Fine Scale Intertidal Monitoring of Manawatū Estuary

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For the People
Mō ngā tāngata

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BACKGROUND

As part of State of Environment monitoring conducted by Horizons Regional Council (HRC), significant estuaries in the region are monitored using New Zealand's National Estuary Monitoring Protocol (NEMP). This report describes a third survey of the Manawatu Estuary, which has been conducted using the fine scale survey methodology described in the NEMP, and was carried out alongside concurrent monitoring of patterns of sediment accretion and erosion using a 'sediment plate' method. The report describes the methods and results of field sampling undertaken in January 2019, discusses the results for the three survey years collectively, and considers the findings in the context of estuary health and needs for future monitoring.

KEY FINDINGS

The sampling sites are positioned within an extensive area of uniform muddy sand tidal flats. The sites are relatively featureless, except for the conspicuous presence of mud snails. No seagrass was recorded over the three surveys, there was very little apparent detritus or accumulation of terrestrial debris, and the sediments have a low shell content.

There were no visible biological growths (e.g. sea lettuce, microalgal mats) or other obvious symptoms that might indicate enriched conditions. The depth of the apparent Redox Potential Discontinuity (aRPD) was reasonably similar across the three survey years, and not unexpected given the mud content of the estuarine sediments. Importantly, there was no evidence of the aRPD occurring at, or close to, the sediment surface, as can occur in highly depositional and enriched situations. Depth profiles of oxidation-reduction potential (ORP) in 2019 corresponded reasonably well with aRPD depth.

By comparison with the first survey conducted in January 2017, there has been an increase in sediment mud content at the two fine scale sites, with highest mud levels recorded in 2019. This change was particularly evident at upstream Site B, where net sediment accretion has also been measured by the simultaneous monitoring of the depth of buried sediment plates.

The reasons for the increased mud content are unclear, but it is not associated with any measurable change in the sediment-dwelling macrofaunal assemblage. Similarly, sediment quality indicators such as nutrients and trace metals occurred at very low concentrations that would not be associated with adverse ecological effects.

Although the sediment-dwelling macrofaunal assemblage was species-poor, it had relatively high abundances of a tube-building corophioid amphipod, along with a limited suite of subdominant species that were similar among sites and surveys. The nature of the species present in the assemblage suggests that the environment is reasonably harsh and strongly influenced by low salinity water from the Manawatu River.

RECOMMENDATIONS

Recommendations are made in the main report relating to the NEMP fine scale methodology and possible improvements. In terms of the fine scale survey results, it is too early to infer trends based on the available data, due to the very short monitoring record (three surveys in three years). Nonetheless, given that increased fine-sediment inputs to estuaries are a key driver of estuarine health, it would be advisable to:

- Continue with monitoring in the Manawatu Estuary. Such monitoring will help to determine whether the temporal changes observed are ongoing and directional, or if they are within the limits of natural change that occurs in this system; for example, due to the dynamic nature of environmental drivers such as river flow variation.
- Given the cost and effort of a full fine-scale survey, the most affordable and practical option to keep track of the sediment mud issue would be to conduct sediment plate monitoring annually (which is typical for this method anyway), and to collect sediment samples for grain size analysis at the same time.
- Simultaneously, we recommend a desktop evaluation to consider whether there are any obvious factors that could explain the increased sediment mud content (e.g. an assessment of temporal changes in catchment sediment loads or flood patterns).

At this stage additional fine-scale surveys for Manawatu Estuary are not scheduled, but it is typical for many councils to repeat such surveys every five years after a baseline has been established (typically a three-year baseline as described here).

1. INTRODUCTION

A long-term objective of Horizons Regional Council (HRC) is to incorporate all significant estuaries within their State of Environment monitoring framework through implementation of New Zealand's National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002a, b, c).

While the region's estuaries received little attention historically, in 2009 the Department of Conservation funded broad scale habitat mapping of the Whanganui River Estuary (Stevens & Robertson 2009), and in late 2015 HRC commissioned an Ecological Vulnerability Assessment (EVA) for all of the estuaries within the region to assess sediment and eutrophication risks, map dominant habitat features, and provide the Council with defensible monitoring recommendations and priorities (Robertson & Stevens 2016).

Subsequently, HRC commissioned NEMP 'broad scale' habitat mapping and 'fine scale' sampling surveys for Manawatu Estuary, in recognition of its high ecological and human use values. A broad scale survey was undertaken in 2016 (Stevens & Robertson 2016) followed by fine-scale surveys in 2017 (Robertson & Stevens 2017) and 2018 (data gathering only). In late 2018, HRC contracted Salt Ecology to undertake the third fine-scale survey of the estuary, completing a planned 3-year baseline.

Alongside the fine scale survey work, Salt Ecology was asked to conduct sediment plate monitoring to provide information on patterns of sediment accretion and erosion over time, and to aid interpretation of changes at fine scale sites. The following report describes the methods and results of field sampling undertaken in January 2019, discusses the results for the three survey years collectively, and considers the findings in the context of estuary health and needs for future monitoring.

The lower Manawatu Estuary is a popular area for recreation

2. BACKGROUND

A synthesis of information on Manawatu Estuary is described in Robertson and Stevens (2017), which is largely repeated here. The estuary is a large (533ha), shallow, short residence, tidal river estuary (SSRTRE) located near Foxton (Fig. 1). It has a large freshwater inflow which, when combined with the marine inflow, has a tidal influence that extends ~11km inland. The upper estuary is often stratified, largely confined within defined river channels, and is characterised by low salinity surface waters. It is flanked by narrow bands of predominantly brackish water tolerant aquatic plants, and pasture. In contrast, the middle and lower reaches have large intertidal flats and salt marsh. The estuary mouth is always open to the sea. The estuary catchment is extensively developed with land use predominantly sheep, beef and dairy farming, but also some urban.

The estuary is a high use area valued for its aesthetic appeal, bathing, boating, fishing, whitebaiting and beach access. Ecologically it is important for freshwater fish and internationally significant for birds. Although the natural vegetated margin is mostly lost and much of the upper estuary channelised, habitat diversity is reasonably high, with relatively extensive areas of salt marsh present (161ha, 30% of the estuary area). It was designated a wetland of international importance under the Ramsar Convention in July 2005.

The estuary has a high nutrient load, the estimated catchment nitrogen (N) areal loading (3,245 $mgNm^2d^{-1}$) exceeding a proposed guideline for low susceptibility tidal river estuaries (~2000$mgNm^2d^{-1}$) (Robertson & Stevens 2016). Despite this situation the estuary has low susceptibility to eutrophication because of its highly flushed nature; it is strongly channelised with very few poorly flushed areas, has high freshwater inflow, is strongly affected by tidal currents and is often turbid (mean ~35 NTU). However, on occasions during low flows when the estuary is stratified, nuisance algal/macrophyte growth may occur.

The presence of elevated chlorophyll-a concentrations at times are likely attributable to phytoplankton blooms in saline bottom waters and from freshwater sources upstream of the estuary.

The current sedimentation rate (CSR) is likely to be >10 times the estimated natural sedimentation rate (NSR), however the estuary is rated as only moderately vulnerable to muddiness issues as it is well-flushed (Robertson & Stevens 2016).

Fig. 1. Map of Manawatu Estuary showing locations of the two fine scale and sediment plate monitoring sites.

3. OVERVIEW OF NEMP PROGRAMME

3.1 OVERVIEW

The NEMP is intended to provide resource managers with a scientifically defensible, cost-effective, easy to use, nationally applied standard protocol with which they can assess and monitor 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 programme has three main elements. The first part is a coarse screening tool that is intended to enable councils to undertake a preliminary assessment of the condition of estuaries in their region in order to establish monitoring priorities (Robertson et al. 2002a), which was the basis for the Ecological Vulnerability Assessment (EVA) conducted for HRC (Robertson & Stevens 2016). Once initial priorities are established, the NEMP monitoring approach itself consists of two protocols described in Robertson et al. (2002c), which are outlined below.

3.2 BROAD SCALE MAPPING OF INTERTIDAL HABITAT CHARACTERISTICS.

The aim of broad scale habitat mapping is to describe and map an estuary according to the dominant habitat (substrate and vegetation) features present. Once a baseline map has been constructed, changes in the position and/or extent or type of dominant habitats can then be monitored by repeating the mapping exercise. This procedure combines the use of aerial photography, detailed ground truthing, and digital mapping using Geographical Information System (GIS) technology. As noted, a detailed broad scale habitat map was developed for Manawatu Estuary in 2016 (Stevens & Robertson 2016).

3.3. FINE SCALE ASSESSMENT OF INTERTIDAL HABITAT CONDITION.

Once an estuary has been classified according to its main distinguishing features, and the dominant broad scale habitats have been described and mapped, 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. The environmental characteristics assessed in fine scale surveys incorporate a suite of commonly used benthic indicators, including biological (e.g. macroinvertebrate infauna) and physico-chemical (e.g. sediment mud content, metals, nutrients) characteristics.

4. FINE SCALE METHODS

4.1 SITES

Sediment plate and fine scale NEMP sampling was conducted on 30 January 2019 at the same two unvegetated soft-muddy sand sites (A & B) previously monitored. Site locations are shown in Fig. 1, with coordinates for each given in Appendix 1. The sites are positioned ~350m apart on the mud/sand flats of the lower Manawatu River Estuary, bordering the low tide river channel. A schematic of the sampling approach for fine-scale and sediment plate monitoring is provided in Fig. 2, with methods described below.

4.2 SEDIMENT PLATE MONITORING

Sediment plate monitoring involves measuring changes in sediment depth over buried concrete pavers, to provide information on patterns of sediment accretion and erosion over time, and to aid interpretation of changes at fine-scale sites. Sedimentation rates are typically measured annually. For this purpose, at Manawatu Estuary concrete plates (19cm x 23cm paving stones) were initially installed in January 2017 (Robertson & Stevens 2017). At each location a 30m transect was aligned along the downstream 30m boundary line of each fine-scale site (Fig.2).

The transect start, midpoint and end point (0, 15 and 30m) were marked with wooden pegs driven into the sediment, with 4 plates buried approximately 20cm beneath the sediment surface at distances of 5, 10, 20 and 25m on the transect line. Each plate was positioned on a 400mm metal warratah driven vertically into the sediment to both stabilise the plate and to enable future relocation with a metal detector, and leveled using a spirit level before being reburied.

Measuring sediment depth over buried concrete pavers

A 2.5m strait edge was placed over the plate to average out any small-scale irregularities in surface

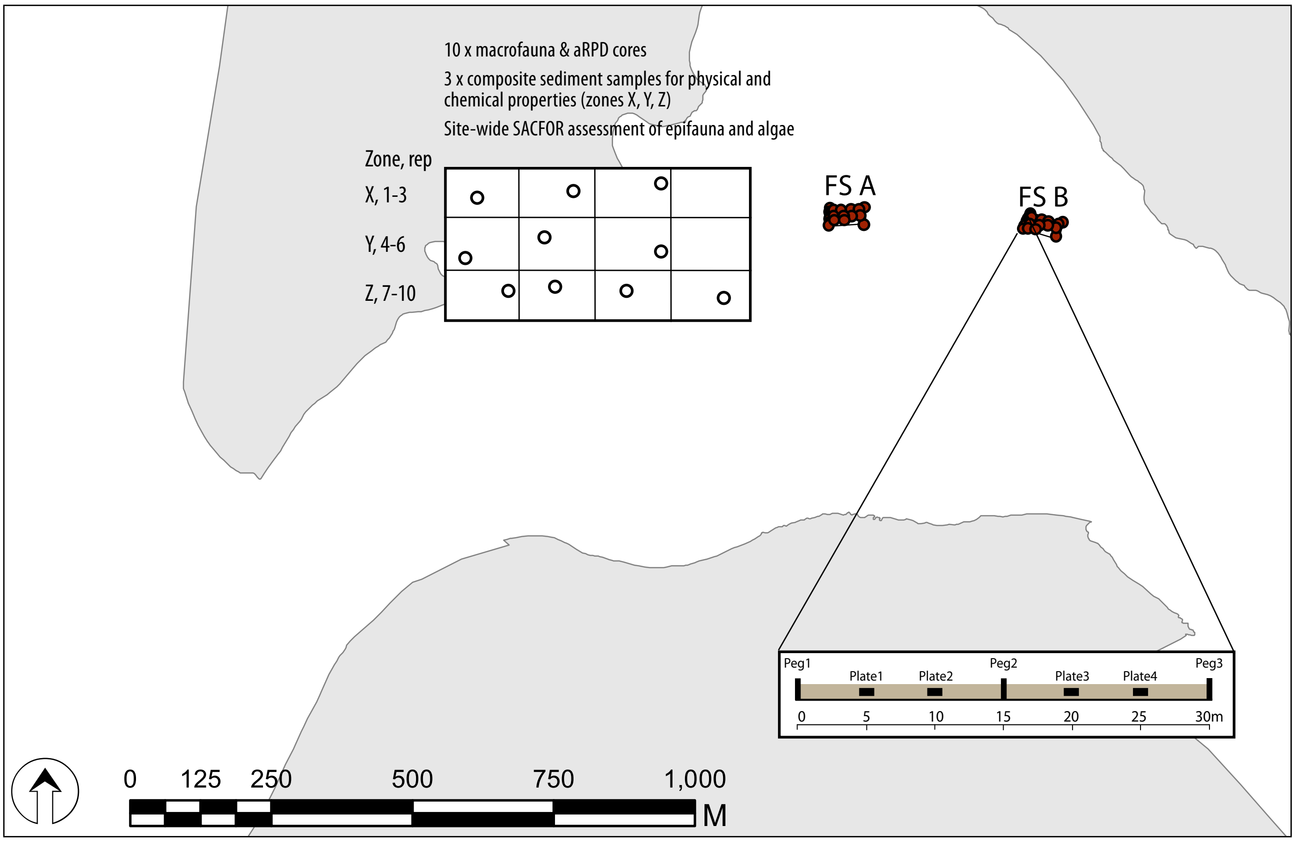


Fig. 2. Schematic illustrating fine scale monitoring and sediment plate methods.

topography. The depth to each buried plate was then measured in triplicate by vertically inserting a measuring probe into the sediment until the plate was located. Depth was measured with a ruler to the nearest mm. Sediment plate depth measurements collected in January 2019 were compared to those from 2018 and from the 2017 baseline, and expressed as an annual change in sediment depth for each plate and site.

4.3 BENTHIC INDICATORS AND FINE SCALE SAMPLING

Each of the two fine scale sites comprised a 60m x 30m area divided into a 3 x 4 grid of 12 plots (see Fig. 2). Fine-scale sampling for sediment indicators was conducted in 10 of these plots, with Fig. 2 showing the standard designation of zones X, Y, Z and numbering sequence for replicates used at both sites.

A summary of the benthic indicators, the rationale for their inclusion, and the field sampling methods, is provided in Table 1. Although the general sampling approach closely follows the NEMP, 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 years. For present purposes we have adopted these modifications as indicated in Table 1.

Three composite sediment samples (each ~250g) were collected from sub-samples (to 20mm depth) pooled across each of plots 1-3, 4-6 and 7-10, which were designated as zones X, Y and Z, respectively. Samples were stored on ice and sent to a laboratory (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 (cadmium, Cd; chromium, Cr; copper, Cu; lead, Pb; nickel, Ni; zinc, Zn; mercury, Hg; arsenic, As). Details of laboratory methods and detection limits are provided in Appendix 2.

In each of three plots (1, 4 and 7), a sediment core (120mm diameter, 150mm deep) was taken for field measurement of vertical profiles of oxidation reduction potential (ORP). ORP was measured at up to five depths in each core (10, 30, 50, 70 and 100mm from the sediment surface) using a YSI Pro10 ORP meter and YSI 1002 ORP (redox) sensor. The sensor probe was inserted horizontally into pre-drilled holes in a perspex sediment corer, and after allowing the probe to stabilise at each level for a consistent 2-minute interval, ORP (mV) was

Table 1. Summary of NEMP fine scale benthic indicators, rationale for their use, field sampling method, and any extensions to the NEMP methods.

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 for each of 10 plots. Arsenic and mercury added as additional parameters
Depth of apparent redox potential discontinuity layer (aRPD)	A 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	A 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		
Infauna	The abundance, composition and diversity of macroinvertebrate infauna (i.e. animals living within the sediment matrix) 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 conspicuious growths as part of SACFOR. Composition requires specialist taxonomic expertise, and is not typically undertaken in NEMP studies.


Measuring oxidation reduction potential


Collecting macrofauna cores

measured. Although ORP is not part of the NEMP (see Table 1), it is increasingly being used in council monitoring studies. Our purpose here was not to comprehensively assess the ORP methodology, but to provide sufficient data to enable comparison against the visual aRPD assessment described below and in Table 1.

At each of the 10 subplots, a large sediment core (130mm diameter, 150mm deep) was taken and placed on a tray. Each core was split vertically, the depth of the apparent redox potential discontinuity (aRPD) layer was recorded, and representative cores (1, 4 and 7) were photographed. The aRPD is a subjective measure of the enrichment state of sediments according to the depth of visual transition between oxygenated surface sediments and deeper deoxygenated black sediments.

Each core was then placed in a 0.5mm sieve bag, which was gently washed in seawater to remove fine sediment. The retained animals living within the sediment matrix were preserved in a 75% isopropyl alcohol 25% seawater mixture for later sorting (Salt Ecology staff) and taxonomic identification (Gary Stephenson, Coastal Marine Ecology Consultants). The type of animals (commonly referred to as 'macrofauna') present, 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.

Epibiota (surface-dwelling animals and macroalgae) visible on the sediment surface within the 60m x 30m sampling area were semi-quantitatively categorised using 'SACFOR' abundance (animals) or percentage cover (macroalgae) ratings shown in Table 2. These ratings represent a scoring scheme simplified from established monitoring methods that have been implemented by the United Kingdom's Joint Nature Conservation Committee since 1990 (MNCR 1990; Blyth-Skyrme et al. 2008). The SACFOR method is ideally suited to characterise conspicuous (nominally >5mm body size) or patchy intertidal epibiota. It was conducted as an alternative to the quantitative quadrat sampling specified in NEMP, which is known to poorly characterise scarce or clumped species (Forrest & Stevens 2019b). Note that our epibiota assessment did not include infaunal species that may be visible on the sediment surface, but whose abundance cannot be reliably determine from surface observation (e.g. cockles).

Table 2. SACFOR ratings for site-scale abundance, and percent cover of epibiota and macroalgae, respectively.

Category	Code	Density m^{-2}	Percent cover
Super abundant	S	> 1000	> 50
Abundant	A	100 - 999	20 - 50
Common	C	10 - 99	10 - 19
Frequent	F	5 - 9	5 - 9
Occasional	O	1 - 4	1 - 4
Rare	R	< 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). Our assessment did not include infaunal species that may be visible on the sediment surface, but whose abundance cannot be reliably determine from surface observation (e.g. cockles).

4.4 DATA RECORDING, QA/QC AND ANALYSIS

All sediment and macrofaunal samples were tracked using standard Chain of Custody forms, and results were transferred electronically to avoid transcription errors. All field measurements from the fine-scale and sediment plate surveys were recorded electronically in templates that were custom-built using Fulcrumapp software (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 or sediment plate). Fulcrum field data were exported to Excel, together with data from the sediment and macrofaunal analyses.

To minimise the risk of subsequent data manipulation errors, Excel sheets for the different data types were imported into the software R 3.5.3 (R Core Team 2019) and merged by common sample identification codes. All summaries of univariate responses were produced in R, including tabulated or graphical representations of data from sediment plates, laboratory sediment quality analyses, and macrofauna (e.g. totals, mean ± 1 standard error). Where results for sediment quality parameters were below analytical detection limits, site 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 adult infaunal assemblage; these were indeterminate juvenile, larval or planktonic life-stages, epibiota (e.g. mud snails), and non-marine organisms (e.g. terrestrial beetles). Macrofaunal response variables included richness and abundance by species and higher taxonomic groupings.

In addition to macrofaunal richness and abundance, 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 relative resilient (EG-V). Scores were calculated based on standard international eco-group classifications (http://ambi.azti.es) where possible. 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-groups sensitivities to amphipods of known genus (Robertson et al. 2016, Robertson 2018), but defaulted to the eco-group designation used in the Berthelsen et al. (2018) study for unknown genera (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 abundance (< 6 individuals).

Multivariate representation of the macrofaunal community data used the software package Primer v7.0.13 (Clarke et al. 2014). Patterns in sample 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. Abundance data were 4th root transformed to down-weight the influence on the ordination pattern of the most dominant species or taxa. The similarity percentages procedure (SIMPER) was used to explore the main groups that characterised the nMDS site clusters, or discriminated clusters from each other. Overlay plots were used to explore relationships between multivariate biological patterns and sediment characteristics.

Extensive mudflats of the Manawatu Estuary

4.5 ASSESSMENT OF ESTUARY CONDITION

In addition to our interpretation of the data, results are assessed within the context of established or developing estuarine health metrics ('condition ratings'), drawing on approaches from New Zealand and overseas. These metrics assign different indicators to one of four 'health status' bands, colour-coded as shown in Table 3. The condition ratings in Table 3 were derived from established international (AMBI) or national (ANZECC 2000) criteria, and/or from more recent development in New Zealand of an Estuarine Trophic Index (Robertson et al. 2016a, b) and subsequent revisions (Zeldis et al. 2017). Key elements of this approach are as follows:

- **ANZECC (2000) sediment quality guidelines:** condition rating categories for trace metals and metalloids are based on ANZECC (2000) sediment quality guidelines, as described in note 1 of Table 3. The Interim Sediment Quality Guideline low (ISQG-low) and high (ISQG-high) values provided in ANZECC are thresholds that can be interpreted as reflecting the potential for possible or probable ecological effects, respectively.
- **New Zealand Estuarine 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, ORP and AMBI are described by Robertson et al. (2016b). We adopt those thresholds for present purposes, except for aRPD, for which we modified the ratings based on the US Coastal and Marine Ecological Classification Standard Catalog of Units (FGDC 2012) which provides a more comprehensive rating than that included in the ETI.

As some of the scoring categories in Table 3 are still provisional or undergoing further development or refinement (notably ORP, aRPD), they 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 (e.g. 'poor' health status should be regarded more as a relative rather than absolute rating). For present purposes, our assessment of the 3-years of data against the rating thresholds is based on site-level mean values for the different parameters.

Table 3. 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	Moderate	Poor
1. General indicators					
Mud	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD	mm	≥ 50	20 to < 50	10 to < 20	< 10
ORP (10mm)	mV	≥ 100	< 100 to -50	< -50 to -150	< -150
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 Intolerant of enrichment	1.2 to ≤ 3.3 Tolerant of slight enrichment	3.3 to ≤ 4.3 Tolerant of moderate enrichment	> 4.3 Tolerant of high enrichment
2. Trace elements					
As	mg/kg	< 10	10 - < 20	20 - < 70	≥ 70
Cd	mg/kg	< 0.75	0.75 - <1.5	1.5 - < 10	≥ 10
Cr	mg/kg	< 40	40 - <80	80 - < 370	≥ 370
Cu	mg/kg	< 32.5	32.5 - <65	65 - < 270	≥ 270
Pb	mg/kg	< 25	25 - <50	50 - < 220	≥ 220
Hg	mg/kg	< 0.075	0.075 - <0.15	0.15 - < 1	≥ 1
Ni	mg/kg	< 10.5	10.5 - <21	21 - < 52	≥ 52
Zn	mg/kg	< 100	100 - <200	200 - < 410	≥ 410

1. General indicator thresholds derived from a New Zealand Estuarine Tropic Index, with adjustments for aRPD as described in the main text. See text for further explanation of the origin or derivation of the different metrics.

2. Trace element thresholds scaled in relation to ANZECC (2000) as follows: Very good: < 0.5 x ISQG-low; Good: 0.5 x ISQG-low to < ISGQ-low; Moderate: ISQG-low to < ISQG-high; Poor: ≥ ISQG high.

5. KEY FINDINGS

5.1 GENERAL FEATURES

The sampling sites are positioned within an extensive area of uniform muddy sand tidal flats. The sites were relatively featureless, except for the conspicuous presence of mud snails (see Section 5.4.1). There were no visible biological growths (e.g. sea lettuce, microalgal mats) or other obvious symptoms that might indicate enriched or otherwise degraded conditions. No seagrass was recorded. There was very little apparent detritus or accumulation of terrestrial debris, and the sediments has a low shell content.

5.2 SEDIMENT PLATES

Mean annual sedimentation patterns were variable across the two sites and over time (Fig. 3, Appendix 3). Mean sediment accretion of ~8mm yr-1 was measured at Site B from 2017 to 2018, which was ~60% greater than the accretion at Site A over the same period. From 2018 to 2019 sediment erosion occurred at both sites, with the overall mean net change in the 2 years from 2017 to 2019 being erosion of 4-5mm at Site A and accretion of ~5mm at Site B. Combined with the considerable within-site variability among sediment plates, both sites appear reasonably dynamic in terms of the balance of sediment erosion and accretion, although the magnitude of net change is relatively small. The variability evident may in part reflect the proximity of the sites to river influences, or sand drift (water-borne or wind-blown). The results may also in part reflect the local redistribution and settling of sediments following the initial disturbance caused by plate installation. It will require a longer annual time series to be established before patterns of net change can be interpreted with greater confidence.

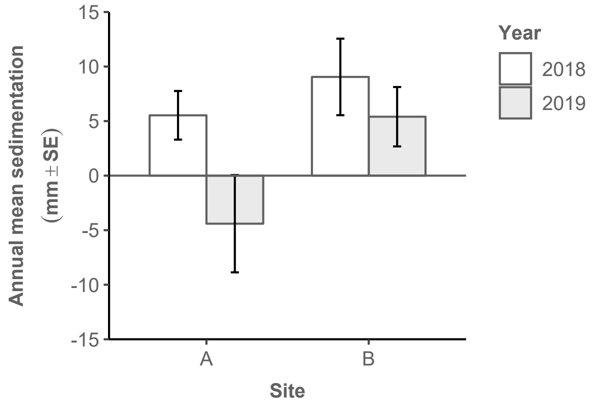


Fig. 3. Mean annual change (± SE) in sediment depth (mm) over buried plates at each of the two fine scale sites. Data for each year are expressed relative to baseline established in 2017.

5.3 SEDIMENT PHYSICAL AND CHEMICAL CHARACTERISTICS

A summary of the composite sediment sample data is provided in Table 4a and 4b (see Appendix 2 for raw data from the laboratory).

5.3.1 SEDIMENT GRAIN SIZE

Laboratory analyses revealed that the sand fraction was dominant at both sites (Fig. 4a, Table 4a). On a year-to-year basis, sediments at Site B had a slightly greater mud component that Site A, but there appears to have been a gradual increase in the mud component over the three survey years. For example, a mean mud content of ~23% in 2017 at Site B had increased to over 37% in 2019 (Fig. 4b). This change possibly reflects increased deposition of fine sediment from the Manawatu River. However, longer-term monitoring and further assessment will be needed

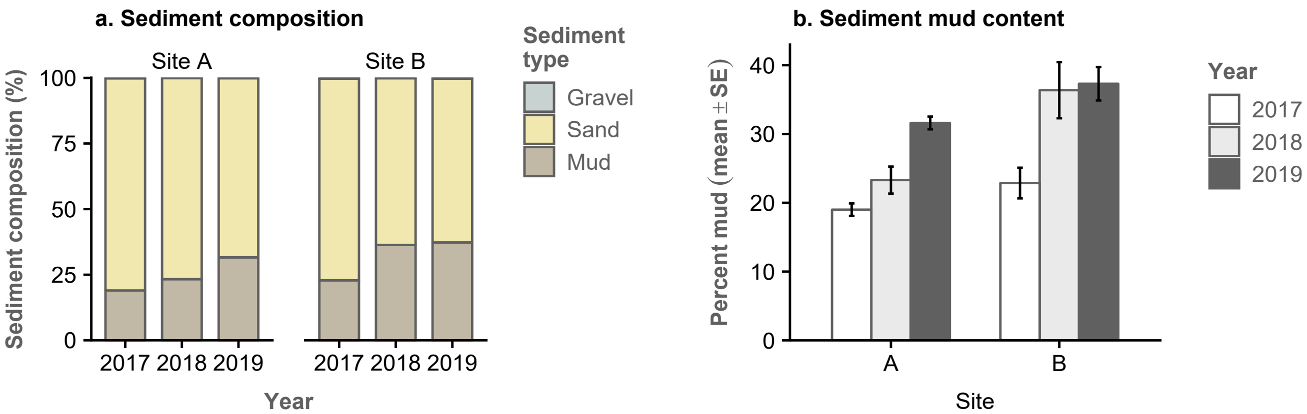


Fig. 4. Sediment particle grain size analysis results for the two fine scale sites over the three surveys, showing (a) Site-averaged percentage composition of mud (<63µm), sand (<2mm to ≥63µm) and gravel (≥2mm), and (b) Sediment mud content (mean ± SE).

Table 4a. Sediment grain size and enrichment indicator results for samples composited within each of the three zones (X-Z), for each of two sites and three surveys. Note aRPD range based on replicates within each zone indicated (n=3 - 4).

Site	Zone	Year	Mud %	Sand %	Gravel %	TOC %	TN mg/kg	TP mg/kg	aRPD mm	ORP 10mm mV	ORP 30mm mV	ORP 50mm mV	ORP 70mm mV	ORP 100mm mV
A	X	2017	19.8	80.1	0.1	0.32	<500	380	20-20	-	-	-	-	-
	Y		20	79.8	0.2	0.29	<500	370	20-20	-	-	-	-	-
	Z		17.2	82.6	0.2	0.28	<500	350	20-20	-	-	-	-	-
B	X	2017	26.9	72.7	0.4	0.28	<500	380	20-20	-	-	-	-	-
	Y		22.5	77.3	0.2	0.26	<500	380	20-20	-	-	-	-	-
	Z		19.2	80.6	0.2	0.23	<500	350	20-20	-	-	-	-	-
A	X	2018	26.7	73.3	<0.1	0.3	500	380	40-40	-68	-76	-73	-	-89
	Y		23.3	76.6	<0.1	0.24	<500	360	40-40	-	-	-	-	-
	Z		19.9	80.1	<0.1	0.21	<500	330	40-40	-	-	-	-	-
B	X	2018	44.1	55.7	0.1	0.39	500	420	25-25	-4	-119	-127	-	-102
	Y		34.8	65.1	<0.1	0.34	<500	390	25-25	-	-	-	-	-
	Z		30.2	69.7	<0.1	0.27	<500	360	25-25	-	-	-	-	-
A	X	2019	33.3	66.6	0.1	0.35	<500	430	27-30	58	0	-82	-115	-104
	Y		31.4	68.4	0.1	0.32	<500	400	20-27	35	2	-43	-101	-98
	Z		30.1	69.8	<0.1	0.34	<500	400	20-30	41	21	-130	-146	-103
B	X	2019	41.3	58.2	0.5	0.42	<500	450	16-18	77	-96	-104	-132	-125
	Y		37.7	62.2	0.1	0.4	<500	410	15-22	-3	-118	-112	-90	-91
	Z		32.9	66.8	0.3	0.29	<500	380	15-20	-78	-96	-70	-185	-84

to confirm whether the apparent trend is ongoing and directional (e.g. due to changed catchment sediment loads) or reflects natural temporal variation in the balance between the factors that influence the nature and extent of fine sediment deposition.

5.3.2 Total organic carbon, nutrients and trace contaminants

Total organic carbon (TOC) values were relatively low and correlated with sediment grain size, with TOC generally being slightly higher in muddier sediments (Table 4a). Total nitrogen (TN) levels were at, or less than, method detection limits at all sites, and total phosphorous (TP) concentrations were low and similar among sites and years. Trace metal and metalloid concentrations were low at all sites, and considerably less than ANZECC (2000) ISQG-low values with the single exception of mercury (Hg). The concentration of Hg was at, or less than, method detection limits except for one of the composite samples from Site A in 2019, for which the concentration of 0.31 mg/kg was twice the ISQG-low value. The reason for this result is unknown, but it is clearly an aberration given that none of the other metals in that sample had elevated concentrations.

5.3.3 REDOX STATUS

No signs of excessive sediment enrichment were evident. The aRPD transition between brown oxic surface sediments and deeper black sediments (indicating reduced oxygenation) typically occurred at ~20-30mm sediment depth (Fig. 5, Fig. 6, Table 4a). The aRPD was shallower at Site B, which likely reflects the muddier particle grain size at that site, meaning there is less capacity for oxygen diffusion into the sediment matrix compared with better-flushed sandier sediments. The recorded aRPD was deepest in 2018 at Site A (40mm); however, not too much weight should be placed on spatial and temporal changes of this magnitude, given that the measure is reasonably subjective and there is likely to be inter-observer variation. Of most importance is that there is no evidence of the aRPD occurring at, or close to (i.e. within a few millimeters of), the sediment surface, as would occur under highly depositional and enriched conditions.

ORP profiles across sediment depth are shown in Fig. 7 for 2019 only. Of most interest is not the absolute ORP values, as these can change according to sediment mineralogy, but the occurrence of a rapid change in ORP from relatively positive to relatively negative measurements across a small change in sediment depth. This point reflects the transition from oxic to reduced sediments and should correspond with

Table 4b. Sediment trace metal and metalloid results for samples composited within each of the three zones (X-Z), for each of two sites and three surveys.

Site	Zone	Year	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	X	2017	3.6	0.019	11.0	5.0	0.02	9.0	5.6	33
	Y		3.3	0.019	10.3	4.5	0.06	8.6	5.4	32
	Z		3.4	0.017	10.2	4.6	0.02	8.7	5.4	32
B	X	2017	3.2	0.019	10.2	4.6	0.02	9.0	5.6	34
	Y		3.1	0.023	9.9	4.5	0.02	8.7	5.4	33
	Z		2.9	0.017	9.3	4.4	0.02	8.4	5.1	31
A	X	2018	3.4	0.014	10.9	4.2	<0.02	8.4	5.9	33
	Y		3.3	0.016	10.3	4.1	0.02	8.3	5.4	31
	Z		3.2	0.012	9.7	4.0	<0.02	8.0	4.9	36
B	X	2018	3.2	0.017	11.4	4.7	0.03	8.9	6.1	35
	Y		2.9	0.016	10.3	4.0	<0.02	8.5	5.3	33
	Z		2.5	0.015	9.7	4.1	0.02	8.3	5.1	33
A	X	2019	4.1	0.018	12.4	4.9	0.31	10.2	6.1	42
	Y		3.7	0.014	11.6	4.6	0.02	9.6	5.8	40
	Z		3.5	0.016	11.1	4.7	0.02	9.9	5.9	40
B	X	2019	3.6	0.021	11.3	5.4	0.03	10.2	6.7	45
	Y		3.2	0.02	11.8	5.3	0.03	10.4	6.4	44
	Z		3.4	0.018	10.8	4.6	0.02	9.5	5.6	41
	ANZECC ISQG-low		20	1.5	80	65	0.15	21	50	200
	ANZECC ISQG-high		70	10	370	270	1	52	220	410

Fig. 5. Example sediment cores from each of the two Manawatu fine scale sites in 2019.

the visual transition in aRPD. For some of the ORP profiles in Fig. 7, this correspondence is quite clear, notably for Sites B (zones X and Y) and Site A-Z to a lesser extent. For Sites A-X and A-Y the ORP transition across depth appears quite gradual, whereas the aRPD was reasonably well-defined (see photo in Fig. 5). The only core for which ORP failed to show a clear profile was Site B-Z. This result likely reflects the occurrence of deeper oxic zones, such as caused by the mixing of surface and deeper sediments by bioturbation or irrigation of worm tubes. Deeper pockets of brown sediment can be seen in some of the core photographs in Fig. 5, and it is a matter of chance whether the ORP probe encounters these areas.

Overall, unlike the core-to-core variability and inconsistency between aRPD and ORP that has been described in some studies (e.g. Forrest & Stevens 2019b), the 2019 data for Manawatu Estuary show a reasonable correspondence between the two measures. Nonetheless, there are a range of potential methodological limitations with ORP assessment that need to be further evaluated from a national perspective, to better understand its general usefulness as an indicator, especially given that measuring ORP greatly adds to field time/cost (Forrest & Stevens 2019a).

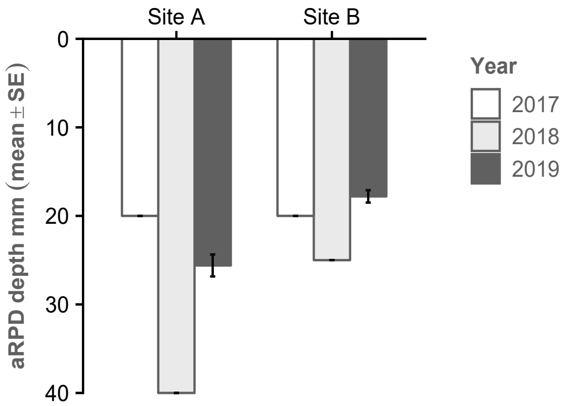
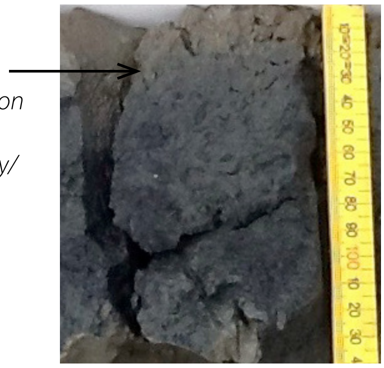


Fig. 6. Depth (mean ± SE) of apparent redox potential discontinuity (aRPD) for each of the two sites across the three surveys.

The aRPD is the transition depth between brown surface and deeper grey/ black sediments.



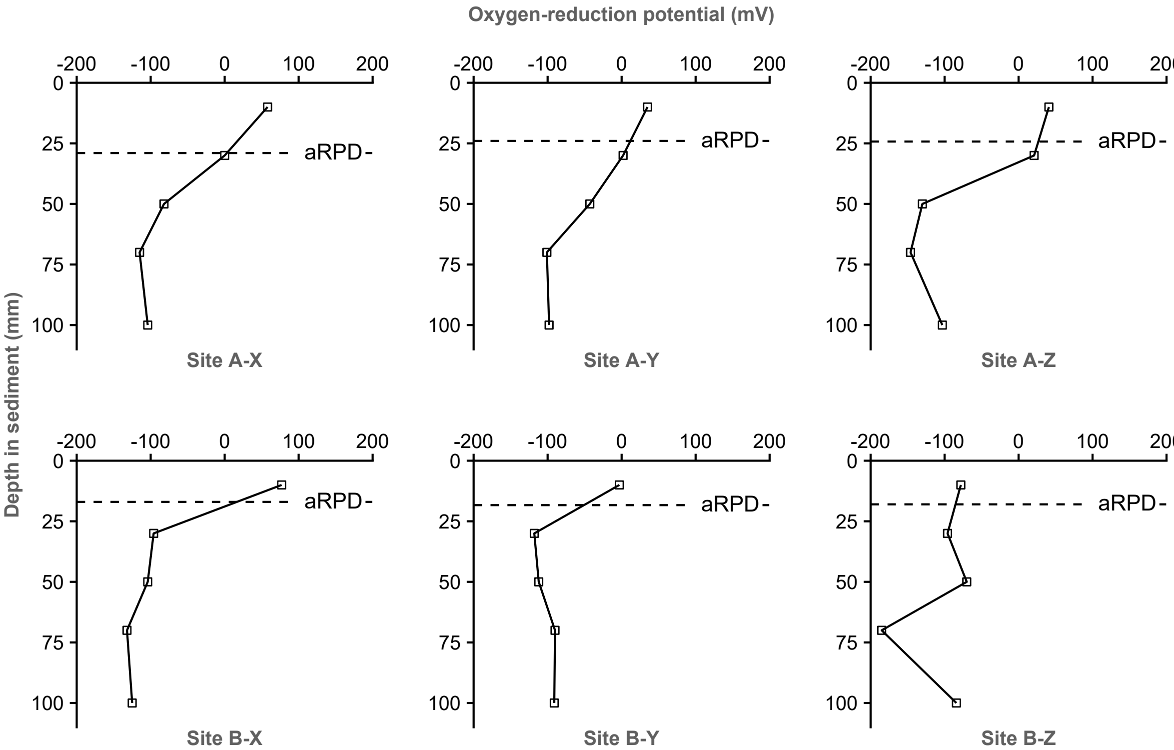


Fig. 7. Oxidation-reduction potential (ORP) profiles for three cores taken from each of the two sites in 2019, showing associated aRPD depth.

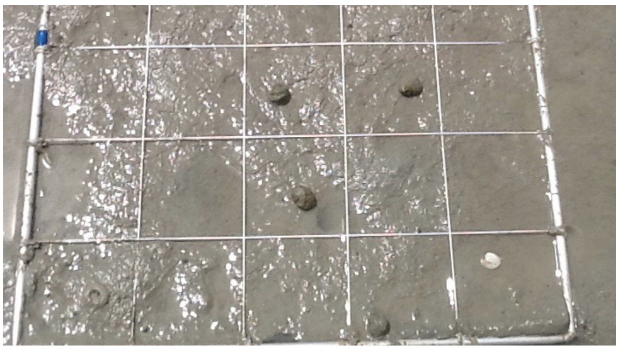
Table 5. SACFOR scores for epibiota for the two sites and three surveys, based on the scale in Table 2.

Species	Description	Year	Site A	Site B
Amphibola crenata	Pulmonate mud snail, endemic to NZ. Common on intertidal mud and sand sediments. A detritus or deposit feeder that extracts bacteria, diatoms and decomposing matter from the surface.	2017	F	C
		2018	R	C
		2019	O	C
Potamopyrgus estuarinus	Small estuarine snail, endemic to NZ. Requires brackish conditions for survival. Feeds on decomposing animal and plant matter, bacteria, and algae. Tolerant of muddy sediments and organic enrichment.	2017	A	A
		2018	A	A
		2019	S	S

5.4 EPIBIOTA AND MACROINVERTEBRATE INFAUNA

5.4.1 Conspicuous epibiota

Results from the site-level visual assessment of conspicuous epibiota in 2019 revealed no species other than mud snails (*Amphibola crenata*) and small brackish-water estuarine snails (*Potamopyrgus estuarinus*), which is consistent with the earlier two surveys (Table 5). Mud snails were given a SACFOR rating in 2019 of 'occasional' at Site A (1/m^2) and 'common' at Site B (20/m^2), with estuarine snails rated as 'super abundant' at both sites (>1000/m^2). Other than these two species, the only evidence of epibiota in 2019 was reflected in the presence of crab holes, most likely made by the stalk-eyed mud crab *Hemiplax hirtipes*. SACFOR ratings differ to some extent from the earlier surveys, but the differences are not dramatic, and such changes are not surprising given the considerable patchiness and variability that can occur in epibiota and their prevalence. For this reason alone, we regard epibiota to be of limited utility as a quantitative fine-scale indicator. Hence, we suggest that the SACFOR approach used here provides an appropriate level of resolution that is suitable for the purpose of broadly characterising the surface-dwelling species at each fine-scale site.



Epibiota were sparse across much of the Manawatu Estuary, except for mud-snails (visible here) and small estuarine snails

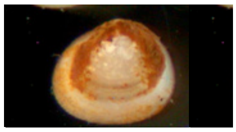
5.4.2 Macrofauna cores

Raw macrofaunal data are given in Appendix 4. The macrofaunal assemblages at the two sites were relatively impoverished, with only 17 taxa in total recorded from core samples, comprising 14 infaunal species used in the macrofaunal analysis below, juvenile nereid ragworms of uncertain taxonomic status (likely reflecting recent recruitment), and the two surface-dwelling estuarine snails that comprised the epibiota described above. Background information on the six most common sediment-dwelling macrofaunal species is given in Table 6.

Species richness among cores ranged from 4-8 at Site A and 3-7 at Site B, resulting in very low mean values (Fig. 8a). Abundances were relatively high (Fig. 8b); however, this result was attributable to the dominance of a freshwater-tolerant tube-building corophioid amphipod (*Paracorophium* sp. 1), which is probably the same species previously reported for the Whanganui River estuary as *Paracorophium lucasi*. The reduced abundance apparent at Site B in 2018 reflects lower densities of *Paracorophium* in that year.

At least seven of the 10 cores collected from each site and year met operational criteria for AMBI application. The mean AMBI values are indicative of a moderately disturbed environment, with little variation in scores within and among sites and over time (Fig. 8c). The high similarity and small core-to-core variance reflects the strong influence on the AMBI score of the numerically dominant *Paracorophium* sp. 1. Nonetheless, the taxa present span EG I, representing species considered indicative of a relatively healthy state, to hardy EG V species (Fig. 9). Other than *Paracorophium* noted above (EG IV), the most commonly occurring of the sensitive to moderately sensitive species were an unnamed amphipod (Amphipod sp. 1) and the freshwater-tolerant ragworm *Nicon aestuariensis*.

Table 6. Description of five sediment-dwelling species that were consistently the most abundant across sites and surveys. For the amphipods, the images are not of the particular species described, but show closely related species in the same group

Main group	Species	Description	Image
Amphipoda	*Paracorophium* sp. 1	Amphipods are shrimp-like crustaceans. 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.	
Amphipoda	Amphipoda sp. 1	Amphipods are shrimp-like crustaceans. This is an unknown species with a laterally compressed body.	
Bivalvia	*Arthritica* sp. 1	A small sedentary deposit feeding bivalve that lives buried in the mud. Toleant of muddy sediments and moderate levels of organic enrichment.	
Decapoda	*Hemiplax hirtipes*	The stalk-eyed mud crab is endemic to NZ and prefers wet areas at the mid to low water level. A deposit feeder that makes extensive burrows in the mud. Previously known as *Macrophthalmus hirtipes*.	
Polychaeta	*Nicon aestuariensis*	A nereid (ragworm) that is tolerant of freshwater and is a surface deposit feeding omnivore. Can live in sediments with a moderate mud content.	

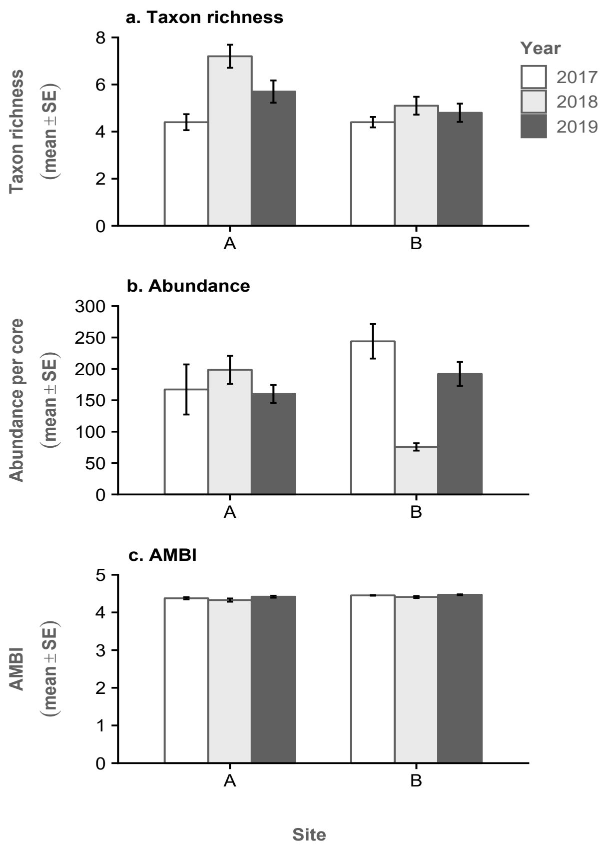


Fig. 8. Patterns (mean ± SE) in: (a) Taxon richness, (n=10); (b) Abundance (n=10); and (c) AMBI scores (n=6-10) for each of the two sites across the three surveys.

Resilient species more able to cope with disturbance included the small bivalve *Arthritica* sp. 1 and the polychaete *Scolecolepides benhami* (both EG IV), with the most hardy being the stalked-eyed mud crab *Hemiplax hirtipes* (EG V). Despite these more resilient species being present, species often associated with highly enriched or otherwise degraded conditions, such as capitellid polychaete worms (e.g. species of *Capitella* in EG IV), were not recorded in any of the surveys. No cockles or pipi were recorded in 2019, unlike in the two previous surveys. However, densities in the early surveys were generally low, hence such species could have been missed in 2019 due to chance sampling variation.

General patterns in the composition of the main taxonomic groups across sites are shown in Fig. 10. In total the species present represented eight main taxonomic groups, the main ones being bivalves, polychaete worms and amphipods. However, none of these groups had many associated species due to the generally species-poor nature of the estuary (Fig. 10a). The representation of abundances among the main groups was overwhelmed by the dominance of amphipods (Fig. 10b), due primarily to the corophioid species noted above.

Overall, the combination of low species richness, high abundance of disturbance-tolerant corophioid amphipods, and other species that characterise freshwater-dominated estuaries (e.g. *Nicon*

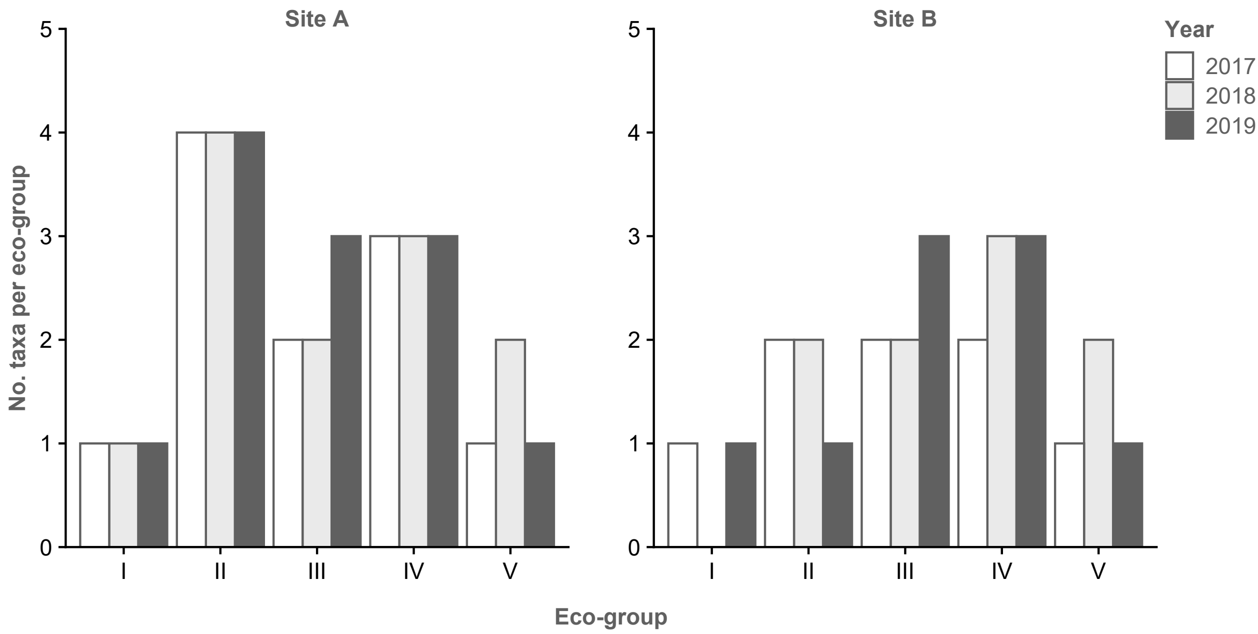


Fig. 9. Site-level data showing number of taxa within each of five eco-groups ranging from relatively sensitive (EG-I) to relative resilient (EG-V) taxa for each of the two sites across the three surveys.

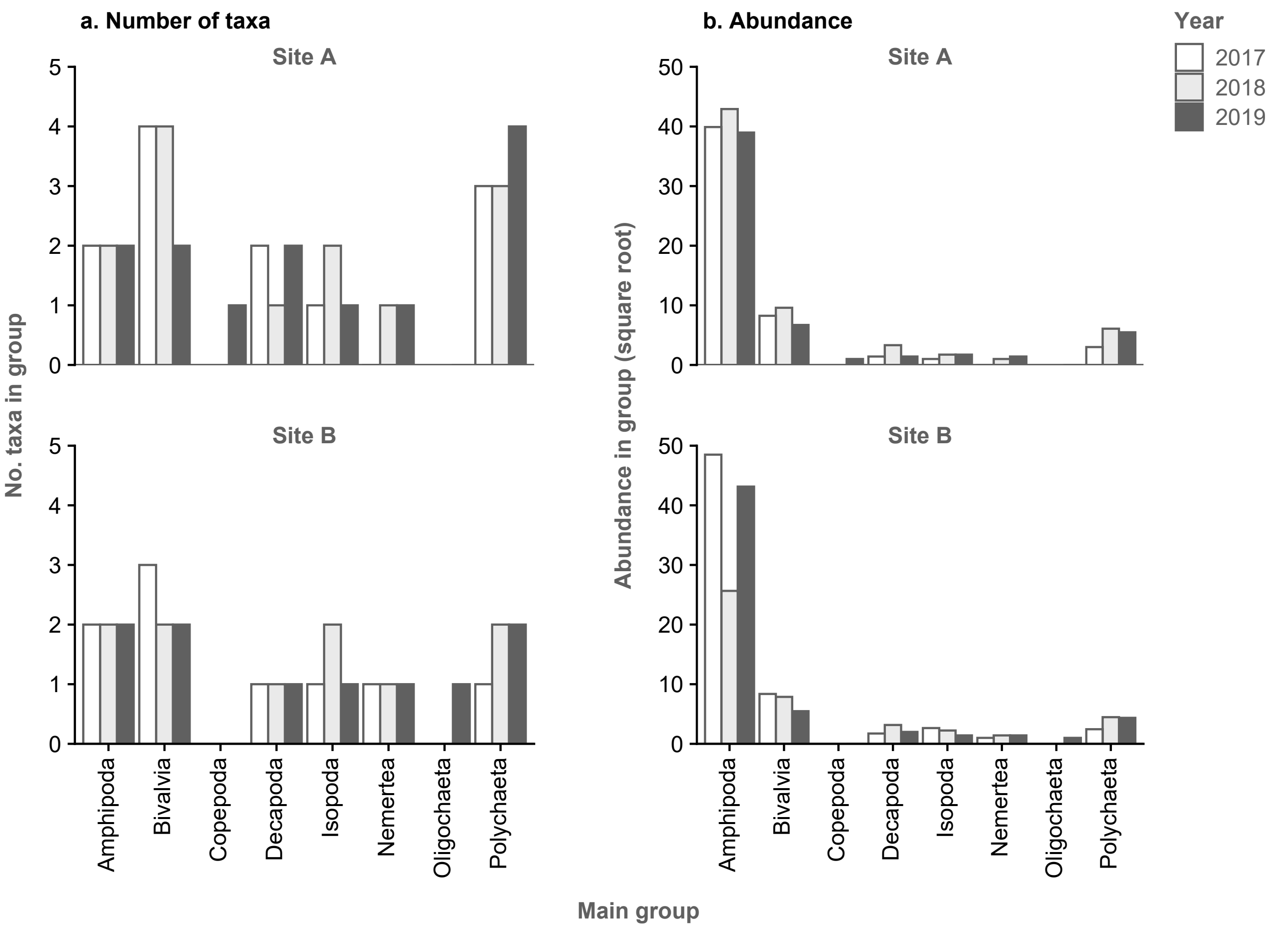


Fig. 10. Site-level data showing the contribution of main taxonomic groups to richness and abundance values for each of the two sites across the three surveys. Note that the abundance scale has been square root transformed so that the less dominant groups are displayed (raw data are in Appendix 4).

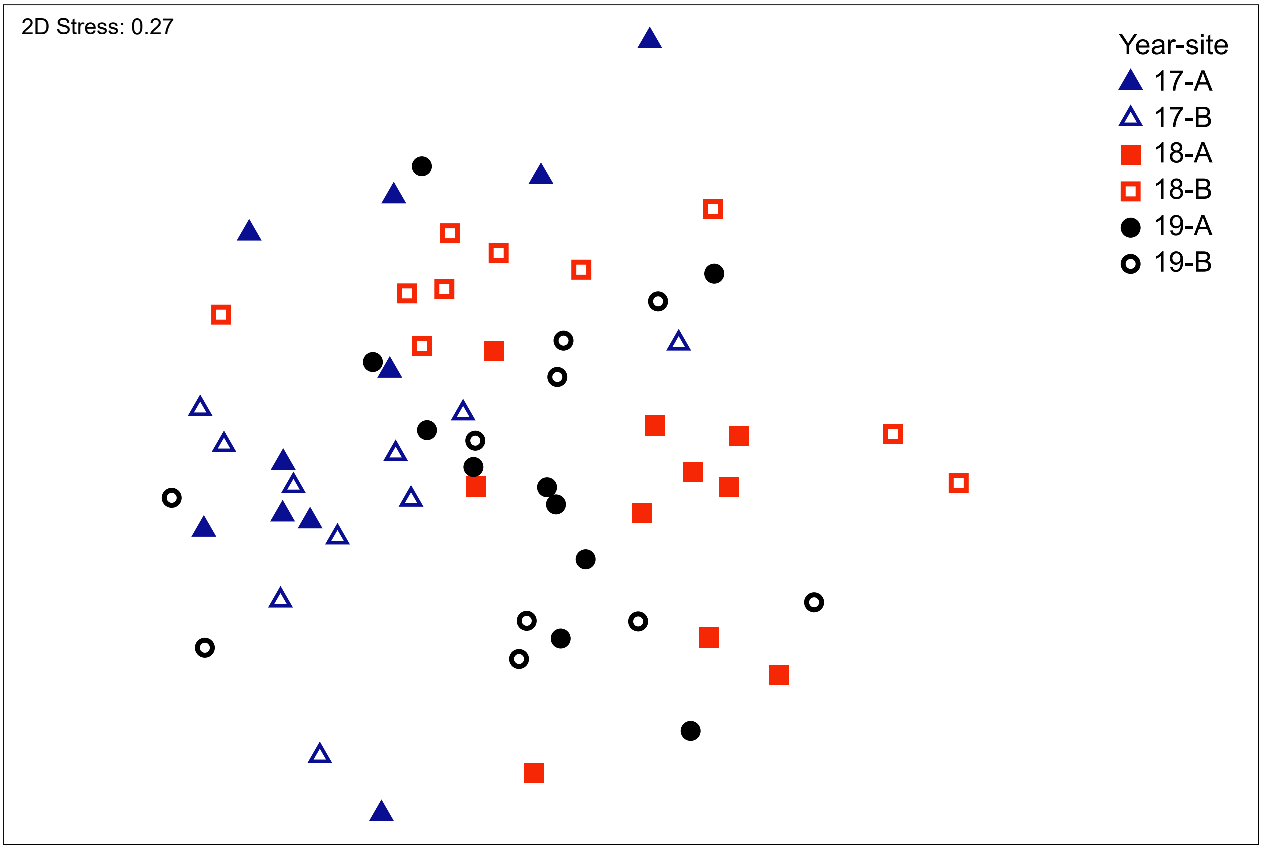


Fig. 11. Non-metric MDC ordination of core samples based on a Bray-Curtis similarity matrix of the composition of main macrofaunal taxa for each of the two sites across the three surveys.

A fourth-root transformation was applied to the data in order that the less abundant taxa had an influence on the ordination pattern. Even then, however, the interspersed nature of the core samples from different sites and years reflects a high similarity of samples and sites in terms of macrofaunal composition (see text).

aestuariensis in the infauna, *Potamopyrgus estuarinus* in the epibiota), suggests that the macrofauna at both sites is exposed to reasonably harsh physical conditions. The major contributing factor is likely to be the effect of brackish (low-salinity) water inundating the tidal flats each day, reflecting mixing of Manawatu River water with incoming tidal seawater.

In order to further explore the differences and similarities among sites and surveys in terms of the macrofaunal assemblage, the core-level nMDS ordination in Fig. 11 attempts to place samples of similar composition close to each other in a 2-dimensional biplot, with less similar samples being further apart.

In this instance, the cluster pattern is somewhat arbitrary, with core samples from the two sites and different years interspersed among each other. This pattern reflects that there is little to differentiate sites and years in terms of the composition of the sediment-dwelling assemblage. The more common species described above and in Table 5 occur similarly across all sites, with only minor core-to-core variation.

In fact, when site-averaged abundance data are analysed (i.e. cores are aggregated across sites), Bray-Curtis similarity values in pair-wise comparisons of each year-site combination are all >74% and in most cases >80%, which is remarkably high for a macrofaunal data set. Moreover, vector overlays of the measured sediment quality variables showed very low correlations with the species ordination pattern. A possible explanation for these results is that the nature of the physical environment (especially low-salinity water) restricts the species assemblage to a limited well-adapted suite, for which spatial and temporal changes in composition are minimal due to a relatively uniform physical habitat; i.e. extensive flats of muddy sand. Accordingly, any compositional differences among sites tend to be reflected in the uncommon species (see Appendix 4), for which sampling variation likely explains presences and absences, rather than any important environmental changes.

Table 7. Condition scores of ecological health for key indicators based on Table 3 criteria and ratings, for each of the two sites across the three surveys.

Data are mean values from the surface to 20mm depth, ORP measured at 10mm.

Site	Year	AMBI	Mud	TOC	TN	aRPD	ORP	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
		na	%	%	mg/kg	mm	mV	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
A	2017	4.33	19	0.3	< 0	20	-	3.4	0.018	10.5	4.7	0.04	8.8	5.5	32.3
	2018	4.32	23.3	0.25	0*	40	-68	3.3	0.014	10.3	4.1	0.01*	8.2	5.4	33.3
	2019	4.39	31.6	0.34	< 500	26	45	3.8	0.016	11.7	4.7	0.12	9.9	5.9	40.7
B	2017	4.45	22.9	0.26	< 0	20	-	3.1	0.02	9.8	4.5	0.02	8.7	5.4	32.7
	2018	4.41	36.4	0.33	0*	25	-4	2.9	0.016	10.5	4.3	0.02*	8.6	5.5	33.7
	2019	4.46	37.3	0.37	< 500	18	-1	3.4	0.02	11.3	5.1	0.03	10	6.2	43.3

** Sample mean includes values below lab detection limits*

< All values below lab detection limit

Very Good | Good | Moderate | Poor

5.5 INTERPRETATION OF ECOLOGICAL HEALTH AGAINST CONDITION RATINGS

Table 7 summarises the ecological condition scores for key indicators, based on the criteria and ratings in Table 3. Based on these coarse categories, AMBI scores were rated 'poor' in all years. There have been few changes in condition over the three survey years, with the most obvious being the increased sediment mud content at both sites moving the mud rating into the 'poor' category. Similarly, in two other instances the rating declined by one category, reflecting increased negative values of ORP at Site B in 2018, and a shallower aRPD depth at Site B in 2019. However, as discussed in the preceding text, these apparent changes have not been associated with measurable ecological responses, and they may reflect the range of physico-chemical conditions that naturally occur. Nonetheless, given that increased fine-sediment inputs to estuaries are one of main drivers of ecological decline nationally, it would be advisable to continue monitoring in the Manawatu Estuary to determine whether the temporal changes observed are ongoing and, simultaneously, to consider possible causes (e.g. increased sediment inputs from land).

6. SYNTHESIS AND RECOMMENDATIONS

6.1 SYNTHESIS OF KEY FINDINGS

This report has described the findings of three consecutive annual surveys conducted at two sites in the Manawatu Estuary, largely following 'fine-scale' survey methods described in a National Estuary Monitoring Protocol. By comparison with the first survey conducted in January 2017, there has been an increase in sediment mud content at the two fine-scale sites, with highest levels recorded in 2019. This change was particularly evident at upstream Site B, where net sediment accretion has been measured by simultaneous monitoring of the depth of buried sediment plates. The reasons for the increased mud content are unclear, but it is not associated with any measurable change in the sediment-dwelling macrofaunal assemblage. Although the sediment-dwelling infaunal (macrofaunal) assemblage was species-poor, it had relatively high abundances of a tube-building corophioid amphipod, along with a limited suite of subdominant species that were similar among sites and surveys. Similarly, sediment quality indicators such as nutrients and trace metals occurred at very low concentrations that would not be associated with adverse ecological effects.

No signs of excessive enrichment were evident, and the depth of the apparent redox potential discontinuity (aRPD) was reasonably similar across the two survey years, and not unexpected given the mud content of the estuarine sediments. Importantly, there was no evidence of the aRPD occurring at, or close to, the sediment surface, as would occur under highly depositional and enriched conditions. Depth profiles of oxidation-reduction potential (ORP) in 2019 corresponded reasonably well with aRPD depth. ORP measurements are not currently a formal part of the NEMP methods, and further work is needed both regionally and nationally to determine the efficacy of ORP for routine monitoring purposes. Epibiota (surface-dwelling animals and seaweeds) were limited to two species of estuarine snail, which occurred in reasonably high abundances. The semi-quantitative SACFOR approach used here is considered more appropriate for the assessment of epibiota than the quantitative quadrat sampling specified in the NEMP.

6.2 RECOMMENDATIONS AND BROADER CONSIDERATIONS

Due to the very short monitoring record (three surveys in three years) it is too early to infer trends based on the available data. Nonetheless, given that increased fine-sediment inputs to estuaries are a key driver of estuarine health, it would be advisable to continue with monitoring in the Manawatu Estuary. Such monitoring will help to determine whether the temporal changes observed are ongoing and directional, or if they are within the limits of natural change that occurs in this system; for example, due to the dynamic nature of environmental drivers such as river flow variation.

The following recommendations are made:

1. At this stage additional fine scale surveys for Manawatu Estuary are not scheduled, but it is typical for many councils to repeat such surveys every five years after a baseline has been established (typically a three-year baseline as described here). Given the cost and effort of a full fine scale survey, the most affordable and practical option to keep track of the sediment mud issue would be to conduct sediment plate monitoring annually (which is typical for this method anyway), and to collect sediment samples at the same time for grain size analysis.
2. Simultaneously, we recommend a desktop evaluation to consider whether there are any obvious factors that could explain the increased sediment mud content (e.g. an assessment of temporal changes in catchment sediment loads, analysis of flood patterns).
3. In terms of the NEMP fine scale methodology, the current sites are appropriate for monitoring purposes. Although they are not species-rich, the relative uniformity of habitats and the high spatio-temporal similarity of the associated macrofaunal assemblage means that any ecologically significant environmental changes are likely to be detected.
4. Although not formally part of NEMP, sediment ORP measurements should continue until such time that there are sufficient data for Manawatu estuaries (or estuaries nationally) to determine the value of undertaking this measurement as a complement to aRPD assessment.
5. In terms of epibiota monitoring, the semi-quantitative SACFOR approach used here should be continued as an alternative to the quantitative quadrat sampling specified in NEMP.
6. As a final consideration relating to the overall approach and purpose of NEMP, a recent report for MDC (Forrest & Stevens 2019a) highlights several areas of improvement to fine-scale surveys that HRC should consider. These include reviewing NEMP survey approaches to ensure they capture key ecological values of interest (e.g. rare or threatened species, shellfish resources) or, conversely, species of potential concern such as invasive plants and animal pests.
7. Additionally, if ongoing sediment plate measurements indicate further increases in sediment muddiness, there would be merit in considering a 'meso-scale' survey approach, to 'fill the gap' between broad-scale habitat mapping and the fine scale approach described here. The purpose would be to better monitor and understand the extent and consequences of habitat change due to muddy sediment, in order to guide management decisions.

7. REFERENCES CITED

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APPENDIX 1. GPS COORDINATES OF FINE-SCALE SITES (CORNERS) AND SEDIMENT PLATE SITES

Fine Scale Site Pegs

Site	Peg	NZTM East	NZTM North
A	1	1788727	5517648
A	2	1788725	5517619
A	3	1788787	5517620
A	4	1788787	5517650
B	1	1789082	5517639
B	2	1789069	5517612
B	3	1789127	5517598
B	4	1789140	5517623

Sediment Plates

Site	Plate	NZTM East	NZTM North
A	1	1788726	5517643
A	2	1788727	5517639
A	3	1788726	5517629
A	4	1788727	5517623
B	1	1789080	5517636
B	2	1789078	5517631
B	3	1789074	5517621
B	4	1789072	5517617

APPENDIX 2. R J HILL ANALYTICAL METHODS AND RESULTS FOR SEDIMENTS

Hill Laboratories
TRIED, TESTED AND TRUSTED

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Certificate of Analysis

Client:	Salt Ecology Limited	**Lab No:**	2118636 SPv1
Contact:	Leigh Stevens	**Date Received:**	02-Feb-2019
	C/- Salt Ecology Limited	**Date Reported:**	27-Feb-2019
	21 Mount Vernon Place	**Quote No:**	97107
	Washington Valley	**Order No:**	
	Nelson 7010	**Client Reference:**	Manawatu Estuary
		Submitted By:	Leigh Stevens

Sample Type: Sediment

Sample Name:		MANA A X 30-Jan-2019	MANA A Y 30-Jan-2019	MANA A Z 30-Jan-2019	MANA B X 30-Jan-2019	MANA B Y 30-Jan-2019
Lab Number:		2118636.1	2118636.2	2118636.3	2118636.4	2118636.5
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	77	75	78	73	77
Total Recoverable Phosphorus	mg/kg dry wt	430	400	400	450	410
Total Nitrogen*	g/100g dry wt	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Total Organic Carbon*	g/100g dry wt	0.35	0.32	0.34	0.42	0.40
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg						
Total Recoverable Arsenic	mg/kg dry wt	4.1	3.7	3.5	3.6	3.2
Total Recoverable Cadmium	mg/kg dry wt	0.018	0.014	0.016	0.021	0.020
Total Recoverable Chromium	mg/kg dry wt	12.4	11.6	11.1	11.3	11.8
Total Recoverable Copper	mg/kg dry wt	4.9	4.6	4.7	5.4	5.3
Total Recoverable Lead	mg/kg dry wt	6.1	5.8	5.9	6.7	6.4
Total Recoverable Mercury	mg/kg dry wt	0.31	0.02	0.02	0.03	0.03
Total Recoverable Nickel	mg/kg dry wt	10.2	9.6	9.9	10.2	10.4
Total Recoverable Zinc	mg/kg dry wt	42	40	40	45	44
3 Grain Sizes Profile						
Fraction >/= 2 mm*	g/100g dry wt	0.1	0.1	< 0.1	0.5	0.1
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	66.6	68.4	69.8	58.2	62.2
Fraction < 63 µm*	g/100g dry wt	33.3	31.4	30.1	41.3	37.7

Sample Name:		MANA B Z 30-Jan-2019				
Lab Number:		2118636.6				
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	79	-	-	-	-
Total Recoverable Phosphorus	mg/kg dry wt	380	-	-	-	-
Total Nitrogen*	g/100g dry wt	< 0.05	-	-	-	-
Total Organic Carbon*	g/100g dry wt	0.29	-	-	-	-
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg						
Total Recoverable Arsenic	mg/kg dry wt	3.4	-	-	-	-
Total Recoverable Cadmium	mg/kg dry wt	0.018	-	-	-	-
Total Recoverable Chromium	mg/kg dry wt	10.8	-	-	-	-
Total Recoverable Copper	mg/kg dry wt	4.6	-	-	-	-
Total Recoverable Lead	mg/kg dry wt	5.6	-	-	-	-
Total Recoverable Mercury	mg/kg dry wt	0.02	-	-	-	-
Total Recoverable Nickel	mg/kg dry wt	9.5	-	-	-	-
Total Recoverable Zinc	mg/kg dry wt	41	-	-	-	-

IANZ ACCREDITED LABORATORY

This Laboratory is accredited by International Accreditation New Zealand (IANZ), which represents New Zealand in the International Laboratory Accreditation Cooperation (ILAC). Through the ILAC Mutual Recognition Arrangement (ILAC-MRA) this accreditation is internationally recognised.
The tests reported herein have been performed in accordance with the terms of accreditation, with the exception of tests marked *, which are not accredited.

Sample Type: Sediment						
	Sample Name:	MANA B Z 30-Jan-2019				
	Lab Number:	2118636.6				
3 Grain Sizes Profile						
Fraction >/= 2 mm*	g/100g dry wt	0.3	-	-	-	-
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	66.8	-	-	-	-
Fraction < 63 µm*	g/100g dry wt	32.9	-	-	-	-

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 clean 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.
Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Sample No
Individual Tests			
Environmental Solids Sample Drying*	Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%.	-	1-6
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation. May contain a residual moisture content of 2-5%.	-	1-6
Dry Matter for Grainsize samples	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-6
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	1-6
Total Recoverable Phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt	1-6
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-6
Total Organic Carbon*	Acid pretreatment to remove carbonates present followed by Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-6
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg	Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level.	0.010 - 0.4 mg/kg dry wt	1-6
3 Grain Sizes Profile			
Fraction >/= 2 mm*	Wet sieving with dispersant, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-6
Fraction < 2 mm, >/= 63 µm*	Wet sieving using dispersant, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-6
Fraction < 63 µm*	Wet sieving with dispersant, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-6

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.

Ara Heron BSc (Tech)
Client Services Manager - Environmental

APPENDIX 3. SEDIMENT PLATE DATA

JANUARY 2019 DATA

date	30/1/19	30/1/19
region	Manawatu	Manawatu
estuary	Manawatu	Manawatu
site	A	B
peg1	95	81
plate1_rep1	-89	-107
plate1_rep2	-90	-111
plate1_rep3	-87	-113
plate1_mean	**-88.7**	**-110.3**
plate2_rep1	-84	-87
plate2_rep2	-83	-88
plate2_rep3	-87	-84
plate2_mean	**-84.7**	**-86.3**
peg2	60	52
plate3_rep1	-104	-87
plate3_rep2	-106	-89
plate3_rep3	-107	-87
plate3_mean	**-105.7**	**-87.7**
plate4_rep1	-76	-92
plate4_rep2	-77	-89
plate4_rep3	-76	-93
plate4_mean	**-76.3**	**-91.3**
peg3	125	108
aRPD (mm)	30	15
sedtype	Soft mud	Firm mud
mud_content (%)	31.6	37.3

SUMMARY OF MEAN ANNUALISED CHANGE BETWEEN THE JANUARY 2017 BASELINE AND THIRD SURVEY IN JANUARY 2019

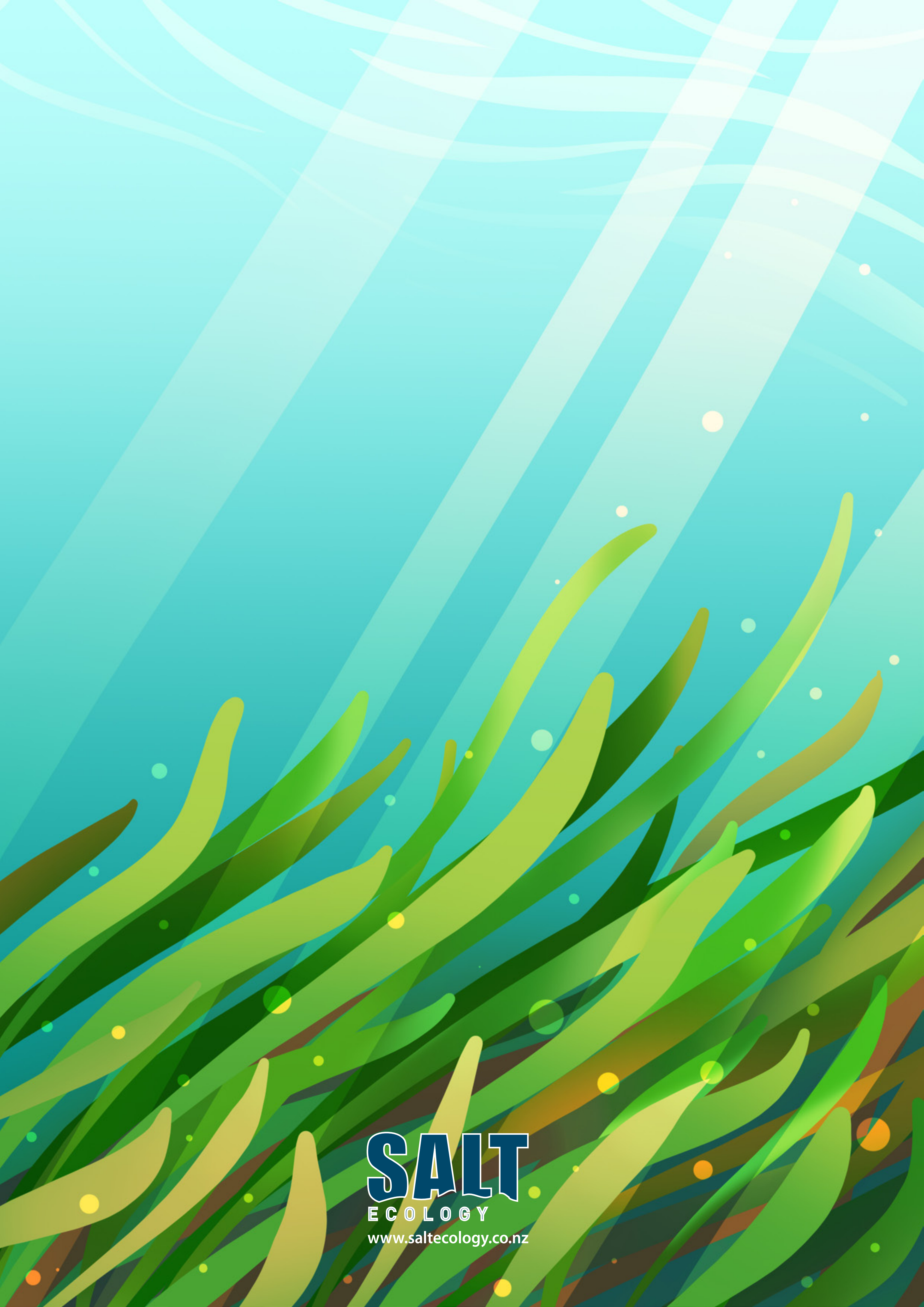
Site-plate	NZTM_E	NZTM_N	Installation depth (mm)	Depth 2018 (mm)	Depth 2019 (mm)	Annual depth change 2017-2018 (mm)	Annual depth change 2018-2019 (mm)	Total depth change 2017-2019 (mm)
A-plate1	1788726	5517643	81.0	91.0	88.7	10.1	-2.3	7.7
A-plate2	1788727	5517639	89.0	89.0	84.7	0.0	-4.3	-4.3
A-plate3	1788726	5517629	113.0	121.0	105.7	8.0	-15.3	-7.3
A-plate4	1788727	5517623	90.0	94.0	76.3	4.0	-17.6	-13.7
B-plate1	1789080	5517636	99.0	118.0	110.3	19.1	-7.6	11.3
B-plate2	1789078	5517631	79.0	85.0	86.3	6.0	1.3	7.3
B-plate3	1789074	5517621	83.0	91.0	87.7	8.0	-3.3	4.7
B-plate4	1789072	5517617	93.0	96.0	91.3	3.0	-4.7	-1.7

** Depth measurement dates: Baseline installation 2017 (31 Jan 2017), 2018 (29 Jan 2018), 2019 (30 Jan 2019)*

APPENDIX 4. MACROFAUNA CORE DATA FOR 2019, SHOWING MAIN TAXONOMIC GROUP AS WELL AS AMBI ECO-GROUP (EG) SCORES

Main group	Taxa	EG	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	B-01	B-02	B-03	B-04	B-05	B-06	B-07	B-08	B-09	B-10
Infaunal organisms																						
Bivalvia	*Cyclomactra tristis*	I	2	1	-	-	3	2	-	2	1	1	-	-	-	1	-	-	1	-	1	1
Isopoda	*Isopoda Anthuroidea*	-	-	-	-	1	-	1	-	1	-	-	-	1	-	-	-	-	-	-	-	1
Amphipoda	*Amphipoda* sp. 1	II	2	1	2	-	1	1	9	-	2	2	-	4	2	-	-	-	4	1	2	-
Copepoda	*Copepoda* sp. 1	II	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polychaeta	*Boccardia syrtis*	II	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polychaeta	*Perinereis vallata*	II	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Decapoda	*Halicarcinus whitei*	III	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Nemertea	*Nemertea sp. 1*	III	-	1	-	-	-	-	-	-	1	-	1	1	-	-	-	-	-	-	-	-
Oligochaeta	*Oligochaeta* sp. 1	III	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Polychaeta	*Nicon aestuariensis*	III	2	1	1	3	1	3	2	3	2	1	-	-	2	1	2	1	1	1	2	1
Amphipoda	*Paracorophium* sp. 1	IV	152	101	187	157	195	228	138	76	140	125	196	236	179	119	174	175	124	190	325	130
Bivalvia	*Arthritica* sp. 1	IV	-	8	5	-	2	2	9	3	3	1	1	3	-	-	1	7	-	5	-	9
Polychaeta	*Scolecolepides benhami*	IV	-	-	-	2	3	3	-	-	-	1	1	1	1	3	-	1	1	-	-	-
Decapoda	*Hemiplax hirtipes*	V	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	-	1	1	-	1
	Infaunal richness per core		4	8	4	4	6	8	5	6	6	6	4	7	4	5	3	4	6	5	4	6
	Infaunal abundance per core		158	115	195	163	205	241	159	86	149	131	199	247	184	125	177	184	132	198	330	143
Epibiota and infaunal juveniles																						
Polychaeta	Nereididae (unidentified juveniles)	-	2	2	5	3	1	4	8	2	2	4	5	4	9	5	8	5	11	9	4	9
Gastropoda	*Amphibola crenata*	III	-	-	-	-	-	-	-	-	1	-	2	1	-	-	-	1	-	2	-	-
Gastropoda	*Potamopyrgus estuarinus*	III	60	78	79	70	47	49	75	56	81	21	62	51	66	67	59	54	24	110	55	57

Cores were 130mm diameter (0.0133 m²) and 150mm deep, and sieved to 0.5mm. Epibiota and other organisms (juvenile infauna of indeterminate species) found in core samples are shown below, but only sediment-dwelling infauna recognisable as different species were used in the macrofaunal core sample analyses.



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