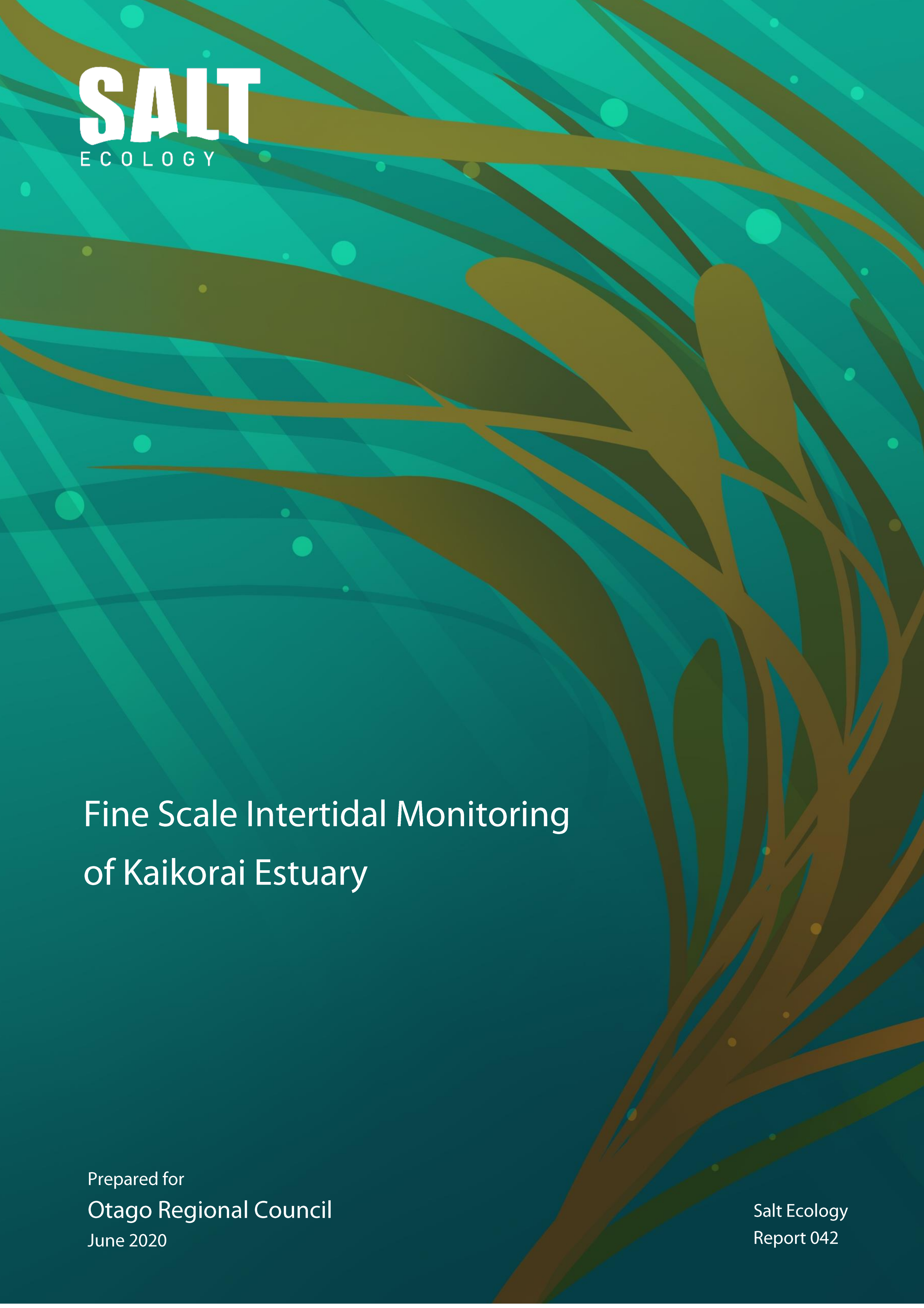

SALT
ECOLOGY

Fine Scale Intertidal Monitoring of Kaikorai Estuary

Prepared for
Otago Regional Council
June 2020

Salt Ecology
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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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Fine Scale Intertidal Monitoring of Kaikorai Estuary

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June 2020

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SALT ECOLOGY

For the People
Mō ngā tāngata

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EXECUTIVE SUMMARY

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 similar investigations undertaken in 2001 and 2007, 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 strongly contrast each other in terms of their general characteristics, ranging from well-flushed mobile intertidal sands with a strong marine influence in the lower estuary, subtidal muds in the middle estuary, and coarse gravels and muds with a strong freshwater influence in the upper estuary. The estuary is moderately degraded in some areas, most notably at Site B, where muddy, enriched sediments with relatively high trace metal (zinc) concentrations are evident. Synoptic water quality sampling conduced in 2018 identified eutrophication symptoms in the bottom waters of the upper estuary. Despite the estuary being presently degraded in parts, there have been no substantive long-term changes at any sites that would indicate a deteriorating situation.

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. The cumulative sedimentation (since baseline) of ~15mm at Site A in 2020 (i.e. 7-8mm/yr) greatly exceeds a provisional 2mm/yr national guideline value, but most likely reflects the movement of relatively mobile sands at that site due to dynamic hydrological conditions, rather than sedimentation from catchment inputs.
- **Sediment quality and trophic state:** The table below highlights that sediment quality was relatively good at Site A, with all indicators rated 'good' or 'very good'. Such results are consistent with this site being relatively sandy and well-flushed. The poorest sediment quality (rated 'fair' or 'poor') was measured at Site B. The muddy sediments at Site B were organically enriched and had relatively high nutrient concentrations, with the depth of the apparent Redox Potential Discontinuity (aRPD) being close to the sediment surface. In addition, in all surveys the concentration of zinc at Site B exceeded sediment quality guidelines for 'possible' ecological effects.
- **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 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 A and B) was reasonably similar despite their contrasting habitats.

There was no obvious macrofaunal response to increased sediment mud or other sediment quality measures, which suggests that other unmeasured factors are more strongly influencing the community. These likely include catchment influences, variable hydrological effects from Kaikorai Stream, and extended periods of low salinity due to closure or flow restriction where the estuary enters the sea.

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

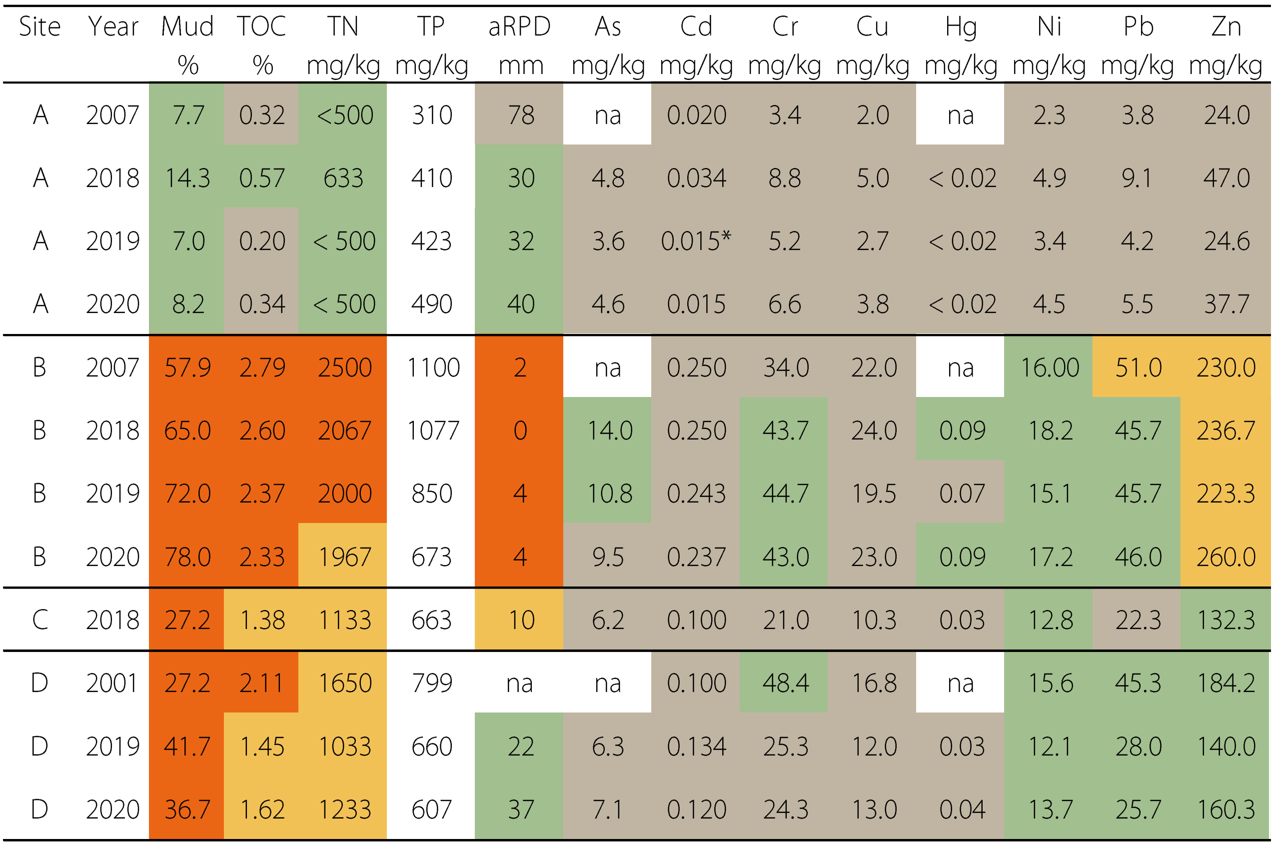
1. Monitoring frequency and locations: Ongoing sedimentation ('sediment plate') monitoring should be continued annually, but it is sufficient to undertake fine scale sampling less frequently (e.g. every 5 years). The current sites are the best available for monitoring purposes. Although they are not species-rich, they have a sufficient range of taxa to enable any ecologically significant environmental changes to be detected.

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 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 Kaikorai Estuary (e.g. salinity and dissolved oxygen monitoring, source tracking of zinc and other potential contaminants), and identify any feasible remedial actions that could be undertaken to improve condition.

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



Site	Year	Mud %	TOC %	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
A	2007	7.7	0.32	<500	310	78	na	0.020	3.4	2.0	na	2.3	3.8	24.0
A	2018	14.3	0.57	633	410	30	4.8	0.034	8.8	5.0	< 0.02	4.9	9.1	47.0
A	2019	7.0	0.20	< 500	423	32	3.6	0.015*	5.2	2.7	< 0.02	3.4	4.2	24.6
A	2020	8.2	0.34	< 500	490	40	4.6	0.015	6.6	3.8	< 0.02	4.5	5.5	37.7
B	2007	57.9	2.79	2500	1100	2	na	0.250	34.0	22.0	na	16.00	51.0	230.0
B	2018	65.0	2.60	2067	1077	0	14.0	0.250	43.7	24.0	0.09	18.2	45.7	236.7
B	2019	72.0	2.37	2000	850	4	10.8	0.243	44.7	19.5	0.07	15.1	45.7	223.3
B	2020	78.0	2.33	1967	673	4	9.5	0.237	43.0	23.0	0.09	17.2	46.0	260.0
C	2018	27.2	1.38	1133	663	10	6.2	0.100	21.0	10.3	0.03	12.8	22.3	132.3
D	2001	27.2	2.11	1650	799	na	na	0.100	48.4	16.8	na	15.6	45.3	184.2
D	2019	41.7	1.45	1033	660	22	6.3	0.134	25.3	12.0	0.03	12.1	28.0	140.0
D	2020	36.7	1.62	1233	607	37	7.1	0.120	24.3	13.0	0.04	13.7	25.7	160.3

** Sample mean includes values below lab detection limits*

< All values below lab detection limit

TOC in 2001 & 2007 calculated from %Ash Free Dry Weight as: TOC = 0.4xAFDW + 0.0025xAFDW^2 *(Robertson et al. 2002).*

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 subsequent to 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 Kaikorai Estuary (Fig. 1). Kaikorai Estuary is one of eight estuaries nationally in which limited sampling was undertaking in 2001 as part of the original NEMP investigations, and which was monitored again in 2007 (Stewart 2008). To build on this background knowledge, 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 conducted in the summer of 2018/19 and 2019/20, respectively.

The following report describes the methods and results of all three surveys, compares key findings with the 2001 and 2007 studies, discusses the status and trends in estuary health, and makes recommendations for future monitoring.

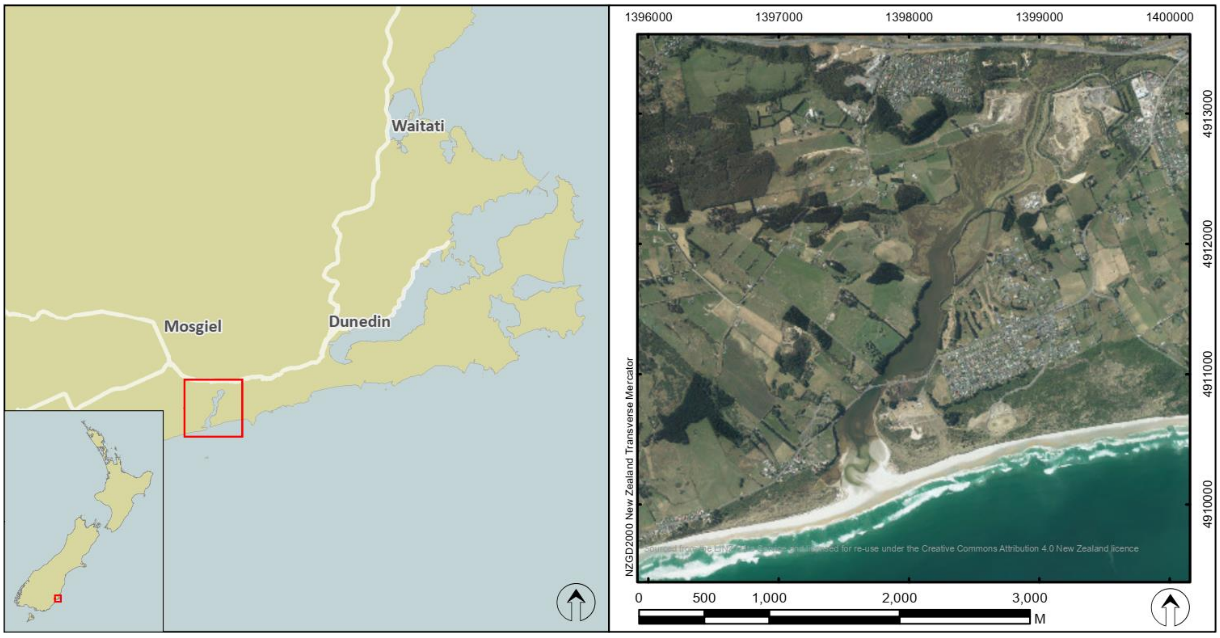


Fig. 1. Location of Kaikorai Estuary.

2. BACKGROUND TO KAIKORAI ESTUARY

Background information on Kaikorai Estuary was described in Stevens (2018), which is repeated here with only minor modification, and supplemented with limited additional information. Situated at the mouth of the Kaikorai Stream (mean flow ~0.46m^3/s) near Waldronville, South Dunedin, Kaikorai Estuary drains a 55km^2 catchment containing high producing exotic pastures (47%) and urban areas (21%) (Fig. 2). It is 94ha in area and classified as a shallow, intertidal dominated estuary (SIDE).

The estuary discharges to the Pacific Ocean via a broad embayment. The mouth is nearly always open but experiences occasional closures, and often has a narrowed entrance that constricts tidal water movement. The impact of sand bar formation and periodic mouth closure has led to relatively rapid sedimentation within the estuary, limiting the tidal input of water (tidal range <1m), with fast-moving water currents confined to the main channels.

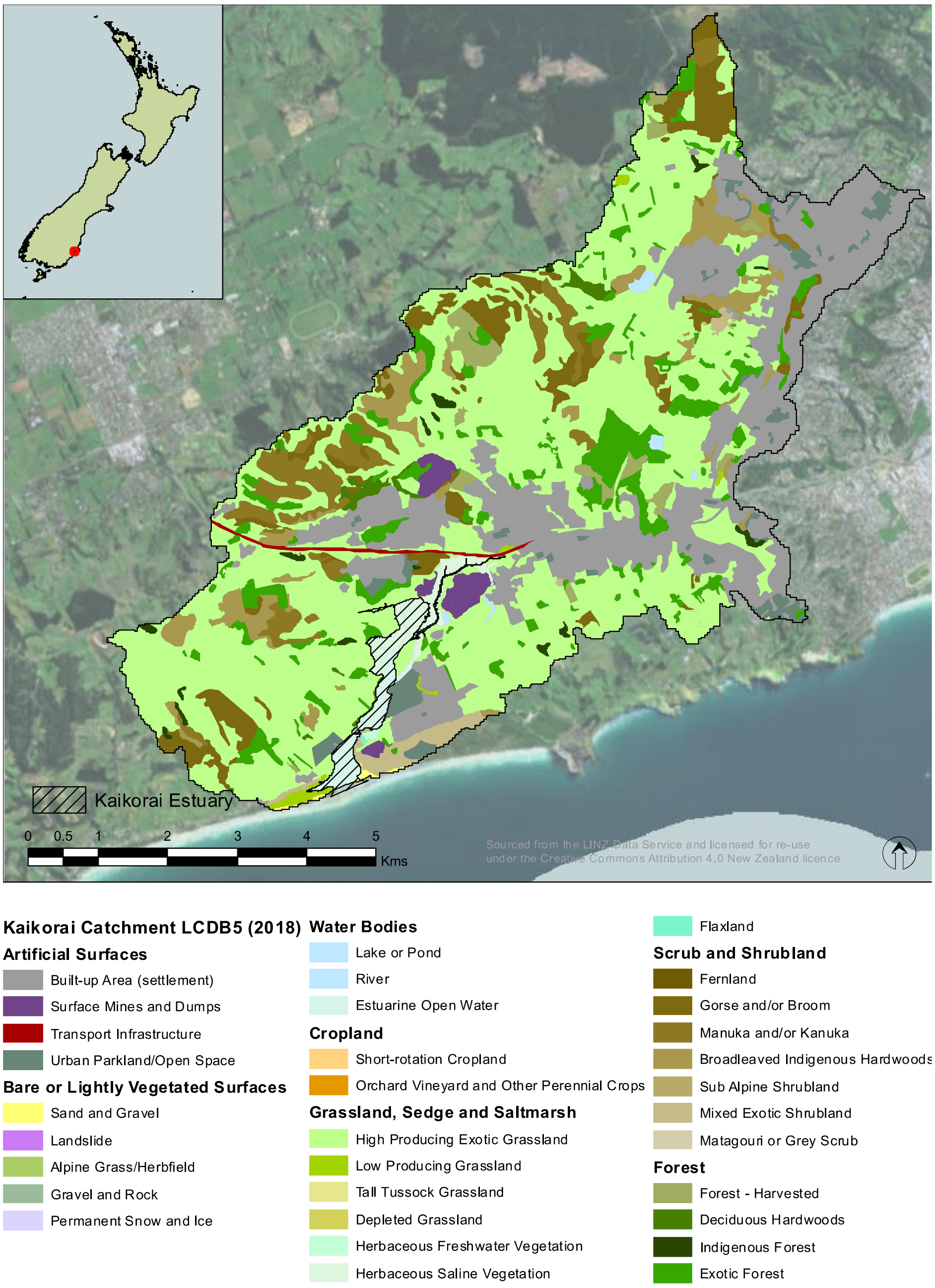


Fig. 2. Kaikorai Estuary (hatched) and surrounding catchment land use classifications from LCDB5 database.

At low tide, most of the estuary is less than 0.7m deep, and dominated by shallow mudflat habitat that traps both marine and land-sourced sediments. Large parts of the central estuary are excessively muddy and highly enriched. Because the estuary is fed by relatively small streams, the main channel of the upper estuary is poorly flushed during baseflows. As a consequence, deeper sections can become stratified with a surface layer of lighter, low salinity freshwater flowing over a layer of dense saline water and making the estuary susceptible to phytoplankton blooms.

Ecologically, habitat diversity is moderate and although large areas remain in saltmarsh (42% of estuary; Stevens 2018), this habitat is dominated by low-lying herbfields. The unvegetated tidal flats have a macrofaunal assemblage dominated by small, short-lived 'opportunistic' species (tolerant to organic enrichment and freshwater) such as oligochaete worms and amphipods, almost certainly reflecting the fact that the estuary is prone to prolonged periods of lowered salinities at times of mouth constriction.

The estuary provides habitat for a large variety of bird species, particularly waterfowl, gulls and waders and including the threatened black billed gull. Most of the natural vegetated margin and extensive areas of saltmarsh have been lost through historical drainage and reclamation for urban and industrial use and grazing. Despite these changes, Kaikorai Estuary is valued for its cultural, spiritual, scientific and aesthetic appeal, and ecological biodiversity.

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 KAIKORAI FINE SCALE AND SEDIMENT PLATE SITE INFORMATION

The history of NEMP sampling in Kaikorai Estuary is provided in Table 1, with site locations shown in Fig. 3. The recent comprehensive baseline surveys have been conducted over the last three summer seasons, on 15 December 2017, 22 February 2019 and 18 December 2019. These surveys are hereafter referred to as 2018, 2019 and 2020, respectively. In 2018, three sampling sites (A, B, C) were established in unvegetated mud/sand habitats (Fig. 3).

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	3 plates 2018, extra plate 2019	Across channel from 'Site 1' sampled in 2007 (Stewart 2008)
B	2018, 2019, 2020	30 x 40	West boundary of FS (outside site)	3 plates 2018, extra plate 2019	Next to shallower 'Site 2' sampled in 2007 (Stewart 2008)
C	2018	30 x 30	Downstream west boundary of FS (outside site)	3 plates 2018	Unsuitable site. Replaced with Site D for 2019 and 2020 surveys.
D	2019, 2020	30 x 60	Upstream edge of FS site	4 plates 2019	Original NEMP site sampled in 2001 (Robertson et al. 2002)

[1] *Fine scale survey and sediment plate installation dates as follows: 2018 (15 Dec 2017), 2019 (22 Feb 2019), 2020 (18 Dec 2019)*

Due to Site C having an impoverished biota (Robertson & Robertson 2018), and following observations in 2019 that it was subject to strong scouring, it was not resampled in 2019 and 2020. Instead it was relocated ~50m to the other side of the Kaikorai Stream channel and positioned in the same location as the original 2001 NEMP survey site. This relocated site is referred to hereafter as Site D.

Site D is the only site having the 30 x 60m dimensions recommended in the NEMP, with the sites established in 2018 (Robertson & Robertson, 2018) having reduced dimensions. Sites A and B are near locations sampled in 2007, referred to in a report by Stewart (2008) as Site 1 and Site 2, respectively (Fig. 3). All present sites have wooden pegs to mark their corners.

Each of the fine scale sites has sediment plates installed either along the upstream margin (Site A & D), or just outside the site perimeter (Sites B & C). This co-location of plates reflects that, in addition to providing information on patterns of sediment accretion and erosion, sediment plate monitoring aids interpretation of physical and biological changes at the fine scale sites.

Due to difficulties in relocating the 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 relative to site boundaries. 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.

3.3 SEDIMENT PLATES AND SAMPLING

Concrete pavers (19 x 23cm) for sediment plate assessment were installed at Kaikorai Estuary Sites A-C during the 2018 fine scale survey on 15 December 2017. Although 4 plates are reported for each site in the 2018 report, only 3 could be relocated at the time of the second survey on 22 Feb 2019. As such, in 2019 a fourth plate was installed at Sites A and B, along with a full set of 4 plates at relocated Site D.

Baseline depths (from the sediment surface to each buried plate) were measured at the time of 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.

Fine scale sampling comprises:
- 10 x macrofauna and aRPD cores.
- 3 x composite sediment samples for physical and chemical properties (zones X, Y, Z).
- Site-wide SACFOR assessment for epifauna and algae.

Fig. 3. Locations of sites A-D in Kaikorai Estuary, and schematic illustrating fine scale monitoring and sediment plate methods. R = sites sampled by Ryder Consulting in 2007 (Stewart 2008).

Site A looking upstream

Site B looking upstream

Site D looking downstream

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 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 mm) after extracting a large sediment core (130mm diameter, 150mm deep) from each of the 10 plots, placing it on a tray, and splitting it vertically. Representative split cores (X1, Y4 and Z7) were also photographed.

Collection of sediment cores at Site D

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

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.

Oxidation reduction potential measurement with probe inserted horizontally into core. Where *in situ* measurement is not possible, cores are extracted and placed on a tray.

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.

Rinsing sediment from macrofauna core bags

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.

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).

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).

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, the data were screened to remove species that were not regarded as a true part of the macrofaunal assemblage; these were planktonic life-stages and non-marine organisms (e.g. terrestrial beetles). 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

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.

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.

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 site bordering the Kaikorai Stream channel. It is characterised by relatively firm rippled sand that drains well on a spring low tide but was exposed for only a short period during a neap tide at the time of the 2020 survey.

Site B is located near the road bridge and consists of very soft mud (e.g. we typically sank to our knees) that does not appear to drain at low tide. As such, the sampling at Site B was conducted while it was submerged in water.

Sites C and D are the furthest upstream. As already noted, Site C is subject to scouring from Kaikorai Stream and was sampled in 2018 only. Site D across the stream channel from Site C was sampled in 2019 and 2020, and is assumed to be relatively stable on the basis that some of the site pegs installed in 2001 were relocated in 2019.

No seagrass was present at any of the sites, consistent with the broad scale survey of Stevens (2018), which described no seagrass anywhere in the estuary. Except for Site A, which appears reasonably 'clean', the most conspicuous feature of the other sites is the large amount of litter (e.g. types, road cones) and terrestrial woody debris present.

Litter and terrestrial woody debris were conspicuous around Sites B and D (latter shown here)

4.2 Sediment plates

Sediment plate raw data are provided in Appendix 3. The summary in Fig. 4 shows a ~5mm of net erosion at Sites B and C compared with the baseline. By contrast, at Site A there was a mean sediment accumulation of ~22mm in 2019, but erosion between 2019 and 2020 resulting in a cumulative change of ~15mm since the baseline was established (i.e. a rate of ~7-8mm/yr). At Site D, ~4mm deposition was measured in the first year of plate deployment. The changes at Site A most likely reflect the movement of relatively mobile sands, as opposed to sedimentation from catchment inputs. That site is likely to experience relatively dynamic hydrological conditions, as it borders the stream channel.

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 ~7-14% over the three surveys). By contrast sediments at Site B were mud-dominated, comprising 58% mud in 2018 which had increased to 78% by 2020. Sites C and D were intermediate between these extremes. These results are largely consistent with the expected hydrological conditions at each site - Site A is relatively well flushed, such that the accumulation of fine muddy sediment is reduced, whereas Site B is isolated from the main flow of Kaikorai Stream, and upstream of the road bridge that constricts drainage, enabling muddy sediment to accumulate.

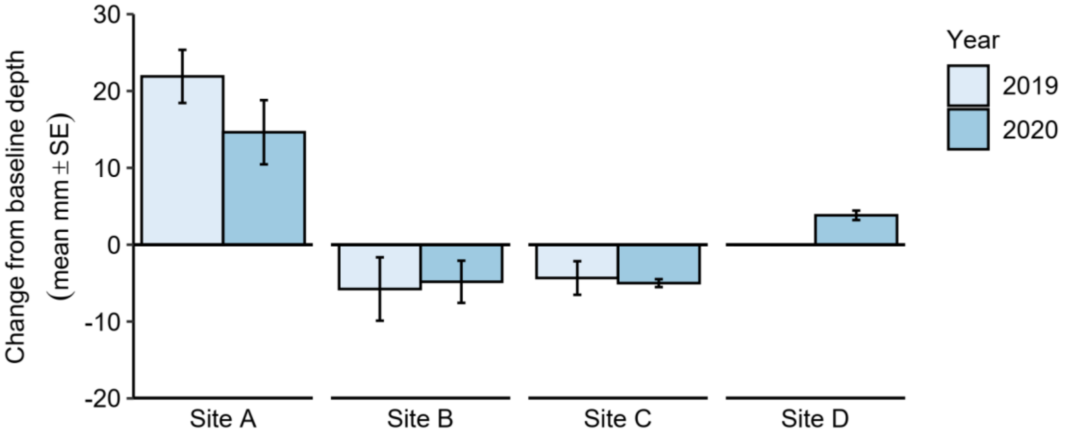


Fig. 4. Mean change (± SE) in sediment depth over buried plates relative to the 2018 baseline. Plates were not installed at Site D until 2019.

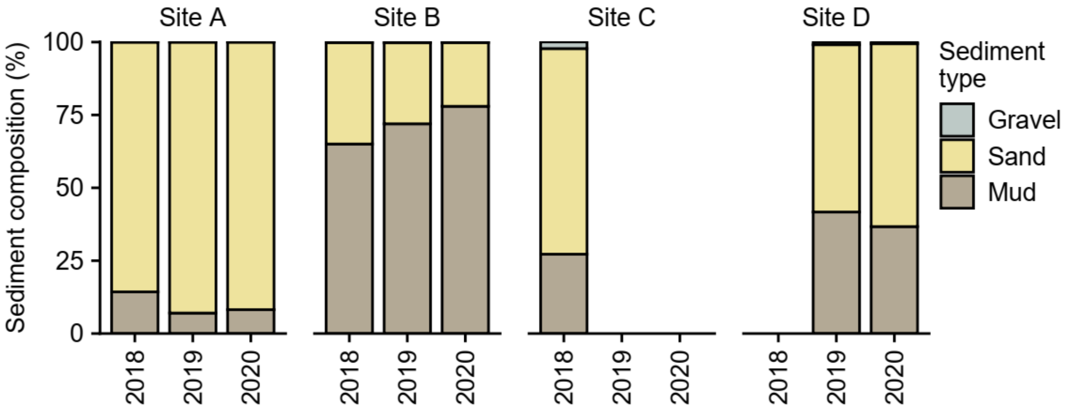


Fig. 5. Sediment particle grain size analysis, showing site-averaged percentage composition of mud (<63µm), sand (<2mm to ≥63µm) and gravel (≥2mm).

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 %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 (Pearson r = 0.96) with sediment mud, their condition rating patterns across sites and years were similar, i.e. except for Site A, TOC and TN levels were rated as 'fair' or 'poor'. The relatively elevated TOC at Site B is consistent with its increased mud content and observations of decaying organic detritus in some of the sediment cores. Total phosphorus (TP) does not have a rating criterion, but values were also moderately correlated (Pearson r = 0.76) with mud content hence also greatest at Site B in all years (Appendix 4).

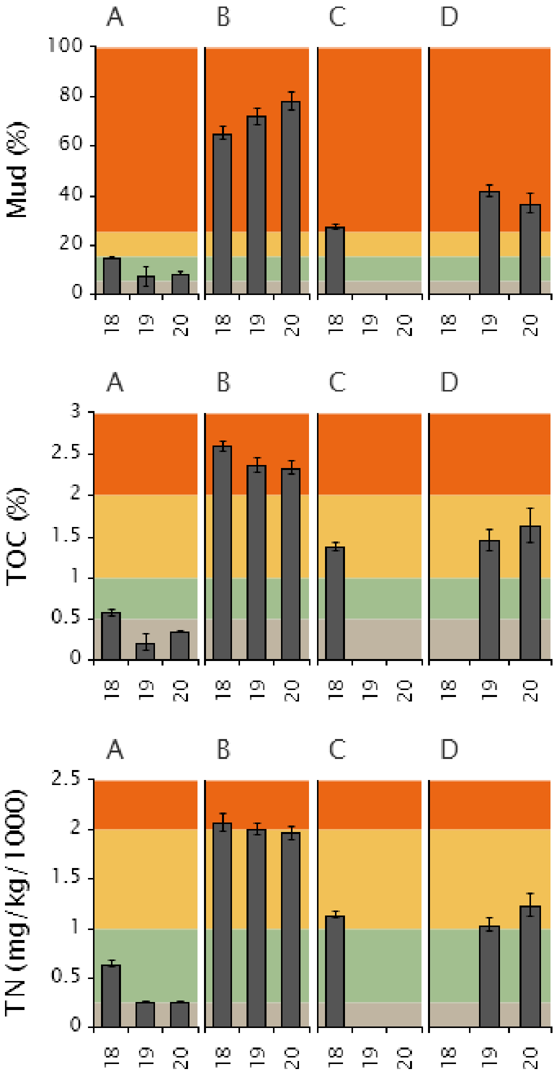


Fig. 6. Sediment mud content, total organic carbon, and total nitrogen concentrations relative to condition ratings.

Condition rating key:

Very Good	Good	Fair	Poor

4.4 Redox status

The depth to the apparent Redox Potential Discontinuity (aRPD) transition was highly variable among sites (Fig. 7). The deeper aRPD at Site A (~30-40mm on average) relative to other sites is consistent with the sandy sediments there, which enable greater oxygenation of the sediment matrix than occurs in muddy sediments. Hence, not surprisingly, mean aRPD depths at the muddy and organically-enriched Site B were shallow across all surveys (≤4mm). This result is evident from photographs, which show a very thin layer of oxic mud overlying highly anoxic black-coloured sediment (Fig. 8).

The aRPD depth at Site D was highly variable among cores, and at times could not be reliably measured. In general, it is apparent from Fig. 8 that the aRPD is not always well-defined, except in muddy anoxic sediments such as at Site B. 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, there is inherent subjectivity in aRPD measurement, and variability across surveys due to interpretation can therefore be expected. As such, it is only gross differences in aRPD that are meaningful.

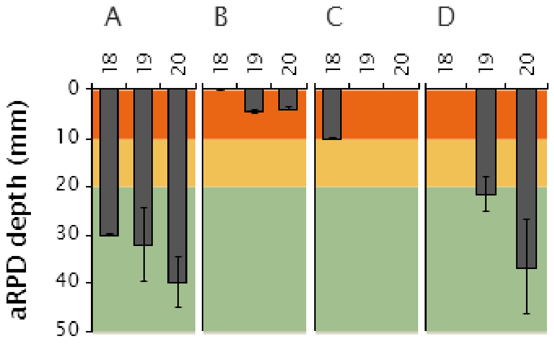


Fig. 7. Condition ratings for aRPD. Condition rating key as per Fig. 6.

2019, Site A 2019, Site B 2019, Site D

2020, Site A 2020, Site B 2020, Site D

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

Vertical oxidation reduction potential (ORP) profiles in the sediment are shown in Fig. 9 for 2020 (data for other years in Appendix 4). Of most 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 Site B as the measurement resolution was coarse relative to the shallow aRPD depth. Fig. 9 does not otherwise show strong or meaningful patterns in ORP profiles. While there is evidence for a moderate decline in ORP values below the aRPD for Site A cores, Site B shows little change in values with increasing depth in the sediment beneath the aRPD, and Site D shows a counter-intuitive trend of increasingly positive ORP values with depth. Similarly, in 2019 there were no clear or consistent trends in ORP with depth (Appendix 4). By contrast, the 2018 data show a reasonably consistent trend for a decrease in ORP values with depth in the sediment, although no evidence for an abrupt decline across the 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 2019b; Forrest & Stevens 2019c, 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.

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

Plots of trace metal contaminants in relation to condition ratings and ANZG (2018) sediment quality guidelines are provided in Fig. 10, with raw data and

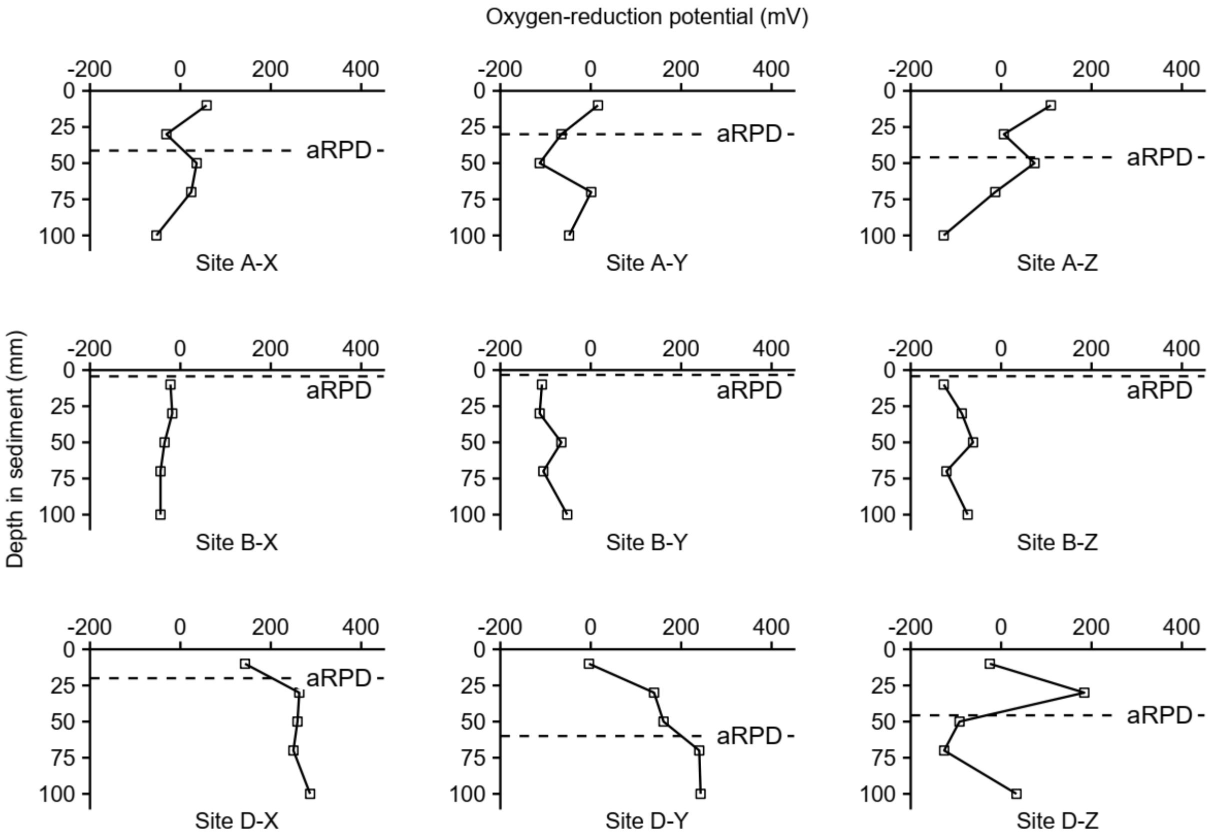


Fig. 9. Oxidation-reduction potential (ORP) profiles for three cores (X, Y, Z) taken from each site in 2020, showing associated aRPD depth for that core.

guideline values in Appendix 4. The main impression from Fig. 10 is that trace metal or metalloid (i.e. arsenic) concentrations are low and generally rated as 'good' or 'very good'. The exception is Site B, where zinc (Zn) exceeded DGV levels in all three surveys. Although other analytes did not exceed their respective DGV, concentrations at Site B were consistently greater than elsewhere. This result reflects the greater mud content of the sediments at Site B (relative to sand, mud-sized particles provide an increased surface area for contaminant adsorption). Not surprisingly, therefore, there was a very tight correlation between sample mud content and contaminant concentrations (e.g. for all metals, Pearson r ≥ 0.91).

4.6 Macrofauna

4.6.1 Conspicuous surface epibiota

Epibiota were almost non-existent at the fine scale sites. In 2018, the mud snail *Amphibola* was rated as 'rare' at Site A, and the green seaweed *Ulva* was rated as 'abundant' at Site C. In 2019 and 2020, *Amphibola* was not evident, although was noted outside site boundaries higher on the shore at Sites A and B.

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. Only 24 species or higher taxa were recorded, with background information on the most common of these provided in Table 5. Mean species richness at Sites A and B was ~5-7 taxa per core over the three surveys, and ~3-5 taxa per core at Site D (Fig. 11a). Site C, where sampling was discontinued, was especially impoverished; mean richness was <1 taxon per core, with half of the 10 cores collected being 'azoic' (i.e. containing no macrofauna).

Despite the low richness values, organism abundances per core were very high in some years, except at Site C (Fig. 11b). These high abundances

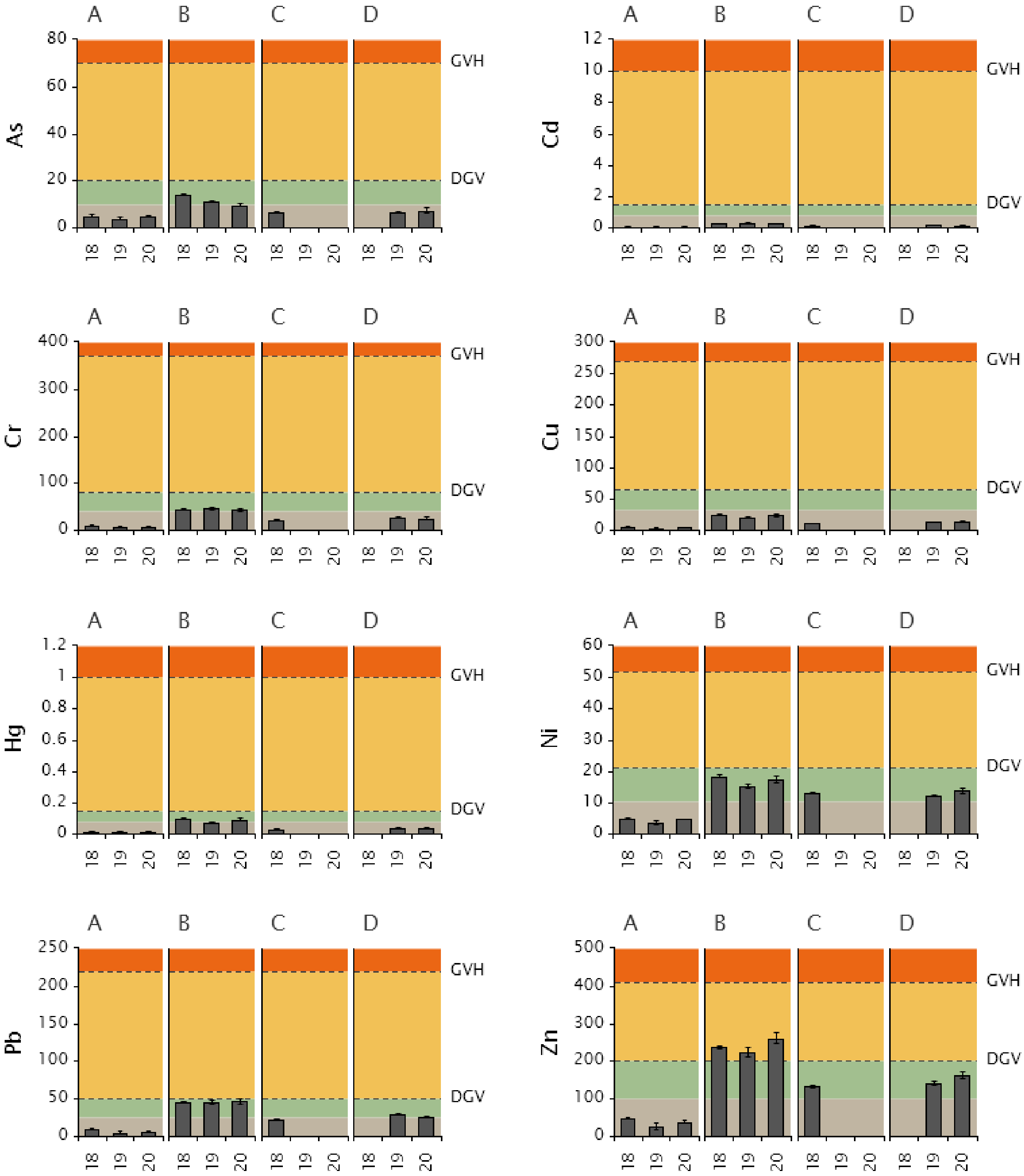
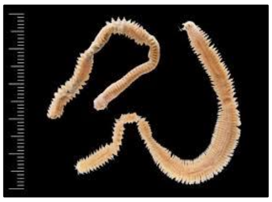


Fig. 10. Condition rating plots for trace metals (site means ± SE). ANZG (2018) sediment quality guideline thresholds are indicated as Default Guideline Value (DVG) and Guideline Value-high (GVH). Note that concentrations of certain analytes are barely visible on the rating scale.

Condition rating key:

Very Good	Good	Fair	Poor

Table 5. 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. Images are illustrative and do not show the exact species, but an example from the general group.

Main group & taxon	Site A	Site B	Site C	Site D	Description	Image
Amphipods (*Paracorophium excavatum*)	6701	5668	71	1616	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.	
Dipteran larvae (Diptera sp. 3)	0	0	3	69	A species in long-legged fly family Dolichopodidae, which inhabits estuaries in the larval stage of its life cycle.	
Oligochaete worms (Oligochaeta sp. 1)	74	16	0	612	Segmented worms in the same group as earthworms. Deposit feeders that are generally considered very pollution tolerant.	
Polychaete worms (*Perinereis vallata*)	351	54	0	1	An intertidal omnivorous nereid worms, associated with mud/sand sediments. Prey item for fish and birds. Considered sensitive to high sedimentation.	
Polychaete worms (*Scolecolepides benhami*)	505	833	0	43	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.	

reflected the numerical dominance of the tube-dwelling amphipod *Paracorophium excavatum* (Table 5). This species was particularly abundant in 2020, reaching a mean density of almost 600 individuals per core at Site A. The subdominant species differed among sites, with the nereid worm *Perinereis vallata* subdominant at Site A, the spionid worm *Scolecolepides benhami* at Site B, and pollution-tolerant oligochaete worms at Site D along with dipteran (long-legged fly) larvae to a lesser extent.

AMBI values were similar across all surveys at Sites A, B and D, with a mean score of ~4 indicative of a moderately disturbed environment (Fig. 12). The high similarity in mean values and small core-to-core variance reflects the strong influence on the AMBI score of the numerically dominant *Paracorophium excavatum*, which is an eco-group (EG) IV species considered to be resilient to disturbance and/or pollution.

The AMBI score of 7 at Site C is the highest (i.e. worst) possible score, but is an artefact of there being so few species present, likely due to river scouring. Consequently the AMBI method scores azoic cores (cores containing no macrofauna) 7 while the other cores were rejected due to their species richness and/or abundances not reaching the operational thresholds defined by Borja et al. (2012) (see Methods Section 3.5).

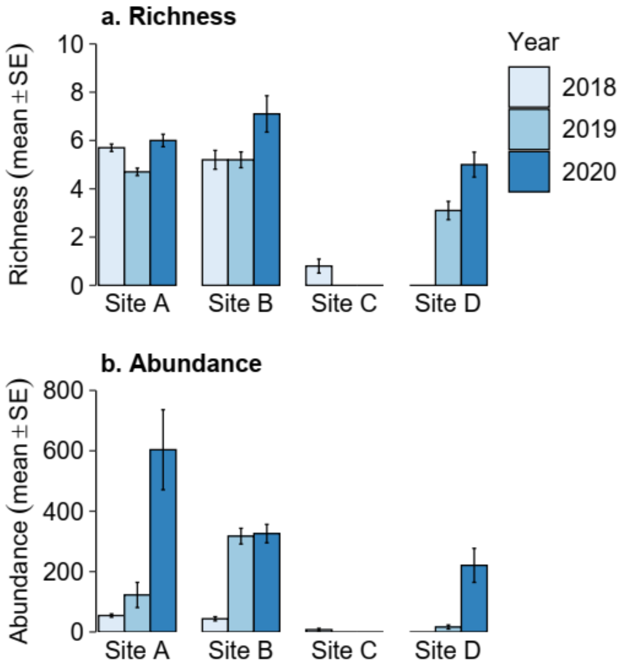


Fig. 11. Patterns (mean ± SE) in taxon richness and abundance per core.

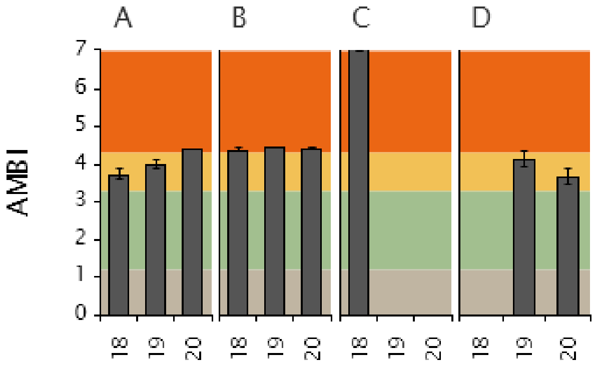


Fig. 12. Patterns (mean ± SE) in AMBI scores compared with condition rating criteria.

Condition rating key:

Very Good	Good	Fair	Poor

Despite the relatively high ('fair' to 'poor') mean AMBI scores at Sites A, B and D, the taxa present nonetheless spanned eco-group (EG) I and II, representing species considered indicative of a relatively healthy state, to more hardy EG IV and V species (Appendix 5), although the distribution of EGs was highly variable among sites and surveys.

An increased prevalence of relatively sensitive EG II species in 2020 at Sites B and D reflects the sampling of species not recorded in earlier surveys, which occurred at very low densities (e.g. various species of Diptera, Amphipoda and turbellarian flatworms, see Appendix 5).

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 10 main taxa. Amphipods and polychaete worms were consistently the most well-represented groups in terms of both richness and abundance.

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 square-root transformed so that the less common groups display (i.e. the numbers need to be squared to obtain the raw value).

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.

Despite the markedly different benthic habitats at Site A ('clean' muddy sand) and Site B (enriched, mud-dominated sediments), their associated macrofaunal assemblages were quite similar. In fact, much of the segregation of sample groups in Fig. 14 is driven by shifts in the relative abundances of the dominant species discussed above. Fig. 14a lists these species in order of their numerical dominance within each ordination group.

Although species dominance plays a role in the ordination pattern, the sample separation in Fig. 14 was also largely maintained when the analysis was conducted on presence/absence data (i.e. relative abundances were not accounted for, only the frequency of occurrence in samples). Hence, 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).

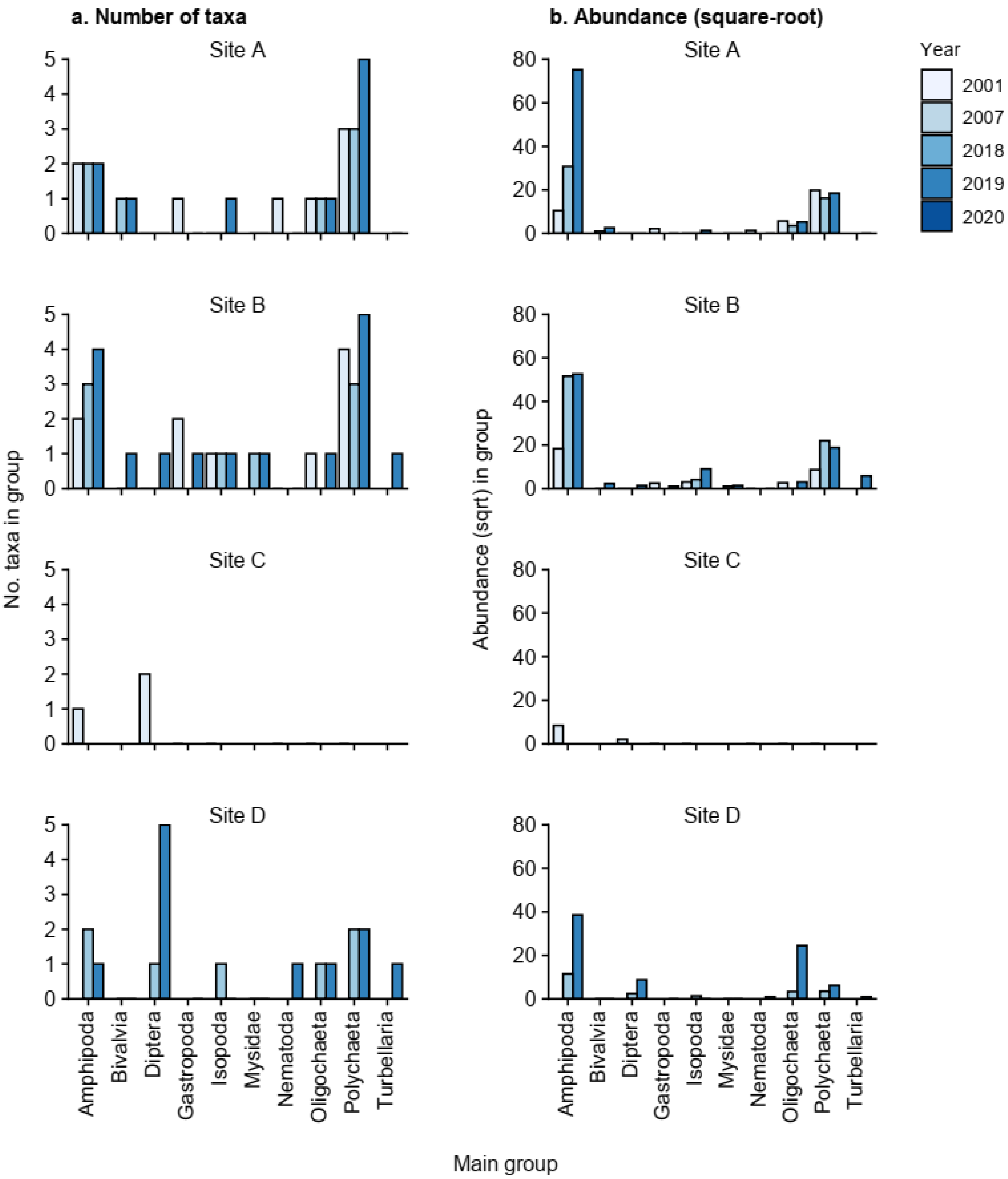
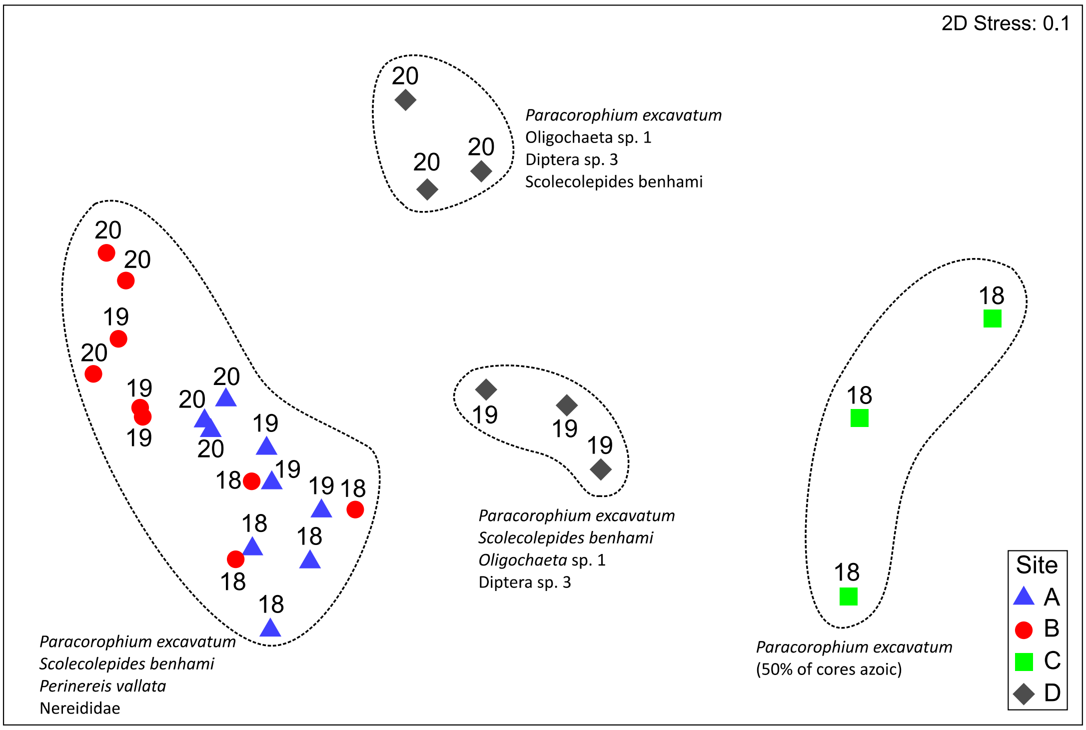


Fig. 13. Data pooled across years showing the contribution of main taxonomic groups to site-level richness and abundance values. For abundance data, the square-root of values is shown so that the less dominant groups are revealed.

a. Species groups



b. Sediment quality overlay

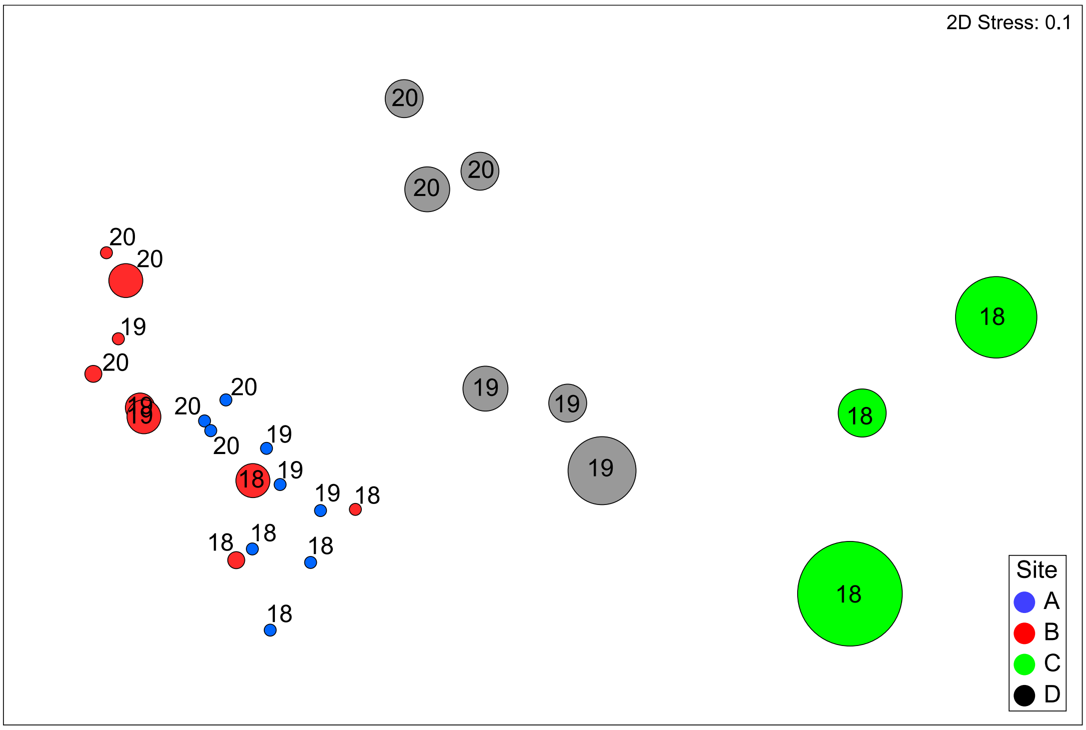


Fig. 14. Non-metric MDS ordination of macrofaunal core samples aggregated with each of zones X, Y and Z (see Fig. 3), resulting in triplicate representation of each year-site combination.

The two panels are as follows: Top: ellipses enclose macrofaunal samples clustering at ≥70% 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 gravel content, which was the sediment quality variable most highly correlated with the macrofaunal patterns.

It is important to recognise that for 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, hence their influence needs to be interpreted with caution.

An analysis of patterns among sites in sediment quality variables, and of relationships between macrofauna and sediment quality, suggested that none of the measured variables were strongly associated with the distribution and abundance of macrofauna. In part this likely reflects a deficiency in the NEMP methodology in that sediment quality assessment is based on sampling the surface 20mm and will not fully represent the conditions over the 150mm depth of the macrofaunal cores.

Nonetheless, sediment gravel content, despite being ≤4% of sample composition, was moderately correlated (Spearman rank correlation coefficient ρ=0.69) with the macrofaunal differences among sites. Gravel content was also reasonably closely associated with the left to right sample separation in the ordination in Fig. 14b (nMDS axis 1, Pearson r = 0.78), as illustrated by scaling circle size in Fig. 14b to gravel content.

The gravel content itself may not have any causal association with macrofaunal distribution and abundance, but may be an indicator of other factors influencing the two upstream sites. For example, compared to downstream sites, Site D was observed to have a higher sieved volume, consisting of gravel, bark and other debris. Such observations suggest a stronger catchment and Kaikorai Stream influence at the upstream sites.

5. SYNTHESIS AND RECOMMENDATIONS

5.1 Synthesis of key findings

This report has described the findings of three surveys of Kaikorai 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 6, including comparison with data from the original 2001 NEMP site (Site D) and sites sampled in 2007 that were close to present Sites A and B (Stewart 2008).

The sites strongly contrast each other in terms of their general characteristics. The most downstream site (Site A) is relatively sandy and well-flushed while Site B is in soft mud habitat and positioned very low in the intertidal zone, to the extent that it did not fully drain during low tide sampling in 2019 and 2020. Site C (sampled 2018 only) and adjacent Site D (2001 NEMP site resampled in 2019 and 2020) are the furthest upstream in the only available area of intertidal flat in the mid-upper estuary, and appear to be subject to relatively strong catchment influences (e.g. sediments contain gravel and woody debris).

Sedimentation has been variable across the sites, with both erosion and accretion events evident over the previous three years. The cumulative sedimentation (since the baseline) of 15mm at Site A in 2020 equates to 7-8mm/yr and greatly exceeds the provisional 2mm/yr guideline value of Townsend and Lohrer (2015). However, as suggested in Section 4.2, this result most likely reflects the movement of relatively mobile sands at that site due to dynamic hydrological conditions. The potential for sedimentation effects can also 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 3.1 (assuming 50% attenuation from wetlands under natural state) falls into Band C of the ETI rating, 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 sedimentation rates in Kaikorai Estuary.

Table 6 highlights that sediment quality was relatively good at Site A, with all indicators rated 'good' or 'very good'. Such results are consistent with this site being relatively sandy and well-flushed. The poorest sediment quality (rated 'fair' or 'poor') was measured at Site B. The muddy sediments at Site B were organically enriched and had relatively high nutrient concentrations, with the depth of the apparent Redox Potential Discontinuity (aRPD) being close to the sediment surface. In addition, in all surveys the concentration of zinc slightly exceeded sediment quality guidelines (ANZG 2018) for 'possible' ecological effects. The actual significance of such concentrations, hence relevance of the guideline values, will be highly location specific. For example, a New Zealand study of intertidal estuarine sediments suggested that ecological effects on the most sensitive species could occur at less than half the concentrations of zinc, copper and lead measured at Site B (Hewitt et al. 2009).

Despite the degraded state of parts of the estuary, there have been no substantive changes at any sites over the last three surveys, nor relative to sampling conducted in 2001 and 2007, that would indicate an increasing decline in estuary health. Although Table 6 suggests that the mud content has gradually increased at Sites B and D, differing providers have been used across the years, which may in part explain such findings.

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 high organism abundances, which were mainly attributable to a tube-building and disturbance-tolerant corophioid amphipod (*Paracorophium excavatum*), as well as a few subdominant species that differed among sites.

Table 6. Synthesis of data for Kaikorai 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 2007 do not correspond directly to the latest three surveys but are included for comparative purposes.

Site	Year	Mud %	TOC %	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
A	2007	7.7	0.32	<500	310	78	na	0.020	3.4	2.0	na	2.3	3.8	24.0
A	2018	14.3	0.57	633	410	30	4.8	0.034	8.8	5.0	< 0.02	4.9	9.1	47.0
A	2019	7.0	0.20	< 500	423	32	3.6	0.015*	5.2	2.7	< 0.02	3.4	4.2	24.6
A	2020	8.2	0.34	< 500	490	40	4.6	0.015	6.6	3.8	< 0.02	4.5	5.5	37.7
B	2007	57.9	2.79	2500	1100	2	na	0.250	34.0	22.0	na	16.00	51.0	230.0
B	2018	65.0	2.60	2067	1077	0	14.0	0.250	43.7	24.0	0.09	18.2	45.7	236.7
B	2019	72.0	2.37	2000	850	4	10.8	0.243	44.7	19.5	0.07	15.1	45.7	223.3
B	2020	78.0	2.33	1967	673	4	9.5	0.237	43.0	23.0	0.09	17.2	46.0	260.0
C	2018	27.2	1.38	1133	663	10	6.2	0.100	21.0	10.3	0.03	12.8	22.3	132.3
D	2001	27.2	2.11	1650	799	na	na	0.100	48.4	16.8	na	15.6	45.3	184.2
D	2019	41.7	1.45	1033	660	22	6.3	0.134	25.3	12.0	0.03	12.1	28.0	140.0
D	2020	36.7	1.62	1233	607	37	7.1	0.120	24.3	13.0	0.04	13.7	25.7	160.3

** Sample mean includes values below lab detection limits*

< All values below lab detection limit

TOC in 2001 & 2007 calculated from %Ash Free Dry Weight as: $TOC = 0.4xAFDW + 0.0025xAFDW^2$ *(Robertson et al. 2002).*

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

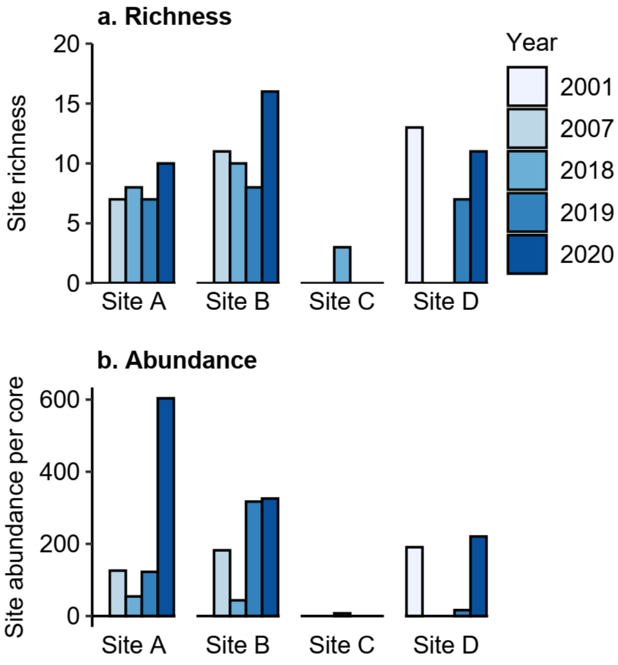


Fig. 15. Long term data for Kaikorai fine scale sites on richness and abundance per core. Note that positions of Sites A and B in 2007 do not correspond directly to the latest three surveys. Only Site D had data from 2001.

The differences in sampling of the less common species across years, especially the apparent increase in richness in 2020 relative to 2018 and 2019, likely reflects sampling variation more than a true change in assemblage composition. In fact, when compared with historical data, it is apparent that the richness and abundance of species in 2020 at Site D were similar to the original NEMP survey in 2001 (Fig. 15). Similarly, at Sites A and B, richness and abundance in 2018 and 2019 were similar to that described in 2007 at adjacent or overlapping sites sampled by Stewart (2008). A more detailed assessment of compositional changes since 2001 and/or 2007 cannot be reliably undertaken, due to differences in taxonomic resolution and naming between recent and older datasets. However, to place Kaikorai Estuary in a regional context, it is evident that the dominant species present are similar to other estuaries sampled in ORC's NEMP programme. The high-level comparison in Fig. 16 indicates that species richness in the estuary is at the lower end of regional values, but abundances are fairly typical. The exception was at Site C, were macrofaunal richness and abundances were the lowest that have been recorded.

One of the more interesting results from the latest three surveys was the similarity in macrofaunal composition among sites (especially A and B) despite their contrasting habitats (e.g. well-flushed sand at Site A vs organic and nutrient-enriched mud-dominated sediment at Site B). 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), which is the basis for inclusion of mud content and trophic state measures as key indicators in the ETI.

The absence of an obvious macrofaunal response to sediment mud and enrichment suggests that other unmeasured factors are more strongly influencing the Kaikorai Estuary community, with only the most resilient species prospering. Although gravel was the single variable that was moderately correlated with the composition and distribution of macrofauna, in Section 4.6.2 it was suggested that gravel content *per se* may not be a driver of the macrofaunal community, but a proxy indicator for other factors, such as a stronger catchment and Kaikorai Stream influence at upstream relative to downstream sites.

Low salinity is also likely to be a key biological stressor across all sites, with species like *Paracorophium excavatum* common in river-dominated estuaries subject to variable and/or low salinity conditions. As noted in Section 2, Kaikorai Estuary is likely to be subject to extended periods of low salinity due to closure or flow restriction at its entrance to the sea. Synoptic water quality sampling conduced in 2018 (Robertson & Robertson 2018) showed low salinity surface waters (0.5-4.8ppt) at upper estuary sites (~1km upstream of Site D). That sampling also revealed eutrophication symptoms in denser saline bottom waters of the upper estuary, which included elevated chlorophyll-*a* (an indicator of phytoplankton production). Such results raise the possibility of diurnal dissolved oxygen declines in the bottom water, which could also stress the resident macrofauna.

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

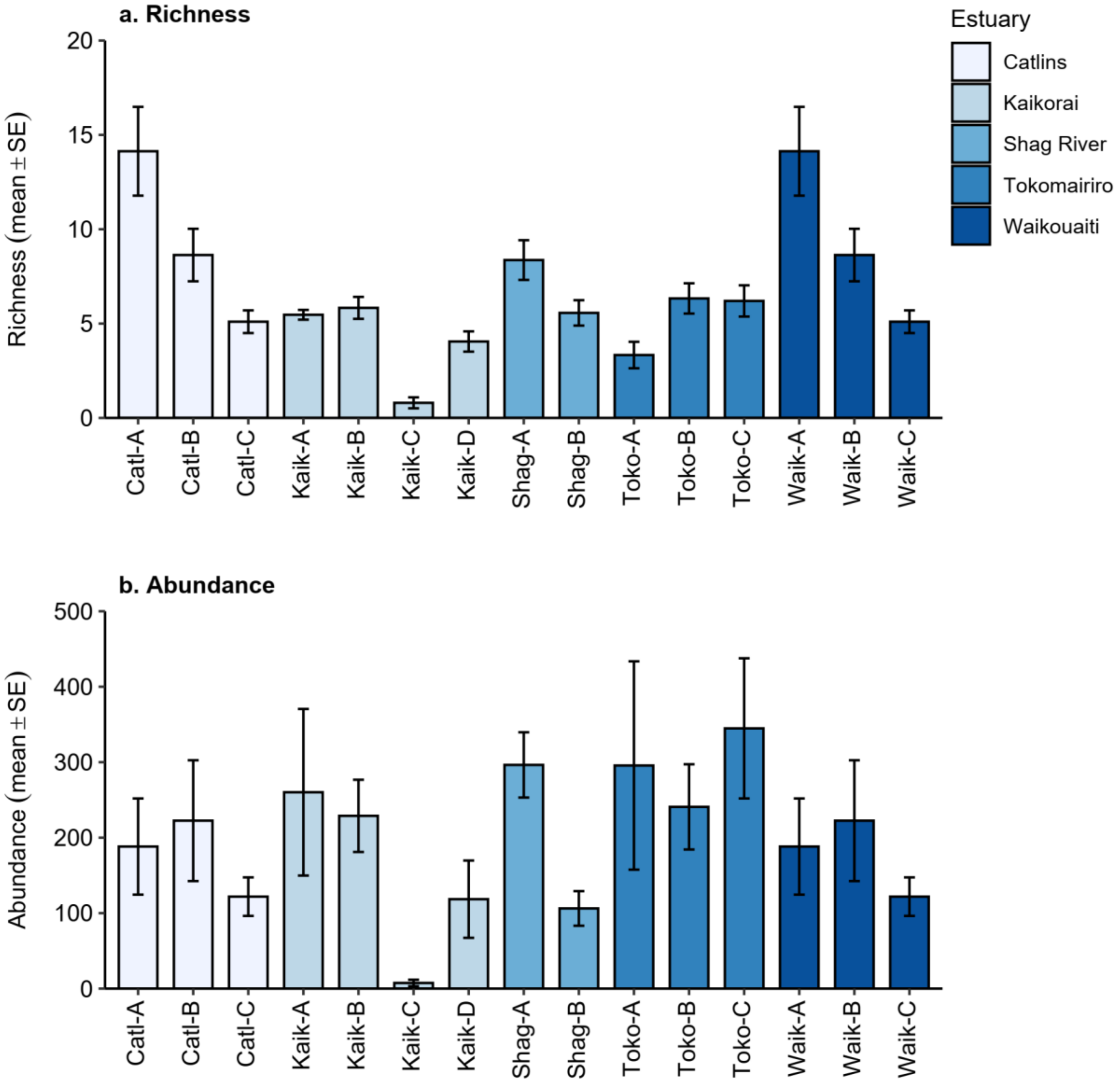


Fig. 16. Macrofauna richness and abundance summary (mean ±SE per core) for estuaries in the Otago region. For illustrative purposes, fine scale site data are averaged across multiple survey years in each location.

data that supports interpretation of ecological condition and long-term change.

Given the absence of any obvious decline in sediment quality and the 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.

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, they have a sufficient range of taxa to enable any ecologically significant environmental changes to be detected. Also, there are no obvious suitable alternative intertidal sites in the estuary.

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 Kaikorai 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.

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 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 Kaikorai 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 (Berthelsen et al. 2018). A reference collection for Kaikorai 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 (e.g. 2 cores will generally capture the taxa that represent at least 90% of site abundance) but to sample 90% of the species present (irrespective of their abundance) requires at least 6 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 Kaikorai 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). The current sites are the best available 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.

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 Kaikorai Estuary (e.g. salinity and dissolved oxygen monitoring, source tracking of zinc and other potential contaminants), and identify any feasible remedial actions that could be undertaken to improve condition.

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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 Kaikorai Estuary, 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. A summary of this information is provided below.

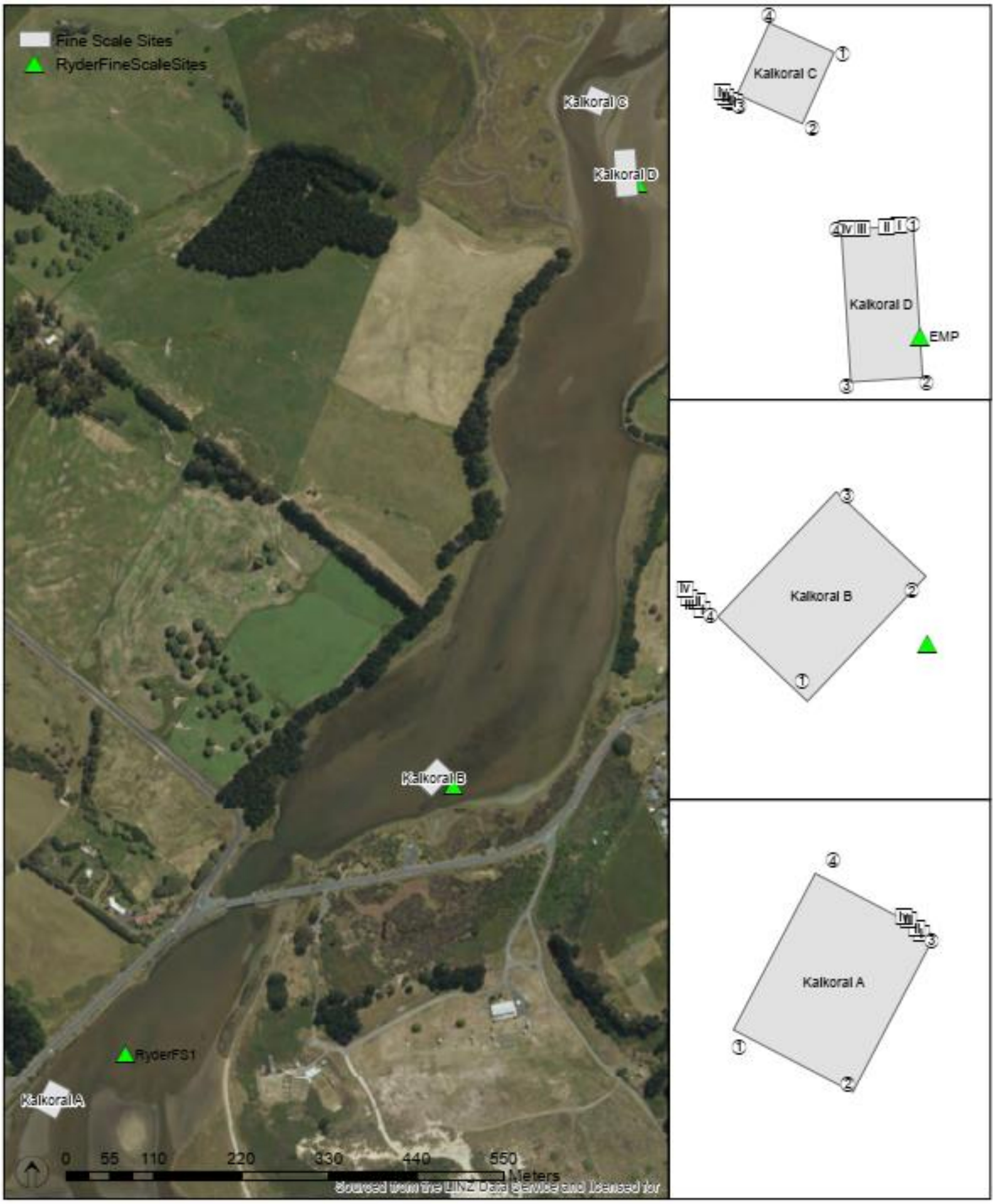
Five sites have been established previously in the estuary, each with different dimensions and orientations. Sites A and B were established and sampled by Ryder Consulting in 2007 (Site A was called Site 1 in the Ryder report by Stewart 2008). In the first 'baseline' survey in 2018, Ryder Site 1 (renamed as Site A) was moved across the main river channel to its current position, and Site C was established as described in Robertson and Robertson (2018).

At the time of the second baseline survey on 22 Feb 2019, it was apparent that Site C was highly physically disturbed, being within the main flow channel and subject to significant scour, with a lot of mobile sands and hummocks present (i.e. changes in height across site of ~200mm). As a consequence, it is near azoic in terms of its macrofauna. As such, Site C was abandoned (although sediment plates were re-measured at the time of the second survey). As an alternative, Site D was established (including sediment plates) across the channel from Site C, and is in the same location as the site sampled during the 2001 NEMP investigations (in fact some of the old site marker pegs were relocated).

Fig. A1.1 & A1.2 below show the general location and orientation of fine scale sites relative to the road and channel, and the layout and spacing of sediment plates and pegs as found or reinstated. In Fig A1.2 the location and alignment of the sediment plates is indicated relative to the origin point defined by the red circle. Site coordinates are provided in Table A1.1.

Note that sediment plates installed in 2018 (Robertson & Robertson 2018) at Site A were positioned within the fine scale site on the upstream edge, while Sites B and C were positioned outside the fine scale site on the downstream edge. Sites A, B and C were subsequently all found to be missing sediment plate 4 that was reported as having been installed in 2018. These missing plates were installed in 2020.

Fig. A1.1. General location of fine scale sites and sediment plates in Kaikorai Estuary.



Peg (1-4) and plate (i-iv) numbers reflect those cited in previous reports. Schematics not to scale. Peg coordinates at Sites A, B and C from Robertson Environmental data (Dec 2017).

Fig A1.2. Layout schematic with reps1-10, relative to site origin at rep1 (red circle). Approximate position of sediment plates indicated by dashed red line. Rectangles not scaled to site dimensions.

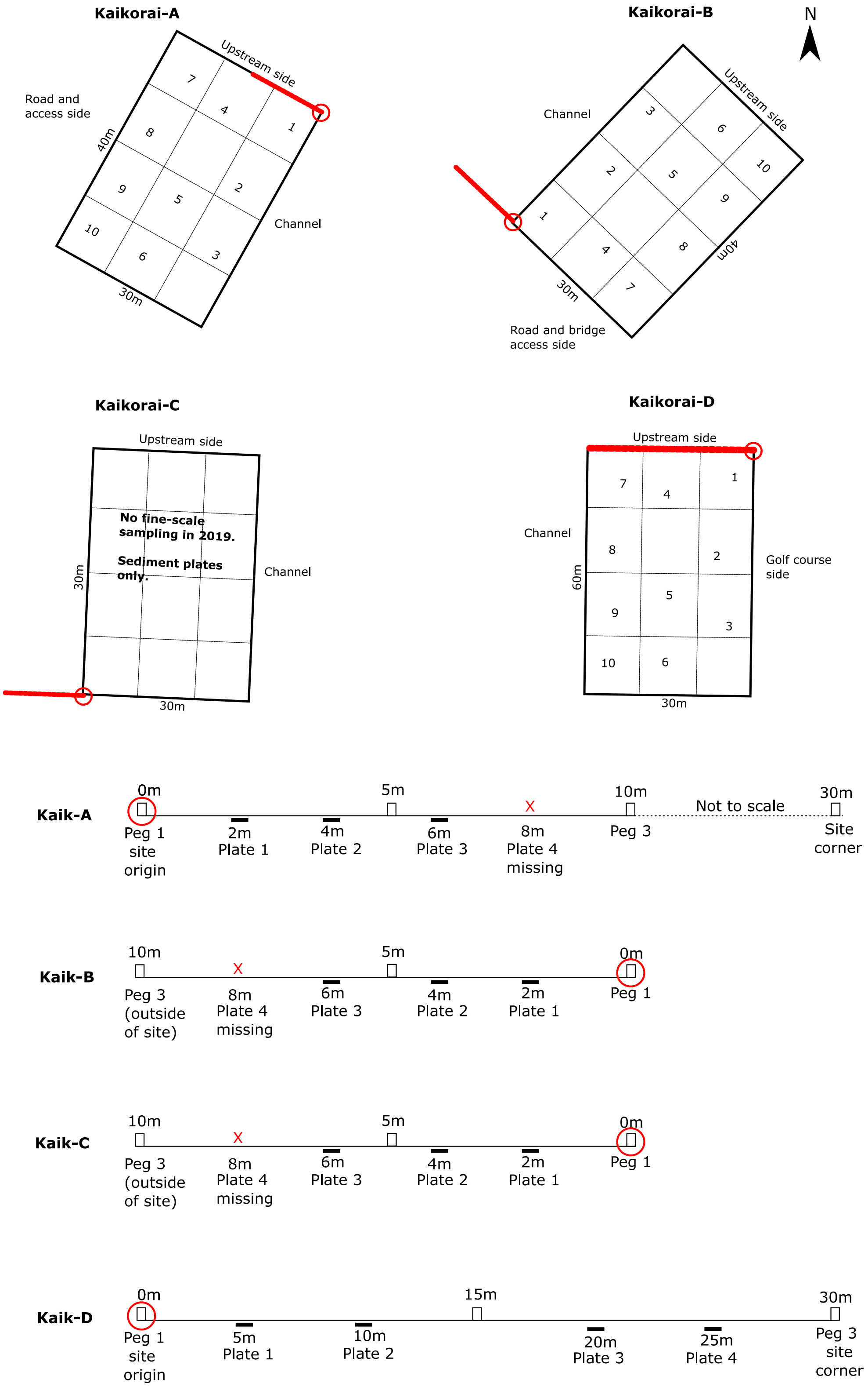


Table A1.1. GPS positions for sites (Corner 1 (C1) is the upstream true left corner) and sediment plates.

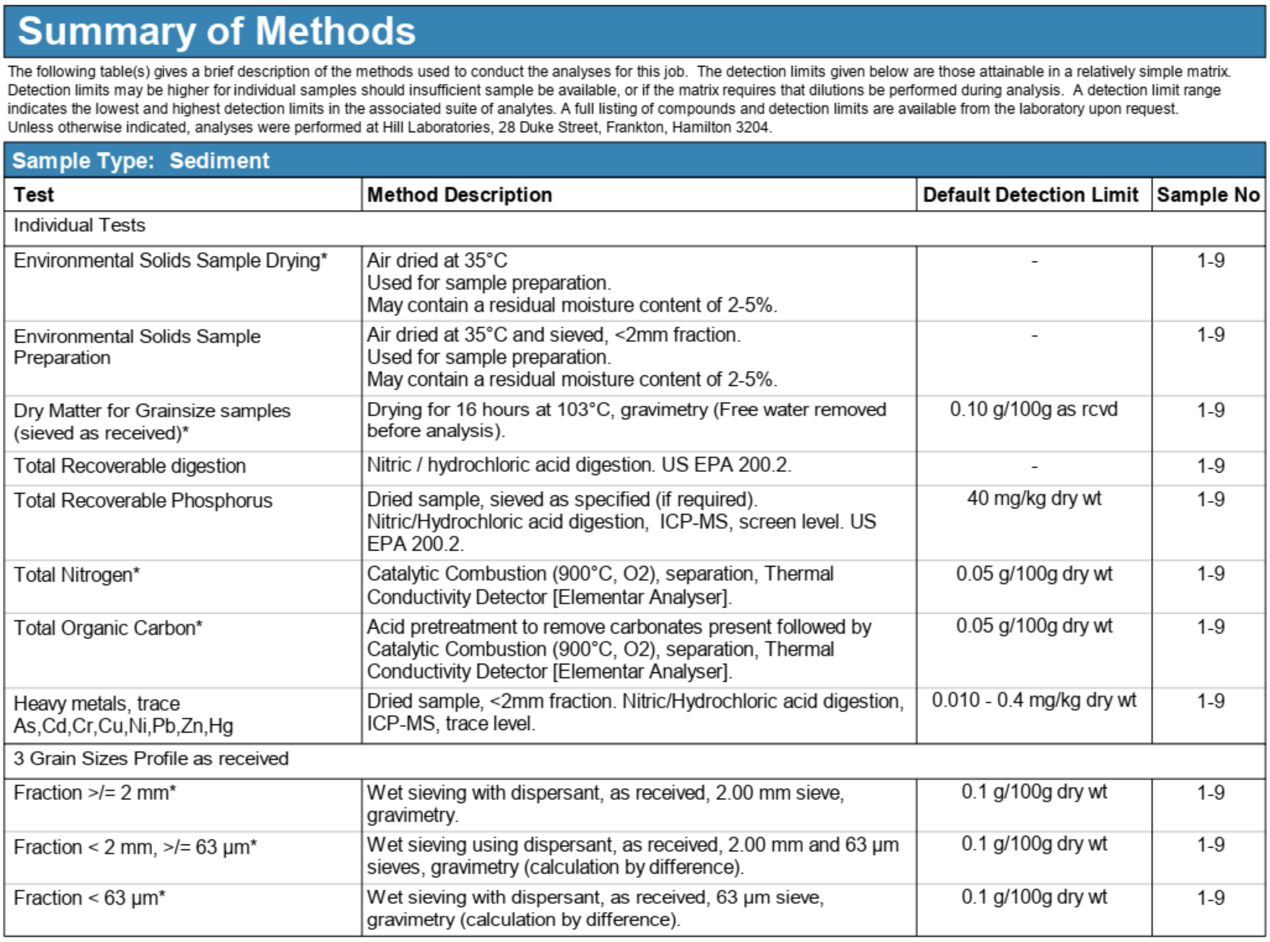
Sites

Estuary	Site	Site Corners	NZTM EAST	NZTM NORTH	Data Source	Source Peg No
Kaikorai	A	C1	1397532	4910668	REC	3
Kaikorai	A	C2	1397513	4910635	REC	2
Kaikorai	A	C3	1397488	4910644	REC	1
Kaikorai	A	C4	1397510	4910687	REC	4
Kaikorai	B	C1	1398011	4911066	REC	2
Kaikorai	B	C2	1397985	4911045	REC	1
Kaikorai	B	C3	1397964	4911060	REC	4
Kaikorai	B	C4	1397996	4911088	REC	3
Kaikorai	C	C1	1398215	4911923	REC	1
Kaikorai	C	C2	1398203	4911894	REC	2
Kaikorai	C	C3	1398175	4911903	REC	3
Kaikorai	C	C4	1398186	4911938	REC	4
Kaikorai	D	C1	1398243	4911856	Salt	1
Kaikorai	D	C2	1398247	4911783	Salt	2
Kaikorai	D	C3	1398200	4911795	Salt	3
Kaikorai	D	C4	1398213	4911854	Salt	4

Sediment plates

Estuary	Site	Plate	NZTM East	NZTM North	Distance (m)
Kaikorai	A	1	1397530	4910670	2
Kaikorai	A	2	1397529	4910671	4
Kaikorai	A	3	1397527	4910673	6
Kaikorai	A	4	1397526	4910674	8
Kaikorai	B	1	1397962	4911061	2
Kaikorai	B	2	1397961	4911063	4
Kaikorai	B	3	1397959	4911064	6
Kaikorai	B	4	1397958	4911066	8
Kaikorai	C	1	1398173	4911904	2
Kaikorai	C	2	1398171	4911905	4
Kaikorai	C	3	1398169	4911906	6
Kaikorai	C	4	1398168	4911908	8
Kaikorai	D	1	1398238	4911856	5
Kaikorai	D	2	1398233	4911855	10
Kaikorai	D	3	1398223	4911854	20
Kaikorai	D	4	1398217	4911854	25

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	Estuary	Site	Plate	Depth (mm)	Baseline depth (mm)	Days since last	Annual adjustment	Annualised change (mm)	Change from baseline (mm)
15/12/2017	2018	Kaik-Otag	A	p1	119	119	NA	NA	NA	0
22/02/2019	2019	Kaik-Otag	A	p1	134	119	434	1.2	12.6	15
18/12/2019	2020	Kaik-Otag	A	p1	125	119	299	0.8	-10.6	6.3
15/12/2017	2018	Kaik-Otag	A	p2	126	126	NA	NA	NA	0
22/02/2019	2019	Kaik-Otag	A	p2	151	126	434	1.2	21	25
18/12/2019	2020	Kaik-Otag	A	p2	145	126	299	0.8	-6.9	19.3
15/12/2017	2018	Kaik-Otag	A	p3	86	86	NA	NA	NA	0
22/02/2019	2019	Kaik-Otag	A	p3	112	86	434	1.2	21.6	25.7
18/12/2019	2020	Kaik-Otag	A	p3	104	86	299	0.8	-9	18.3
15/12/2017	2018	Kaik-Otag	B	p1	112	112	NA	NA	NA	0
22/02/2019	2019	Kaik-Otag	B	p1	101	112	434	1.2	-9.5	-11.3
19/12/2019	2020	Kaik-Otag	B	p1	112	112	300	0.8	13.4	-0.3
15/12/2017	2018	Kaik-Otag	B	p2	121	121	NA	NA	NA	0
22/02/2019	2019	Kaik-Otag	B	p2	123	121	434	1.2	2	2.3
19/12/2019	2020	Kaik-Otag	B	p2	113	121	300	0.8	-13	-8.3
15/12/2017	2018	Kaik-Otag	B	p3	98	98	NA	NA	NA	0
22/02/2019	2019	Kaik-Otag	B	p3	90	98	434	1.2	-7	-8.3
19/12/2019	2020	Kaik-Otag	B	p3	87	98	300	0.8	-2.8	-10.7
19/12/2019	2020	Kaik-Otag	B	p4	63	63	NA	NA	NA	0
15/12/2017	2018	Kaik-Otag	C	p1	63	63	NA	NA	NA	0
23/02/2019	2019	Kaik-Otag	C	p1	54	63	435	1.2	-7.3	-8.7
18/12/2019	2020	Kaik-Otag	C	p1	59	63	298	0.8	5.3	-4.3
15/12/2017	2018	Kaik-Otag	C	p2	61	61	NA	NA	NA	0
23/02/2019	2019	Kaik-Otag	C	p2	59	61	435	1.2	-2	-2.3
18/12/2019	2020	Kaik-Otag	C	p2	56	61	298	0.8	-2.9	-4.7
15/12/2017	2018	Kaik-Otag	C	p3	77	77	NA	NA	NA	0
23/02/2019	2019	Kaik-Otag	C	p3	75	77	435	1.2	-1.7	-2
18/12/2019	2020	Kaik-Otag	C	p3	71	77	298	0.8	-4.9	-6
22/02/2019	2019	Kaik-Otag	D	p1	54	54	NA	NA	NA	0
18/12/2019	2020	Kaik-Otag	D	p1	58	54	299	0.8	4.9	4
22/02/2019	2019	Kaik-Otag	D	p2	53	53	NA	NA	NA	0
18/12/2019	2020	Kaik-Otag	D	p2	58	53	299	0.8	6.5	5.3
22/02/2019	2019	Kaik-Otag	D	p3	55	55	NA	NA	NA	0
18/12/2019	2020	Kaik-Otag	D	p3	58	55	299	0.8	4.5	3.7
22/02/2019	2019	Kaik-Otag	D	p4	63	63	NA	NA	NA	0
18/12/2019	2020	Kaik-Otag	D	p4	66	63	299	0.8	2.8	2.3

Appendix 4. Sediment quality raw data

For aRPD, the range of values in 2019 and 2020 is based on 3-4 measurements made for each of zones X, Y and Z.

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	<0.1	86.1	13.8	0.52	600	360	30	-20	-56	-	-183	-294	4.40	0.029	8.30	4.80	<0.02	4.70	9.00	44
		Y	<0.1	86.0	14.1	0.54	600	430	30	-43	-67	-	-154	-275	4.50	0.034	8.40	4.80	<0.02	4.80	8.60	46
		Z	<0.1	85.0	15.0	0.65	700	440	30	-47	-65	-	-173	-264	5.60	0.040	9.60	5.40	<0.02	5.10	9.70	51
	B	X	0.1	35.5	64.4	2.70	2200	1060	0	-350	-364	-	-400	-410	14.30	0.260	44.00	25.00	0.10	18.10	47.00	240
		Y	<0.1	30.1	69.8	2.60	2100	1070	0	-345	-382	-	-413	-426	13.60	0.240	42.00	23.00	0.09	17.40	45.00	230
		Z	0.4	38.7	60.9	2.50	1900	1100	0	-337	-372	-	-407	-402	14.10	0.250	45.00	24.00	0.09	19.00	45.00	240
	C	X	2.3	70.3	27.5	1.44	1200	640	10	-220	-330	-	-317	-337	6.00	0.096	20.00	10.30	0.03	12.50	22.00	125
		Y	3.8	67.2	29.1	1.42	1100	680	10	-218	-317	-	-346	-334	6.70	0.103	22.00	10.60	0.03	13.20	23.00	135
		Z	0.8	74.1	25.1	1.28	1100	670	10	-227	-324	-	-319	-331	5.90	0.101	21.00	9.90	0.03	12.70	22.00	137
2019	A	X	<0.1	96.9	3.1	0.10	<500	570	15 to 40	122	-56	-35	72	-41	3.00	<0.010	3.90	1.80	<0.02	3.00	2.60	15
		Y	<0.1	96.5	3.5	0.11	<500	370	12 to 25	107	-37	73	95	50	3.20	0.012	3.40	2.00	<0.02	2.70	2.70	17
		Z	<0.1	85.5	14.5	0.40	<500	330	15 to 80	-21	-28	-15	71	104	4.70	0.028	8.40	4.20	<0.02	4.50	7.30	42
	B	X	0.3	27.8	72.0	2.50	2000	870	2 to 6	-137	-124	-140	-154	-130	11.30	0.260	49.00	21.00	0.07	16.10	49.00	240
		Y	0.4	22.1	77.5	2.40	2100	850	4 to 6	-101	-93	-88	-154	-190	11.10	0.260	45.00	20.00	0.08	15.80	48.00	230
		Z	<0.1	33.5	66.4	2.20	1900	830	3 to 5	-26	-44	-130	-137	-166	10.00	0.210	40.00	17.50	0.07	13.40	40.00	200
	D	X	0.5	55.8	43.7	1.60	1100	670	2 to 5	219	211	196	178	163	6.80	0.146	27.00	13.00	0.04	12.80	30.00	153
		Y	1.6	53.9	44.5	1.55	1100	660	20 to 40	-	-	-	-	-	6.00	0.134	24.00	11.80	0.03	11.90	27.00	133
		Z	0.7	62.5	36.9	1.20	900	650	20 to 25	-	-	-	-	-	6.20	0.122	25.00	11.10	0.03	11.50	27.00	134
2020	A	X	<0.1	91.2	8.8	0.35	<500	530	32 to 58	58	-31	36	24	-53	4.40	0.016	7.10	4.20	<0.02	4.70	6.30	41
		Y	<0.1	92.7	7.3	0.31	<500	530	22 to 45	16	-65	-113	1	-48	4.40	0.013	5.90	3.60	<0.02	4.30	4.80	34
		Z	<0.1	91.5	8.5	0.36	<500	410	24 to 72	110	6	74	-13	-127	4.90	0.015	6.70	3.70	<0.02	4.60	5.30	38
	B	X	0.1	16.2	83.7	2.50	2100	690	4 to 5	-22	-18	-35	-44	-44	10.50	0.280	48.00	26.00	0.10	19.20	52.00	290
		Y	<0.1	21.3	78.7	2.30	1900	620	3 to 4	-108	-113	-65	-105	-52	9.00	0.220	43.00	22.00	0.09	16.90	45.00	250
		Z	0.4	28.1	71.5	2.20	1900	710	2 to 6	-127	-87	-62	-121	-74	8.90	0.210	38.00	21.00	0.07	15.50	41.00	240
	D	X	0.5	61.6	37.9	1.95	1400	610	2 to 55	143	263	259	250	287	9.20	0.139	26.00	13.80	0.04	15.40	26.00	167
		Y	0.7	56.7	42.6	1.68	1300	640	60	-4	140	161	240	243	6.40	0.139	26.00	14.20	0.04	13.10	27.00	171
		Z	0.5	69.9	29.6	1.24	1000	570	34 to 65	-25	184	-92	-126	34	5.60	0.081	21.00	11.00	0.03	12.60	24.00	143
														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

Main group	Taxa	Habitat	EG	2018 A1	2018 A2	2018 A3	2018 A4	2018 A5	2018 A6	2018 A7	2018 A8	2018 A9	2018 A10	2018 B1	2018 B2	2018 B3	2018 B4	2018 B5	2018 B6	2018 B7	2018 B8	2018 B9	2018 B10	2018 C1	2018 C2	2018 C3	2018 C4	2018 C5	2018 C6	2018 C7	2018 C8	2018 C9	2018 C10
Gastropoda	Potamopyrgus estuarinus	epibiota	III	0	0	0	2	1	1	0	0	0	1	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gastropoda	Potamopyrgus pupoides	epibiota	III	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipoda	Amphipoda sp. 1	infauna	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipoda	Amphipoda sp. 3	infauna	II	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Amphipoda	Amphipoda sp. 4	infauna	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipoda	Paracorophium excavatum	infauna	IV	1	9	40	3	2	2	6	1	27	18	13	52	29	7	64	10	47	48	25	41	1	0	3	34	0	0	0	0	1	32
Bivalvia	Austrovenus stutchburyi	infauna	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isopoda	Exosphaeroma planulum	infauna	V	0	0	0	0	0	0	0	0	0	0	2	3	1	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
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	0	0	0	0	0	0	0	0	0	0
Nematoda	Nematoda	infauna	II	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligochaeta	Oligochaeta sp. 1	infauna	III	2	7	4	5	5	2	1	4	1	2	0	3	0	0	1	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0
Polychaeta	Capitella sp. 1	infauna	IV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaeta	Nicon aestuariensis	infauna	III	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Polychaeta	Perinereis vallata	infauna	II	17	10	17	19	5	7	6	2	5	3	1	1	1	0	3	2	4	1	0	2	0	0	0	0	0	0	0	0	0	0
Polychaeta	Polydora sp. 1	infauna	III	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaeta	Sabellidae sp. 1	infauna	I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaeta	Scolecolepides benhami	infauna	IV	15	19	24	13	26	23	14	29	25	28	1	4	3	3	3	2	8	9	5	4	0	0	0	0	0	0	0	0	0	0
Turbellaria	Turbellaria sp. 1	infauna	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaeta	Nereididae (unidentified juv)	infauna juv	NA	1	6	8	16	14	8	11	4	10	9	4	2	1	1	0	0	4	1	2	3	0	0	0	0	0	0	0	0	0	0
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	0	0	0	0	0	0	0	0	0	0	0
Diptera	Diptera sp. 2	larva	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Diptera	Diptera sp. 3	larva	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0
Diptera	Diptera sp. 4	larva	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Diptera sp. 5	larva	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Main group	Taxa	Habitat	EG	2019 A1	2019 A2	2019 A3	2019 A4	2019 A5	2019 A6	2019 A7	2019 A8	2019 A9	2019 A10	2019 B1	2019 B2	2019 B3	2019 B4	2019 B5	2019 B6	2019 B7	2019 B8	2019 B9	2019 B10	2019 D1	2019 D2	2019 D3	2019 D4	2019 D5	2019 D6	2019 D7	2019 D8	2019 D9	2019 D10
Gastropoda	Potamopyrgus estuarinus	epibiota	III	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gastropoda	Potamopyrgus pupoides	epibiota	III	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipoda	Amphipoda sp. 1	infauna	II	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	2	0
Amphipoda	Amphipoda sp. 3	infauna	II	0	0	0	0	0	0	0	0	0	0	6	5	12	4	5	5	4	7	9	4	0	0	0	0	0	0	0	0	0	0
Amphipoda	Amphipoda sp. 4	infauna	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipoda	Paracorophium excavatum	infauna	IV	124	70	27	51	3	37	111	460	42	21	133	196	265	187	397	278	201	259	374	319	3	0	11	3	0	15	1	2	29	65
Bivalvia	Austrovenus stutchburyi	infauna	II	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isopoda	Exosphaeroma planulum	infauna	V	0	0	0	0	0	0	0	0	0	0	2	2	5	2	2	1	0	0	2	1	0	0	1	0	0	0	0	0	1	0
Mysidae	Tenagomysis sp. 1	infauna	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Nematoda	Nematoda	infauna	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligochaeta	Oligochaeta sp. 1	infauna	III	0	0	1	5	0	1	0	3	1	2	0	0	0	0	0	0	0	0	0	0	1	2	5	0	1	0	0	1	1	0
Polychaeta	Capitella sp. 1	infauna	IV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaeta	Nicon aestuariensis	infauna	III	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaeta	Perinereis vallata	infauna	II	11	9	9	17	10	10	9	5	13	10	5	1	2	1	1	2	0	1	2	1	0	0	0	1	0	0	0	0	0	0
Polychaeta	Polydora sp. 1	infauna	III	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaeta	Sabellidae sp. 1	infauna	I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaeta	Scolecolepides benhami	infauna	IV	18	14	14	15	13	4	4	12	15	9	53	52	40	57	58	59	35	57	29	25	0	1	2	0	0	1	0	1	2	4
Turbellaria	Turbellaria sp. 1	infauna	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaeta	Nereididae (unidentified juv)	infauna juv	NA	6	7	3	3	3	3	8	0	4	6	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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	0	0	0	0	0	0	0	0	0	0	0
Diptera	Diptera sp. 2	larva	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Diptera sp. 3	larva	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	2	1	0	0	0
Diptera	Diptera sp. 4	larva	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	Diptera sp. 5	larva	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Main group	Taxa	Habitat	EG	2020 A1	2020 A2	2020 A3	2020 A4	2020 A5	2020 A6	2020 A7	2020 A8	2020 A9	2020 A10	2020 B1	2020 B2	2020 B3	2020 B4	2020 B5	2020 B6	2020 B7	2020 B8	2020 B9	2020 B10	2020 D1	2020 D2	2020 D3	2020 D4	2020 D5	2020 D6	2020 D7	2020 D8	2020 D9	2020 D10
Gastropoda	Potamopyrgus estuarinus	epibiota	III	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Gastropoda	Potamopyrgus pupoides	epibiota	III	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipoda	Amphipoda sp. 1	infauna	II	2	1	0	1	1	0	0	5	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
Amphipoda	Amphipoda sp. 3	infauna	II	0	0	0	0	0	0	0	0	0	0	14	7	0	6	0	0	3	4	0	5	0	0	0	0	0	0	0	0	0	0
Amphipoda	Amphipoda sp. 4	infauna	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amphipoda	Paracorophium excavatum	infauna	IV	1644	589	536	837	217	242	333	392	480	376	360	282	112	329	350	163	210	345	307	265	0	3	361	2	10	481	11	10	151	458
Bivalvia	Austrovenus stutchburyi	infauna	II	0	1	1	3	1	1	0	0	0	0	0	0	2	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Isopoda	Exosphaeroma planulum	infauna	V	0	0	1	0	0	0	0	0	1	0	27	5	3	11	4	1	10	16	2	3	0	0	0	0	0	0	0	0	0	0
Mysidae	Tenagomysis sp. 1	infauna	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Nematoda	Nematoda	infauna	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Oligochaeta	Oligochaeta sp. 1	infauna	III	1	0	1	1	0	2	5	2	10	6	0	0	0	0	0	0	0	3	3	3	155	109	22	103	41	10	59	47	22	33
Polychaeta	Capitella sp. 1	infauna	IV	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaeta	Nicon aestuariensis	infauna	III	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaeta	Perinereis vallata	infauna	II	16	30	22	17	13	16	10	16	11	6	3	3	2	3	0	2	1	2	4	3	0	0	0	0	0	0	0	0	0	0
Polychaeta	Polydora sp. 1	infauna	III	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	2	4
Polychaeta	Sabellidae sp. 1	infauna	I	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Polychaeta	Scolecolepides benhami	infauna	IV	9	21	23	18	22	15	15	17	13	18	51	53	28	21	10	34	29	30	41	29	0	0	6	1	6	4	1	0	4	10
Turbellaria	Turbellaria sp. 1	infauna	II	0	0	0	0	0	0	0	0	0	0	5	1	3	7	2	0	6	11	0	0	0	0	0	0	0	0	1	0	0	0
Polychaeta	Nereididae (unidentified juv)	infauna juv	NA	0	1	3	4	1	1	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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	0	0	0	0	0	0	0	3	0	0	0
Diptera	Diptera sp. 2	larva	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
Diptera	Diptera sp. 3	larva	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	2	6	18	9	1	7	3	9	4
Diptera	Diptera sp. 4	larva	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	1	0	0	0	4	1	0	0	1
Diptera	Diptera sp. 5	larva	II	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	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 within the range of 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; *Polydora cornuta* vs *Polydora* 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-named Sabellidae sp. 1 is most likely what NIWA have called *Pseudopotamilla* sp.

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 Kaikorai 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 Kaikorai 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.

Taxa	A_CMEC (mean, n=10)	A_NIWA (n=1)	Comment
Amphipoda sp. 1	1	0	Possibly NIWA Paracalliope novizealandiae or Protohyale sp.
Austrovenus stutchburyi	0.7	3	
Capitella sp. 1	0.1	0	Assumed NIWA Capitella spp.
Capitella spp.	0	12	Assumed CMEC Capitella sp. 1
Exosphaeroma planulum	0.2	0	Likely a chance miss due to low density
Nereididae (unidentified juveniles)	1.3	0	Likely a chance miss due to low density
Nicon aestuariensis	0.1	0	Likely a chance miss due to low density
Oligochaeta	0	14	Assumed CMEC Oligochaeta sp. 1
Oligochaeta sp. 1	2.8	0	Assumed NIWA Oligochaeta
Paracalliope novizealandiae	0	1	Possibly CMEC Amphipoda sp. 1
Paracorophium excavatum	564.6	495	
Perinereis vallata	15.7	26	
Protohyale sp.	0	1	Possibly CMEC Amphipoda sp. 1
Scolecolepides benhami	17.1	19	
Number of taxa	**10**	**8**	
Sum abundance	**604**	**571**	

Taxa	B_CMEC (mean, n=10)	B_NIWA (n=1)	Comment
Amphipoda sp. 1	0.3	0	Likely a chance miss due to low density
Amphipoda sp. 3	3.9	0	Likely NIWA Melita awa
Amphipoda sp. 4	0.2	0	Likely a chance miss due to low density
Austrovenus stutchburyi	0.5	0	Likely a chance miss due to low density
Capitella spp.	0	1	Likely a chance miss due to low density
Diptera sp. 4	0.2	0	Likely a chance miss due to low density
Exosphaeroma planulum	8.2	5	
Melita awa	0	6	Assumed one of CMEC amphipoda
Mysidae	0	1	Assumed CMEC Tenagomysis sp. 1
Nereididae (unidentified juveniles)	0.1	0	Likely a chance miss due to low density, or NIWA Nicon aestuariensis
Nicon aestuariensis	0	1	Possibly CMEC Nereididae (unidentified juveniles)
Oligochaeta	0	9	Assumed CMEC Oligochaeta sp. 1
Oligochaeta sp. 1	0.9	0	Assumed NIWA Oligochaeta
Paracorophium excavatum	272.3	503	
Perinereis vallata	2.3	1	
Polydora cornuta	0	1	Assumed CMEC Polydora sp. 1
Polydora sp. 1	0.1	0	Assumed NIWA Polydora cornuta
Potamopyrgus estuarinus	0.1	0	Likely a chance miss due to low density
Pseudopotamilla sp.	0	27	Assumed CMEC Sabellidae sp. 1
Sabellidae sp. 1	0.4	0	Assumed NIWA Pseudopotamilla sp.
Scolecolepides benhami	32.6	36	
Tenagomysis sp. 1	0.2	0	Assumed NIWA Mysidae
Turbellaria sp. 1	3.5	0	Likely a chance miss due to low density
Number of taxa	**16**	**11**	
Sum abundance	**326**	**591**	

Taxa	D_CMEC (mean, n=10)	D_NIWA (n=1)	Comment
Diptera sp. 1	0.3	0	Likely a chance miss due to low density
Diptera sp. 2	0.2	0	Likely a chance miss due to low density
Diptera sp. 3	6.3	0	Likely a chance miss due to low density
Diptera sp. 4	0.8	0	Likely a chance miss due to low density
Diptera sp. 5	0.1	0	Likely a chance miss due to low density
Nematoda	0.1	1	
Oligochaeta	0	64	Assumed CMEC Oligochaeta sp. 1
Oligochaeta sp. 1	60.1	0	Assumed NIWA Oligochaeta
Paracorophium excavatum	148.7	36	
Polydora sp. 1	0.7	0	Likely a chance miss due to low density
Scolecolepides benhami	3.2	9	
Turbellaria sp. 1	0.1	0	Likely a chance miss due to low density
Number of taxa	**11**	**4**	
Sum abundance	**221**	**110**	

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 uncommon or rare species, an asymptote is unlikely to ever be reached in practice, i.e. due to chance sampling of such 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. A6.2 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. A6.2 shows that the cumulative species richness curve is generally still slowly increasing at 10 samples, but is nonetheless reasonably flat. Excluding Site C (where sampling has been discontinued), Table A6.2.1 suggests that with 10 samples, the number of species being detected is at least 88% of the estimated maximum. One way to interpret the results is that it may take >10 samples before actual richness reached the estimated total for a given year-site. Table A6.2.2 indicates that to sample 90% of the predicted species present, somewhere between 6 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.

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.

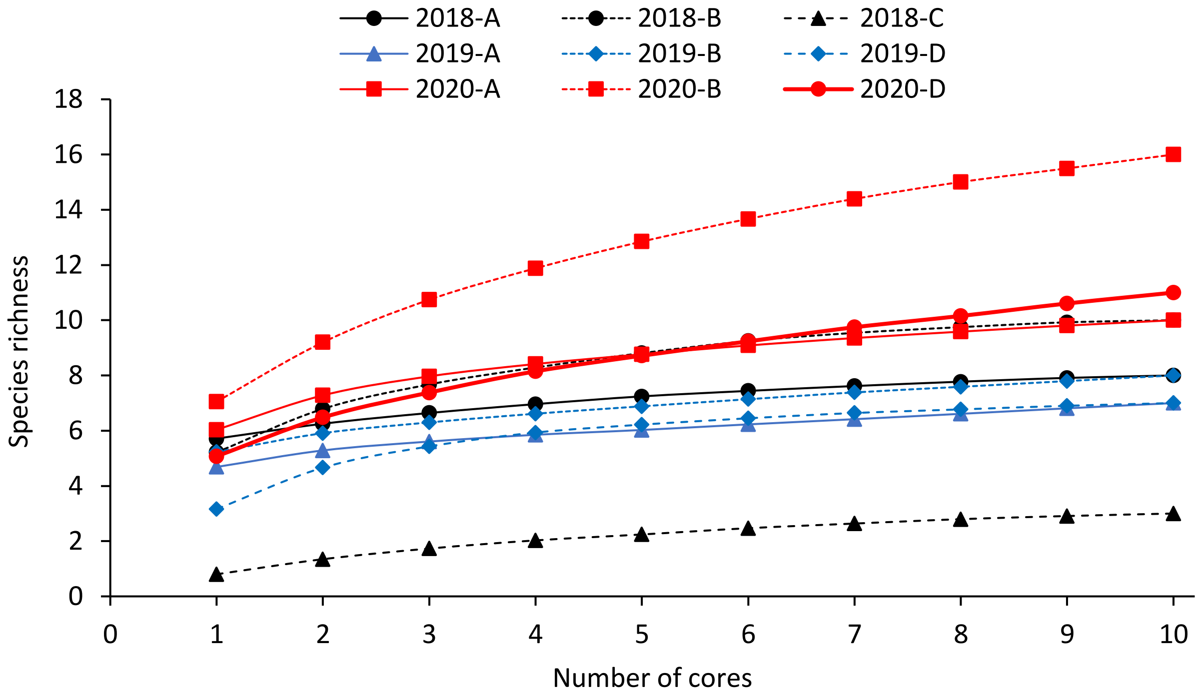


Fig. A6.2 Cumulative species richness in relation to sampling effort for each year-site.

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 = 8.5, S2 estimate = 8.1

Samp#	S_obs	S_obs (% total)	S_obs as % of S1	S_obs as % of S2	Median%
1	5.7	71.4	67.5	70.8	69.2
2	6.3	78.1	73.9	77.5	75.7
3	6.6	83.0	78.5	82.3	80.4
4	7.0	87.0	82.3	86.3	84.3
5	7.2	90.5	85.6	89.8	87.7
6	7.4	93.0	87.9	92.2	90.1
7	7.6	95.2	90.0	94.4	92.2
8	7.8	97.2	91.9	96.4	94.1
9	7.9	98.9	93.5	98.1	95.8
10	8.0	100.0	94.5	99.2	96.8

2018B S1 estimate = 10.7, S2 estimate = 11.0

Samp#	S_obs	S_obs (% total)	S_obs as % of S1	S_obs as % of S2	Median%
1	5.2	52.2	48.9	47.3	48.1
2	6.8	67.9	63.6	61.5	62.6
3	7.7	76.7	71.9	69.5	70.7
4	8.3	82.9	77.6	75.1	76.4
5	8.8	88.1	82.5	79.8	81.2
6	9.2	92.5	86.6	83.8	85.2
7	9.5	95.4	89.4	86.5	87.9
8	9.7	97.5	91.3	88.4	89.8
9	9.9	99.2	92.9	89.9	91.4
10	10.0	100.0	93.7	90.6	92.1

2018C S1 estimate = 3.5, S2 estimate = 4.3

Samp#	S_obs	S_obs (% total)	S_obs as % of S1	S_obs as % of S2	Median%
1	0.8	26.7	23.2	18.6	20.9
2	1.3	44.9	38.9	31.3	35.1
3	1.7	57.7	50.1	40.3	45.2
4	2.0	67.6	58.6	47.1	52.9
5	2.2	74.7	64.9	52.1	58.5
6	2.5	82.3	71.4	57.4	64.4
7	2.6	87.9	76.3	61.3	68.8
8	2.8	93.2	80.9	65.0	72.9
9	2.9	97.0	84.2	67.6	75.9
10	3.0	100.0	86.8	69.7	78.3

2019A S1 estimate = 7.7, S2 estimate = 7.0

Samp#	S_obs	S_obs (% total)	S_obs as % of S1	S_obs as % of S2	Median%
1	4.7	67.0	60.9	67.0	63.9
2	5.3	75.5	68.6	75.5	72.1
3	5.6	80.1	72.8	80.1	76.5
4	5.9	83.6	76.0	83.6	79.8
5	6.0	86.1	78.3	86.1	82.2
6	6.2	89.0	80.9	89.0	84.9
7	6.4	91.7	83.4	91.7	87.5
8	6.6	94.4	85.9	94.4	90.2
9	6.8	97.3	88.5	97.3	92.9
10	7.0	100.0	90.9	100.0	95.5

2019B S1 estimate = 8.7, S2 estimate = 8.0

Samp#	S_obs	S_obs (% total)	S_obs as % of S1	S_obs as % of S2	Median%
1	5.2	65.4	59.9	65.4	62.6
2	5.9	73.9	67.7	73.9	70.8
3	6.3	78.7	72.2	78.7	75.5
4	6.6	82.7	75.8	82.7	79.2
5	6.9	86.0	78.9	86.0	82.5
6	7.1	89.2	81.8	89.2	85.5
7	7.4	92.3	84.6	92.3	88.5
8	7.6	94.9	87.0	94.9	90.9
9	7.8	97.5	89.4	97.5	93.4
10	8.0	100.0	91.7	100.0	95.8

2019D S1 estimate =7.5, S2 estimate = 8.1

Samp#	S_obs	S_obs (% total)	S_obs as % of S1	S_obs as % of S2	Median%
1	3.2	45.2	42.2	39.0	40.6
2	4.7	66.6	62.3	57.5	59.9
3	5.4	77.6	72.6	67.0	69.8
4	5.9	84.7	79.2	73.2	76.2
5	6.2	88.8	83.1	76.7	79.9
6	6.4	92.1	86.1	79.6	82.8
7	6.6	94.9	88.7	81.9	85.3
8	6.8	96.7	90.5	83.5	87.0
9	6.9	98.6	92.2	85.1	88.7
10	7.0	100.0	93.5	86.4	89.9

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%
1	6.0	60.4	55.9	58.2	57.0
2	7.3	72.8	67.4	70.2	68.8
3	8.0	79.7	73.7	76.8	75.3
4	8.4	84.1	77.9	81.1	79.5
5	8.8	87.7	81.1	84.5	82.8
6	9.1	90.9	84.1	87.6	85.8
7	9.4	93.5	86.6	90.2	88.4
8	9.6	95.9	88.7	92.4	90.6
9	9.8	98.1	90.7	94.5	92.6
10	10.0	100.0	92.5	96.4	94.5

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%
1	7.1	44.1	39.1	39.7	39.4
2	9.2	57.5	51.1	51.8	51.4
3	10.7	67.1	59.6	60.5	60.0
4	11.9	74.2	65.9	66.9	66.4
5	12.8	80.3	71.3	72.3	71.8
6	13.7	85.4	75.8	76.9	76.4
7	14.4	90.0	79.9	81.0	80.4
8	15.0	93.8	83.3	84.5	83.9
9	15.5	96.9	86.0	87.2	86.6
10	16.0	100.0	88.8	90.1	89.4

2020D 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%
1	5.1	46.1	40.5	43.0	41.7
2	6.5	58.9	51.7	54.9	53.3
3	7.4	67.1	58.9	62.5	60.7
4	8.1	74.1	65.0	69.0	67.0
5	8.7	79.2	69.6	73.8	71.7
6	9.2	83.9	73.7	78.2	75.9
7	9.7	88.6	77.8	82.5	80.1
8	10.2	92.3	81.0	86.0	83.5
9	10.6	96.4	84.6	89.8	87.2
10	11.0	100.0	87.8	93.1	90.5

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.

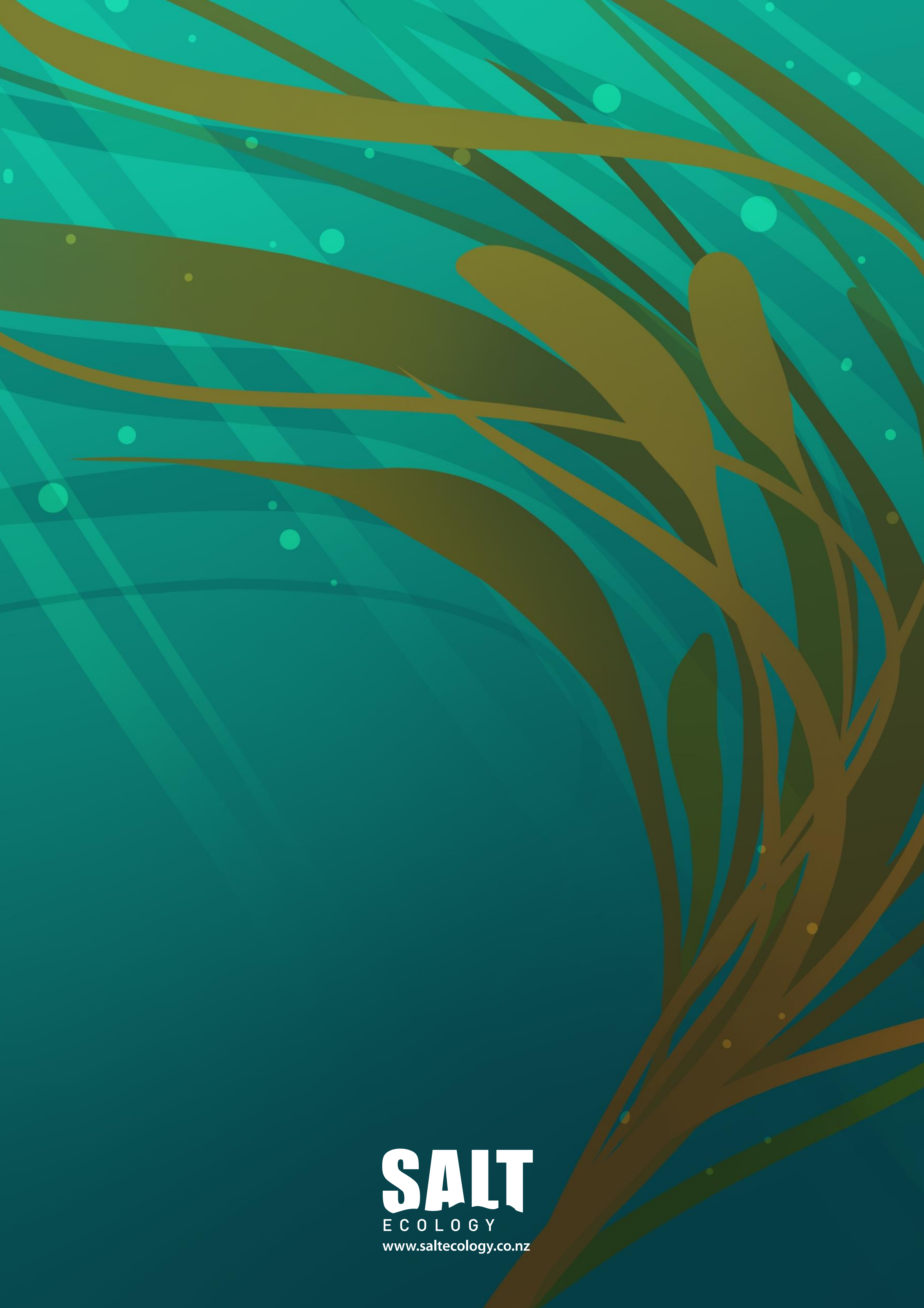
Year-site	S (observed)	S (predicted)	Min #cores to sample >90% of predicted S	# S to sample >90% of N	Percent of observed S	Min #cores to achieve >90% of N
2018A	8	8.3	6	4	50	1
2018B	10	10.9	9	3	30	1
2018C	3	3.9	>10	1	33	2
2019A	7	7.4	8	3	43	1
2019B	8	8.4	8	2	25	1
2019D	7	7.8	>10	3	43	2
2020A	10	10.6	8	1	10	1
2020B	16	17.9	>10	2	13	1
2020D	11	12.2	10	2	18	1

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

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 4 taxa, reflecting the dominance of the macrofauna by *Paracorophium excavatum* and a few subdominant species. As a consequence, to consistently sample 90% of macrofaunal abundance would require no more than 2 cores to be collected.

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, in the order of 8-9 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. 2 cores as indicated above) is that increased environmental stress may not be reliably reflected. For example, at Site C in 2018 half of the cores were azoic (i.e. having no macrofauna), which is consistent with very high environmental stress. If only two cores had been collected, this result may not have been reliably reflected (e.g. by chance, both cores may have been azoic, or both may have contained macrofauna).

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 Kaikorai 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).



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