3	-80	-54	-1	179	14	6.40	0.047	11.00	8.00	0.03	9.00	7.30	51
	C	X	2.9	32.0	65.1	1.73	2000	750	3	-22	-106	-67	-62	70	8.70	0.041	13.40	8.30	0.03	9.50	8.60	60
		Y	5.1	37.8	57.1	1.34	1600	600	2 to 4	-56	-41	25	8	24	6.80	0.038	12.00	7.80	0.03	8.70	7.70	55
		Z	9.9	37.6	52.5	1.35	1600	710	10 to 8	-42	-34	-41	-16	13	7.80	0.036	12.40	8.00	0.03	9.00	7.80	56
															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

Year	Main_group	Taxa	Habitat	EG	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
18	Anthozoa	Edwardsia sp. 1	epibiota	II	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	Anthozoa	Edwardsia sp. 1	epibiota	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	Anthozoa	Edwardsia sp. 1	epibiota	II	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	3	0	0	0
20	Gastropoda	Amphibola crenata	epibiota	III	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
18	Gastropoda	Potamopyrgus estuarinus	epibiota	III	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1
19	Gastropoda	Potamopyrgus estuarinus	epibiota	III	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
20	Gastropoda	Potamopyrgus estuarinus	epibiota	III	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
18	Amphipoda	Amphipoda sp. 1	infauna	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
19	Amphipoda	Amphipoda sp. 1	infauna	II	0	0	0	0	0	0	0	0	0	0	47	3	3	3	9	48	14	3	32	6
20	Amphipoda	Amphipoda sp. 1	infauna	II	0	0	0	2	0	0	0	0	1	0	68	81	11	73	19	19	8	189	37	150
20	Amphipoda	Amphipoda sp. 2	infauna	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	Amphipoda	Amphipoda sp. 3	infauna	II	0	0	0	0	0	0	0	0	0	0	4	1	0	0	0	2	0	7	2	0
20	Amphipoda	Amphipoda sp. 3	infauna	II	0	0	0	0	0	0	0	0	0	0	14	23	0	10	0	27	0	7	3	0
19	Amphipoda	Amphipoda sp. 4	infauna	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
19	Amphipoda	Amphipoda sp. 5	infauna	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	Amphipoda	Amphipoda sp. 5	infauna	II	0	0	0	0	0	0	0	0	0	0	82	3	1	5	0	9	1	4	0	14
18	Amphipoda	Paracorophium excavatum	infauna	IV	0	0	0	0	0	0	0	0	0	0	64	16	48	32	52	4	96	8	12	8
19	Amphipoda	Paracorophium excavatum	infauna	IV	1	1	1	0	0	0	0	0	0	0	294	356	379	389	365	464	229	194	280	308
20	Amphipoda	Paracorophium excavatum	infauna	IV	784	739	1188	821	268	1039	701	960	862	1148	82	332	263	156	47	442	46	288	171	78
18	Bivalvia	Arthritica sp. 1	infauna	IV	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	Bivalvia	Arthritica sp. 1	infauna	IV	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	2	4	8	5
20	Bivalvia	Arthritica sp. 1	infauna	IV	0	0	0	0	0	0	0	0	1	0	5	5	0	3	0	3	0	1	2	0
19	Bivalvia	Austrovenus stutchburyi	infauna	II	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0
20	Bivalvia	Austrovenus stutchburyi	infauna	II	0	0	0	0	0	0	0	0	0	0	4	3	2	0	1	1	0	0	0	0
20	Bivalvia	Paphies australis	infauna	II	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	Copepoda	Copepoda sp. 1	infauna	II	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	Decapoda	Hemiplax hirtipes	infauna	V	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
20	Decapoda	Hemiplax hirtipes	infauna	V	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
19	Isopoda	Exosphaeroma planulum	infauna	V	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
20	Isopoda	Exosphaeroma planulum	infauna	V	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	4	0	0
20	Mysidae	Tenagomysis sp. 1	infauna	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	Nematoda	Nematoda	infauna	II	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
18	Nemertea	Nemertea sp. 1	infauna	III	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
19	Nemertea	Nemertea sp. 1	infauna	III	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	Nemertea	Nemertea sp. 2	infauna	III	2	1	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0
20	Oligochaeta	Oligochaeta sp. 1	infauna	III	0	0	1	0	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0
19	Polychaeta	Boccardia sp. 1	infauna	II	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
20	Polychaeta	Boccardia sp. 1	infauna	II	0	0	0	0	0	0	2	2	8	7	0	0	0	0	0	0	0	0	0	0
19	Polychaeta	Capitella sp. 1	infauna	IV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
20	Polychaeta	Capitella sp. 1	infauna	IV	0	0	0	0	0	0	0	1	4	1	0	28	0	0	1	0	0	7	2	2
18	Polychaeta	Nicon aestuariensis	infauna	III	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
19	Polychaeta	Nicon aestuariensis	infauna	III	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
18	Polychaeta	Perinereis vallata	infauna	II	13	6	3	0	0	0	0	4	1	0	4	10	7	10	4	14	5	12	6	8
19	Polychaeta	Perinereis vallata	infauna	II	2	3	1	7	5	1	7	4	3	1	5	6	6	4	3	4	1	2	6	7
20	Polychaeta	Perinereis vallata	infauna	II	2	2	1	5	2	3	1	1	3	0	0	6	10	0	1	6	1	1	0	1
18	Polychaeta	Scolecolepides benhami	infauna	IV	28	20	4	0	0	0	0	19	0	0	6	2	5	1	3	0	2	5	3	6
19	Polychaeta	Scolecolepides benhami	infauna	IV	1	0	0	0	0	0	7	2	0	0	17	42	29	24	32	30	28	17	25	15
20	Polychaeta	Scolecolepides benhami	infauna	IV	1	1	1	0	3	3	2	3	14	15	7	7	4	14	3	7	8	11	5	10
20	Polychaeta	Scoloplos cylindrifer	infauna	I	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
20	Turbellaria	Turbellaria sp. 1	infauna	II	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
18	Polychaeta	Nereididae (unidentified juv)	infauna juv	NA	16	18	7	0	0	0	5	8	1	0	1	0	0	0	1	0	2	0	2	0
19	Polychaeta	Nereididae (unidentified juv)	infauna juv	NA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0
20	Polychaeta	Nereididae (unidentified juv)	infauna juv	NA	4	1	10	4	5	4	4	6	3	2	0	8	0	1	0	0	1	5	5	0
20	Diptera	Diptera sp. 1	larva	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
19	Diptera	Diptera sp. 2	larva	II	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
20	Diptera	Diptera sp. 2	larva	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1
20	Diptera	Diptera sp. 4	larva	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0

Year	Main_group	Taxa	Habitat	EG	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
18	Anthozoa	Edwardsia sp. 1	epibiota	II	0	0	0	0	0	1	3	2	0	0
19	Anthozoa	Edwardsia sp. 1	epibiota	II	0	3	0	1	0	0	0	0	0	0
20	Anthozoa	Edwardsia sp. 1	epibiota	II	1	2	0	1	0	0	1	0	1	0
20	Gastropoda	Amphibola crenata	epibiota	III	0	0	0	0	0	0	0	0	0	0
18	Gastropoda	Potamopyrgus estuarinus	epibiota	III	4	0	0	2	0	0	0	0	0	0
19	Gastropoda	Potamopyrgus estuarinus	epibiota	III	0	0	0	0	0	0	0	0	0	0
20	Gastropoda	Potamopyrgus estuarinus	epibiota	III	0	0	0	0	0	0	0	0	0	1
18	Amphipoda	Amphipoda sp. 1	infauna	II	0	0	0	0	1	0	0	0	1	0
19	Amphipoda	Amphipoda sp. 1	infauna	II	2	4	1	15	1	6	7	4	6	2
20	Amphipoda	Amphipoda sp. 1	infauna	II	15	28	66	17	56	17	4	52	116	59
20	Amphipoda	Amphipoda sp. 2	infauna	II	0	0	0	0	0	0	0	0	4	2
19	Amphipoda	Amphipoda sp. 3	infauna	II	0	0	0	0	0	0	0	0	0	0
20	Amphipoda	Amphipoda sp. 3	infauna	II	1	0	3	2	1	0	1	3	12	2
19	Amphipoda	Amphipoda sp. 4	infauna	II	0	0	0	0	0	0	0	0	0	0
19	Amphipoda	Amphipoda sp. 5	infauna	II	0	0	0	0	0	1	0	0	0	0
20	Amphipoda	Amphipoda sp. 5	infauna	II	0	0	8	0	16	0	0	32	104	11
18	Amphipoda	Paracorophium excavatum	infauna	IV	0	8	60	0	28	52	80	80	20	20
19	Amphipoda	Paracorophium excavatum	infauna	IV	219	231	371	454	168	309	331	268	452	282
20	Amphipoda	Paracorophium excavatum	infauna	IV	1029	854	342	772	501	50	597	362	276	757
18	Bivalvia	Arthritica sp. 1	infauna	IV	0	0	0	1	0	0	0	0	0	0
19	Bivalvia	Arthritica sp. 1	infauna	IV	5	4	10	2	1	0	2	0	1	1
20	Bivalvia	Arthritica sp. 1	infauna	IV	2	2	2	1	0	0	2	2	0	0
19	Bivalvia	Austrovenus stutchburyi	infauna	II	0	0	0	0	0	1	1	2	1	0
20	Bivalvia	Austrovenus stutchburyi	infauna	II	0	0	0	0	0	1	0	0	1	0
20	Bivalvia	Paphies australis	infauna	II	0	0	0	0	0	0	0	0	0	0
20	Copepoda	Copepoda sp. 1	infauna	II	0	0	0	0	0	0	0	0	0	0
19	Decapoda	Hemiplax hirtipes	infauna	V	0	0	0	0	1	0	0	0	0	0
20	Decapoda	Hemiplax hirtipes	infauna	V	0	0	0	0	0	0	0	0	0	0
19	Isopoda	Exosphaeroma planulum	infauna	V	0	0	0	0	0	0	0	1	2	0
20	Isopoda	Exosphaeroma planulum	infauna	V	2	2	2	1	1	0	0	3	0	0
20	Mysidae	Tenagomysis sp. 1	infauna	II	0	3	0	0	0	2	0	0	0	0
20	Nematoda	Nematoda	infauna	II	0	0	0	0	0	0	0	0	0	0
18	Nemertea	Nemertea sp. 1	infauna	III	0	0	0	0	0	0	0	0	0	0
19	Nemertea	Nemertea sp. 1	infauna	III	0	0	0	0	0	0	0	0	0	0
20	Nemertea	Nemertea sp. 2	infauna	III	0	0	0	0	0	0	0	0	0	0
20	Oligochaeta	Oligochaeta sp. 1	infauna	III	0	11	0	0	1	1	0	0	16	0
19	Polychaeta	Boccardia sp. 1	infauna	II	0	0	0	0	0	0	0	0	0	0
20	Polychaeta	Boccardia sp. 1	infauna	II	0	0	0	0	1	0	0	0	0	0
19	Polychaeta	Capitella sp. 1	infauna	IV	0	0	0	0	0	0	0	0	0	0
20	Polychaeta	Capitella sp. 1	infauna	IV	1	0	0	0	0	0	0	0	2	2
18	Polychaeta	Nicon aestuariensis	infauna	III	0	0	0	0	0	0	0	0	0	0
19	Polychaeta	Nicon aestuariensis	infauna	III	0	0	0	0	0	0	0	0	0	0
18	Polychaeta	Perinereis vallata	infauna	II	10	15	18	20	19	6	22	16	21	17
19	Polychaeta	Perinereis vallata	infauna	II	12	14	6	6	8	8	14	8	13	10
20	Polychaeta	Perinereis vallata	infauna	II	4	1	0	2	6	5	6	8	1	4
18	Polychaeta	Scolecolepides benhami	infauna	IV	0	2	0	0	1	1	3	1	4	7
19	Polychaeta	Scolecolepides benhami	infauna	IV	6	9	30	10	11	25	3	9	17	25
20	Polychaeta	Scolecolepides benhami	infauna	IV	1	7	15	2	10	14	3	4	14	12
20	Polychaeta	Scoloplos cylindrifer	infauna	I	0	0	0	0	0	0	0	0	0	0
20	Turbellaria	Turbellaria sp. 1	infauna	II	0	2	0	0	0	0	0	0	0	0
18	Polychaeta	Nereididae (unidentified juv)	infauna juv	NA	0	0	0	0	1	0	2	3	0	0
19	Polychaeta	Nereididae (unidentified juv)	infauna juv	NA	0	0	0	0	0	1	0	0	0	0
20	Polychaeta	Nereididae (unidentified juv)	infauna juv	NA	0	1	0	0	0	0	0	0	0	0
20	Diptera	Diptera sp. 1	larva	II	0	0	0	0	0	0	0	0	0	0
19	Diptera	Diptera sp. 2	larva	II	0	0	0	0	0	0	0	0	0	0
20	Diptera	Diptera sp. 2	larva	II	0	0	0	0	0	0	0	0	0	0
20	Diptera	Diptera sp. 4	larva	II	0	4	0	3	0	1	0	0	1	1

Appendix 6. Macrofauna core taxonomy QA/QC results and preliminary assessment of sampling adequacy

A6.1 Taxonomy QA/QC

In the taxonomic QA/QC assessment, Salt Ecology picked the macrofauna from each sieved sample. The 10 routine samples were then sent for taxonomic identification to Gary Stephenson (Coastal Marine Ecology Consultants; CMEC), with an additional core sample from plot Y5 sent to NIWA. Results below compare the two providers for each site separately.

As indicated in the Table A6.1.1 below, for each site, species richness and abundance in the QA/QC sample assessed by NIWA were comparable to the other samples sent to CMEC. The greater overall richness of species described by CMEC in Table A6.1.1 simply reflects the greater number of samples assessed (i.e. greater sampling effort).

Overall, the species complement was judged as very similar between the two providers with many apparent differences likely explained by the following:

(i) Species likely missed by chance due to their low density. For example, the CMEC assessment of 10 cores describes many species whose mean density was <1/core. As such, it is not surprising that not all these species were detected in the single core sent to NIWA for QA/QC.

(ii) Subtle differences between providers in the naming of taxa that are very probably the same species, e.g. Oligochaeta vs Oligochaeta sp. 1; *Capitella* spp. vs *Capitella* sp. 1.

(iii) Different levels of taxonomic resolution attempted. For example, for taxa that are time-consuming to identify, CMEC focuses on using consistent 'placeholder' names. During the QA/QC process, NIWA took some of these to a more detailed level of taxonomic resolution (but at ~3 times the cost per core); e.g. CMEC names Amphipoda as sp. 1, 2, 3 etc, whereas NIWA have keyed these to genus and species.

In order to be certain that the above assumptions are correct, it would be necessary for the same voucher specimens to be compared among the taxonomic providers. This depth of assessment was beyond the present scope, but would be a useful subsequent step towards developing a reference collection for Tokomairiro Estuary.

A6.2 Macrofauna sampling adequacy

The NEMP approach recommends 10 macrofauna core samples to be collected per site, with the replication effort based on a detailed analysis of a national dataset as part of the original study (and driven primarily by sediment chemistry as opposed to macrofauna). It was beyond the present scope to undertake a comprehensive re-assessment, but some simple methods can be applied to evaluate whether the number of macrofauna core samples taken is sufficient to capture the main species present in Tokomairiro Estuary or, alternatively, whether sampling effort could be reduced without losing important information.

To make this assessment, species accumulation curves were constructed for each year-site combination using a permutation-based method available in Primer 7. This method determines the increasing total number of different species observed (S_obs), as samples are successively pooled. The number of species for each of sample numbers 1-10 is the average based on 999 random selections from the total number of samples. This approach produces a smoothed S_obs curve, with S at sample 10 being the total actual number sampled for that fine scale site and survey year.

Table A6.1.1 Macrofaunal QA/QC results and provider comparison.

SITE A

Taxa	A_CMEC (mean, n=10)	A_NIWA (n=1)	Comment
Amphipoda sp. 1	0.3	0	Likely a chance miss due to low density
Arthritica sp. 1	0.1	0	Likely a chance miss due to low density
Boccardia sp. 1	1.9	0	Possibly a chance miss due to low density
Capitella sp. 1	0.6	0	Assumed NIWA Capitella spp.
Capitella spp.	0	2	Assumed CMEC Capitella sp. 1
Copepoda sp. 1	0.1	0	Likely a chance miss due to low density
Nematoda	0.1	1	
Nemertea sp. 2	0.6	0	Likely a chance miss due to low density
Nereididae (unidentified juveniles)	4.3	0	Possibly a chance miss due to low density
Oligochaeta	0	1	Assumed CMEC Oligochaeta sp. 1
Oligochaeta sp. 1	0.3	0	Assumed NIWA Oligochaeta
Paphies australis	0.1	0	Likely a chance miss due to low density
Paracorophium excavatum	851	116	
Perinereis vallata	2	13	
Scolecolepides benhami	4.3	17	
Number of taxa	**13**	**6**	(CMEC range/core 4-8)
Sum abundance	**866**	**150**	(CMEC range/core 279-1201)

SITE B

Taxa	B_CMEC (mean, n=10)	B_NIWA (n=1)	Comment
Amphibola crenata	0.3	0	Likely a chance miss due to low density
Amphipoda sp. 1	65.5	0	Assumed one of NIWA amphipods
Amphipoda sp. 3	8.4	0	Assumed one of NIWA amphipods
Amphipoda sp. 5	11.9	0	Assumed one of NIWA amphipods
Arthritica bifurca	0	8	Assumed CMEC Arthritica sp. 1
Arthritica sp. 1	1.9	0	Assumed NIWA Arthritica bifurca
Asellota	0	1	Assumed CMEC Exosphaeroma planulum
Austrovenus stutchburyi	1.1	2	
Capitella sp. 1	4	0	Assumed NIWA Capitella spp.
Capitella spp.	0	17	Assumed CMEC Capitella sp. 1
Diptera sp. 1	0.1	0	Likely a chance miss due to low density
Diptera sp. 2	0.3	0	Likely a chance miss due to low density
Diptera sp. 4	0.1	0	Likely a chance miss due to low density
Edwardsia sp. 1	0.4	0	Likely a chance miss due to low density
Exosphaeroma planulum	0.5	1	Assumed NIWA Asellota
Hemiplax hirtipes	0.1	0	Likely a chance miss due to low density
Melita awa	0	8	Assumed one of CMEC amphipoda
Nereididae (unidentified juveniles)	2	0	Possibly a chance miss due to low density
Nicon aestuariensis	0	2	Possibly a chance miss due to low density
Oligochaeta	0	4	Assumed CMEC Oligochaeta sp. 1
Oligochaeta sp. 1	0.2	0	Assumed NIWA Oligochaeta
Paracalliope novizealandiae	0	126	Assumed one of CMEC amphipoda
Paracorophium excavatum	190.5	217	
Paramoera chevreuxi	0	6	Assumed one of CMEC amphipoda
Perinereis vallata	2.6	8	
Potamopyrgus estuarinus	0.1	0	Likely a chance miss due to low density
Scolecolepides benhami	7.6	19	
Scoloplos cylindrifer	0.1	0	Likely a chance miss due to low density
Turbellaria sp. 1	0.2	0	Likely a chance miss due to low density
Number of taxa	**21**	**13**	(CMEC range/core 6-12)
Sum abundance	**298**	**419**	(CMEC range/core 68-521)

Table A6.1.1 (cont.)

SITE C

Taxa	A_CMEC (mean, n=10)	A_NIWA (n=1)	Comment
Amphipoda sp. 1	43	0	Assumed one of NIWA amphipods
Amphipoda sp. 2	0.6	0	Likely a chance miss due to low density
Amphipoda sp. 3	2.5	0	Assumed chance miss one of NIWA amphipods
Amphipoda sp. 5	17.1	0	Assumed one of NIWA amphipods
Arthritica bifurca	0	5	Assumed CMEC Arthritica sp. 1
Arthritica sp. 1	1.1	0	Assumed NIWA Arthritica bifurca
Austrovenus stutchburyi	0.2	1	
Boccardia sp. 1	0.1	0	Likely a chance miss due to low density
Capitella sp. 1	0.5	0	Assumed NIWA Capitella spp.
Capitella spp.	0	49	Assumed CMEC Capitella sp. 1
Diptera sp. 4	1	0	Likely a chance miss due to low density
Edwardsia sp.	0	4	Assumed CMEC Edwardsia sp. 1
Edwardsia sp. 1	0.6	0	Assumed NIWA Edwardsia sp.
Exosphaeroma planulum	1.1	7	
Idoteidae	0	2	Possibly a chance miss due to low density
Ischyroceridae	0	10	Assumed one of CMEC Amphipoda
Melita awa	0	9	Assumed one of CMEC Amphipoda
Mysidae	0	7	Assumed CMEC Tenagomysis sp. 1
Nereididae (unidentified juveniles)	0.1	0	Likely a chance miss due to low density
Oligochaeta	0	42	Assumed CMEC Oligochaeta sp. 1
Oligochaeta sp. 1	2.9	0	Assumed NIWA Oligochaeta
Paracalliope novizealandiae	0	142	Assumed one of CMEC Amphipoda
Paracorophium excavatum	554	418	
Paramoera chevreuxi	0	42	Assumed one of CMEC Amphipoda
Perinereis vallata	3.7	4	
Potamopyrgus estuarinus	0.1	0	Likely a chance miss due to low density
Pseudopotamilla sp.	0	1	Likely a chance miss due to low density
Scolecolepides benhami	8.2	23	
Tenagomysis sp. 1	0.5	0	Assumed NIWA Mysidae
Turbellaria sp. 1	0.2	0	Likely a chance miss due to low density
Number of taxa	**19**	**16**	(CMEC range/core 7-12)
Sum abundance	**638**	**766**	(CMEC range/core 91-1056)

If sampling has adequately captured all species at the site, the curve would reach an asymptote, with no further species detected with subsequent sampling. Due to the presence of rare (i.e. uncommon) species, an asymptote is unlikely to ever be reached in practice, i.e. due to chance sampling of rare species with increasing effort, as evidenced in the CMEC vs NIWA comparison above. However, methods are available that estimate the species richness that corresponds to the point where the asymptote is theoretically reached. For present purposes, we use two species estimation methods from Primer 7, a non-parametric bootstrap method (referred to here as S1) and a parametric Michaelis-Menton model (referred to here as S2).

Fig. A6.1 below shows the S_obs curves for each year-site, and Table A6.2.1 shows the two estimates of 'true' species richness for each year-site, as well as the proportion of that richness captured with increasing sampling effort. As expected, Fig. A6.1 shows that the cumulative species richness curve is generally still slowly increasing at 10 samples, but is nonetheless reasonably flat. Table A6.2.1 suggests that with 10 samples, the number of species being detected for each year-site ranges from ~76-97% of the estimated maximum. One way to interpret the results is that it may take >10 samples before actual richness reaches the estimated total for a given year-site. Table A6.2.2 indicates that to sample 90% of the predicted species present, somewhere between 8 and >10 cores will be required. However, with increasing sampling effort it will be the rare species that are represented, with the most dominant species collected with far fewer cores.

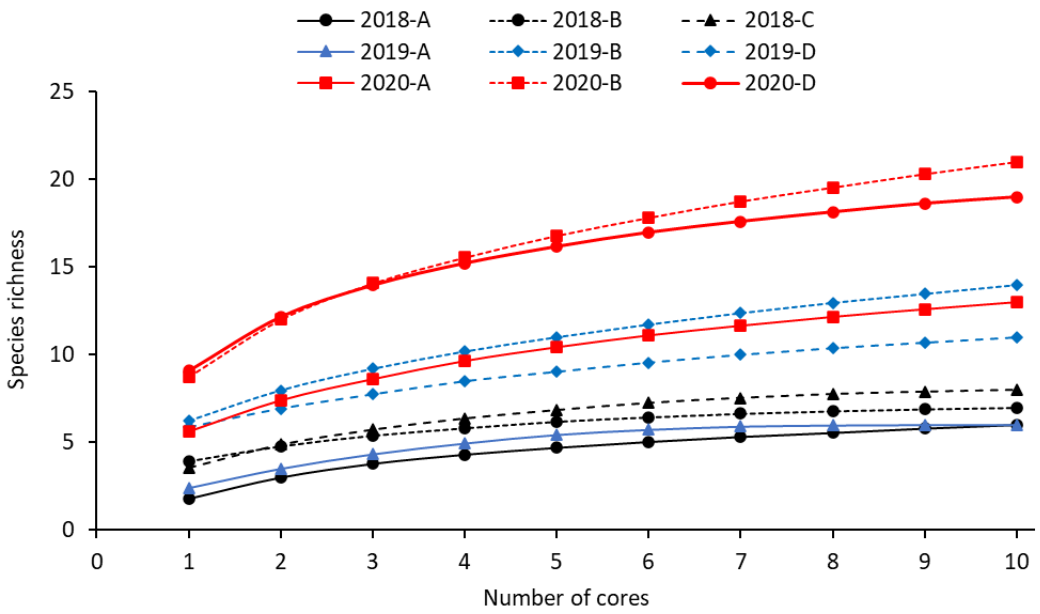


Fig. A6.1 Cumulative species richness in relation to sampling effort for each year-site.

As there are ever diminishing returns with increased effort, and the chance presence/absence of rarer species can be difficult to interpret ecologically, a complementary and defensible way to consider sampling adequacy is to focus on richness among the most dominant species. For this purpose, we assessed the number of species for a given year-site that captured at least 90% of total site abundance, and assessed the percentage of total year-site richness that this number of species represented. From that information, we then used the median of the S1 and S2 total richness estimates from Table A6.2.1 to determine the minimum number of samples required to reach that percentage for each year-site combination. The results are given in Table A6.2.2.

The likelihood of a species being detected is assumed to be directly proportional to its abundance, so defining the number of species required to capture >90% of a site's abundance (in a given year) allows minimum sampling effort to be defined. Table A6.2.2 shows that, across all year-site combinations, at least 90% of site abundance is represented by between 1 and 5 taxa, reflecting the dominance of the macrofauna by *Paracorophium excavatum*. As a consequence, to consistently sample 90% of macrofaunal abundance would often require only one core to be collected, but in the case of 2019-A the estimate was 6 cores (reflecting the absence of any dominant species).

The above assessment shows that sampling sufficiency needs to be tailored to the response variable of most interest. If it is considered desirable to capture the richness of species present, sampling effort needs to be far greater than when only the most dominant species are targeted. However, on average across the sites, roughly 9 samples would capture close to 90% of taxa present. Even though some of the uncommon species may be missed, these do not greatly contribute to determination of temporal change anyway. The risk in taking very few cores to sample just the dominant species (i.e. 1 core as indicated above) is that increased environmental stress may not always be reliably reflected. For example, at Site A in 2018, four cores were azoic (i.e. having no macrofauna), hence taking 1 core could have skewed the results (e.g. by chance, the cores may have been azoic).

As such, to achieve a reasonable balance between capturing the most abundant taxa, as well as most of the less common ones, it is suggested that the macrofaunal sampling effort in future surveys could be reduced to 9 cores. This will ensure comparability of future sampling results with existing data from Tokomairiro Estuary (and among estuaries regionally and even nationally), and will provide sufficient sampling effort to account for years when the assemblage is reasonably species-poor and a greater number of cores is needed. This approach has the additional benefits of reducing cost and providing a more balanced sampling design with a 3 x 3 layout of sampling plots, rather that the subsampling of 10 plots with the 3 x 4 present layout (see Fig. 3 of the main report).

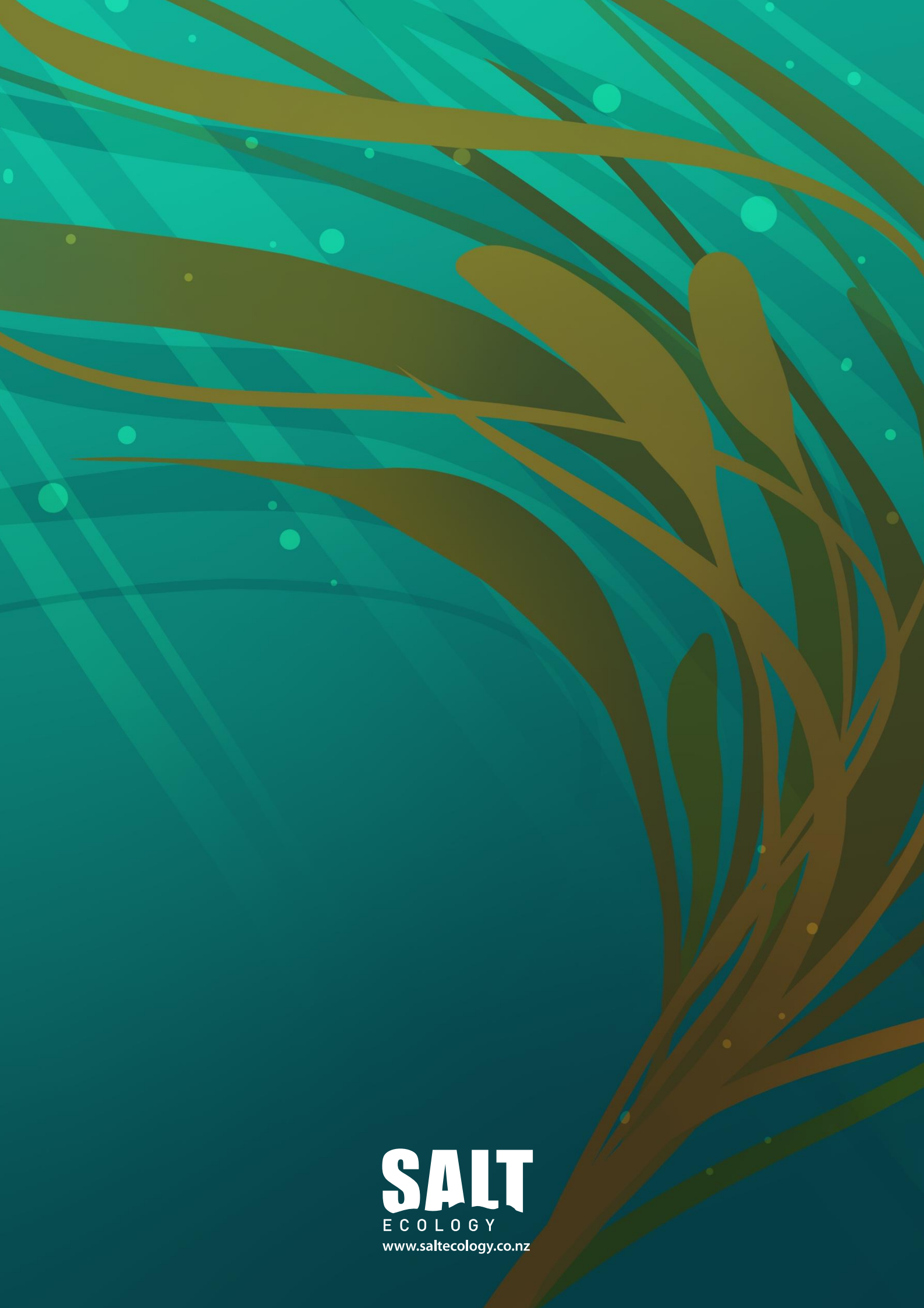
Table A6.2.1 Macrofaunal sampling species richness estimates and percentage of theoretical richness captured in relation to sampling effort. Median % is median of the two columns to the left, and is used in Table A6.2.2 to determine minimum sample size (see text for details).

2018A	S1 estimate = 6.85, S2 estimate = 7.9					2019A	S1 estimate = 7.7, S2 estimate = 7.0					2020A	S1 estimate =10.8, S2 estimate = 10.4				
Samp#	S_obs	S_obs (% total)	S_obs as % of S1	S_obs as % of S2	Median%	Samp#	S_obs	S_obs (% total)	S_obs as % of S1	S_obs as % of S2	Median%	Samp#	S_obs	S_obs (% total)	S_obs as % of S1	S_obs as % of S2	Median%
1	1.8	30.2	26.6	23.0	24.8	1	2.4	40.0	38.5	31.5	35.0	1	5.6	43.4	38.5	38.8	38.7
2	3.0	50.3	44.3	38.3	41.3	2	3.5	58.3	56.2	46.0	51.1	2	7.4	57.0	50.6	51.0	50.8
3	3.8	63.2	55.7	48.1	51.9	3	4.3	72.1	69.5	56.8	63.2	3	8.6	66.3	58.8	59.3	59.1
4	4.3	71.9	63.4	54.7	59.0	4	4.9	82.4	79.5	65.0	72.3	4	9.7	74.3	65.9	66.5	66.2
5	4.7	78.4	69.0	59.6	64.3	5	5.4	90.5	87.3	71.4	79.4	5	10.4	80.3	71.2	71.9	71.5
6	5.0	83.9	73.9	63.9	68.9	6	5.7	95.4	92.0	75.2	83.6	6	11.1	85.4	75.8	76.5	76.2
7	5.3	88.6	78.1	67.4	72.7	7	5.9	98.4	94.9	77.6	86.3	7	11.7	89.7	79.6	80.3	79.9
8	5.5	92.5	81.4	70.4	75.9	8	6.0	99.5	96.0	78.5	87.2	8	12.2	93.6	83.0	83.8	83.4
9	5.8	96.6	85.1	73.5	79.3	9	6.0	100.0	96.5	78.8	87.6	9	12.6	96.9	86.0	86.7	86.4
10	6.0	100.0	88.1	76.1	82.1	10	6.0	100.0	96.5	78.8	87.6	10	13.0	100.0	88.7	89.5	89.1
2018B	S1 estimate = 10.7, S2 estimate = 11.0					2019B	S1 estimate = 8.7, S2 estimate = 8.0					2020B	S1 estimate =18.0, S2 estimate = 17.8				
Samp#	S_obs	S_obs (% total)	S_obs as % of S1	S_obs as % of S2	Median%	Samp#	S_obs	S_obs (% total)	S_obs as % of S1	S_obs as % of S2	Median%	Samp#	S_obs	S_obs (% total)	S_obs as % of S1	S_obs as % of S2	Median%
1	3.9	55.6	51.9	51.6	51.8	1	6.2	44.4	38.9	40.8	39.9	1	8.8	41.7	36.8	37.0	36.9
2	4.8	68.0	63.6	63.2	63.4	2	8.0	56.9	49.9	52.3	51.1	2	12.0	57.2	50.5	50.7	50.6
3	5.4	76.9	71.9	71.4	71.6	3	9.2	65.7	57.5	60.3	58.9	3	14.1	67.0	59.2	59.4	59.3
4	5.8	83.0	77.6	77.1	77.3	4	10.2	72.8	63.8	66.8	65.3	4	15.6	74.1	65.4	65.6	65.5
5	6.2	88.4	82.6	82.1	82.4	5	11.0	78.6	68.9	72.2	70.5	5	16.8	80.0	70.6	70.8	70.7
6	6.4	92.1	86.1	85.5	85.8	6	11.7	83.8	73.4	76.9	75.2	6	17.8	84.9	74.9	75.2	75.0
7	6.7	95.1	88.8	88.3	88.5	7	12.4	88.5	77.5	81.2	79.4	7	18.8	89.3	78.8	79.1	78.9
8	6.8	97.1	90.8	90.2	90.5	8	13.0	92.7	81.2	85.1	83.1	8	19.5	93.1	82.1	82.4	82.3
9	6.9	98.7	92.3	91.7	92.0	9	13.5	96.3	84.4	88.4	86.4	9	20.3	96.7	85.4	85.7	85.5
10	7.0	100.0	93.5	92.9	93.2	10	14.0	100.0	87.6	91.8	89.7	10	21.0	100.0	88.3	88.6	88.4
2018C	S1 estimate = 3.5, S2 estimate = 4.3					2019C	S1 estimate =7.5, S2 estimate = 8.1					2020C	S1 estimate = 12.5, S2 estimate = 11.8				
Samp#	S_obs	S_obs (% total)	S_obs as % of S1	S_obs as % of S2	Median%	Samp#	S_obs	S_obs (% total)	S_obs as % of S1	S_obs as % of S2	Median%	Samp#	S_obs	S_obs (% total)	S_obs as % of S1	S_obs as % of S2	Median%
1	3.6	44.8	41.6	38.8	40.2	1	5.9	53.3	47.8	51.2	49.5	1	9.1	47.9	43.8	43.2	43.5
2	4.9	61.2	56.8	53.0	54.9	2	6.9	63.0	56.5	60.5	58.5	2	12.2	64.1	58.7	57.8	58.2
3	5.7	71.8	66.6	62.1	64.4	3	7.7	70.4	63.2	67.5	65.3	3	14.0	73.6	67.3	66.3	66.8
4	6.4	79.7	74.0	69.0	71.5	4	8.5	77.2	69.3	74.1	71.7	4	15.2	80.1	73.4	72.3	72.8
5	6.9	85.7	79.5	74.1	76.8	5	9.0	82.2	73.7	78.8	76.2	5	16.2	85.2	78.0	76.8	77.4
6	7.3	90.8	84.2	78.5	81.4	6	9.6	86.9	77.9	83.3	80.6	6	17.0	89.4	81.9	80.6	81.2
7	7.5	94.4	87.6	81.6	84.6	7	10.0	90.9	81.6	87.2	84.4	7	17.6	92.7	84.8	83.6	84.2
8	7.8	97.1	90.1	84.0	87.0	8	10.4	94.4	84.6	90.5	87.6	8	18.1	95.5	87.4	86.1	86.8
9	7.9	98.7	91.6	85.4	88.5	9	10.7	97.3	87.2	93.3	90.2	9	18.6	98.1	89.8	88.5	89.1
10	8.0	100.0	92.8	86.5	89.7	10	11.0	100.0	89.7	95.9	92.8	10	19.0	100.0	91.5	90.2	90.9

Table A6.2.2 Determination of minimum sample size (rounded up to the nearest whole number) needed to capture the most abundant taxa, using a threshold cumulative abundance value of 90%. See text for details.

Year-site	S (observed)	S (predicted)	Min #cores to sample >90% of predicted S	# S to sample >90% of N	Percent of observed S	Min #cores to achieve >90% of N
2018A	6	7.4	>10	3	50	3
2018B	7	7.5	8	2	29	1
2018C	8	8.9	10	2	25	1
2019A	6	6.9	>10	5	83	6
2019B	14	15.6	10	2	14	1
2019C	11	11.9	9	1	9	1
2020A	13	14.6	>10	1	8	1
2020B	21	23.8	>10	3	14	1
2020C	19	20.9	10	2	11	1

S = richness (no. of taxa), N = abundance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