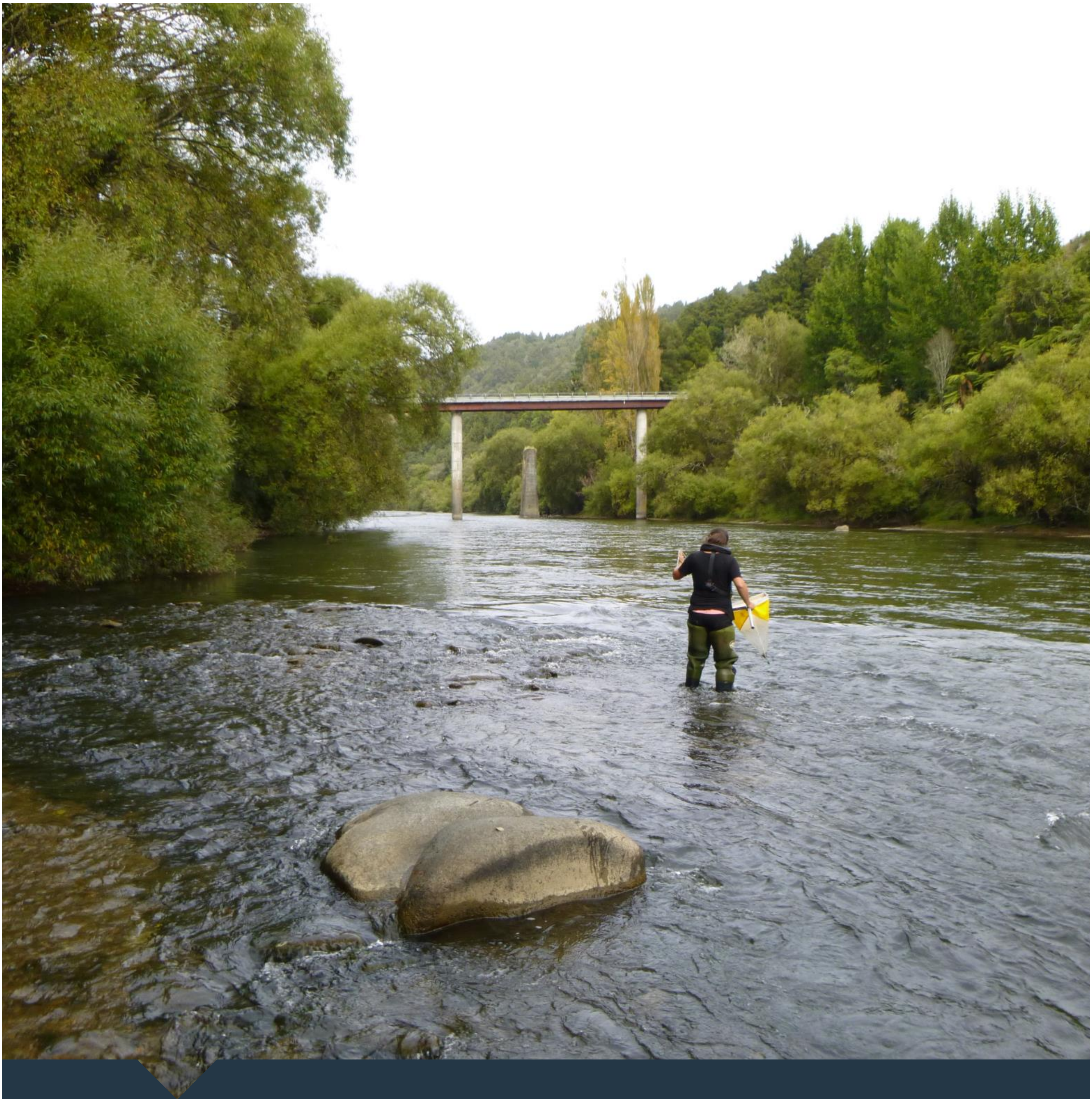


Final Scale Intertidal Monitoring of Whanganui Estuary

April 2021

horizons
REGIONAL COUNCIL

Prepared for:

Mark Mitchell
Scientist – Water Quality (Lakes and Coast)

29/04/2021
Report No. 2021/EXT/1734
ISBN 978-1-99-000964-8

Prepared by:

Barrie Forrest, Keryn Roberts and Leigh Stevens
SALT Ecology
21 Mount Vernon Place
Washington Valley
Nelson 7010

SALT
ECOLOGY

Fine Scale Intertidal Monitoring of Whanganui Estuary

Prepared for

Horizons Regional Council

March 2021

Salt Ecology
Report 065

RECOMMENDED CITATION

Forrest BM, Roberts KL, Stevens LM. 2021. Fine Scale Intertidal Monitoring of Whanganui Estuary. Salt Ecology Report 065, prepared for Horizons Regional Council, March 2021. 31p.

SALT ECOLOGY

For the People
Mō ngā tāngata

Fine Scale Intertidal Monitoring of Whanganui Estuary

Prepared by

Barrie Forrest,

Keryn Roberts

and Leigh Stevens

for

Horizons Regional Council

March 2021

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

www.saltecology.co.nz

For the environment
Mō te taiao

GLOSSARY

AMBI	AZTI Marine Biotic Index
ANZECC	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000)
ANZG	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018)
aRPD	Apparent Redox Potential Discontinuity
As	Arsenic
Cd	Cadmium
Cr	Chromium
Cu	Copper
DGV	Default Guideline Value
ETI	Estuarine Trophic Index
Hg	Mercury
HRC	Horizons Regional Council
NEMP	National Estuary Monitoring Protocol
Ni	Nickel
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

ACKNOWLEDGEMENTS

We thank Mark Mitchell (Horizons) for report review comments. Thanks also to Hayden Rabel (Salt Ecology) with R coding assistance, Sally O'Neill and team (Salt Ecology) for macrofauna sample processing, and Gary Stephenson (Coastal Marine Ecology Consultants) for taxonomic identifications.

TABLE OF CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

BACKGROUND

As part of its State of the Environment programme, Horizons Regional Council (HRC) monitors the ecological condition of significant estuaries in its region. Surveys are based on methodologies described in New Zealand's National Estuary Monitoring Protocol (NEMP), supplemented by assessment of sedimentation patterns based on a 'sediment plate' method that is widely used in New Zealand. This report represents the culmination of a baseline of three annual ecological surveys undertaken in Whanganui Estuary from January 2019 to December 2020, using the NEMP 'fine scale' approach at two monitoring sites (Sites A and B) in the lower estuary. The report describes the findings of the third and final survey undertaken on 13 December 2020. Results are compared to the two prior surveys, assessed against ecological condition rating criteria (see Table next page), and discussed in the context of future monitoring needs.

KEY FINDINGS

Sedimentation

- Sediment plate monitoring revealed highly variable sedimentation rates of ~6-83mm/yr. These values greatly exceed the provisional guideline value for New Zealand of 2mm/yr above which significant adverse impacts may occur, and were rated as 'poor' against that criterion.
- Sedimentation effects were also inferred from the ratio of estimated current to natural sedimentation rate. The estimated ratio of 3.7 (assuming 50% wetland attenuation under natural state conditions) falls into the 'fair' band (Band C) of the Estuary Trophic Index (ETI) rating scale. Band C is described in the ETI as equating to 'moderate' stress on aquatic life with potential loss of sensitive species.

Sediment quality and trophic status

- Sediments were consistently soft and typically mud-dominated. Due to mud exceeding 25% in most samples, the fine scale sites were generally scored as 'poor' against the rating criteria. The exception was December 2020, for which Site A showed a marked decline in mud content compared to January 2020. This decline was attributed to a probable scouring effect from flood flows in Whanganui River that occurred immediately before the survey was undertaken.
- Sediment quality trophic state variables (organic matter, nutrients) were at similar concentrations to those described in earlier surveys, with condition rating scores of 'good' or 'very good'. A key visual indicator of organic enrichment ('aRPD') greatly improved in December 2020 (rated 'good' or 'very good') relative to earlier surveys, consistent with the reduced sediment mud content. There were no superficial symptoms of excessive organic matter or nutrient inputs (e.g. algal growth on the sediment surface). Overall, results indicate that there are no significant eutrophication symptoms at the sites.
- Trace metal contaminant concentrations have consistently been very low relative to 'acceptable' upper thresholds set by national sediment quality guidelines. Such results indicate that there are no catchment-derived inputs of chemical contaminants that are of widespread significance.

Macrofauna

- Visible surface-dwelling animals at the sites were limited to two species of estuarine snail, one of which occurred in reasonably high abundances. The macrofauna sampled in sediment cores was species-poor, but had relatively high abundances of tube-building corophioid amphipod and a small bivalve species. Species present ranged from sensitive to highly resilient, with AMBI biotic index scores reflecting a moderate level of disturbance.
- Spatio-temporal changes in macrofauna were in part attributed to changes in sediment mud content. However, other potential explanatory variables include physical scouring effects from river flood flows, and altered salinity and sedimentation patterns. Overall, it is suggested that the fine scale sites are exposed to reasonably harsh physical conditions.

Summary of scores of ecological condition based on mean values of key indicators

Site	Year	Sed rate mm/yr	Mud %	TOC %	TN mg/kg	aRPD mm	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg	AMBI
A	Jan-19	-	31.2	0.29	< 500	24	2.8	0.014	11.5	4.9	< 0.02	8.7	4.9	33.3	4.5
	Jan-20	85.8	55.2	0.83	733	15	4.2	0.027	15.7	8.3	0.03	13.5	8.1	47.7	4.4
	Dec-20	-	7.8	0.19	< 500	86	1.8	0.019	11.2	4.2	< 0.02	9.8	5.3	35.7	4.1
B	Jan-19	-	54.9	0.73	633	13	3.8	0.026	15.2	7.6	0.02	12.7	7.5	49.7	4.4
	Jan-20	6.7	57.5	0.9	700	8	4	0.029	17.8	8.5	0.02	13.7	8.1	52.7	4.3
	Dec-20	31.0	45.9	0.87	633	38	3.1	0.03	14.6	6.7	0.02	11.5	7.5	50.3	4

< All values below lab detection limit

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

RECOMMENDATIONS

Based on the results of all three surveys, the following is recommended:

1. Monitoring frequency: The baseline survey results highlight that Whanganui Estuary is a dynamic river-dominated system, with the three surveys appearing to have captured a broad range of environmental conditions. As such, in the absence of any major changes in the catchment, there is no compelling reason to annually repeat the survey. Instead, it would be reasonable to undertake future surveys at intervals of approximately five-years, which is typical for the NEMP fine scale method once a baseline has been established.

2. Monitoring sites: The current sites appear generally appropriate 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. Although Site A appears particularly dynamic and environmentally variable, it nonetheless represents the reasonably harsh conditions that sites in river-dominated estuaries are typically exposed to. Consideration could nonetheless be given to establishing a third site further downstream, if a more stable habitat can be identified.

3. Methods and indicators: In terms of the NEMP fine scale methodology and indicators, vertical profiles of oxidation redox potential (ORP) measurements have already been trialed and discontinued. Visual assessment of aRPD provides a suitable and simple alternative for assessment of gross change in trophic status. The other well-established indicators described in this report are appropriate for long-term monitoring purposes.

4. Future-proofing and optimising monitoring: Effort has already been made to provide a reference list of named species for those most commonly occurring. It would be beneficial to complete this work and obtain agreed names for all species recorded, to future-proof the programme against a future change in taxonomic provider. Consideration could also be given to optimization of the sampling design for future surveys. The main purpose would be to consider whether sampling effort could be reduced, hence cost savings made, without compromising the ability of the programme to detect change.

1. INTRODUCTION

Monitoring the ecological condition of estuarine habitats is critical to their management. Estuary monitoring is undertaken by most councils in New Zealand as part of their State of the Environment (SOE) programmes. The most widely-used monitoring framework is that outlined in New Zealand's National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002). The NEMP is intended to provide resource managers nationally with a scientifically defensible, cost-effective and standardised approach for monitoring the ecological status of estuaries in their region. The results establish a benchmark of estuarine health in order to better understand human influences, and against which future comparisons can be made. The NEMP approach involves two main types of survey:

- Broad scale mapping of estuarine intertidal habitats. This type of monitoring is typically undertaken every 5 to 10 years.
- Fine scale monitoring of estuarine biota and sediment quality. This type of monitoring is typically conducted at intervals of 5 years after initially establishing a baseline.

One of the key additional methods that has been put in place subsequent to the NEMP being developed is 'sediment plate' monitoring. This component typically involves an annual assessment of patterns of sediment accretion and erosion in estuaries, based on changes in sediment depth over buried concrete pavers. Sediment plate monitoring stations are often established at NEMP fine scale sites, or nearby, to provide an additional explanatory variable for interpreting site-level changes.

While the Horizon region's estuaries have received little attention historically, in 2009 the Department of Conservation funded broad scale habitat mapping of the Whanganui Estuary (Stevens & Robertson 2009), and in late 2015 HRC commissioned an Ecological Vulnerability Assessment for all of the estuaries within the region to assess sediment and eutrophication risks, map dominant habitat features, and provide the Council with monitoring recommendations and priorities (Robertson & Stevens 2016). Subsequently, HRC commissioned NEMP broad scale and fine scale surveys (including sediment plate monitoring), for the Whanganui and Manawatu estuaries, along with more targeted surveys in other smaller estuaries.

Broad scale habitat mapping was undertaken in 2017 in the Whanganui Estuary (Stevens & Robertson 2017) and two of three planned baseline fine scale surveys were completed in January 2019 and January 2020 (Forrest & Stevens 2019c; Forrest et al. 2020). This report describes the methods and results of the third and final fine scale baseline survey, which was conducted in Whanganui Estuary on 13 December 2020. Results are compared with the two prior surveys and discussed in the context of estuary condition and future monitoring needs.

Fig. 1. Location of Whanganui Estuary.

2. BACKGROUND TO WHANGANUI ESTUARY

A synthesis of information on the Whanganui Estuary is provided in Stevens and Robertson (2017), which was included in the previous survey reports and is largely repeated here. The estuary is a large (353ha), shallow, generally well-flushed, macrotidal (>1.8m tidal range) river estuary located at Whanganui (Fig. 1). It has a high freshwater inflow (Mean Annual Low Flow 210m^3/s) which, when combined with the marine inflow, has a tidal influence that extends ~12km inland.

The estuary is highly modified and mostly confined within defined river channels and flood protection works, although the lower reaches have large intertidal flats. The estuary mouth is always open to the sea. The large estuary catchment (7,169km^2) is mud and sandstone dominated (71%). Land cover comprises large areas of forest (56% native, 8% exotic) and areas extensively developed (35%), especially for sheep, beef and dairy farming (Fig. 2).

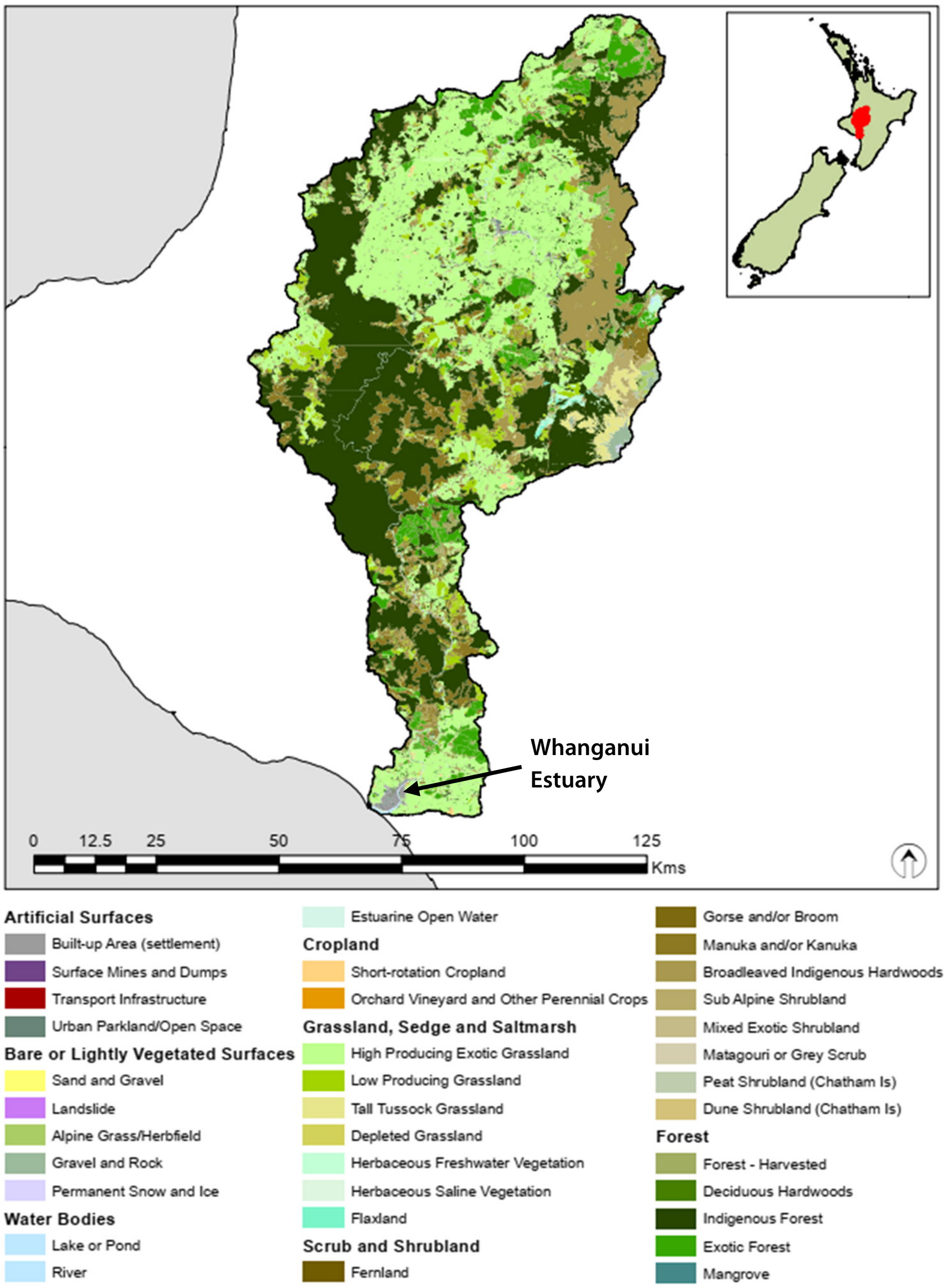


Fig. 2. Whanganui Estuary and surrounding catchment land use classifications from LCDB5 database.

The estuary is a high use area valued for its port, aesthetic appeal, swimming, boating, fishing, whitebaiting and beach access. Ecologically it is important for freshwater fish and birds. Because the natural vegetated margin is mostly lost to development, and much of the upper estuary is channelised, habitat diversity is relatively low, with very little salt marsh (0.5ha) and no seagrass. A large coastal dune system in the lower estuary supports a range of native species and is relatively intact but is under threat from exotic weeds. There has been extensive planting and development of public walkways and recreation areas along the estuary margins, which are very well utilised.

The estuary has a high nutrient load (estimated catchment N areal loading of 3,144mgN/m^2/d which exceeds the guideline for low susceptibility tidal river estuaries of ~2,000mgN/m^2/d; Robertson & Stevens 2016), but despite this the estuary has a low susceptibility to eutrophication. This is primarily because it is strongly channelised with very few poorly flushed areas, has high freshwater inflow, is strongly affected by tidal currents, and is often turbid. The presence of elevated chlorophyll-*a* concentrations at times is likely attributable to freshwater sources upstream of the estuary. Despite a high estimated sediment load (Stevens & Robertson 2017), the estuary is considered only moderately vulnerable to 'muddiness' issues due to its well-flushed nature.

3. FINE SCALE METHODS

3.1 OVERVIEW OF NEMP FINE SCALE APPROACH

Once the main habitats in an estuary have been mapped using the NEMP broad scale approach, representative areas are selected for fine scale monitoring. The NEMP advocates that fine scale monitoring is undertaken in soft sediment (sand/mud) habitat in the mid to low tidal range of priority estuaries, 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 such as the 'macrofaunal' assemblage and various 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 WHANGANUI FINE SCALE AND SEDIMENT PLATE SITE INFORMATION

The Whanganui fine scale survey involves sampling two unvegetated mud/sand sites (A & B) in the lower estuary, bordering the low tide channel of the Whanganui River (Fig. 3). The sites are ~500m apart, with Site B being the most upstream.

Site A has the same 30 x 60m dimensions recommended in the NEMP for fine scale sites, whereas Site B is constrained to dimensions of 15 x 60m to minimise the influence of cross-shore slope and associated sediment changes due to the Whanganui River.

Each of the fine scale sites has sediment plates installed along the downstream margin. In addition to providing information on patterns of sediment accretion and erosion, sediment plate monitoring aids interpretation of physical and biological changes at fine scale sites.

Fine scale site boundaries and locations of sediment plates are marked with wooden pegs, with coordinates provided 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. For the latest survey, all field sampling was undertaken on 13 December 2020.

3.3 SEDIMENT PLATES AND SAMPLING

Concrete pavers (19cm x 23cm) for sediment plate monitoring were installed at Whanganui Estuary during the first fine scale sampling on 31 January 2019. Baseline depths (from the sediment surface to each buried plate) were measured at that time. To make measurements of sediment depth during the baseline and on subsequent occasions, a 2.5m straight edge was placed over each plate position to average out any small-scale irregularities in surface topography. The depth to each plate was then measured in triplicate by vertically inserting a probe into the sediment until the plate was located. Depth was measured with a ruler to the nearest mm.

3.4 FINE SCALE SAMPLING AND BENTHIC INDICATORS

For all three surveys, each of the two fine scale sites was divided into a 3 x 4 grid of 12 plots (see Fig. 3). Fine scale sampling for sediment indicators was conducted in 10 of these plots, with Fig. 3 showing the standard numbering sequence for replicates at both sites, and the designation of zones X, Y and Z (for compositing sediment samples; see below).

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 or more years. For present purposes we have adopted these modifications as indicated in Table 1.

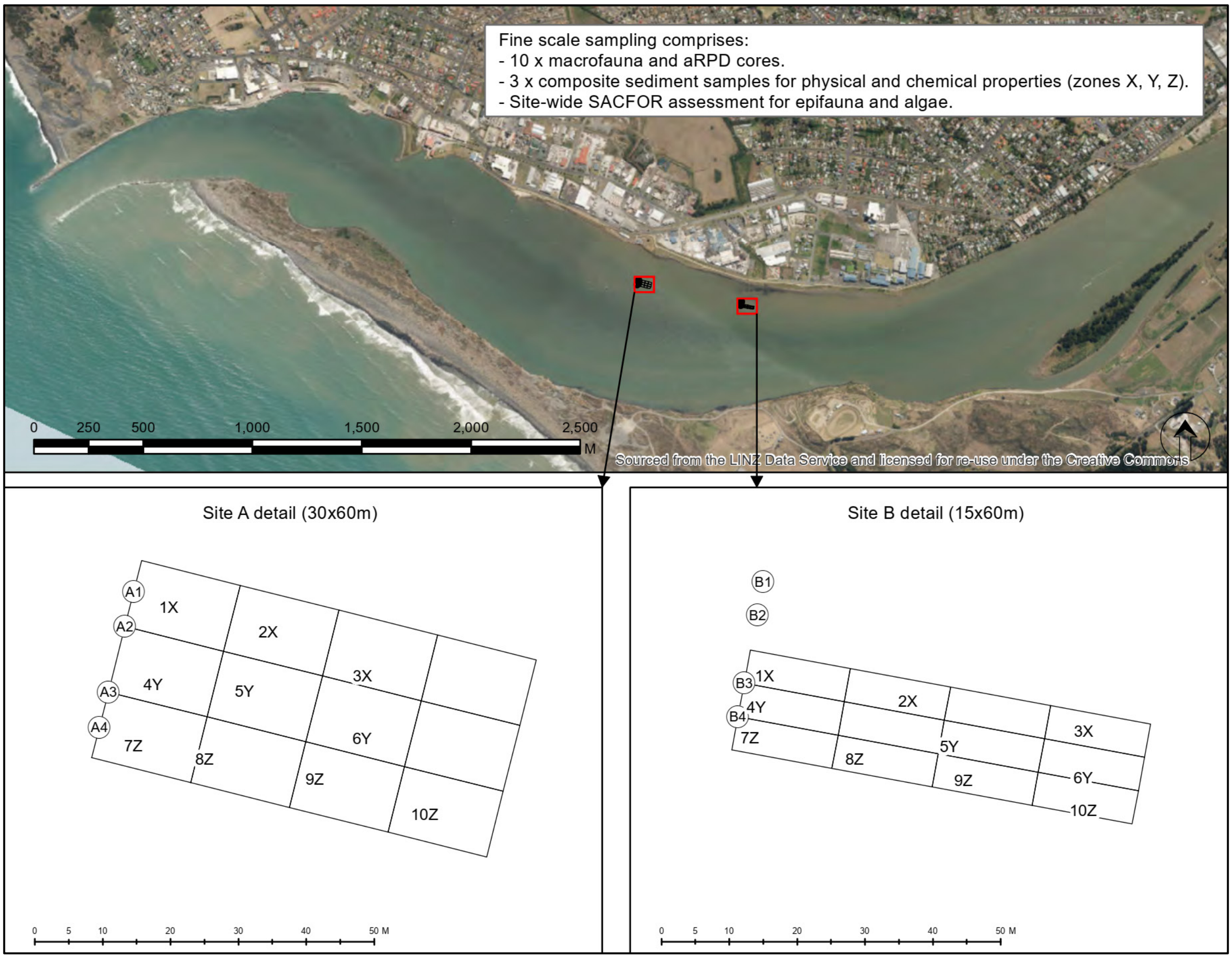


Fig. 3. Locations of the two sites in Whanganui Estuary, and schematic illustrating fine scale monitoring and sediment plate methods.

Table 1. Summary of NEMP fine scale benthic indicators, rationale for their use, and sampling method. Any meaningful departures from NEMP are described in footnotes.

NEMP benthic indicators	General rationale	Sampling method
Physical and chemical		
Sediment grain size	Indicates the relative proportion of fine-grained sediments that have accumulated.	1 x surface scrape to 20mm sediment depth, with 3 composited samples taken across the 10 plots (see note 1).
Nutrients (nitrogen and phosphorus) and organic matter	Reflects the enrichment status of the estuary and potential for algal blooms and other symptoms of enrichment.	1 x surface scrape to 20mm sediment depth, with 3 composited samples taken across the 10 plots (see note 1).
Trace metals (copper, chromium, cadmium, lead, nickel, zinc)	Common toxic contaminants generally associated with human activities.	1 x surface scrape to 20mm sediment depth, with 3 composited samples taken across the 10 plots (see notes 1, 2).
Depth of apparent redox potential discontinuity layer (aRPD)	Subjective time-integrated measure of the enrichment state of sediments according to the visual transition between oxygenated surface sediments and deeper deoxygenated black sediments. The aRPD can occur closer to the sediment surface as organic matter loading increases.	1 x 130mm diameter sediment core to 150mm deep for each of 10 plots, split vertically, with depth of aRPD recorded in the field where visible.
Biological		
Macrofauna	The abundance, composition and diversity of macrofauna, especially the infauna living with the sediment, are commonly-used indicators of estuarine health.	1 x 130mm diameter sediment core to 150mm deep (0.013m^2 sample area, 2L core volume) for each of 10 plots, sieved to 0.5mm to retain macrofauna.
Epibiota (epifauna)	Abundance, composition and diversity of epifauna are commonly-used indicators of estuarine health.	Abundance score based on ordinal SACFOR scale in Table 2 (see note 3).
Epibiota (macroalgae)	The composition and prevalence of macroalgae are indicators of nutrient enrichment.	Percent cover score based on ordinal SACFOR scale in Table 2 (see note 3).
Epibiota (microalgae)	The composition and prevalence of microalgae are indicators of nutrient enrichment.	Visual assessment of conspicuous growths based on ordinal SACFOR scale in Table 2 (see notes 3, 4).

Notes:

[1] For cost reasons, sediment quality is assessed in 3 composite samples rather than 10 discrete samples as specified in the NEMP.

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

[3] Assessment of epifauna, macroalgae and microalgae used SACFOR in favour of quadrat sampling outlined in NEMP. Quadrat sampling is subject to considerable within-site variation for epibiota that have clumped or patchy distributions.

[4] NEMP recommends taxonomic composition assessment for microalgae but this is not typically undertaken due to unavailability of expertise and lack of demonstrated utility of microalgae as a routine indicator.

Three composite sediment samples (each ~250g) were collected from sub-samples (to 20mm depth) pooled across each of zones X, Y and Z (replicates 1-3, 4-6 and 7-10, respectively; see Fig. 3). Samples were stored on ice and sent to RJ Hill Laboratories for analysis of: particle grain size in three categories (%mud <63µm, sand <2mm to ≥63µm, gravel ≥2mm); organic matter (total organic carbon, TOC); nutrients (total nitrogen, TN; total phosphorus, TP); and trace metals or metalloids (arsenic, As; cadmium, Cd; chromium, Cr; copper, Cu; mercury, Hg; lead, Pb; nickel, Ni; zinc, Zn). Details of laboratory methods and detection limits are provided in Appendix 2.

Sediment plate measurements

The apparent redox potential discontinuity (aRPD) depth (Table 1) is a subjective measure of the enrichment state of sediments according to the depth of visible transition between oxygenated surface sediments (typically brown in colour) and deeper less oxygenated sediments (typically dark grey or black in colour). The aRPD depth in all surveys was measured (to the nearest mm) after extracting a large sediment core (130mm diameter, 150mm deep) from each of the 10 plots, placing it on a tray, and splitting it vertically. Representative split cores (X1, Y4 and Z7) were also photographed. Although not part of the NEMP, the measurement of oxidation reduction potential (ORP) in vertical core profiles was trialed in January 2019 and January 2020 as a complementary method to aRPD. However, due to limitations identified, the January 2020 survey report recommended that ORP assessment be discontinued, hence it was not undertaken in December 2020.

To sample sediment-dwelling macrofauna, each of the large sediment cores used for assessment of aRPD was placed in a separate 0.5mm sieve bag, which was gently washed in seawater to remove fine sediment. The retained animals were preserved in a 75% isopropyl alcohol and 25% seawater mixture for later sorting by Salt Ecology staff and taxonomic identification by Gary Stephenson, Coastal Marine Ecology Consultants (CMEC). The types of animals present in each sample, as well as the range of different species (i.e. richness) and their abundance, are well-established indicators of ecological health in estuarine and marine soft sediments.

In addition to macrofaunal core sampling, epibiota (macroalgae, and conspicuous surface-dwelling animals nominally >5mm body size) visible on the sediment surface at each site were semi-quantitatively categorised using 'SACFOR' abundance (animals) or percentage cover (macroalgae) ratings shown in Table 2. These ratings represent a scoring scheme simplified from established monitoring methods (MNCR 1990; Blyth-Skyrme et al. 2008). Note that the ratings used in January and December 2020 differ slightly to that described in the 2019 report.

The SACFOR method is ideally suited to characterise intertidal epibiota with patchy or clumped distributions. It has been conducted 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).

Collecting sediment cores for macrofauna

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

SACFOR category	Code	Density per m²	Percent cover
Super abundant	S	> 1000	> 50
Abundant	A	100 - 999	20 - 50
Common	C	10 - 99	10 - 19
Frequent	F	2 - 9	5 - 9
Occasional	O	0.1 - 1	1 - 4
Rare	R	< 0.1	< 1

3.5 DATA RECORDING, QA/QC AND ANALYSIS

All sediment and macrofaunal samples were tracked using standard Chain of Custody forms, and results were transferred electronically to avoid transcription errors. Field measurements from the fine scale and sediment plate surveys were recorded electronically in templates that were custom-built using software available at www.fulcrumapp.com. Pre-specified constraints on data entry (e.g. with respect to data type, minimum or maximum values) ensured that the risk of erroneous data recording was minimised. Each sampling record created in Fulcrum generated a GPS position for that record (e.g. a sediment core). Field data were exported to Excel, together with data from the sediment and macrofaunal analyses.

To assess changes over the three surveys, and minimise the risk of data manipulation errors, Excel sheets for the different data types and three survey 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. Taxonomy QA cross-checks were also undertaken by sending a sample of the main species to NIWA for taxonomic identification. For all three surveys this step has enabled definitive genus and/or species names to be given to many species previously assigned with provisional names. As such, some of the macrofaunal names in this report differ to those used in the two previous survey reports.

Macrofaunal response variables included richness and abundance by species and higher taxonomic groupings. In addition, scores for the biotic health index AMBI (Borja et al. 2000) were derived. AMBI scores reflect the proportion of taxa falling into one of five eco-groups (EG) that reflect sensitivity to pollution (in particular eutrophication), ranging from relatively sensitive (EG-I) to relatively resilient (EG-V).

To meet the criteria for AMBI calculation, macrofauna data were reduced to a subset that included only adult 'infauna' (those organisms living within the sediment matrix), which involved removing surface dwelling epibiota and any juvenile organisms. AMBI scores were calculated based on standard international eco-group classifications where possible (http://ambi.azti.es). 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; Robertson et al. 2016c; Robertson 2018). Note that AMBI scores were not calculated for macrofaunal cores that did not meet operational limits defined by Borja et al. (2012), in terms of the percentage of unassigned taxa (>20%), or low sample richness (<3 taxa) or abundances (<6 individuals).

Multivariate representation of the macrofaunal community data used the software package Primer v7.0.13 (Clarke et al. 2014). Patterns in similarity as a function of macrofaunal composition and abundance were assessed using an 'unconstrained' 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. 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). Overlay vectors and bubble plots were used to visualise relationships between multivariate biological patterns and sediment quality variables.

Additionally, the Primer procedure Bio-Env was used to evaluate the suite of variables that best explained the biological ordination pattern. For all nMDS analyses, abundance data were log(x+1)-transformed to down-weight the influence on the ordination of the most dominant species or taxa, and sediment quality data were log(x+1)-transformed and normalised to a standard scale.

3.6 ASSESSMENT OF ESTUARY CONDITION

To supplement our analysis and interpretation of the data, results for all three surveys 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 rating bands, colour-coded as shown in Table 3.

Most of the condition ratings in Table 3 were derived from those described in a New Zealand Estuary Trophic Index (Robertson et al. 2016a, b), which includes purpose-developed criteria for eutrophication, and also draws on wider national and international environmental quality guidelines. Key elements of this approach are as follows:

- *New Zealand Estuary Trophic Index (ETI):* The ETI provides screening guidance for assessing where an estuary is positioned on a eutrophication gradient. While many of the constituent metrics are intended to be applied to the estuary as a whole (i.e. in a broad scale context), site-specific thresholds for %mud, TOC, TN, aRPD and AMBI are described by Robertson et al. (2016b). We adopted those thresholds for present purposes, except: (i) for %mud we adopted the refinement to the ETI thresholds described by Robertson et al. (2016c); and (ii) for aRPD we modified the ETI ratings based on the US Coastal and Marine Ecological Classification Standard Catalog of Units (FGDC 2012).

- *ANZG (2018) sediment quality guidelines*. The condition rating categories for trace metals and metalloids are benchmarked to ANZG (2018) sediment quality guidelines as described in Table 3. The Default Guideline Value (DGV) and Guideline Value-High (GV-high) specified in ANZG are thresholds that can be interpreted as reflecting the potential for 'possible' or 'probable' ecological effects, respectively. Until recently, these thresholds were referred to as ANZECC (2000) Interim Sediment Quality Guideline low (ISQG-low) and Interim Sediment Quality Guideline high (ISQG-high) values, respectively.

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

- Townsend and Lohrer (2015) propose a DGV of 2mm of sediment accumulation per year above natural deposition rates. Where unknown, natural deposition rates are conservatively assumed to be 0mm/yr. The 2mm/yr value has been used as the threshold between the 'fair' and 'poor' bands in Table 1 on the basis that exceeding the DGV is expected to result in an increased likelihood of adverse ecological effects.

- 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. 2016b). We estimate these parameters based on NIWA's estuary sediment load estimator (Hicks et al. 2019).

Note that the scoring categories described above and in Table 3 should be regarded only as a general guide to assist with interpretation of estuary condition. Accordingly, it is major spatio-temporal changes in the categories that are of most interest, rather than their subjective condition descriptors; i.e. descriptors such as 'poor' condition should be regarded more as a relative rather than absolute rating. For present purposes, our assessment of the multi-year data against the rating thresholds is based on site-level mean values for the different parameters.

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

Indicator	Unit	Very good	Good	Fair	Poor
General indicators [1]					
Sedimentation rate[a]	mm/yr	< 0.5	≥0.5 to < 1	1 to < 2	≥ 2
Mud content[b]	%	< 5	5 to < 10	10 to < 25	≥ 25
aRPD depth[c]	mm	≥ 50	20 to < 50	10 to < 20	< 10
TN[b]	mg/kg	< 250	250 to < 1000	1000 to < 2000	≥ 2000
TOC[b]	%	< 0.5	0.5 to < 1	1 to < 2	≥ 2
AMBI[b]	na	0 to 1.2	> 1.2 to 3.3	> 3.3 to 4.3	≥ 4.3
Trace elements [2]					
As	mg/kg	< 10	10 to < 20	20 to < 70	≥ 70
Cd	mg/kg	< 0.75	0.75 to <1.5	1.5 to < 10	≥ 10
Cr	mg/kg	< 40	40 to <80	80 to < 370	≥ 370
Cu	mg/kg	< 32.5	32.5 to <65	65 to < 270	≥ 270
Hg	mg/kg	< 0.075	0.075 to <0.15	0.15 to < 1	≥ 1
Ni	mg/kg	< 10.5	10.5 to <21	21 to < 52	≥ 52
Pb	mg/kg	< 25	25 to <50	50 to < 220	≥ 220
Zn	mg/kg	< 100	100 to <200	200 to < 410	≥ 410

1. Ratings derived or modified from: [a]Townsend and Lohrer (2015), [b]Robertson et al. (2016) with modification for mud content described in text, [c]FGDC (2012).

2. Trace element thresholds scaled in relation to ANZG (2018) as follows: Very good = < 0.5 x DGV; Good = 0.5 x DGV to < DGV; Fair = DGV to < GV-high; Poor = > GV-high. DGV = Default Guideline Value, GV-high = Guideline Value-high. These were formerly the ANZECC (2000) sediment quality guidelines whose exceedance roughly equates to the occurrence of 'possible' and 'probable' ecological effects, respectively.

4. KEY FINDINGS

4.1 GENERAL FEATURES OF FINE SCALE SITES

The two sampling sites are positioned within an area of uniform tidal flats, along a narrow margin between the low tide river channel and road. The sites are relatively featureless, with soft mud/sand sediments that contain very little shell material or surface-dwelling epibiota (see Section 4.4.1). In December 2020, as in the two earlier surveys, there were no conspicuous biological growths (e.g. sea lettuce, microalgal mats) or other obvious symptoms that might indicate enriched or degraded conditions. No seagrass was recorded. There were small amounts of driftwood and logs scattered across the flats or along the upper shore strand line, but there was very little accumulation of small terrestrial debris or detritus. Salt marsh and other vegetation along the estuary margin was minimal, as described by Stevens and Robertson (2017).

4.2 SEDIMENT PLATES

Sediment plate raw data are provided in Appendix 3. Fig. 4 shows the mean sediment accumulation in each year since the baseline was established, with ~83mm measured at Site A and ~6mm at Site B from January 2019 to January 2020. At the time of the December 2020 survey, the plates and pegs at Site A could not be relocated. The site had the appearance of disturbance by flooding in the Whanganui River in the two days prior to the survey, hence it is conceivable that the plates and pegs were either washed away or buried.

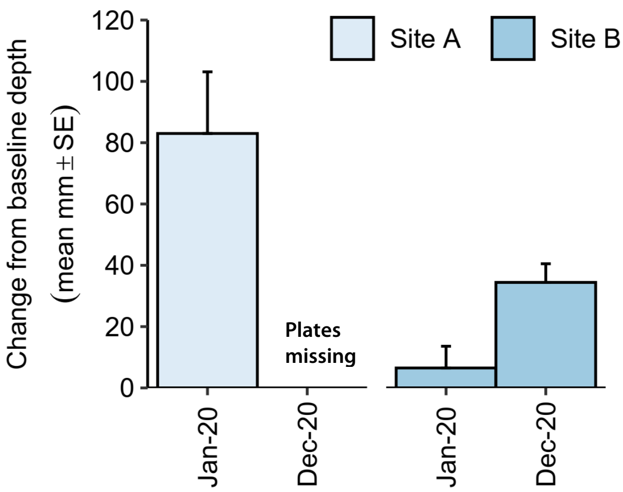


Fig. 4. Mean change (± SE) in sediment depth over buried plates, for two surveys since the baseline established January 2019.

However, Site B plates were still present and showed ~31mm of sediment deposition since January 2020. Hence, from the records available, and from annualized data in Appendix 3, sedimentation at both sites has greatly exceeded the provisional guideline for New Zealand estuaries of 2mm/yr.

4.3 SEDIMENT CHARACTERISTICS

4.3.1 Sediment grain size, TOC and nutrients

Composite sediment sample raw data are tabulated in Appendix 4. Laboratory analyses revealed that sediment mud content was lower at both sites in December 2020 relative to the two earlier surveys (Fig. 5). However, the greatest reduction was at Site A, where the mean mud content declined from ~55% in January 2020 to 8% in December. It is likely that the sandier sediments present in December 2020 reflect scouring and removal of muddy sediments during flooding.

The muddiness of Site A in December 2020 (bottom) was notably less than in January 2020 (top), possibly attributable to the effects of flood scouring

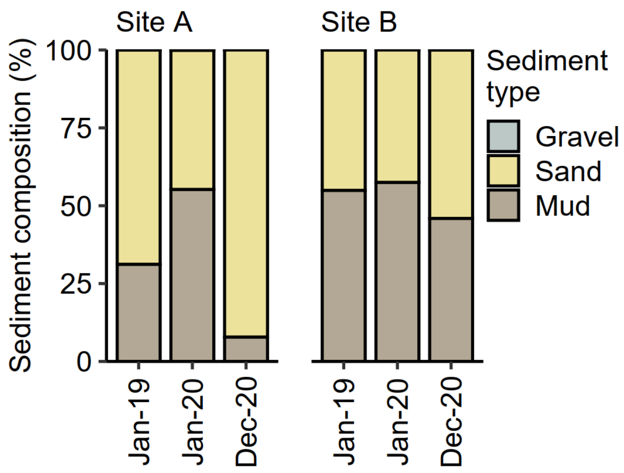


Fig. 5. Sediment particle grain size analysis, showing site-averaged percentage composition of mud (<63µm), sand (<2mm to ≥63µm) and gravel (≥2mm).

To provide a visual impression of sediment quality relative to the Table 3 condition ratings, Fig. 6 compares the mean percentage mud, total organic carbon (TOC) and total nitrogen (TN) from composite samples against the rating thresholds. The marked decrease in mud in December 2020 at Site A resulted in a rating of 'good'. Other sites were rated as 'poor' in all years due to mud content exceeding a biologically relevant threshold of 25%.

Concentrations of TOC and TN were similar at Site B in all years, and at Site A reflected the changing sediment mud content (Fig 5 and 6). In all instances concentrations were <1% and rated as 'good' or 'very good'. Total phosphorus (not plotted) does not have a rating criterion, but values were also low across all years and followed a similar trend to TN at both sites (Appendix 4).

4.3.2 Redox status

The absence of superficial signs of excessive sediment enrichment as noted above is consistent with the expectation of the sites being relatively well-flushed by the Whanganui River. Nonetheless, there was a moderate level of enrichment within the sediment matrix at both sites in the first two surveys (e.g. aRPD ratings of 'poor' or 'fair') that reflects limited diffusion of oxygen into the sediment due to its high mud content (Fig. 7). In December 2020, the aRPD transition between brown oxic surface sediments and deeper black sediments (indicating reduced oxygenation) occurred deeper at both sites than in earlier surveys (Fig. 8), with a rating of 'good' at Site B and 'very good' at Site A. At the latter site, the change from a mud-dominated to sandy sediment would enable greater oxygen penetration into the sediment matrix, reflected in the mean aRPD depth being ~90mm.

Despite these general trends, it is apparent from some of the photographs in Fig. 8 that the aRPD is not always well-defined. Factors such as bioturbation (e.g. by shellfish, crabs) can lead to mixing of oxic surface sediments with deeper oxygen-reduced sediments.

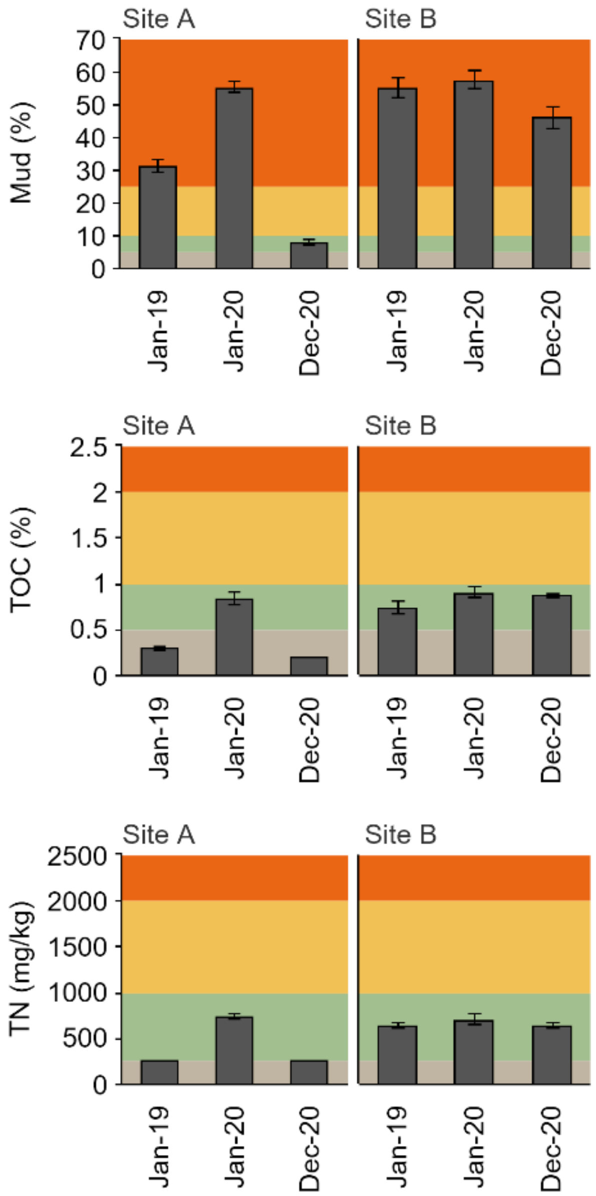


Fig. 6. Sediment mud content, total organic carbon (TOC), and total nitrogen (TN) concentrations relative to condition ratings.

Condition rating key:

Very Good	Good	Fair	Poor

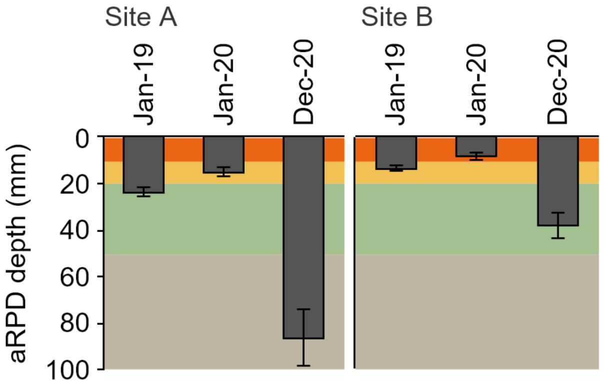


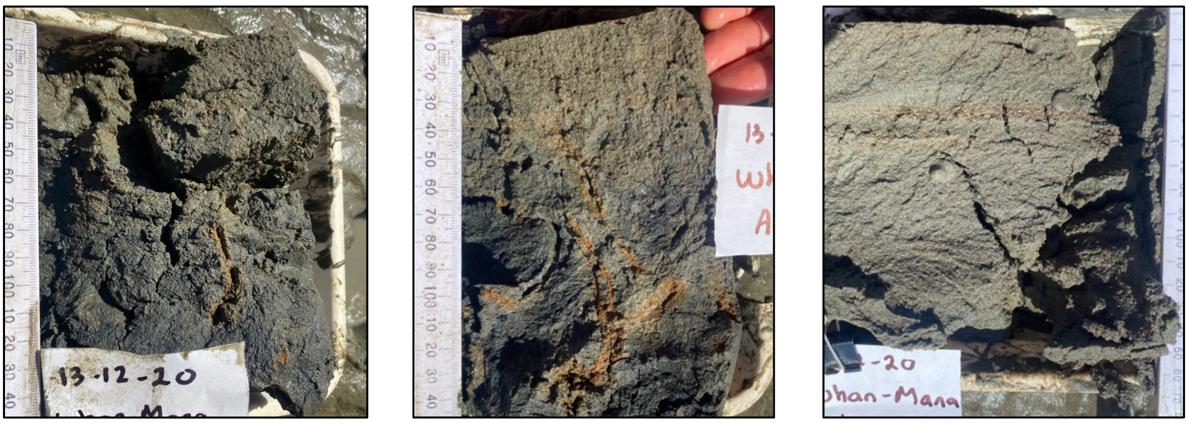
Fig. 7. Condition ratings for aRPD. Rating key as per Fig. 6.

Furthermore, there is inherent subjectivity in aRPD measurement, hence some variability across surveys due to interpretation can be expected. However, gross shifts in aRPD that are meaningful still provide a good indication of shifts in sediment condition. Importantly, none of the surveys provide evidence of mean aRPD values being at, or within a few millimeters of, the sediment surface, as would occur under enriched conditions.

4.3.3 Trace contaminants

Plots of trace metal contaminants in relation to condition ratings and ANZG (2018) sediment quality guidelines are provided in Fig. 9 (see also Appendix 4). The main impression from Fig. 9 is that trace metal concentrations are low and generally rated as 'good' or 'very good'. Slightly elevated concentrations were apparent in December 2020, which is consistent with the greater mud content; relative to sand, mud-sized particles provide an increased surface area for contaminant adsorption. However, none of the trace metals are at levels likely to be associated with discernible ecological effects. These results suggest that there are no sources in the adjacent catchment that are of widespread ecological significance.

Site A



Site B

Fig. 8. Example sediment cores from each of the two fine scale sites in December 2020.

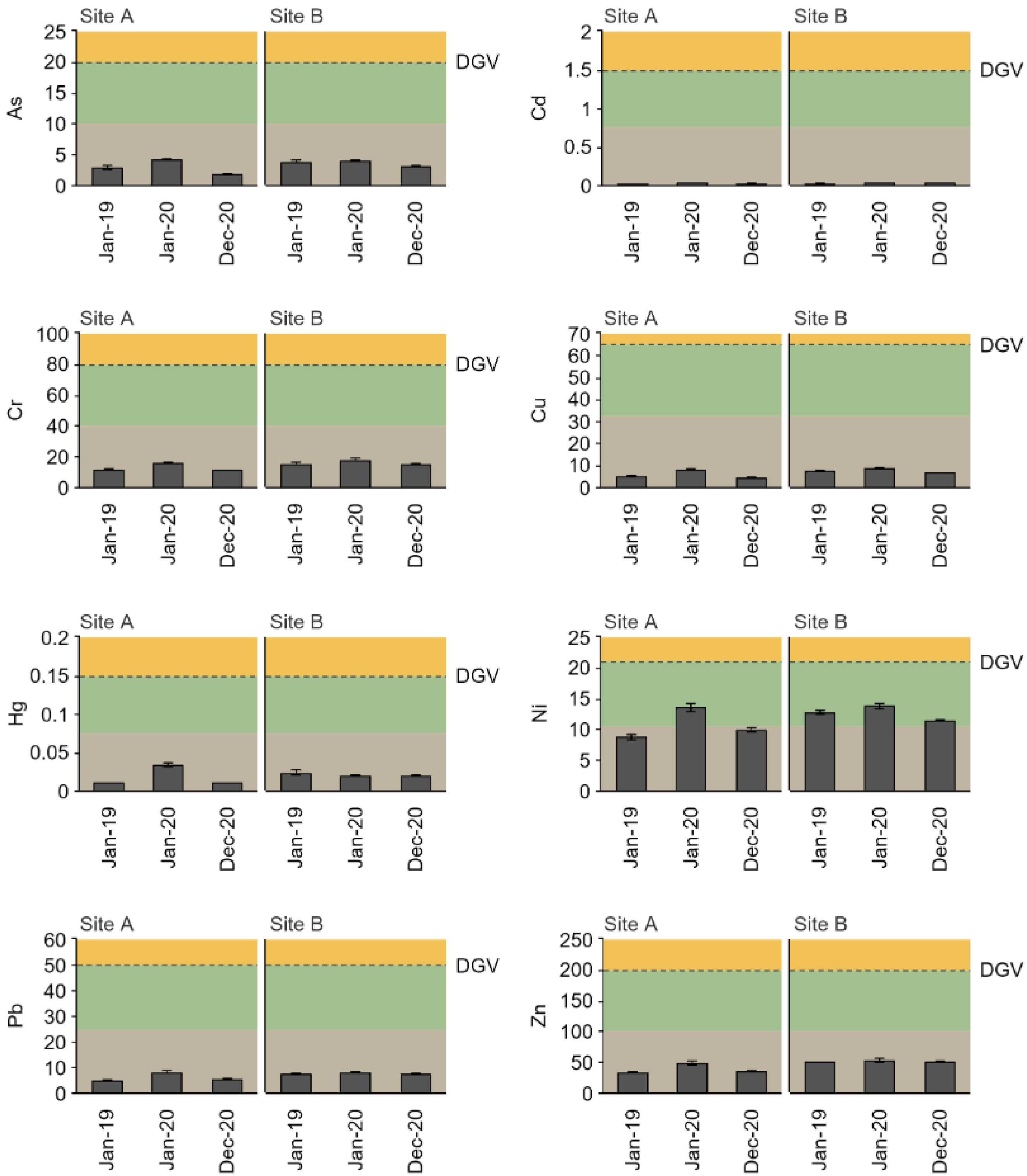


Fig. 9. Condition rating plots for trace metals (site means ± SE). ANZG (2018) sediment quality guideline thresholds are indicated as Default Guideline Values (DGV). Note that concentrations of cadmium (Cd) are so low as to be barely visible on the rating scale.

Condition rating key:

Very Good	Good	Fair	Poor

4.4 MACROFAUNA

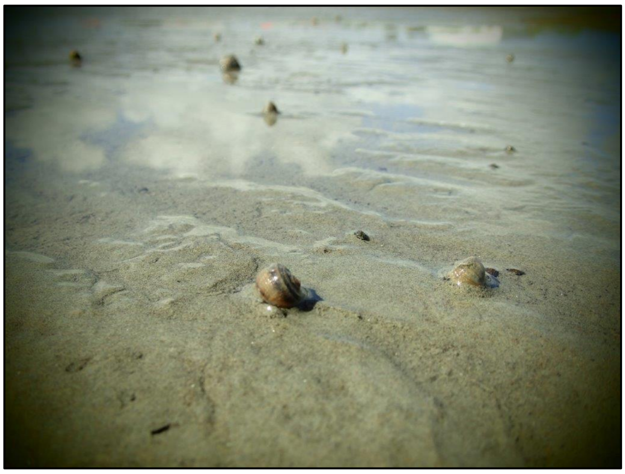
4.4.1 Conspicuous surface epibiota

Results from the site-level assessment of surface-dwelling epibiota in December 2020 are compared with previous surveys in Table 4.

In all surveys, the only species recorded were mud snails (*Amphibola crenata*) and small brackish-water estuarine snails (*Potamopyrgus estuarinus*). SACFOR ratings for *Amphibola* varied from 'rare' (<0.1/m^2) to 'frequent' (2-9/m^2) at both sites, whereas *Potamopyrgus* was consistently rated as 'abundant' (100-999/m^2). However, note that final ratings for *Potamopyrgus* were estimated from macrofauna core data, as this species can be difficult to see when surface muds are present, hence is difficult to reliably assess under field conditions.

Within sites there was considerable patchiness and variability in epibiota distribution and abundance, especially in the case of *Amphibola*.

Burrows and mud casts provided evidence of other biological activity in the sediment, with the occasional crab seen on the surface.



Although burrows and mud casts provided evidence of biological activity within the sediment (top), conspicuous surface epibiota were sparse across all surveys, with mud snails the most visible (bottom)

Table 4. SACFOR scores for epibiota over the three surveys, based on the scale in Table 2.

Species	Description	Site	Jan-19	Jan-20	Dec-20
Amphibola crenata	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.	Site A	F	R	F
		Site B	F	R	O
Potamopyrgus estuarinus	Small estuarine snail, endemic to NZ. Requires brackish conditions. Feeds on decomposing animal and plant matter, bacteria, and algae. Tolerant of muddy sediments and organic enrichment.	Site A	A	A	A
		Site B	A	A	A

4.4.2 Macrofauna cores

Richness, abundance and AMBI

Raw macrofaunal data are provided in Appendix 5. In all years, the macrofaunal assemblages at the two sites were relatively impoverished. In total 18 taxa were recorded in December 2020, compared with 15 in January 2020 and 19 taxa in January 2019. A description of the most common species, as well as their relative abundances, is provided in Table 5.

Species richness among cores was similar across sites and years, ranging from 5-10 at Site A and 6-11 at Site B, resulting in low mean values (Fig. 10a). Abundances in December 2020 were greatly reduced by comparison with previous surveys (Fig. 10b). This result was attributable to the reduced dominance of a freshwater-tolerant tube-building corophioid amphipod, *Paracorophium* sp. 1 (Table 5). This species is likely to be the same one previously reported for Whanganui Estuary as *Paracorophium lucasi*.

AMBI biotic index values were similar at both sites, with a mean score of ~4 being indicative of a moderately disturbed environment (Fig. 11). The high year-site similarity and small core-to-core variance reflects the strong influence on the AMBI score of numerically dominant eco-group (EG) IV species *Paracorophium* sp. 1 and a small bivalve *Arthritica* sp. 1 (likely to be *A. bifurca*). The slightly lower mean AMBI scores in December 2020 reflect the decline in dominance of *Paracorophium* sp. 1 noted above. The taxa present in all years nonetheless spanned EG I, representing sensitive species considered indicative of a relatively healthy state, to hardy EG V species (Fig. 12, Appendix 5). For example, the highly sensitive bivalve *Cyclomactra tristis* (EG I) was recorded in both surveys (not at Site A in January 2019), but at low densities. The most commonly occurring of the species that have an intermediate disturbance tolerance (EG III) included the freshwater tolerant ragworm *Nicon aestuariensis*, estuarine brackish water snail *Potamopyrgus estuarinus* and pillbox crab *Halicarcinus whitei* (Table 5).

Among the more resilient species able to cope with disturbance, the only common ones, other than EG IV *Paracorophium* and *Arthritica* noted above, were the polychaete worm *Scolecolepides benhami* (EG IV), and occasional very hardy (EG V) mud crabs, namely *Austrohelice crassa* (January 2019 and December 2020 only) and *Hemiplax hirtipes* (January 2020 only). Despite these and other resilient species being present, organisms often associated with highly enriched or otherwise degraded conditions, such as capitellid polychaete worms, were not recorded.

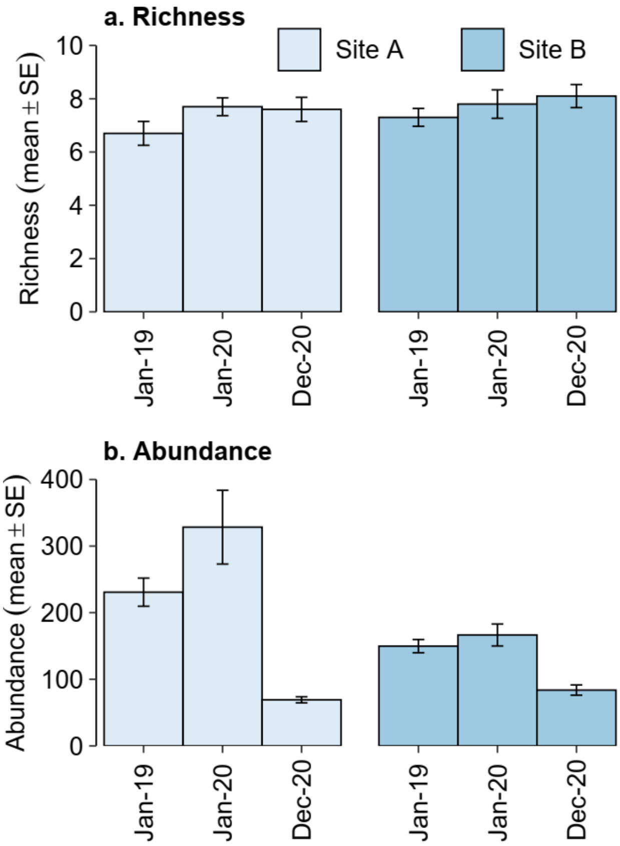


Fig. 10. Patterns (mean ± SE) in taxon richness and abundance per core.

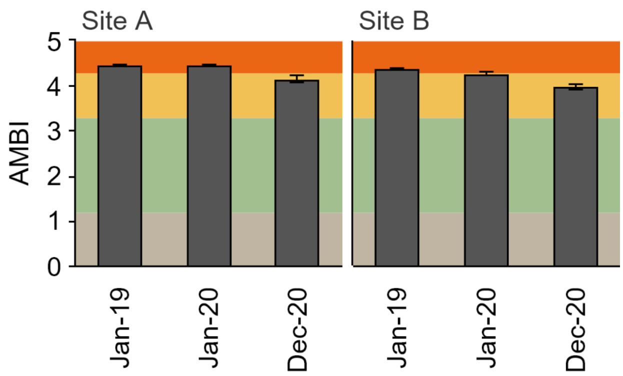
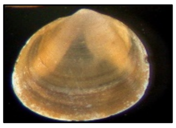
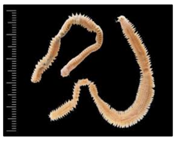


Fig. 11. Patterns (mean ± SE) in AMBI scores compared with condition rating criteria.

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 both sites. The Table shows site abundances pooled within each of the three surveys. Images are illustrative and do not necessary show the exact species, but are an example from the general group.

Main group and species	A-Jan-19	A-Jan-20	A-Dec-20	B-Jan-19	B-Jan-20	B-Dec-20	Description	Image
Amphipoda, Amphipoda sp. 1	0	20	18	22	53	47	Amphipods are shrimp-like crustaceans. This is a little-known species with a laterally compressed body. The adjacent image is illustrative.	
Amphipoda, *Paracorophium* sp. 1	2030	2977	206	1098	772	186	Opportunistic tube-dwelling amphipod that can occur in high densities in mud and sand, often in estuaries subject to disturbance and low salinity.	
Bivalvia, *Arthritica* sp. 1	0	23	151	137	459	263	A small sedentary deposit feeding bivalve that lives buried in the mud. Tolerant of muddy sediments and moderate levels of organic enrichment.	
Bivalvia, *Cyclomactra tristis*	0	1	3	7	2	10	Filter-feeding bivalve shellfish, endemic to New Zealand. It is found intertidally and in shallow water, buried in soft mud in estuaries and tidal flats.	
Decapoda, *Halicarcinus whitei*	7	6	0	12	6	4	A species of pillbox crab. Lives in intertidal and subtidal sheltered environments.	
Gastropoda, *Potamopyrgus estuarinus*	155	143	234	128	162	183	Small endemic estuarine snail, requiring brackish conditions. Feeds on decomposing matter, bacteria, and algae. Tolerates mud and organic enrichment.	
Polychaeta (Nereididae), *Nicon aestuariensis* & juveniles	88	89	61	86	193	122	*Nicon aestuariensis* is a deposit feeding omnivorous worm that is tolerant of freshwater. Unidentified juvenile nereids were also present.	
Polychaeta (Spionidae), *Scolecolepides benhami*	4	17	2	3	7	14	A spionid, surface deposit feeder that is rarely absent in sandy/mud estuaries.	

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 nine main taxa, which differed slightly between the two sites. None of the main groups had many associated species (Fig. 13a), reflecting the generally species-poor nature of the estuary. The representation of abundances among the main groups was overwhelmed by the dominance of the corophioid species noted above (Fig. 13b). The greater prevalence of bivalves at Site B reflects the high relative abundance of *Arthritica* sp. 1, with gastropods solely reflecting *Potamopyrgus estuarinus*.

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 plot, with less similar samples being further apart.

In January 2019 and December 2020 there was a separation of Site A from all other groupings due to some key differences in macrofaunal composition. In January 2019, Site A was dominated by *Paracorophium* sp. 1, but also present were occasional small pipi (*Paphies australis*; 2-5mm shell width) and cockles (*Austrovenus stutchburyi*; 2-4mm shell width), which were absent in subsequent years. By contrast, Site A in December 2020 was characterised by moderate relative densities of *Potamopyrgus estuarinus*, the absence of species occurring in other groups (e.g. the crab *Halicarcinus whitei*), and the presence of species either absent or less prevalence in other groups (e.g. Amphipoda sp. 3, and the isopod *Pseudaega* sp. 1).

However, other than these examples, the discrimination of the clusters from each other was attributable mainly to shifts in dominance. In fact, based on the Bray-Curtis index used to compare the macrofaunal community among the zone aggregated core samples, the similarity among groups was typically very high (>80%).

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 may not be an accurate reflection of the true situation, and needs to be interpreted with caution. That said, the results suggest that Site A is more dynamic and subject to stronger macrofaunal composition shifts than Site B. For example, it is plausible that an increase in muddiness and significant sedimentation at Site A between Jan 2019 and January 2020 explains the absence of species like cockles and pipi, with flood flows just prior to the December 2020 survey explaining the decrease in muddiness and an associated decline in *Paracorophium* densities.

An analysis of relationships between macrofauna and sediment quality revealed that, of all sediment quality variables, mud content best explained spatio-temporal patterns in macrofaunal composition. However, the overall association was not strong (Spearman rank correlation 0.43) and only marginally improved (Spearman correlation, $\rho = 0.44\text{-}0.45$) when sand and total organic carbon (TOC) were also accounted for. Nonetheless, these variables explained much of the bottom-top separation of macrofauna samples in the Fig. 14 MDS ordination plot (y-axis Pearson r^2, mud = 0.82, sand = -0.77, TOC = 0.74). By contrast, none of the measured variables explained the left-right shift in the MDS plot. While associations between mud and macrofaunal composition in estuaries are well recognised (Robertson et al. 2015), it appears that other unmeasured variables may be having an important and possibly overriding role in determining temporal changes in macrofaunal composition in Whanganui Estuary. Plausible drivers include the physical effects of river flow, such as flood-related scouring or decreases in water salinity.

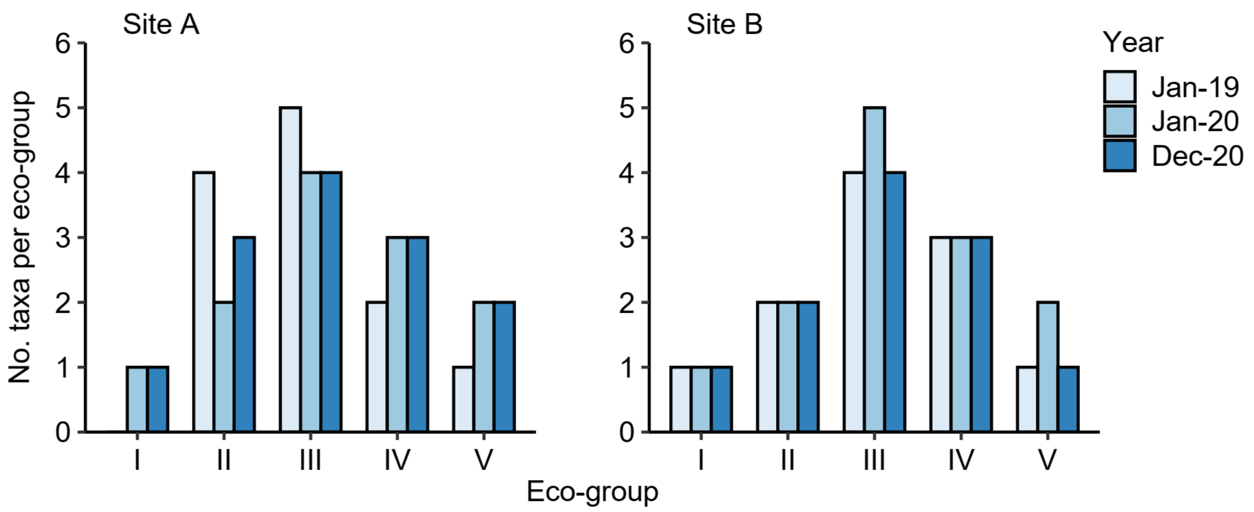


Fig. 13. Site-level data for each of the two sites showing number of taxa within each of five eco-groups ranging from relatively sensitive (EG-I) to relatively resilient (EG-V).

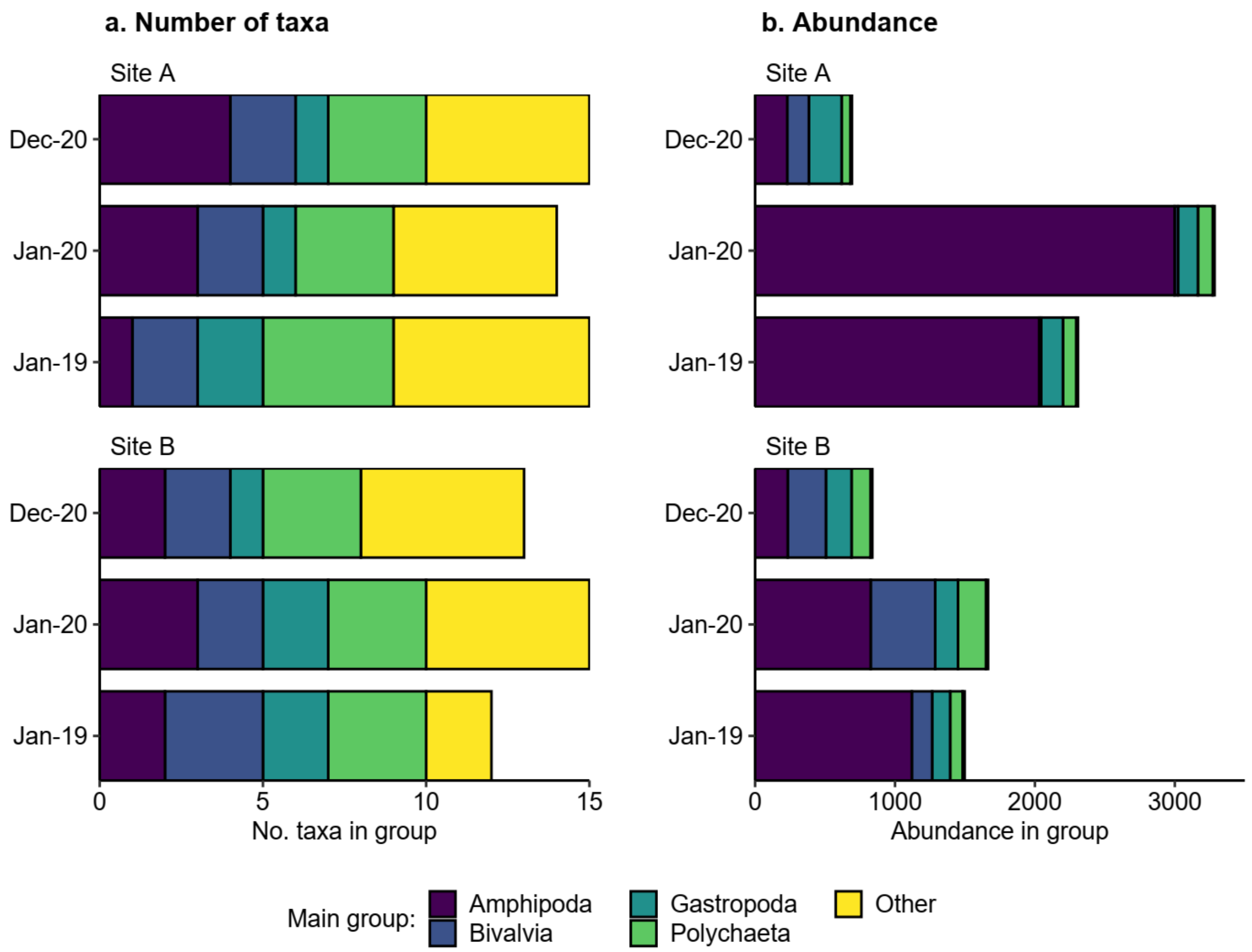


Fig. 12. Pooled data showing the contribution of main taxonomic groups to site-level richness and abundance values.

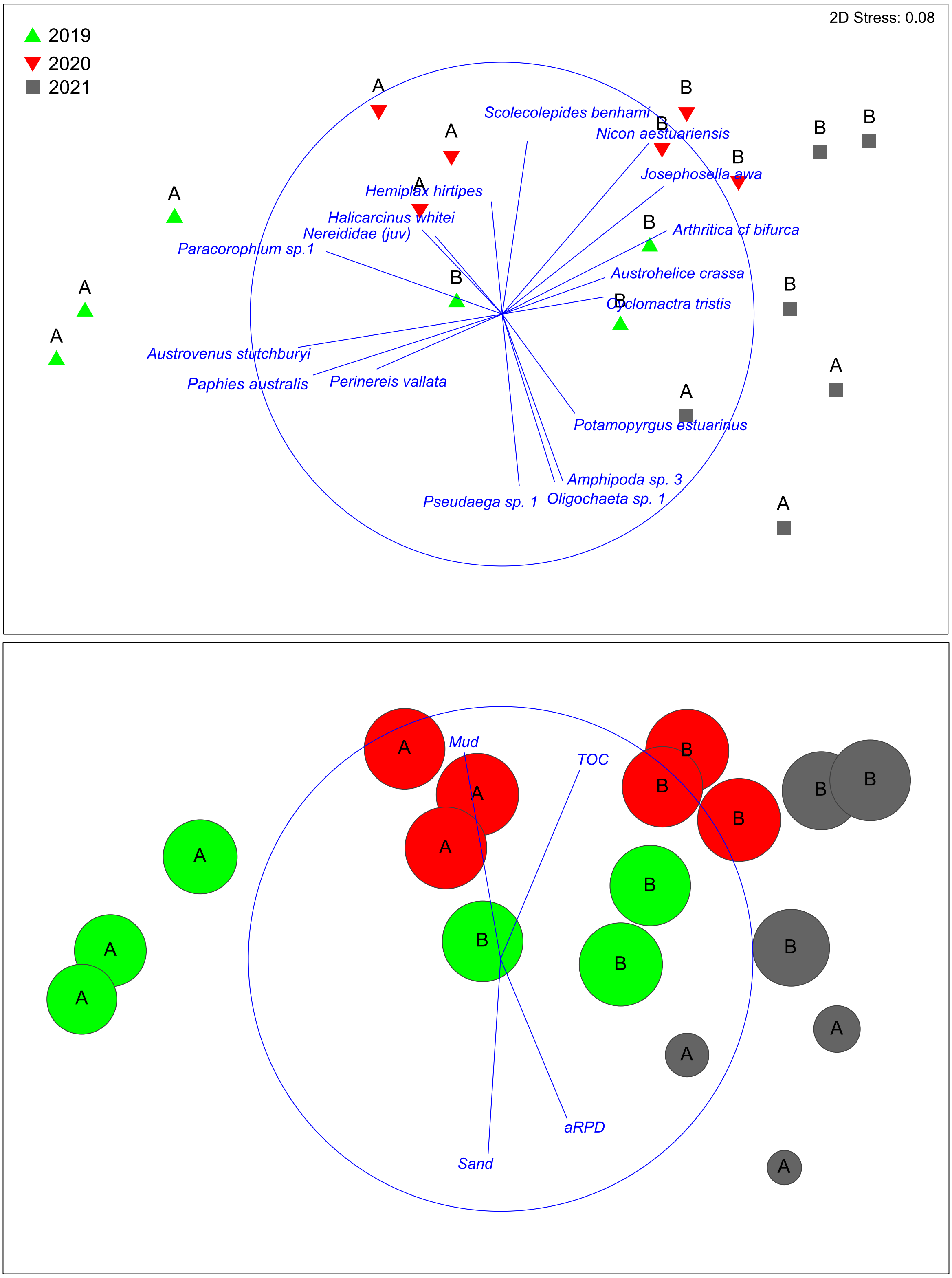


Fig. 14. Non-metric MDS ordination of macrofaunal core samples at Sites A and B aggregated within each of zones X, Y and Z (see Fig. 3), resulting in triplicate representation of each site-year.

Site-year-zone groups are placed such that closer groups are more similar than distant groups in terms of macrofaunal composition. The low 'stress' value (0.08) indicates that a 2-dimesnional plot provides a reasonably accurate representation of group similarity. Vector overlays indicate the direction and strength of association (length of line relative to circle) of grouping patterns in terms of the most correlated macrofauna species (top) and key sediment quality variables (bottom). Bubble sizes in the bottom pane are scaled to sediment mud content, which was the sediment quality variable most closely correlated with macrofaunal composition differences.

5. SYNTHESIS AND RECOMMENDATIONS

5.1 SYNTHESIS OF KEY FINDINGS

This report has described the findings of three monitoring surveys conducted at two sites in the Whanganui 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.

Sediment quality for most variables in the December 2020 survey was similar to that described in the two earlier surveys, the main differences being an improvement at both sites due to decreased mud content (especially at Site A) and a deepening of the aRPD reflecting improved redox conditions. A decrease in sediment mud content will enable greater oxygen penetration into the sediment matrix, explaining the improved redox status. Nonetheless, Site B was still rated in the 'poor' category for mud, reflecting an ongoing prevalence of >25% mud content.

As suggested in the report above, the decrease in %mud content at Site A in December 2020 was possibly attributable to the physical effects of flood-related scouring. Data from HRC reveal that river stage levels in the two days prior to the December 2020 survey (conducted 13 December 2020) were at least double (up to 140% greater) than measured at typical low flows (Fig. 15). There was also a flood peak in Sep-2020. If flood scouring explains the changes, it is conceivable that muddier conditions will re-develop at Site A during periods of lower flow.

Despite the widespread occurrence of muddy sediments, there has been no evidence of significant eutrophication (symptoms of excessive enrichment) in the estuary, consistent with it being reasonably well-flushed. Similarly, no significant levels of trace metal contaminants have been identified in any of the surveys. Such results do not necessarily mean that there are no significant inputs of contaminants to the estuary, as there may be elevated concentrations around point sources (e.g. urban stormwater). However, the results suggest that there are no significant diffuse-source contaminant inputs derived from the catchment that are having a widespread influence.

Visible epibiota (surface-dwelling animals) at the sites were limited to two species of estuarine mud snail. One of these occurred in reasonably high abundances (*Potamopyrgus estuarinus*), while the other (*Amphibola crenata*) was more conspicuous but relatively sparse. As suggested in the two previous reports, the semi-quantitative SACFOR approach used here is considered more appropriate

Table 6. Summary of condition scores of ecological health for each of the two sites, based on mean values of key indicators, and criteria and ratings in Table 4.

Site	Year	Sed rate mm/yr	Mud %	TOC %	TN mg/kg	aRPD mm	As mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Hg mg/kg	Ni mg/kg	Pb mg/kg	Zn mg/kg	AMBI
A	Jan-19	-	31.2	0.29	< 500	24	2.8	0.014	11.5	4.9	< 0.02	8.7	4.9	33.3	4.5
	Jan-20	85.8	55.2	0.83	733	15	4.2	0.027	15.7	8.3	0.03	13.5	8.1	47.7	4.4
	Dec-20	-	7.8	0.19	< 500	86	1.8	0.019	11.2	4.2	< 0.02	9.8	5.3	35.7	4.1
B	Jan-19	-	54.9	0.73	633	13	3.8	0.026	15.2	7.6	0.02	12.7	7.5	49.7	4.4
	Jan-20	6.7	57.5	0.9	700	8	4	0.029	17.8	8.5	0.02	13.7	8.1	52.7	4.3
	Dec-20	31.0	45.9	0.87	633	38	3.1	0.03	14.6	6.7	0.02	11.5	7.5	50.3	4

< All values below lab detection limit

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

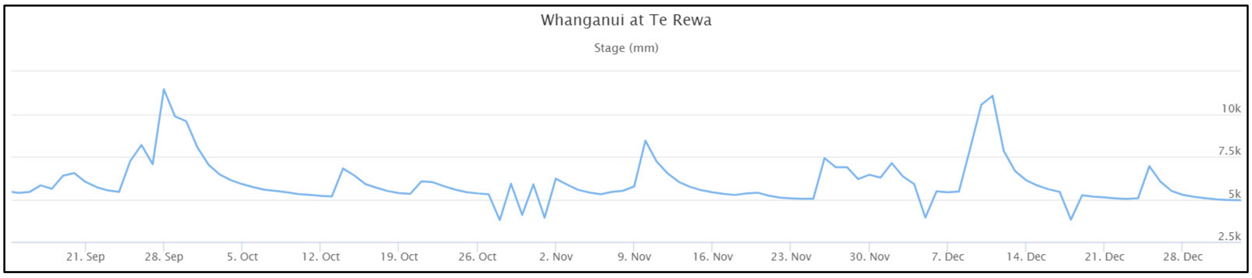


Fig. 15. Whanganui River levels (stage) for the three-month period leading up to the 13 December 2020 survey, showing flood peaks for the two days prior and also in late September. Source: https://envirodata.horizons.govt.nz/

for the assessment of epibiota (at least for conspicuous species like *Amphibola*) than the quantitative quadrat sampling specified in the NEMP.

In terms of the macrofauna sampled in sediment cores, the assemblage was species-poor, but had relatively high abundances of tube-building corophioid amphipods and a small bivalve species, both of which are tolerant of disturbance. The most substantive differences between sites over the three surveys reflected changes in dominance patterns, with changes in species composition *per se* being relatively subtle. Nonetheless, there have been some shifts that are consistent with the observed changes in sediment mud content, such as the apparent loss of two mud-sensitive bivalve species (cockles and pipi) at Site A between Jan 2019 and January 2020. As discussed in the second survey report (Forrest et al. 2020), the mud content of sediments in January 2020 was greater than the predicted optimal maximum for these species (<45%; Robertson et al. 2015). Furthermore, mud has consistently been the sediment indicator most closely associated with spatio-temporal changes in macrofauna, although this effect was less apparent in December 2020.

Other potential explanatory variables noted above include physical scouring effects from river flow, and altered salinity and sedimentation patterns, with these potential drivers likely to be highly inter-correlated. For example, low salinity conditions may persist for a few days during flood flows that also deliver enhanced sediment mass loads. Sediment deposition effects alone potentially explain some of the biological changes, as values recorded (see Fig. 4) greatly exceed the provisional guideline value for New Zealand estuaries of 2mm/yr (greater than natural background). Above this value, significant adverse impacts may occur (Townsend & Lohrer 2015). It is unfortunate that the sediment plates at Site A were unable to be relocated in December 2020, as the 31mm of deposition measured at Site B, together with the results from the previous year at Site A, suggest that sedimentation in the estuary in general may be exerting a strong ecological influence.

Potential sedimentation effects can also be inferred from the ratio of the current to natural sedimentation rate (Appendix 6) predicted from the NIWA estuary sediment load estimator (Hicks et al. 2019). The estimated ratio of 3.7 (assuming 50% wetland attenuation under natural state conditions) 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. 2016b).

As well as the potential loss of sensitive species, the low species richness assemblages at Sites A and B are characterised by a combination of relatively high abundances of disturbance-tolerant species, and the occurrence of subdominant species that are typical of freshwater-dominated estuaries. Clearly, therefore, the fine scale sites are exposed to reasonably harsh physical conditions. In addition to the effects of events such as river flood flows that may deliver pulses of increased sediment and low salinity water, a major ongoing stressor is likely to be the effect of brackish (low salinity) turbid water inundating the tidal flats each day due to the relative high base flow of Whanganui River.

In this context, one of the questions raised in the January 2020 survey report was whether the significant sedimentation measured at Site A in January 2020 was a reflection of a change in the catchment (e.g. land-disturbance), a climatic event that delivered a large pulse of sediment, and/or simply reflected a highly dynamic sedimentary environment. The present survey, which revealed a variable macrofauna community at Site A, coupled with the loss of sediment plates and pegs, suggest that the estuary environment is relatively dynamic and experiences naturally-driven temporal variability consistent with its river-dominated nature.

5.2 CONCLUSIONS AND RECOMMENDATIONS

This report represents the culmination of a baseline of three annual ecological surveys undertaken in Whanganui Estuary from January 2019 to December 2020. Based on the results of all three surveys, the following is recommended:

1. Monitoring frequency: The baseline survey results highlight that Whanganui Estuary is a dynamic river-dominated system, with the three surveys appearing to have captured a broad range of environmental conditions. As such, in the absence of any major changes in the catchment, there is no compelling reason to annually repeat the survey. Instead, it would be reasonable to undertake future surveys at intervals of approximately five-years, which is typical for the NEMP fine scale method (i.e. once a baseline has been established).

2. Monitoring sites: The current sites appear generally appropriate 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. Although Site A appears particularly dynamic and environmentally variable, it nonetheless represents the typically harsh conditions that sites in river-dominated estuaries are exposed to. Consideration could nonetheless be given to establishing a third site further downstream, if a more stable habitat can be identified. In this context, there will need to be further thought given to the merit of re-installing sediment plates at Site A.

3. Methods and indicators: In terms of the NEMP fine scale methodology and indicators, vertical profiles of oxidation redox potential (ORP) measurements have already been trialed and discontinued. Visual assessment of aRPD provides a suitable and simple alternative for assessment of gross change in trophic status. The suite of other indicators described in this report is appropriate for long-term monitoring purposes.

4. Future-proofing and optimising monitoring: Effort has already been made to provide a reference list of named species for those most commonly occurring. It would be beneficial to complete this work and obtain agreed names for all species recorded, to future-proof the programme against a future change in taxonomic provider. Consideration could also be given to optimization of the sampling design for future surveys. The main purpose would be to consider whether sampling effort could be reduced, hence cost savings made, without compromising the ability of the programme to detect change.

6. REFERENCES CITED

ANZECC 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. National Water Quality Management Strategy Paper No. 4. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand. Updated 2018 and available at: https://www.waterquality.gov.au/anz-guidelines/guideline-values/default/sediment-quality-toxicants.

ANZG 2018. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian State and Territory Governments, Canberra ACT, Australia. Available at https://www.waterquality.gov.au/anz-guidelines/guideline-values/default/sediment-quality-toxicants.

Berthelsen A, Atalah J, Clark D, Goodwin E, Patterson M, Sinner J 2018. Relationships between biotic indices, multiple stressors and natural variability in New Zealand estuaries. Ecological Indicators 85: 634-643.

Blyth-Skyrme V, Lindenbaum C, Verling E, Van Landeghem K, Robinson K, Mackie A, Darbyshire T 2008. Broad-scale biotope mapping of potential reefs in the Irish Sea (north-west of Anglesey). JNCC Report No. 423, Joint Nature Conservation Committee. 210p.

Borja A, Franco J, Pérez V 2000. A Marine Biotic Index to Establish the Ecological Quality of Soft-Bottom Benthos Within European Estuarine and Coastal Environments. Marine Pollution Bulletin 40(12): 1100-1114.

Borja Á, Mader J, Muxika I 2012. Instructions for the use of the AMBI index software (Version 5.0). Revista de Investigación Marina, AZTI-Tecnalia 19(3): 71-82.

Clarke KR, Gorley RN, Somerfield PJ, Warwick RM 2014. Change in marine communities: an approach to statistical analysis and interpretation, 3rd edition. PRIMER-E, Plymouth, UK. 260p.

FGDC 2012. Coastal and Marine Ecological Classification Standard. Standard FGDC-STD-018-2012, Marine and Coastal Spatial Data Subcommittee, Federal Geographic Data Committee, June, 2012.. 343p. Available at: https://www.fgdc.gov/standards/projects/cmecs-folder/CMECS_Version_06-2012_FINAL.pdf.

Forrest B, Stevens L 2019a. Synoptic overview of the Marlborough District Council estuarine State of the Environment monitoring programme. Salt Ecology Report 010. Prepared for Marlborough District Council, April 2019. 32p.

Forrest BM, Stevens LM 2019b. Fine scale monitoring of Manawatu Estuary. Salt Ecology Report 016, prepared for Horizons Regional Council. 27p.

Forrest BM, Stevens LM 2019c. Fine scale monitoring of Whanganui Estuary. Salt Ecology Report 019, prepared for Horizons Regional Council. 26p.

Forrest BM, Stevens LM, Rabel H 2020. Fine Scale Intertidal Monitoring of Whanganui Estuary. Salt Ecology Report 037, prepared for Horizons Regional Council, June 2020. 31p.

Hicks DM, Semadeni-Davies A, Haddadchi A, Shankar U, Plew D 2019. Updated sediment load estimator for New Zealand. NIWA Client Report No: 2018341CH, prepared for Ministry for the Environment, March 2019. 190p.

Keeley NB, Macleod CK, Forrest BM 2012. Combining best professional judgement and quantile regression splines to improve characterisation of macrofaunal responses to enrichment. Ecological Indicators 12: 154-166.

MNCR 1990. Use of the Marine Nature Conservation Review SACFOR abundance scales. Joint Nature Conservation Committee. www. jncc.gov.uk/page-2684 (accessed 15 April 2019).

R Core Team 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Robertson B, Stevens L 2016. Manawatu-Wanganui estuaries: habitat mapping, vulnerability assessment and monitoring recommendations related to issues of eutrophication and sedimentation. Prepared for Envirolink Medium Advice Grant: 1624-HZLC127 Assessment of the susceptibility of Horizons' estuaries to nutrient enrichment and sedimentation. MBIE/NIWA Contract No:CO1X1513. 102p plus appendices.

Robertson B, Gillespie P, Asher R, Frisk S, Keeley N, Hopkins G, Thompson S, Tuckey B 2002. Estuarine Environmental Assessment and Monitoring: A National Protocol. Part A, Development; Part B, Appendices; and Part C, Application. Prepared for supporting Councils and the Ministry for the Environment, Sustainable Management Fund Contract No. 5096. Part A, 93p; Part B, 159p; Part C, 40p plus field sheets.

Robertson BM, Stevens L, Robertson B, Zeldis J, Green M, Madarasz-Smith A, Plew D, Storey R, Hume T, Oliver M 2016a. NZ Estuary Trophic Index Screening Tool 1: Determining eutrophication susceptibility using physical and nutrient load data. Prepared for Envirolink Tools Project: Estuarine Trophic Index, MBIE/NIWA Contract No: C01X1420. 47p.

Robertson BM, Stevens L, Robertson B, Zeldis J, Green M, Madarasz-Smith A, Plew D, Storey R, Hume T, Oliver M 2016b. NZ Estuary Trophic Index Screening Tool 2: determining monitoring indicators and assessing estuary trophic state. Prepared for Envirolink Tools Project: Estuarine Trophic Index MBIE/NIWA Contract No: C01X1420. 68p.

Robertson BP 2018. Optimising indicators of ecological condition in shallow tidal estuaries as function of nitrogen loading. A thesis submitted for the degree of Doctor of Philosophy at the University of Otago, Dunedin, New Zealand. 125p.

Robertson BP, Gardner JPA, Savage C 2015. Macrobenthic–mud relations strengthen the foundation for benthic index development: A case study from shallow, temperate New Zealand estuaries. Ecological Indicators 58: 161-174.

Robertson BP, Savage C, Gardner JPA, Robertson BM, Stevens LM 2016c. Optimising a widely-used coastal health index through quantitative ecological group classifications and associated thresholds. Ecological Indicators 69: 595-605.

Stevens LM, Robertson BM 2009. Whanganui Estuary Broad Scale Habitat Mapping 2008/09. Report prepared by Wriggle Coastal Management for Department of Conservation. 17p.

Stevens LM, Robertson BP 2016. Manawatu Estuary 2016 Broad Scale Habitat Mapping. Prepared by Wriggle Coastal Management for Horizons Regional Council . 28p

Stevens LM, Robertson BM 2017. Whanganui Estuary 2017 Broad Scale Habitat Mapping. Prepared by Wriggle Coastal Management for Horizons Regional Council. 26p.

Townsend M, Lohrer D 2015. ANZECC Guidance for Estuary Sedimentation. NIWA client report number HAM2015-096, prepared for Ministry for the Environment. 45p.

APPENDICES

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

Fine Scale Site Corners

Site	Peg	NZTM East	NZTM North
A	1	1771920	5575634
A	2	1771913	5575605
A	3	1771969	5575592
A	4	1771979	5575620
B	1	1772387	5575520
B	2	1772385	5575507
B	3	1772445	5575496
B	4	1772448	5575509

Sediment Plates

Site	Plate	NZTM East	NZTM North
A	1	1171919	5575628
A	2	1171918	5575624
A	3	1171914	5575613
A	4	1171913	5575608
B	1	1172390	5575530
B	2	1172388	5575524
B	3	1172386	5575514
B	4	1172386	5575511

Appendix 2. RJ Hill analytical methods for sediments

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request. Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Sample No
Individual Tests			
Environmental Solids Sample Drying*	Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%.	-	1-6
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation May contain a residual moisture content of 2-5%.	-	1-6
Dry Matter for Grainsize samples (sieved as received)*	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-6
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	1-6
Total Recoverable Phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt	1-6
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-6
Total Organic Carbon*	Acid pretreatment to remove carbonates present followed by Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-6
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg	Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level.	0.010 - 0.8 mg/kg dry wt	1-6
3 Grain Sizes Profile as received			
Fraction >/= 2 mm*	Wet sieving with dispersant, as received, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-6
Fraction < 2 mm, >/= 63 µm*	Wet sieving using dispersant, as received, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-6
Fraction < 63 µm*	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-6

Appendix 3. Sediment plate raw data

The baseline depth was measured on 31 January 2019 at the time of plate installation.

Date	Site	Plate	Depth (mm)	Baseline (mm)	Interval (days)	Annual adjustment (mm)	Annualized change (mm)	Change from baseline (mm)
31/01/2019	A	p1	93	93				
31/01/2019	A	p2	70	70				
31/01/2019	A	p3	77	77				
31/01/2019	A	p4	77	77				
19/01/2020	A	p1	144	93	353	0.97	52.7	51
19/01/2020	A	p2	148	70	353	0.97	80.7	78
19/01/2020	A	p3	218	77	353	0.97	145.8	141
19/01/2020	A	p4	139	77	353	0.97	64.1	62
31/01/2019	B	p1	69	69				
31/01/2019	B	p2	66	66				
31/01/2019	B	p3	59	59				
31/01/2019	B	p4	60	60				
19/01/2020	B	p1	65	69	353	0.97	-4.1	-4
19/01/2020	B	p2	92	66	353	0.97	26.9	26
19/01/2020	B	p3	55	59	353	0.97	-4.1	-4
19/01/2020	B	p4	68	60	353	0.97	8.3	8
13/12/2020	B	p1	91	69	329	0.9	29.2	22.3
13/12/2020	B	p2	110	66	329	0.9	19.6	43.7
13/12/2020	B	p3	85	59	329	0.9	32.9	25.7
13/12/2020	B	p4	106	60	329	0.9	42.2	46

Appendix 4. Sediment quality raw data for all three surveys

Oxidation reduction potential (ORP) was not measured in December 2020, but measured values are presented in the previous reports.

Site	Survey	Zone	Gravel	Sand	Mud	TOC	TN	TP	aRPD*	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
			%	%	%	%	mg/kg	mg/kg	mm	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
A	Jan-2019	X	<0.1	65	34.9	0.26	<500	300	22 to 33	3	0.013	11.8	4.5	<0.02	8.7	4.7	32
		Y	<0.1	69	31	0.34	<500	360	18 to 22	3.3	0.014	12.1	5.3	<0.02	9.3	5.1	36
		Z	<0.1	72.4	27.6	0.27	<500	320	18 to 33	2.2	0.016	10.6	4.8	<0.02	8	4.9	32
	Jan-2020	X	<0.1	42.1	57.9	0.96	800	510	12 to 20	4.2	0.034	16.9	8.9	0.04	14.7	8.8	54
		Y	0.3	47.7	52	0.76	700	460	15 to 25	4.3	0.024	15.5	8	0.03	12.6	7.8	46
		Z	0.2	44.2	55.7	0.77	700	450	12 to 2	4.1	0.024	14.7	7.9	0.03	13.3	7.7	43
	Dec-2020	X	<0.1	90.8	9.2	0.2	<500	290	50 to 70	1.9	0.021	11.6	4.4	<0.02	10.4	5.4	37
		Y	<0.1	91.8	8.2	0.19	<500	290	60 to 80	1.7	0.02	10.9	4.1	<0.02	9.5	5.2	35
		Z	<0.1	94	6	0.19	<500	280	100 to 60	1.9	0.017	11	4.2	<0.02	9.6	5.4	35
B	Jan-2019	X	0.2	48.3	51.5	0.67	600	420	16 to 22	3.4	0.025	15.7	7.4	0.02	12.4	7	49
		Y	<0.1	38.9	61.2	0.87	700	430	12 to 15	4.1	0.028	15.9	8.2	0.03	13.2	8	51
		Z	<0.1	48	52	0.66	600	370	10 to 8	3.9	0.025	14	7.1	0.02	12.5	7.4	49
	Jan-2020	X	<0.1	39.9	60.1	1.03	800	530	12 to 2	3.9	0.032	20	9.5	0.02	14.5	8.5	61
		Y	<0.1	39.2	60.8	0.86	700	470	7 to 9	3.9	0.027	16.5	8	0.02	13.7	7.8	48
		Z	<0.1	48.5	51.5	0.81	600	460	12 to 5	4.1	0.027	17	8	0.02	13	7.9	49
	Dec-2020	X	<0.1	55.7	44.3	0.83	700	440	20 to 50	3.2	0.029	14.4	6.8	0.02	11.4	7.5	52
		Y	<0.1	47.8	52.2	0.89	600	430	20 to 70	3	0.031	14.1	6.6	0.02	11.3	7.5	50
		Z	<0.1	58.7	41.2	0.89	600	440	25 to 65	3.1	0.029	15.3	6.6	0.02	11.7	7.4	49
									DGV	20	1.5	80	65	0.15	21	50	200
									GV-high	70	10	370	270	1	52	220	410

*aRPD shows the range of values across 3-4 replicates

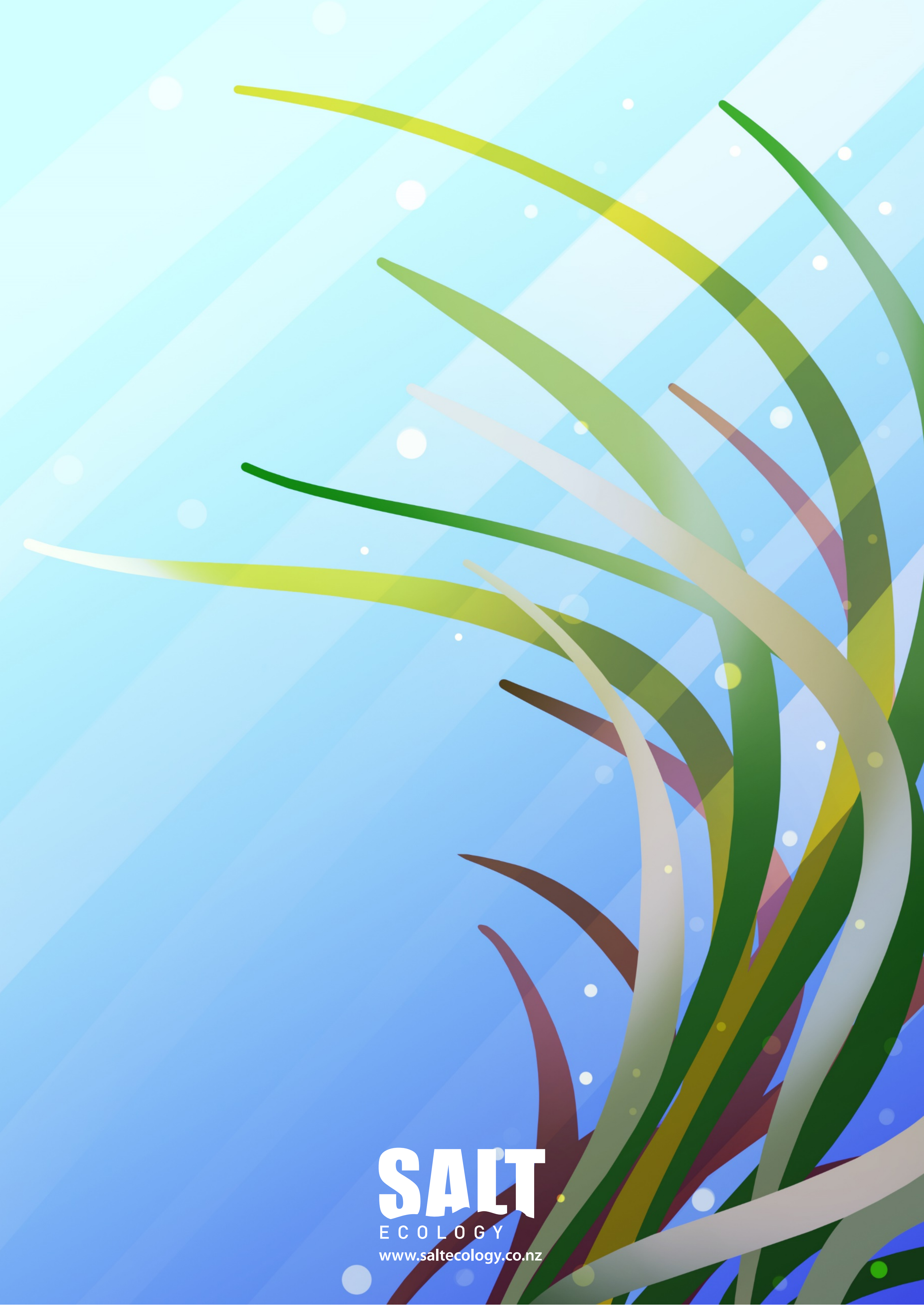
Appendix 5. Macrofauna core raw data for December 2020.

Raw data from earlier surveys is presented in previous reports.

Main group	Species	Habitat	EG	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Amphipoda	Amphipoda sp. 3	Infauna	II						1	2	1	1											
Amphipoda	Josephosella awa	Infauna	II	1	1	2	2	2	1	1	1	3	4	12	4	1	10	7	2	2	3	1	5
Amphipoda	Paracalliope novizealandiae	Infauna	II							1													
Amphipoda	Paracorophium sp. 1	Infauna	IV	5	15	15	44	44	12	13	14	26	18	35	3	2	31	11	9	40	15	27	13
Bivalvia	Arthritica cf bifurca	Infauna	IV	24	34	11	15	12	12		4	21	18	41	25	28	41	26	14	27	8	16	37
Bivalvia	Cyclomactra tristis	Infauna	I								3						2	2	4	1			1
Decapoda	Austrohelice crassa	Infauna	V		1										1	2	1			1			
Decapoda	Halicarcinus whitei	Infauna	III											1	1		1	1					
Gastropoda	Potamopyrgus estuarinus	Epibiota	III	33	18	19	24	17	22	53	22	9	17	21	17	15	10	7	11	19	25	32	26
Isopoda	Exosphaeroma sp. 1	Infauna	V		1			1															
Isopoda	Isopoda Anthuroidea	Infauna	NA																	1		1	
Isopoda	Pseudaega sp. 1	Infauna	NA				1		1		1	1											
Mysidacea	Tenagomysis sp. 1	Infauna	II																				1
Nemertea	Nemertea sp. 1	Infauna	III		1							1			1								
Oligochaeta	Oligochaeta sp. 1	Infauna	III					1		1													
Polychaeta	Nereididae (unidentified juv)	Infauna Juv	NA	4	4	4	8	5	4	3	4	1	3	5	10	6		2	4	3	3	5	3
Polychaeta	Nicon aestuariensis	Infauna	III		2	4	2	3	3	1		3	3	14	8	9	6	9	5	6	5	11	8
Polychaeta	Scolecolepides benhami	Infauna	IV				1		1						3	4	1	5		1			
			Richness	5	9	6	8	8	9	8	8	9	6	7	10	8	9	9	7	10	6	7	8
			Abundance	67	77	55	97	85	57	75	50	66	63	129	73	67	103	70	49	101	59	93	94

Appendix 6. NIWA model outputs (Hicks et al. 2019)

Data source	Whanganui River	
Stevens & Robertson 2015	Estuary Area (Ha)	354
Hicks et al. 2019	Mean freshwater flow (m^3/s)	227.23
Hicks et al. 2019	Catchment Area (Ha)	713573
NIWA CLUES model	Catchment nitrogen load (TN/yr)	3479.1
NIWA CLUES model	Catchment phosphorus load (TP/yr)	868.8
Hicks et al. 2019	Catchment sediment load (KT/yr)	3438
NIWA CLUES model	Estimated N areal load in estuary ($mg/m^2/d$)	2693
NIWA CLUES model	Estimated P areal load in estuary ($mg/m^2/d$)	672
Hicks et al. 2019	CSR:NSR ratio	1.8
modified from previous	CSR/NSR ratio with 50% natural wetland attenuation	3.7
Hicks et al. 2019	Trap efficiency (sediment retained in estuary)	32%
Hicks et al. 2019	Estimated rate of sed. trapped in estuary (mm/yr)	208.0


SALT
ECOLOGY
www.saltecology.co.nz

horizons
REGIONAL COUNCIL

horizons.govt.nz

24 hour freephone 0508 800 800
fax 06 952 2929 | **email** help@horizons.govt.nz
Private Bag 11025, Manawatu Mail Centre, Palmerston North 4442