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Havelock Estuary, Marlborough

Fine Scale Monitoring and Ecological Assessment

For Marlborough District Council

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REPORT INFORMATION & QUALITY CONTROL

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Contents

List of Appendices

List of Tables

List of Figures

Executive Summary

Robertson Environmental Ltd has been engaged by Marlborough District Council (MDC) to undertake the fine scale monitoring of Havelock Estuary, a relatively large, shallow, intertidal dominated (SIDE) type estuary situated at the head of Pelorus Sound. It is one of the key estuaries in Marlborough District Council's (MDC's) long-term coastal monitoring programme.

The purpose of the assessment was to characterise current ecological condition of the estuary's main intertidal basin in relation to several key coastal stressors (i.e. eutrophication, sedimentation, and trace metal toxicity), and compare the findings with relevant national standards (NZ Estuary Trophic Index), to provide recommendations regarding future monitoring and management priorities in the estuary. The survery was undertaken in January 2019, and the results, risk indicator ratings, overall estuary condition, and monitoring recommendations are summarised below.

As summarised in the below table, the baseline (2014-19) benthic assessment identified the following, with risk indicator ratings and previous surveys (2001) included:

- Opportunistic macroalgae, a primary indicator of eutrophication, was low at all four intertidal sites, while seagrass habitat was absent;
- Sediment mud content was moderate (<25% mud) at Site B and high (averaging 28.7-60.6 % mud) at Sites A, C and D, and had not changed since 2001;
- Based on sediment plate monitoring results, the overall rate of sediment infilling was moderate, an across-site average of 3.7 mm yr^{-1}, with greater infilling occurring in the upper Eastern Arm of the estuary (mean increase of 6.5 mm yr^{-1});

Summary of NZ ETI-based risk ratings, Havelock Estuary, baseline years and 2001.

Estuary Issue	Indicator	Risk indicator rating[1]					Narrative change since 2001
		2001	Baseline years				
			2014	2015	2017	2019	
Sedimentation	Sediment mud content (% mud)	Mod-High	Mod-High	Mod-High	Mod-High	Mod-High	No notable change
Eutrophication	Apparent Redox Potential Discontinuity (aRPD)	*na*	Moderate	Moderate	Moderate	Moderate	Not applicable
	Redox Potential (mV) upper 3cm	*na*	*na*	*na*	High	High	Not applicable
	Total Organic Carbon (TOC)	Moderate	Low	Low-Mod	Low-Mod	Low-Mod	No notable change
	Total Nitrogen (TN)	Very Low-Low	Very Low-Low	Low-Mod	Low-Mod	Low-Mod	No notable change
Sedimentation/ Eutrophication	Macroinvertebrate Condition Index (NZ-Hybrid RI-AMBI)	Low	Low	Low	Low	Low	No notable change
Toxic Contamination	Trace Metals[2]	Low	Low	Low	Low	Low	No notable change

[1] 2001 and 2014 ratings based on data from Sites A and B only; post-2014 ratings based on data from Sites A, B, C and D.
[2] All below ANZEEC Low Trigger Limit except for naturally elevated Nickel concentrations that were below the High Trigger Limit.

- Sediment oxygenation depth in 2019, and previous years, at all sites was moderate-poor;
- The indicators of organic enrichment (total organic carbon) and nutrient enrichment (total nitrogen and phosphorus) were at low concentrations across all fine scale sites;
- Sediment-based trace metals (Cd, Cu, Cr, Ni, Pb, Hg, Zn and As) were at concentrations that were unlikely to cause toxicity to macroinvertebrates;
- The estuary macroinvertebrate community index (NZ AMBI) indicated relatively low to moderate stress on benthic macrofauna across sites, with communities generally dominated by taxa tolerant of slight organic enrichment and moderate-high mud content.

A comparison of the 2001 (Robertson et al. 2001) and baseline (2014-19) results show that 2001 benthic physicochemical results were similar to those from fine scale sites in 2019 and previous baseline years, indicating Havelock's main intertidal basin was unlikely to have significantly changed in terms of sediment mud, TOC, TN, TP, and trace metal concentrations in the past almost two decades. Based on NZ AMBI scores, macroinvertebrate communities, which consisted of a broad range of taxomonic and functional groupings, were in good condition in baseline years and 2001. However, in the absence of a full baseline dataset (i.e. the 2001 fine scale survey data represented only a single-year sampling event rather than sampling over a recommended 3-4 consecutive year period), these temporal trends should be considered with caution. Future monitoring will determine if results reflect ongoing trends in fine scale estuary conditions.

Based on the combined results from the January 2019 fine scale survey, Havelock Estuary's main intertidal basin is considered to be in a moderate-poor state in relation to sedimentation, eutrophication and trace metal toxicity, the poor status reflecting an ongoing sediment muddiness issue and the uniform absence of high-value seagrass habitat. Macroinvertebrate communities are relatively impaired but remain in good (diverse and functional) condition. In terms of nutrient-induced disturbance, the current results, when combined with 2019 broad scale monitoring outputs, yield a NZ Estuary Trophic Index (NZ ETI) score of 0.67, indicating that the estuary overall is expressing moderate symptoms of eutrophication.

In terms of future monitoring and management, Havelock Estuary has been identified by MDC as a priority ecosystem. Fine scale monitoring (including sedimentation rate monitoring), in conjunction with broad scale habitat mapping, provides valuable information on current estuary condition and trends over time. The following fine scale monitoring recommendations are proposed by Robertson Environmental Ltd for consideration by MDC:

- Because the estuary is expressing moderate symptoms of eutrophication as well as an ongoing muddiness issue, fine scale conditions could quickly deteriorate, particularly given that catchment-derived nitrogen inputs are close to critical thresholds. It is therefore recommended that data only monitoring of macroinvertebrates and eutrophication-related indicators (e.g. sediment mud, TOC, TN and TP concentrations, and sediment oxygenation via aRPD and redox probe) be undertaken annually at high susceptibility Sites C and D (next recommended in 2020), with comprehensive fine scale monitoring undertaken every 5 years (next recommended in 2024);
- Sediment muddiness remains a priority issue in the estuary. It is therefore recommended that existing sediment plate depths be measured annually, and a single composite sediment sample be analysed for grain size at each site;
- Broad scale monitoring recommendations are presented in Robertson (2019).

In terms of management, given the ongoing sedimentation issue and more recent establishment of gross eutrophic conditions in the estuary, previous recommendations (e.g. Stevens and Robertson 2014) are reiterated for the prioritised development of catchment nutrient and sediment guideline criteria to derive thresholds protecting against adverse sediment and nutrient impacts. To provide more robust catchment load estimates, it is recommended that future river total nitrogen and suspended sediment load sampling be undertaken during representative lowflow, baseflow and floodflow periods. This would enable local calibration of modelled load estimates thereby strengthening their usefulness for associated management initiatives.

1 Introduction

1.1 Project Brief

The Marlborough District Council (MDC) coastal monitoring strategy (Tiernan 2012) identifies priorities for long-term coastal and estuarine monitoring in the region. This includes fine scale monitoring of intertidal sediments and broad scale habitat mapping in key estuaries. As part of this work, MDC recently engaged Robertson Environmental to assess several existing fine scale monitoring sites within Havelock Estuary located at the head of Pelorus Sound, Marlborough (Figure 1). The purpose of the work was to provide MDC with information on the estuary's ecological condition for state of the environment monitoring purposes and to help support planning and resource consent decision-making. The following report describes the methods and results of fine scale sampling and sediment plate monitoring undertaken in January 2019.

1.2 Background

Estuary monitoring in NZ generally comprises three components developed from the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002) to address major issues identified in NZ estuaries (see Appendix A). The tiered approach includes:

i. Ecological Vulnerability Assessment (EVA) of estuaries to major coastal issues and the design of prioritised and targeted monitoring programmes. This has been partially completed for Havelock Estuary through a preliminary assessment for NZ Landcare Trust (Robertson and Stevens 2009), within the MDC coastal monitoring strategy (Tiernan 2012), and in reports documenting ecologically significant marine sites in Marlborough (e.g. Davidson et al. 2011). The specific vulnerability of Havelock Estuary to key coastal issues has not yet been specifically assessed.

ii. Broad Scale Habitat Mapping (NEMP approach). This component documents the key biophysical features and habitats within the estuary, enables changes to these habitats to be assessed over time, and is used to define fine scale monitoring needs and management priorities. Broad scale mapping of Havelock Estuary was undertaken in 2001 (Robertson et al. 2002) and 2014 (Stevens and Robertson 2014). The current report describes a repeat of broad scale habitat mapping undertaken in early 2019.

iii. Fine Scale Monitoring (NEMP approach): Monitoring physical, chemical and biological indicators within estuary sediments. This component, which provides more detailed information on the condition of Havelock Estuary, was first undertaken in 2001 (Robertson et al. 2002), subsequently in 2014 (Robertson and Robertson 2014), 2015 (Stevens and Robertson 2017) and 2017 (Stevens 2017), and repeated in 2019 (this report).

This report focuses on detailed fine scale monitoring undertaken in January 2019 to assess the current state of Havelock Estuary and uses a range of established fine scale indicators to assess ecological condition. Key sediment-based (benthic) indicators are described in Table 1 and Appendix A and include assessment of:

- Grainsize distributions (e.g. mud, sand);
- Sediment oxygenation;
- Nutrients (e.g. nitrogen, organic carbon);
- Trace metals (e.g. zinc, copper, lead);
- Sediment-dwelling macroinvertebrate communities.

Assessment of results uses a suite of indicator ratings developed for estuarine assessment (Table 1), many of which are included in the recently developed NZ Estuary Trophic Index (ETI) (Robertson et al. 2016a,b). The NZ ETI is designed to enable the consistent assessment of estuary state in relation to nutrient enrichment, and also includes assessment criteria for sediment muddiness.

1.3 Report Structure

The current report presents a brief introduction to the Havelock Estuary (Section 1.4), the sampling methods, monitoring indicators and assessment criteria used (Section 2), and results and discussion of the field sampling (Section 3). To help the reader interpret the 2019 monitoring findings, results are related to relevant condition and/or risk indicator ratings to facilitate the assessment of overall fine scale estuary condition (summarised in Section 4 with conclusions in Section 5), and to guide monitoring/management recommendations (Section 6).

1.4 Site Details and Previous Investigations

Havelock Estuary is a large (~800 ha, Robertson et al. 2002; Stevens and Robertson 2014) shallow, intertidal dominated (SIDE; NZ ETI classification in Robertson et al. 2016a) type estuary situated at the head of Pelorus Sound, a long, deep, subtidally dominated estuary (DSDE) (Figure 1). Formed by the sediment output from the Kaituna and Pelorus Rivers (mean flows 3.7 and 45 $m^3.s^{-1}$ respectively), the estuary is macrotidal (2.17 m spring tidal range), has one opening, one main basin, and several poorly flushed tidal arms.

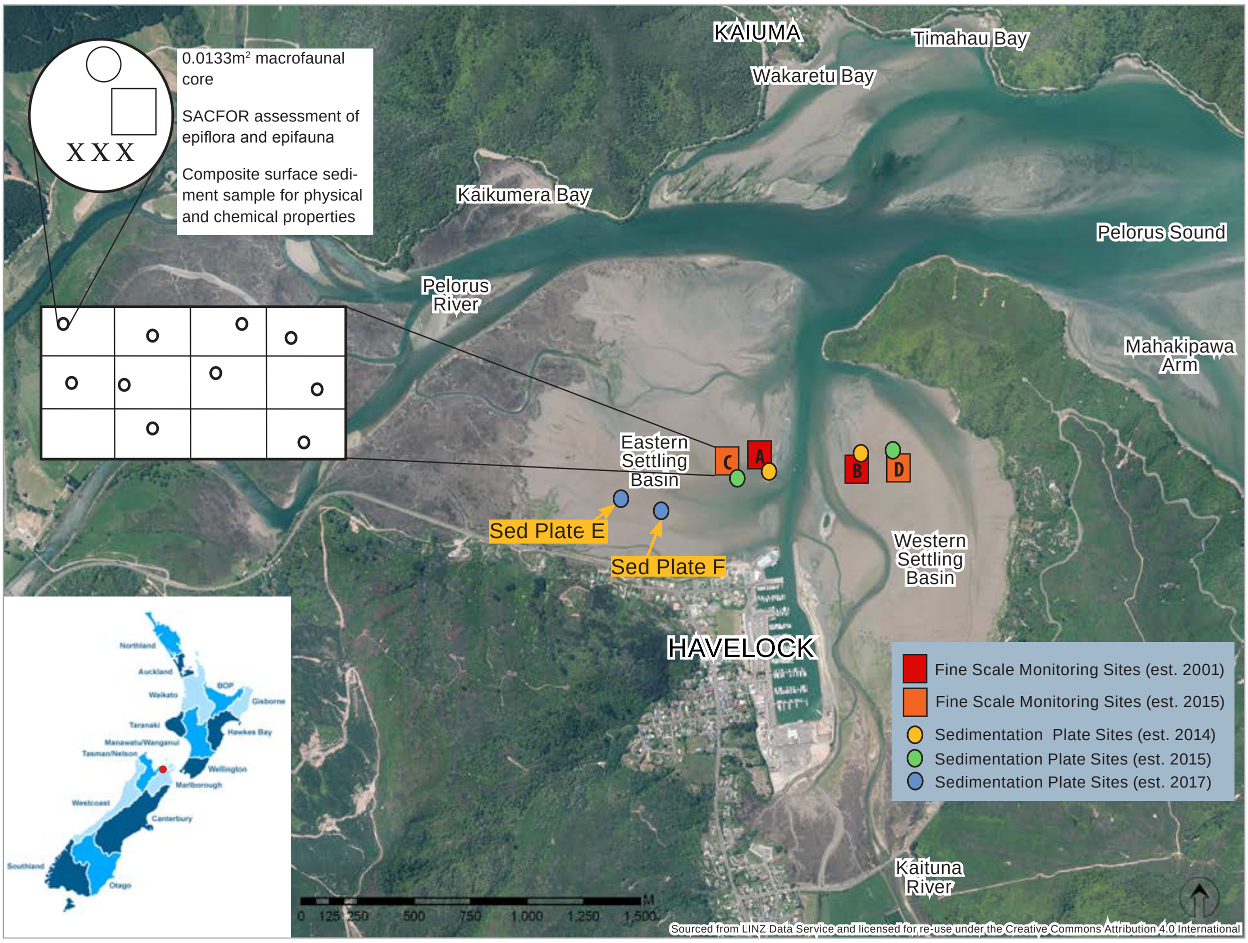


Figure 1. Havelock Estuary, including location of fine scale sampling (A-D) and sediment plate (A-F) monitoring sites, sampling approach, and regions vulnerable to sedimentation impacts (settling basins).

The estuary has high use and is valued for its aesthetic appeal, biodiversity, shellfish collection, bathing, waste assimilation, whitebaiting, fishing, boating, walking, and scientific appeal. It is recognised as a valuable nursery area for marine and freshwater fish, an extensive shellfish resource, and is very important for birdlife. A small port and marina is located at Havelock near the Kaituna River mouth.

The catchment (1,149 km^2) is partially developed and dominated by native forest (72%), exotic forestry (14%), dairying (4%), other pasture (8%) and scrub (2%) (source LCDB4, 2012/13). Part of the estuary margin is directly bordered by developed urban and rural land, roads, and seawalls. Like much of the Marlborough Sounds, Pelorus Sound is a drowned valley system characterised by steep hillsides that slope directly to narrow rocky shorelines. Intertidal estuarine flats are largely confined to the upper tidal reaches of the elongate and narrow arms where sediment deposition from catchment erosion contributes to the natural build up of river and stream deltas (Figure 1). The extent and nature of the intertidal estuarine deltas is determined largely by the combined influences of the underlying geology, the size and steepness of the catchment, and the volume of freshwater flowing to the coast. The type of land cover also has a strong influence on substrata composition, particularly as rates of sediment erosion (and subsequent deposition at the coast) are increased where land cover is disturbed either through natural events such as landslides or fires, or more commonly through human activities such as land clearance for farming or forestry. The drainage of wetland areas (which are very effective at trapping terrestrial sediments) can also significantly increase the delivery of fine sediment to coastal areas.

Despite the catchment being dominated by mixed native and exotic forest/scrub and hard sedimentary rock types which do not readily erode, the terrain is often steep, and therefore erosion can be elevated from developed areas. This erosion is exacerbated by the frequent and high rainfall in the catchments, which in a typical year has several rainfall events that deliver between 50-200 mm of rain in one day. As a consequence, freshwater inputs to Havelock Estuary tend to include intermittent pulses that carry elevated loads of suspended sediments and nutrients, some of which settle in the estuary, promoting a mud-dominated benthic environment (>70% of intertidal flats characterised by soft/very soft muds), with low clarity water, while the remainder settles in the deeper waters of the subtidal zone - the predominant area of fine sediment deposition in the Marlborough Sounds (see Handley et al. 2017). The cloudy waters and muddy bed can lead to the loss of high value seagrass from intertidal and shallow subtidal areas, and reduced phytoplankton production, seabed life and fish communities. However, due to the relatively large area of upper intertidal shallows, the estuary has extensive beds of high value saltmarsh (predominantly jointed wire rush and sea rush), that provide important habitat for birdlife, macroinvertebrates and, at high water, likely fish.

The highly elevated mud content of the estuary has also provided ideal habitat for the invasion of opportunists (both plant and animal) such as the introduced cordgrass (*Spartina townsendii)* and the Pacific oyster (*Crassostrea gigas*), both acting as stabilisers of the mud. Both species established new habitat on unvegetated estuary flats and therefore caused limited displacement of native species. Currently Pacific oyster distribution is expanding in the estuary but *Spartina* has been eradicated, releasing a large amount of mud and associated nutrients to the water column for redistribution within the estuary (e.g. through erosion of fine sediments previously bound up in root masses) and adjacent sounds.

In terms of catchment loading rates, the estuary receives a relatively moderate nutrient load (estimated catchment total nitrogen (N) areal loading of ~70 mg N m^{-2} d^{-1} which is approaching the proposed guideline for SIDE estuaries of ~100 mg N m^{-2} d^{-1} (Robertson et al. 2016b; Robertson 2018; Robertson & Savage in review), and consequently currently has moderate susceptibility to eutrophication. This is supported by previous surveys of Havelock Estuary which identified localised macroalgal blooms (restricted to poorly flushed upper estuary habitat) as a primary catchment-related issue in the estuary.

Estimated current suspended sediment load (CSSL) compared to the estimated natural state sediment load (NSSL) is 2.4 equates to a ratio of 2.4 (see details in Appendix F), an NZ ETI rating of moderate, indicating that the current sedimentation rate is likely to exceed the natural state sedimentation rate and therefore contribute to sedimentation issues in the estuary, despite the relatively high forest/scrub cover in the catchment.

A 2009 synoptic catchment impact assessment (Robertson and Stevens 2009) and subsequent broad scale (Stevens and Robertson 2014) and fine scale (Robertson and Robertson 2014) surveys identified excessive muddiness, highly localised macroalgal issues, and moderate disease risk as the most significant catchment-related issues in the estuary.

Havelock Estuary is currently being broad scale habitat mapped every five years, and the 2019 fine scale survey (this report) marks the final survey of a three (Sites C and D) and four (Sites A and B) consecutive year baseline at four established monitoring sites (Figure 1). This latter monitoring yields quantitative results, which are used to determine the extent to which the estuary is affected by major estuary issues (Appendix A), and to provide a baseline to detect future changes in physical, chemical, and biological parameters.

2 Sampling Methodology

2.1 Fine Scale Monitoring

Fine scale monitoring is based on the methods described in the National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002), and subsequent extensions (e.g. Robertson et al. 2016b) and provides detailed information on indicators of chemical and biological condition of the dominant habitat type in the estuary. This is most commonly unvegetated intertidal mudflats at low-mid water in SIDEs estuaries. Synoptic water quality samples from surface and bottom waters, and subtidal sediment samples, are also collected to support intertidal assessments where SIDE estuaries include subtidal habitat that is at risk from eutrophication and sedimentation (e.g. deep stratified areas or main channel sections in estuaries where the mouth is restricted). This latter monitoring was not considered necessary for Havelock Estuary at this point in time.

Using the outputs of the broad scale habitat mapping, representative sampling sites (actual number varies with estuary size) are selected and samples collected and analysed for the following variables:

- Salinity, Oxygenation (Redox Potential Discontinuity depth - aRPD or RPmV), Grain size (% mud, sand, gravel);
- Organic Matter and Nutrients: Total Organic Carbon (TOC), Total Nitrogen (TN), Total Phosphorus (TP). Note for TN, when the analytical detection limit (500 mg kg^{-1}) is not exceeded, samples will default into NZ ETI Band B (Table 1);
- Heavy Metals and Metalloids: Antimony (Sb), Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Nickel (Ni), and Zinc (Zn) plus mercury (Hg) and Arsenic (As). Analyses are based on non-normalised whole sample fractions to allow direct comparison with ANZECC (2000) Guidelines;
- Macroinvertebrate abundance and diversity (infauna and epifauna);
- Other potentially toxic contaminants: these are measured in certain estuaries where a risk has been identified.

For Havelock Estuary, four fine scale sampling sites have been established in the estuary (Figure 1). Sites A and B were established in 2001 in unvegetated, mid-low water firm muddy sand/soft mud habitat (Robertson et al. 2002) and, in 2015, Sites C and D were established in the dominant very soft mud habitat of the estuary. At both sites, a 60 m x 30 m area in the lower intertidal zone was marked out and divided into 12 equal sized plots. Within each area, ten plots were selected, a random position defined within each (precise locations are in Appendix C and field photos in Appendix H), with sampling undertaken as follows:

Physicochemical Analyses: At each site, average apparent Redox Potential Discontinuity (aRPD) depth was recorded within three representative plots, and redox potential (mV) was directly measured with an oxidation-reduction potential (ORP) meter at 0, 1, 3, 6 and 10 cm depths below the surface in three plots. Three samples (two a composite from four plots and one a composite from two plots) of the top 20 mm of sediment (each approx. 250 g for trace metals and nutrients and 500 g for grainsize) were collected adjacent to each macroinvertebrate core (composite sample details in Appendix C) for chemical analysis. All samples were kept in a chilly bin in the field before dispatch to R.J. Hill Laboratories for chemical analysis (raw data and details of lab methods and detection limits in Appendices C and D). Samples were tracked using standard Chain of Custody forms and results checked and transferred electronically to avoid transcription errors. Photographs were taken to record the general site appearance.

Infauna (animals within sediments) and Epiflora/Fauna (surface dwelling plants and animals): From each of 10 plots, 1 randomly placed sediment core [130 mm diameter (area = 0.0133 m^2) tube] was taken. The core tube was manually driven 150 mm into the sediments, removed with the core intact and inverted into a labelled 0.5 mm nylon mesh bag. Once all replicates had been collected at a site, the bags were transported to a nearby source of seawater and fine sediments were washed from the core. The infauna remaining were carefully emptied into a plastic container with a waterproof label and preserved in 70% isopropyl alcohol - seawater solution.

Table 1. Summary of NZ ETI condition and risk indicator ratings used in the present report.

NZ ETI Condition Bands and Risk Indicator Ratings (indicate risk of adverse ecological impacts)					
Fine Scale Indicators	NZ ETI Condition Rating*	Very Good (Band A)	Good (Band B)	Moderate (Band C)	Poor (Band D)
	Risk Rating	Very Low Risk	Low Risk	Moderate Risk	High Risk
Apparent Redox Potential Discontinuity (aRPD)***		Unreliable	Unreliable	0.5 - 2 cm	<0.5 cm
Redox Potential (mV) upper 3cm***		>+100	-50 to +100	-50 to -150	<-150
Sediment Mud Content (%mud)*		<5%	5-15%	>15-25%	>25%
Macroinvertebrate Enrichment Index (NZ (Hybrid RI) AMBI)****		0 - 1.2 None to minor stress on benthic fauna	>1.2 - 3.3 Minor to moderate stress on benthic fauna	>3.3 - 4.3 Moderate to high stress on benthic fauna	>4.3 - 7.0 Persistent, high stress on benthic fauna
Total Organic Carbon (TOC)*		<0.5%	0.5-<1%	1-<2%	>2%
Total Nitrogen (TN)*		<250 mg kg^{-1}	250-1000 mg kg^{-1}	>1000-2000 mg kg^{-1}	>2000 mg kg^{-1}
Trace Metals		<0.2 x ISQG Low	0.2 - 0.5 x ISQG Low	0.5 x to ISQG Low	>ISQG Low
	NZ ETI score*	**0 - 0.25**	**0.25 - 0.50**	**0.50 - 0.75**	**0.75 - 1.0**

*NZ ETI (Robertson et al. 2016b), ***Hargrave et al. (2008), Robertson (2018), and Keeley et al. (2012), **** Robertson et al. (2016) - Refer to Appendix B for further information.

The processed samples were sent to a commercial laboratory (SLR Consulting, Nelson) for taxonomic identification and QA/QC procedures as per Hewitt et al. (2014). Where present, macroalgae and seagrass vegetation (including roots) was collected within each of three representative 0.0625 m^2 quadrats, squeezed (to remove free water), and weighed in the field. In addition, the % cover of each plant type was measured. Conspicuous epifauna visible on the sediment surface within the designated sampling area were semi-quantitatively assessed based on the UK MarClim approach (MNCR 1990, Hiscock 1996, 1998). Epifauna are identified and allocated a SACFOR abundance category based on percentage cover (Table A, Appendix C), or by counting individual organisms >5 mm in size within quadrats placed in representative areas (Table B, Appendix C). Species size determines both the quadrat size and SACFOR density rating applied, while photographs are taken and archived for future reference. This method is ideally suited to characterise often patchy intertidal epifauna, and macroalgal and microalgal cover.

Sedimentation Plate Deployment: Determining the future sedimentation rate involves a simple method of measuring how much sediment builds up over a buried plate over time. Once a plate has been buried and levelled, probes are pushed into the sediment until they hit the plate and the penetration depth is measured. A number of measurements on each plate are averaged to account for irregular sediment surfaces, and a number of plates are buried to account for small scale variance.

Four sites, each with four plates (20 cm square concrete paving stones) have previously been established in Havelock Estuary at fine scale Sites A and B (2014) and Sites C and D (2015). In 2017, two additional sites were established in the western basin of the estuary (Sites E and F). Site F corresponds to NIWA site HV-2, sampled in March 2017 to estimate the historical accrual of sediment in the estuary.

Plates were buried within the sediments where stable substrate was located and positioned 2 m apart in a linear configuration along the baseline of each fine scale site or a transect line. Wooden pegs were used to mark the start, middle and end of each transect (0 m, 5 m and 10 m respectively). To ensure plate stability, steel waratahs (0.8 or 1.6 m long) were driven into the sediments until firm substrate was encountered beneath the plates, and the plates placed on these. Steel reinforcing rod was also placed horizontally next to buried plates to enable relocation with a metal detector.

The GPS positions of each plate were logged, and the depth from the undisturbed mud surface to the top of the sediment plate recorded using a 2 m long strait edge, sediment probe, and ruler (results in Appendix C). In the future, it is recommended that these depths be measured annually which, over the long term, will help provide an indicative measure of the rate of sedimentation in the estuary. In addition, while the current sediment plate monitoring sites are considered fit-for-purpose with regard to setup and configuration, it is recommended that future deployment of additional sediment plates in the estuary should follow the methodologies proposed in Hunt (2019).

2.2 Data Analysis

Determination of temporal variability among baseline years is unnecessary and potentially misleading in SoE estuary monitoring because the combined baseline results are used rather than individual years to assess post-baseline change. Accordingly, levels of temporal variability among “baseline” [2014 (Sites A and B only), 2015, 2017 and 2019] monitoring datasets in Havelock Estuary were not evaluated in the current report. In addition, the 2001 survey data, while included, have not been comprehensively assessed herein as they did not meet the requirements of a full baseline (3-4 consecutive years) survey [i.e. involved one-off sampling >13 years ago, and sampling effort (sample *n*) was not consistent]. In future, baseline/post-baseline comparisons should involve the use of either one-way ANOVA (tests for overall mean differences) followed by post-hoc (Tukey HSD) pair-wise comparisons (tests for between-year differences) and/or trend analyses (typically requires annual post-baseline sampling), and with reference to analytical differences between the 2001 and post-2001 data (e.g. TOC and Cd values).

With a focus on documenting the condition of Havelock Estuary in 2019, details on statistical analyses applied to the present fine scale data are described in relevant sections of this report.

3 Results and Discussion

The 2019 fine scale survey assessed benthic condition at four established intertidal monitoring sites located in the middle-lower estuary adjacent to Havelock Township and Marina. A summary of the results of the 2001 and “baseline” [2014 (Sites A and B only), 2015, 2017 and 2019] fine scale monitoring of Havelock Estuary is presented in Tables 2 (Environmental Indicators) and 4 (Biological Indicators), with detailed results in Appendices C and H. Although included, the 2001 (Sites A and B only) data have not been comprehensively assessed in the current report because (1) they did not meet the requirements of a full (3-4 consecutive years) baseline survey (i.e. involved one-off sampling >13 years ago), and (2) sampling effort differed between 2001 and baseline years (i.e. sample *n* was not consistent). Therefore any inferences based on associations between baseline and 2001 datasets should be considered with particular caution.

Analysis and discussion of the results are presented as two main steps:

1. Exploring the primary benthic environmental variables that are most likely to be driving the ecological response in relation to the key issues of sedimentation (Section 3.1), eutrophication (Section 3.2) and trace metal toxicity (Section 3.3);
2. Investigating the biological response to these environmental variables using the benthic macroinvertebrate community (Section 3.4).

In the following sections, relevant risk ratings (Table 1) are applied to assess the estuary’s condition in 2019 in relation to these said issues, with outputs intended to help the MDC address future monitoring and management needs, and to act as a comprehensive baseline to assess future change.

3.1 Sedimentation (muddiness)	**NZ ETI Condition Rating**	**Poor**
	Risk Rating	**High**

The primary environmental variables that are most likely to be driving the ecological response in relation to estuary muddiness are sediment mud content (often the primary controlling factor) and sedimentation rate. Sediment mud content data are presented and assessed alongside the sedimentation rate monitoring (2014-19) results below.

Sediment mud content (i.e. % grain size <63 µm) provides a good indication of the muddiness of a particular site. Estuaries with undeveloped catchments are generally sand dominated (i.e. grain size from 63 µm to 2 mm) with very little mud (e.g. ~1% mud at sites in the unmodified Freshwater Estuary, Stewart Island), unless naturally erosion-prone with few wetland filters (e.g. Whareama Estuary, Wairarapa). Conversely, estuaries draining developed catchments typically have high sediment mud contents (e.g. >25% mud) in the primary sediment settlement areas, for example where salinity driven flocculation occurs, or in areas that experience low energy tidal currents and waves (i.e. upper estuary intertidal margins and deeper subtidal basins). Well flushed channels or intertidal flats exposed to regular wind-wave disturbance generally have sandy sediments with a relatively low mud content (e.g. 2-10% mud).

Results showed the Havelock Estuary fine scale sites in 2019, except for Site B where average mud concentrations were moderate (18.5% mud), all had high (mean 28.7% mud at Site A, 60.6% at Site C and 49.3% mud at Site D) sediment mud contents (Table 2, Figure 2), and indicated relatively consistently high levels of mud across all fine scale sites between baseline years and most likely since 2001.

In 2019, Site B (Eastern Basin) showed the sandiest sediments, primarily because of the site’s relative proximity to the main river channel where physical scouring and access to ocean-derived sands which may intermittently mix with catchment derived muds is highest. Meanwhile, nearby Sites A, C and D showed the highest mud contents (mean 28.7-60.6% mud) reflecting each site’s physical position in the estuary as a natural deposition zone for fine muddy sediments. The overall

Table 2. Summary of fine scale physicochemical (mean, *n* = 10 in 2001, and 3 post-2001) results, Havelock Estuary, 2001, and baseline (2014, 2015, 2017, and 2019) years. *aRPD=apparent Redox Potential Discontinuity Depth.

Year/ Site[a]	Environmental Indicators																			
	Grain Size Distribution			Trace metals								Nutrients			Sediment Oxygenation					
	Mud	Sand	Gravel	Cd[d]	Cr	Cu	Ni	Pb	Zn	As	Hg	TOC[b]	TN	TP	aRPD*	Redox Profile 0 cm	1 cm	3 cm	6 cm	10 cm
	%			mg kg^{-1}								%	mg kg^{-1}		cm	mV				
2001 A	20.4	73.6	6.0	0.40	70.1	11.2	38.1	5.6	51.1	-	-	1.8	663	394	-	-	-	-	-	-
2014 A	27.2	70.9	1.9	0.04	50.7	11.6	39.3	5.8	41.7	4.4	0.04	0.6	650	380	1.0	-	-	-	-	-
2015 A	36.9	61.1	2.0	0.04	54.3	14.3	45.7	7.4	46.7	5.5	0.05	0.8	900	490	1.0	-	-	-	-	-
2017 A	23.2	74.8	1.9	0.04	47.0	11.2	42.0	5.4	40.3	4.0	0.04	1.9	<500[c]	390	0.5	-25	-332	-344	-418	-432
2019 A	28.7	68.9	2.4	0.04	51.3	10.6	40.3	5.8	44.3	4.0	0.04	0.6	633	400	1.0	-3	-218	-263	-373	-415
2001 B	17.8	80.6	1.6	0.41	27.4	10.1	14.8	5.7	34.8	-	-	1.3	<500[c]	266	-	-	-	-	-	-
2014 B	16.9	82.0	1.2	0.02	24.0	7.9	18.8	4.0	26.3	2.1	0.01	0.5	<500[c]	223	1.0	-	-	-	-	-
2015 B	18.3	81.3	0.4	0.03	23.3	8.3	20.2	4.6	28.0	2.5	0.02	0.5	800	260	1.0	-	-	-	-	-
2017 B	15.1	84.3	0.6	0.02	21.0	6.9	18.5	3.5	24.0	1.9	0.01[c]	0.6	<500[c]	217	0.5	-28	-210	-327	-364	-375
2019 B	18.5	81.2	0.2	0.02	17.0	5.6	14.0	3.4	22.0	1.4	<0.02[c]	0.2	<500[c]	193	1.0	-59	-234	-328	-386	-391
2015 C	59.9	38.5	1.6	0.04	66.3	18.4	58.0	9.1	50.0	5.1	0.07	1.2	1133	457	1.0	-	-	-	-	-
2017 C	56.4	43.1	0.6	0.05	69.0	18.9	63.3	8.3	50.7	5.5	0.06	0.6	1033	470	0.5	-25	-261	-292	-293	-320
2019 C	60.6	39.5	<0.1	0.04	66.7	15.1	52.0	7.8	49.7	4.4	0.06	1.2	1067	423	0.5	-112	-259	-280	-280	-269
2015 D	54.2	44.7	1.1	0.04	29.0	13.1	25.7	7.1	37.3	3.9	0.03	1.0	933	383	1.0	-	-	-	-	-
2017 D	39.4	59.4	1.3	0.03	22.3	10.6	21.0	5.2	29.7	2.9	0.03	1.3	700	320	0.5	-70	-300	-333	-338	-355
2019 D	49.3	49.7	1.0	0.03	24.0	9.8	18.3	5.4	32.3	2.7	<0.02[c]	0.8	667	333	0.5	-97	-226	-267	-326	-330

[a] 2001 results from Robertson et al. (2002), 2014 from Robertson and Robertson (2014), 2015 from Stevens and Robertson (2015), and 2017 from Stevens (2017).
[b] 2001 TOC data was measured as ash-free dry weight (AFDW) and converted to TOC using the following equation (TOC = AFDW x 0.25; Lindquist et al. 2008). Note: All fine scale sites including this data (i.e. Sites A and B) have been excluded from all relevant aspects of the current report (e.g. Section 3.4).
[c] below detection limit (Appendix D). Note: All fine scale sites including this data (i.e. Sites A, B and D) have been excluded from all relevant aspects of the current report (e.g. Section 3.4).
[d] 2001 results (obtained from Cawthron Lab) were often reported above the detection limit (Robertson et al. 2001). Given that such elevated Cd levels were not recorded at the same sites in later years (post-2001) by R.J. Hill Labs with much lower detection limits, it is concluded that the Cawthron methods were inaccurate in those years. Consequently, any site including 2001 data has been excluded from all relevant aspects of the current report (e.g. Section 3.4).

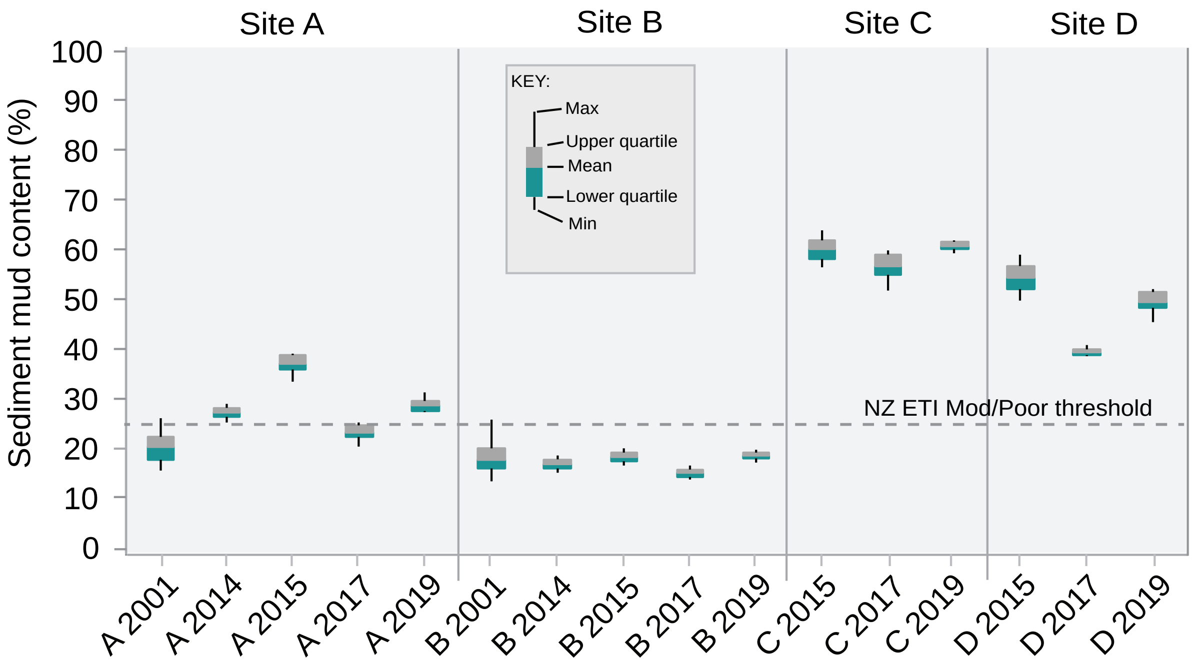


Figure 2. Mean sediment mud content (raw values, median, interquartile range, total range), Havelock Estuary, 2001 and baseline (2014, 2015, 2017 and 2019) years.

high mud content fits the NZ ETI Band D rating, and indicates the following ecological conditions are likely:

- *Significant, persistent stress on a range of aquatic organisms caused by the indicator exceeding tolerance levels. A likelihood of local extinctions of key stone species and loss of ecological integrity, especially if nutrient loads are excessive.*

In terms of sedimentation within the estuary's main intertidal basin, Table 3 presents the January 2019 sedimentation rate monitoring results for the plates buried in the Eastern (Sites A, C, E and F) and Western (Sites B and D), Havelock Estuary (refer to Figure 1 for locations), including site-averaged cumulative changes in sediment height over time (2014-2019 for SoE Sites A and B, 2015-2019 for SoE Sites C and D, and 2017-2019 for upper Western Settling Basin Sites E and F).

In the main intertidal basin where SoE Sites A, B, C and D are located, average sedimentation rates measured over the past 3-5 years have indicated moderate accural (>2-5 mm yr^{-1}), except for Site C which rated as very low (<1 mm yr^{-1}). Rates of sediment deposition were greatest in the upper Eastern Arm of the estuary (overall mean increase of 6.5 mm yr^{-1} at Site F) and was rated in the "high" category.

To document the sediment mud content at each site, and allow assessment of future changes, composite samples of surface (0-2 cm) sediment were collected from each site in 2019 (Table 3). Results showed substrata at all six monitoring sites were characterised by elevated (>20%) mud contents, with upper Western Arm Sites E and F showing the highest concentrations (>70% mud). Between 2017 and 2019, mud contents have increased (2.5-34.9%) at all sites, apart from Site C where they appear to have decreased slightly (-1.4%) (Table 4).

The results of this section, taken together, reflect a limited capacity for fine muddy sediments to be liberated and flushed once they have accumulated on the sediment surface within the estuary's mud-dominated main interidal basin. Overall, both sedimentation and muddiness remains a key ecological issue for Havelock Estuary in 2019.

Table 3. Mean sedimentation rate results showing cumulative change from baseline and average change (mm yr^{-1}) at six sites in Havelock Estuary, March 2014-January 2019. 2017/19 sediment grain size results (*n* = 1) also included.

Site	Mean cumulative change since baseline (mm)			Average change from baseline (mm yr^{-1})	Sedimentation rate condition rating	Mean sediment mud content (%) results	
	2014-15	2016-17	2018-19			2017	2019
Site A	0.0	6.8	20.8	3.5	Moderate	23.2	31.3
Site B	10.0	6.5	16.0	2.7	Moderate	19.8	20.3
Site C		-0.3	2.3	0.5	Very low	56.4	55.6
Site D		-18.8	-6.5	-1.3	Very low	39.4	45.4
Site E			12.8	4.3	Moderate	74.9	78.1
Site F			19.5	6.5	High	65.5	73.2

*changes based on sediment plate depth measurements for Sites C and D in 2015 and Sites E and F in 2017 are indicative baseline depths only which were recorded during site establishment.

3.2 Eutrophication	NZ ETI Condition Rating	Moderate
	Risk Rating	Moderate

In this section the primary variables indicating eutrophication impacts are investigated, and included sediment oxygenation [measured through apparent Redox Potential Discontinuity (aRPD) depth (cm) and down-core Redox Potential (mV)], sediment organic matter, nitrogen and phosphorus concentrations, sediment mud content, and macroalgal and seagrass cover.

Macroalgae and Seagrass

The presence of opportunistic macroalgae on the sediment surface or entrained in the sediment, can provide organic matter and nutrients to the sediment which can lead to a degraded benthic ecosystem (Robertson et al. 2016b). This is because they are highly effective at utilising excess nutrients (primarily nitrogen both from water column and sediment sources; Robertson 2018, Robertson and Savage 2018), enabling them to out-compete other seaweed and macrophyte species and, at nuisance levels, can form mats on the estuary surface which adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and saltmarsh. Decaying macroalgae can also accumulate subtidally and on shorelines causing oxygen depletion and nuisance odours and conditions. The greater the density, persistence, and extent of macroalgal entrainment within sediments, the greater the consequent impacts. In addition, seagrass (*Zostera muelleri*) cover on the sediment surface is also measured when present because seagrass can mitigate and/or offset the negative affects of eutrophication. When seagrass losses occur it provides a clear indication of a shift towards a more degraded estuary state.

Results for 2019, and previous baseline years, showed generally low macroalgal cover (<5% cover and biomass (<20 g wet weight m^{-2}) of opportunistic macroalgae, and the absence of seagrass at all sites (Table 5). The slight decrease in cover and/or biomass at all fine scale sites between 2019 and the previous sampling year (Table 5) most likely reflects temporal (seasonal and/or interannual) variability and/or recent flooding action causing scouring and a consequent reduction in macroalgal cover rather than a meaningful decline in primary eutrophication symptoms at these sites. Cover of microphytobenthos (MPB) on surface sediments was very low (if not absent) in 2019.

Sediment Muddiness

This indicator has been discussed in the previous sediment section and is not repeated here. However, in relation to eutrophication, given that elevated sediment mud content limits oxygen transfer across the water-sediment interface, the moderate-high mud contents throughout the middle-lower fine scale sites indicate sediment oxygenation is likely to be moderate-poor in that part of the estuary.

Sediment Oxygenation

The depth of the aRPD boundary provides an indirect measure of the extent of oxygenation within sediments. Results of a relevant PhD study (Robertson 2018), in which aRPD and redox potential (RP) measured directly with an ORP electrode and meter were assessed for a gradient of eutrophication symptoms, support the recommended NZ ETI aRPD and RP thresholds put forward by Hargrave et al. (2008). Figure 3 shows the aRPD depths from the surface for the five sites in 2019 and previous years. At Sites B, C and D, the aRPD depth was at a moderate depth (0.5-1 cm) in all years.

Table 4. Summary of fine scale macroalgae (mean, *n* = 3) and macrofauna (mean, *n* = 12 in 2001, and 10 post-2001) results, Havelock Estuary, 2001, and baseline (2014-19) years.

Year/Site/ Rep c	Biological Indicators								
	Primary Producers						Secondary Producers		
	Seagrass	Micro-phytob-enthos	Macroalgae				Macrofauna		
	Cover		Dominant Species	Cover	Bio-mass	Sedi-ment en-trained	Abun-dance	Rich-ness	NZ AMBI[a]
	%			%	g m^{-2}	Yes/No	per core		
2001 A	-	-	-	-	-	-	27.3	11.5	2.4
2014 A	-	-	-	-	-	-	24.1	9.2	2.1
2015 A	-	-	-	-	-	-	21.2	8.2	2.1
2017 A	-	-	*Gracilaria chilensis*	20	110	-	21.3	8.8	2.3
2019 A	-	Not present	*Gracilaria chilensis*	<5	<20	No	19.1	8.1	2.2
2001 B	-	-	-	-	-	-	18.7	6.3	2.6
2014 B	-	-	-	-	-	-	14.1	7.4	1.8
2015 B	-	-	-	-	-	-	17.6	7.7	1.8
2017 B	-	-	*Gracilaria chilensis*	<5	20	-	14.4	6.9	2.3
2019 B	-	Not present	*Gracilaria chilensis*	<5	<20	No	13.5	7.6	2.1
2015 C	-	-	-	-	-	-	18.2	6.6	2.6
2017 C	-	-	*Gracilaria chilensis*	<5	510	-	14.5	7.2	2.7
2019 C	-	<5	*Gracilaria chilensis*	<5	<20	No	12.1	6.1	2.4
2015 D	-	-	-	-	-	-	10.5	5.8	2.6
2017 D	-	-	*Gracilaria chilensis*	<5	50	-	8.6	5.7	2.6
2019 D	-	Not present	*Gracilaria chilensis*	<5	<20	No	9.3	4.5	2.9

[a] NZ (R-Hybrid EGs) AMBI (Robertson et al. 2015, 2016).

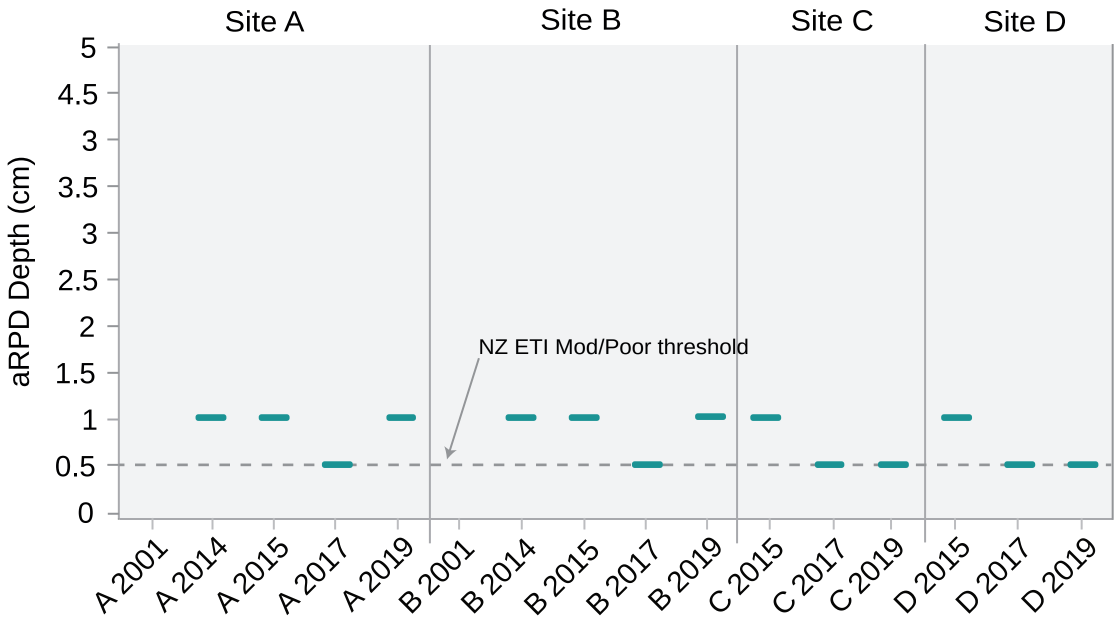


Figure 3. Mean apparent Redox Potential Discontinuity (aRPD) depth, Havelock Estuary, 2014-19, *n* = 3.

The more recent (2017 and 2019), and more accurate, redox potential data (measured directly with an ORP electrode and meter) for the fine scale sites (Figure 4) identified moderate-poor oxygenation conditions throughout the majority of sediment profiles (i.e. <-150mV below 1 cm) at all sites, with surface (0-1 cm) sediments slightly more well oxygenated (i.e. >-150mV) than those below. While these findings support the absence of advanced eutrophication symptoms, in this case highly anoxic surface sediments, from the bulk of the estuary in 2019 (Robertson 2019), the apparent lack of oxygen below ~1 cm means sediments were likely to support an impacted macrofaunal community. Profiles were mostly comparable between 2017 and 2019, but were slightly less anoxic (i.e. more positive redox values) at Sites A and D (1-6 cm depths) in 2019. This was most likely to be related to bioturbation (reworking) of sediments by macrofauna (discussed in Section 3.4 below).

Total Organic Carbon and Nutrients

The concentrations of sediment organic carbon (TOC) and nutrients (TN and TP) provide valuable trophic state information. In particular, if concentrations are elevated and eutrophication symptoms are present [i.e. shallow aRPD, excessive algal growth, high NZ AMBI biotic coefficient (see the following macroinvertebrate condition section)], then elevated TN, TP and TOC concentrations provide strong supporting information to indicate that loadings are exceeding the assimilative capacity of the estuary.

The Havelock Estuary results for 2019, and most previous years, showed TOC and TN were usually in the very low-low risk indicator ratings at Sites A, B and D. At Site C, where very soft muddy (>60% mud) substrata dominate (Table 2), conditions showed slightly greater enrichment and a moderate risk rating. The TP results (rating not yet developed) showed a similar pattern of moderate levels at Site C, and lower levels at Sites A, B and D (Figure 5).

Overall, the results in this section support an absence of advanced eutrophication symptoms (i.e. dense macroalgal canopy underlain by sediments with surface anoxia and highly elevated concentrations of organic carbon and nutrients) from the wider middle-lower interidal basin as reported in Robertson (2019). However, on the basis of all fine scale sites exhibiting a muddiness/moderate-poor oxygenation issue, a combined condition/risk rating of moderate has been applied in relation to eutrophication stress across the four fine scale sites assessed.

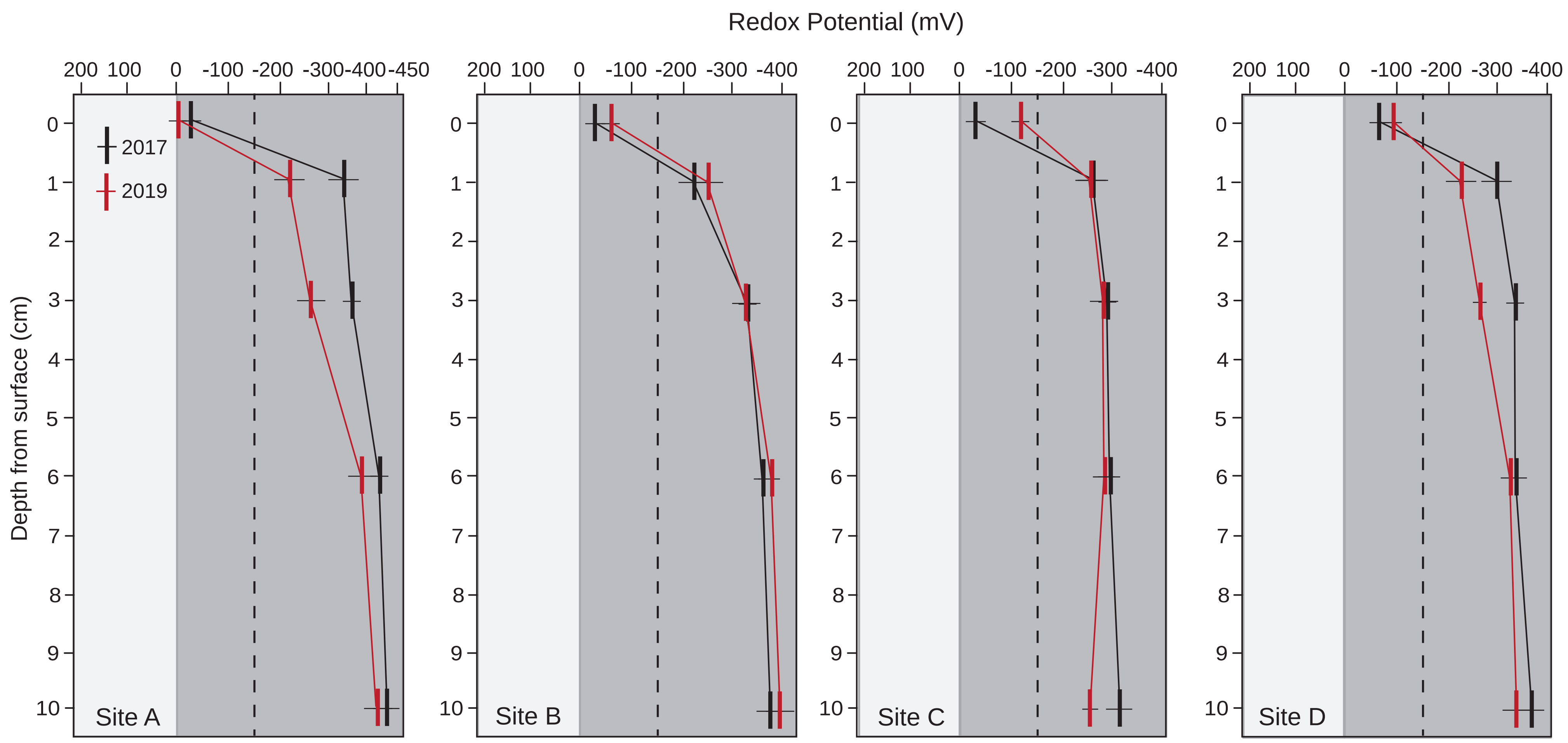


Figure 4. Mean (n = 3, ±SD) down-core sediment Redox Potential (mV) measured at 0, 1, 3, 6 and 10 cm depths at six fine scale sites, Havelock Estuary, 2017 and 2019. Dashed line indicates NZ ETI Moderate/Poor threshold.

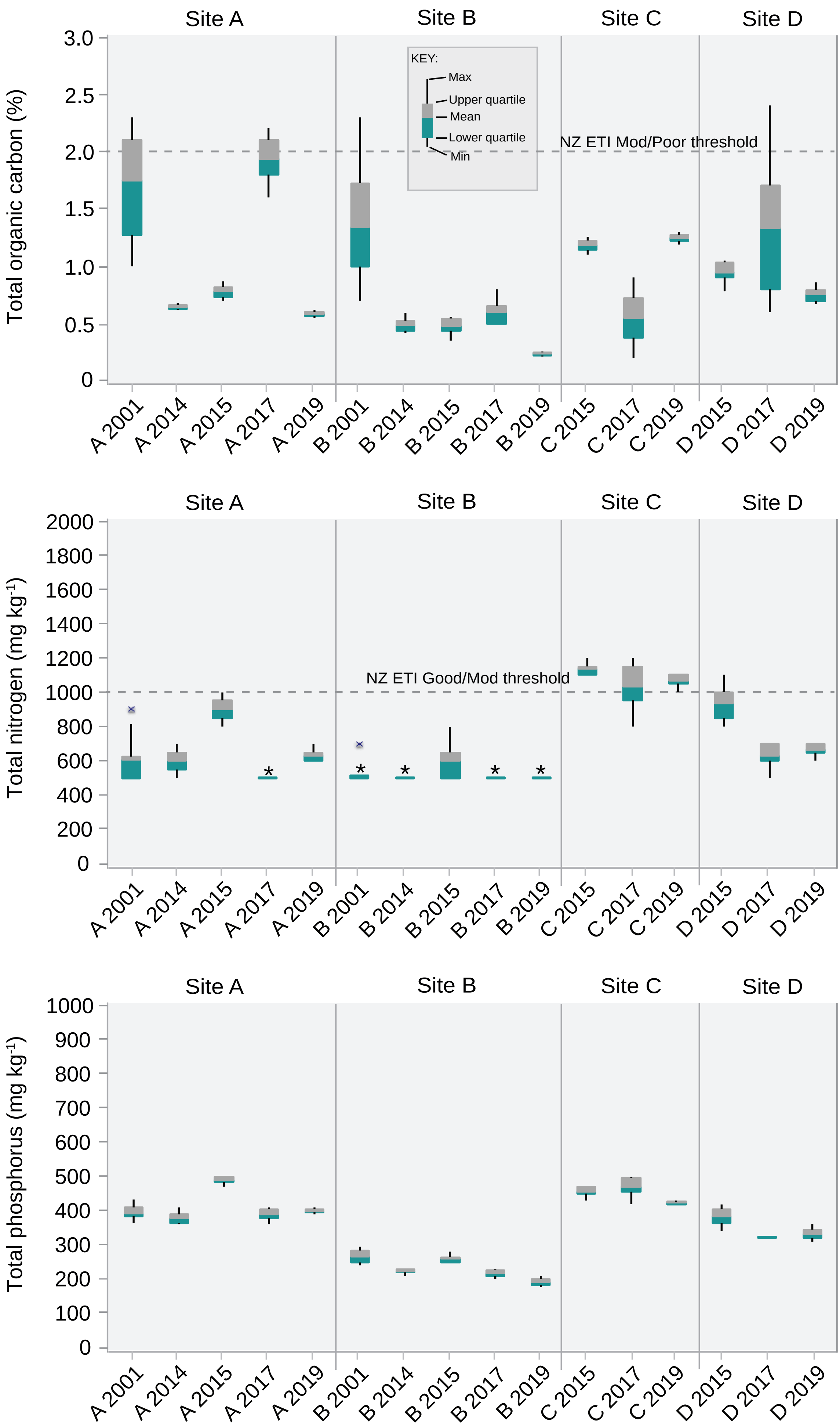


Figure 5. Mean total organic carbon, nitrogen and phosphorus, Havelock Estuary, 2001, 2014 - 2019. *denotes total nitrogen sample data below detection limit (<500 mg kg[-1]). NZ ETI rating not developed for total phosphorus.

3.3 Trace Metal Toxicity	NZ ETI Condition Rating	Good
	Risk Rating	Low

The influence of non-eutrophication related toxicity is primarily indicated by concentrations of trace metals, with pesticides, PAHs, and SVOCs generally only assessed where inputs are likely, or trace metal concentrations are found to be elevated beyond natural levels.

The results for the heavy metals Cd, Cr, Cu, Hg, Pb, Ni, Zn, As and Hg (indicators of potential toxicants) were at “very low” to “low” concentrations in all years at all sites (Appendices C and E). However, nickel and chromium at Sites A and C were present at concentrations exceeding the ISQG Low Trigger limits (Appendix C). This exceedance was likely attributable to elevated inputs in run-off from the geologically nickel and chromium enriched catchment (Robinson et al. 1996, Rattenbury et al. 1998), and the high affinity of heavy metals for muds acting to transport and sequester them into estuarine sediments (Whitehouse et al. 1999). Such findings are typical of other estuaries in the Tasman Bay/Marlborough region. In such cases as this, where the ISQG Low limit is exceeded, but not the ISQG High limit, and the likely cause is natural, the ANZECC (2000) guidelines recommend no further investigation.

Although baseline concentrations for the majority of trace metals across the fine scale sites in Havelock Estuary were below the ANZECC (2000) ISQG-Low trigger values (i.e. no toxicity threat to aquatic life expected), a relevant study indicates that even at such low levels trace metals can influence macrofaunal assemblages in NZ estuaries (e.g. Rodil et al. 2016). For this reason, their potential influence on macrofaunal community structure in Havelock Estuary has been assessed in this report.

3.4 Macroinvertebrate Community Condition	NZ ETI Condition Rating	Good
	Risk Rating	Low

Benthic macroinvertebrate communities are considered good indicators of ecosystem health in shallow estuaries because of their strong primary linkage to sediments and secondary linkage to the water column (Dauer et al. 2000, Thrush et al. 2003, Warwick and Pearson 1987, Robertson et al. 2016, Robertson 2018). Because they integrate recent disturbance history in the sediment, macroinvertebrate communities are therefore very effective in showing the combined effects of pollutants or stressors, particularly as it relates to increased muddiness and organic enrichment.

To determine the condition of macroinvertebrates in relation to measured environmental conditions in Havelock Estuary during baseline (2014-2019) years and 2001, the following four-pronged (community-level down to taxon-specific) approach has been applied:

1. Ordination plots to enable an initial visual overview (in 2-dimensions) of the spatial and temporal structure of the macroinvertebrate community at each fine scale site;
2. The BIO-ENV program in the PRIMER (v6) package was used to evaluate and compare the relative importance of environmental factors and their influence on the identified macrobenthic communities;
3. Assessment of species richness, abundance, diversity (including taxonomic and feeding groups); and,
4. Assessment of the response of the macroinvertebrate community to increasing mud and organic matter among fine scale sites over time, based on identified tolerance thresholds for NZ taxa coupled with the NZ (Hybrid RI) AMBI benthic index (Robertson et al. 2015, 2016). Outputs from this latter step were used to apply the above NZ ETI Condition/Risk Rating.

Macroinvertebrate Community Ordination

Principle Coordinate Analysis (PCO - refer to Appendix G for supporting details), based on macrofaunal abundance data collected at Sites A, B, C and D, revealed only subtle structural differences in macroinvertebrate communities across baseline years (Figure 6a,b,c), with slightly more pronounced differences observed at Sites A and B when compared to 2001 data. Generally speaking, these results suggest macrofaunal community composition within the estuary's main intertidal basin has not changed substantially since the 2014, and most likely 2001, surveys.

Vector overlays of environmental variables (based on Spearman correlations) are also presented in order to provide preliminary information in relation to the potential influence (if any) of environmental factors on macrofaunal community structure at monitoring sites over the years. To avoid potential multicolinearity (i.e. when there are high correlations among environmental variables, leading to unreliable and unstable results), environmental factors were retained in the models only where Variable Inflation Factors (VIF) were <10 (Lin, 2008) and regression coefficients (R^2) <0.9 (Chen and Rothschild, 2010).

The results identified likely partial explanations for the subtle differences in community structure between these years. Comparison of the macrofaunal results with environmental factors using the BIOENV procedure (correlates rank values of faunal similarities between sites with rank Euclidean distances based on environmental factors between sites) indicated the following at each site:

- At Site A, the combination of sediment mud and zinc was weakly correlated with the faunal results (Spearman correlation coefficient rho = 0.27);
- At Site B, the combination of sediment oxygenation (measured via aRPD depth) and copper concentrations was moderately correlated with the faunal results (Spearman correlation coefficient rho = 0.50);

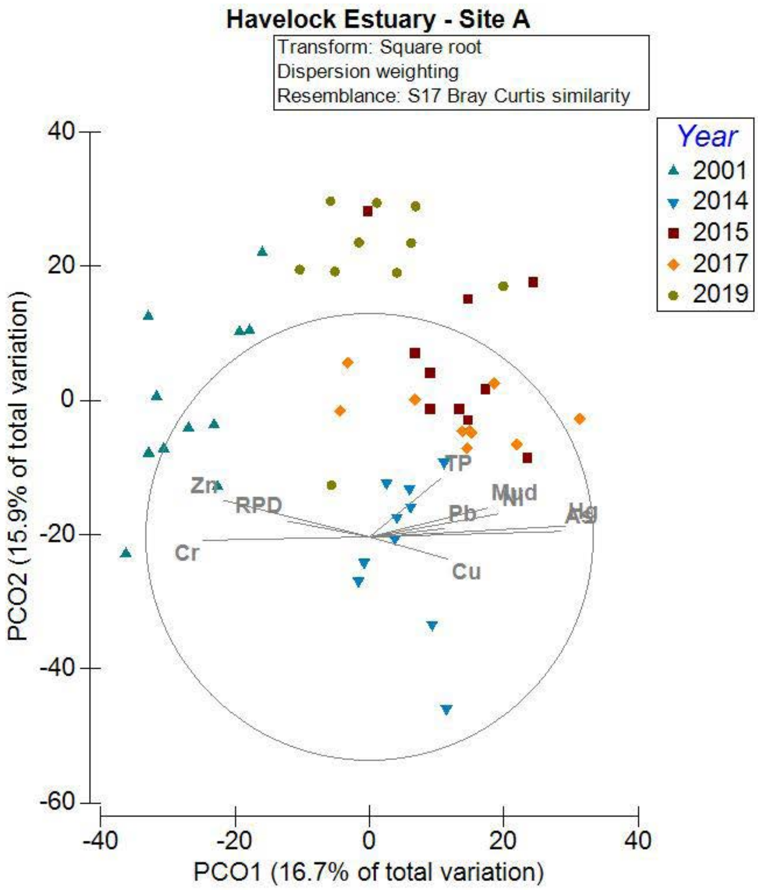
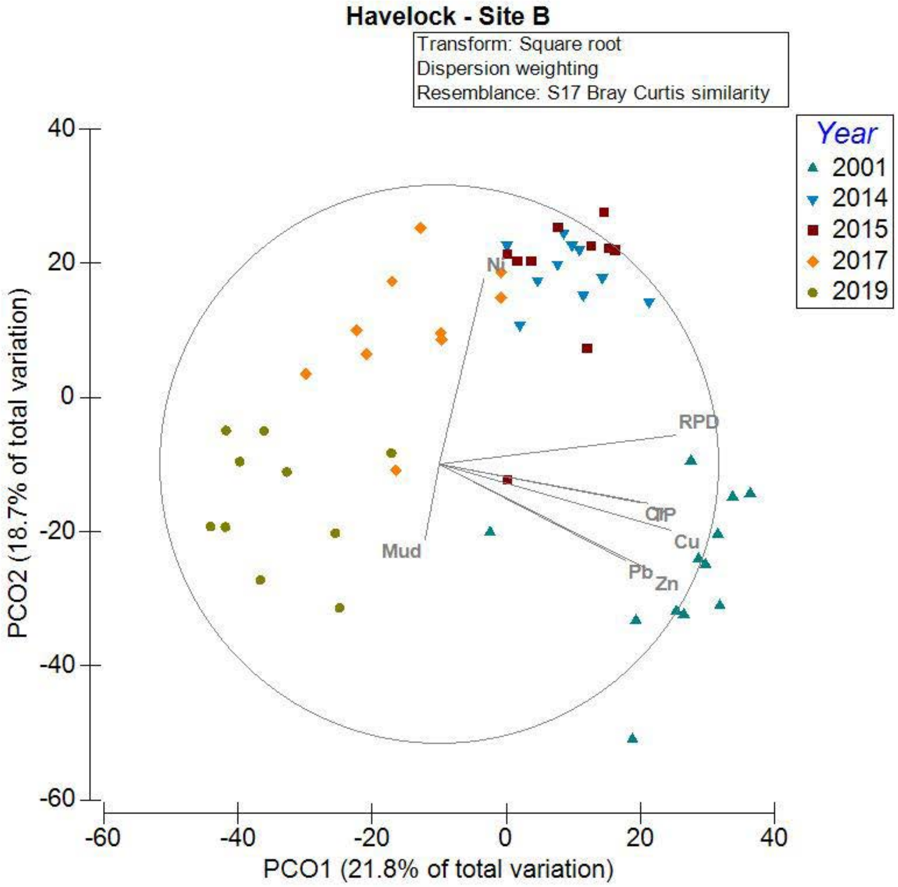


Figure 6a. Principle coordinates analysis (PCO) ordination plots and vector overlays reflecting structural differences in the macroinvertebrate community at Site A, and the environmental variables mud and zinc that partially explain any observed differences.



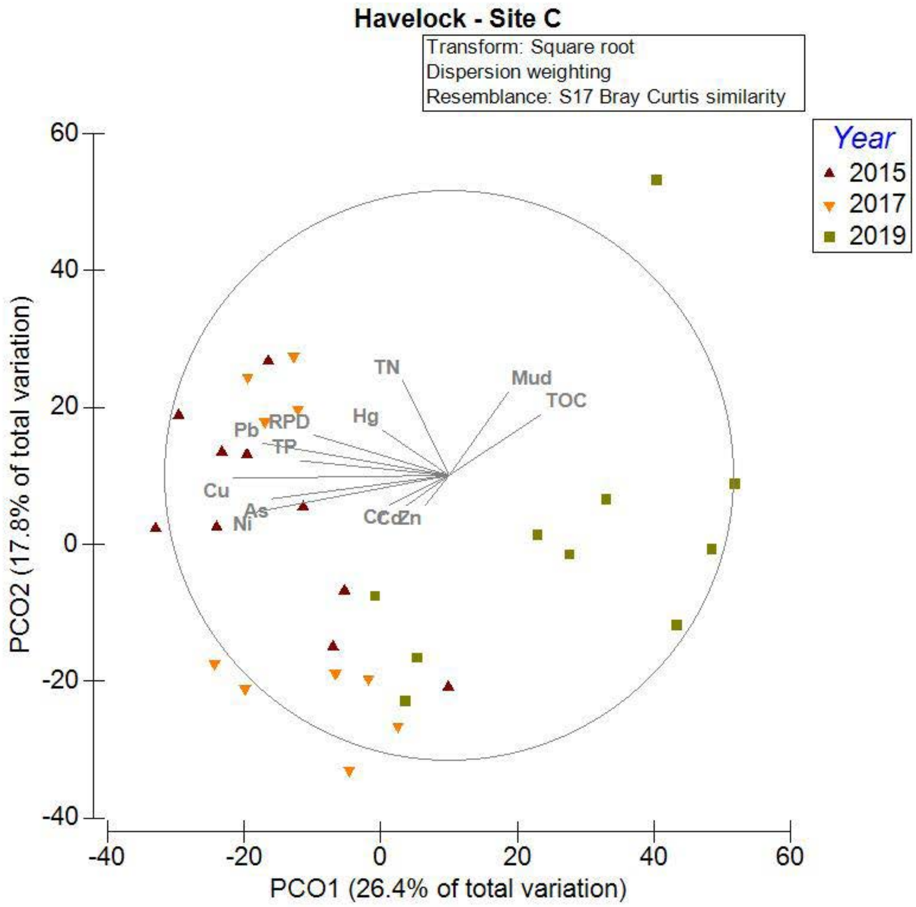


Figure 6b. Principle coordinates analysis (PCO) ordination plots and vector overlays reflecting structural differences in the macroinvertebrate community at Sites B (top graph) and C (bottom graph), and the environmental variables aRPD depth and copper (Site B) and copper (Site C) that partially explain any observed differences.

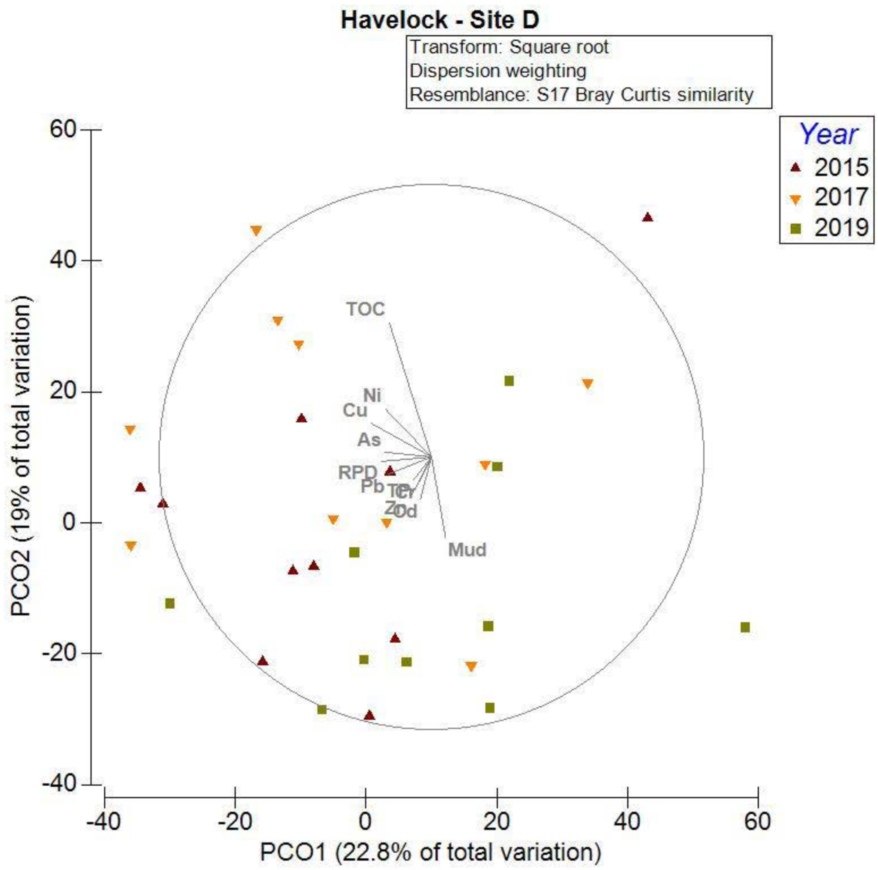


Figure 6c. Principle coordinates analysis (PCO) ordination plots and vector overlays reflecting structural differences in the macroinvertebrate community at Site D, and the environmental variables TOC and cadmium that partially explain any observed differences.

- At Site C, copper content was relatively moderately correlated with the faunal results (Spearman correlation coefficient rho = 0.40); and,
- At Site D, TOC and cadmium was relatively moderately correlated with the faunal results (Spearman correlation coefficient rho = 0.30).

Richness, Abundance and Diversity

The next step was to assess whether simple univariate whole community indices, richness (no. of taxa), abundance and diversity at each site (Figure 7), could help explain the small differences in community structure between years indicated by the PCO analyses.

Figure 8 shows that across all fine scale sites and sampling years in Havelock Estuary, there was relatively low mean taxa richness (4.5-11.5 per core), abundance (8.6-27.3 per core) and Shannon diversity (0.19-0.23 per core), reflecting each site's muddy and poorly oxygenated substrata when compared to less impacted NZ SIDE type estuaries (e.g. Freshwater Estuary, Stewart Island, or Westhaven Inlet, Tasman). Visual comparison of the 2019 and previous monitoring results indicate that all three measures at each of the fine scale sites appear to have remained relatively stable with only small fluctuations overtime, as is supported by overlapping box and whiskers for each site and year indicating that mean values were not likely to be different. Notwithstanding, these small fluctuations most likely partially contributed to the subtle differences among baseline years and 2001 (Sites A and B) as portrayed in the PCO plots (Figure 6a,b,c).

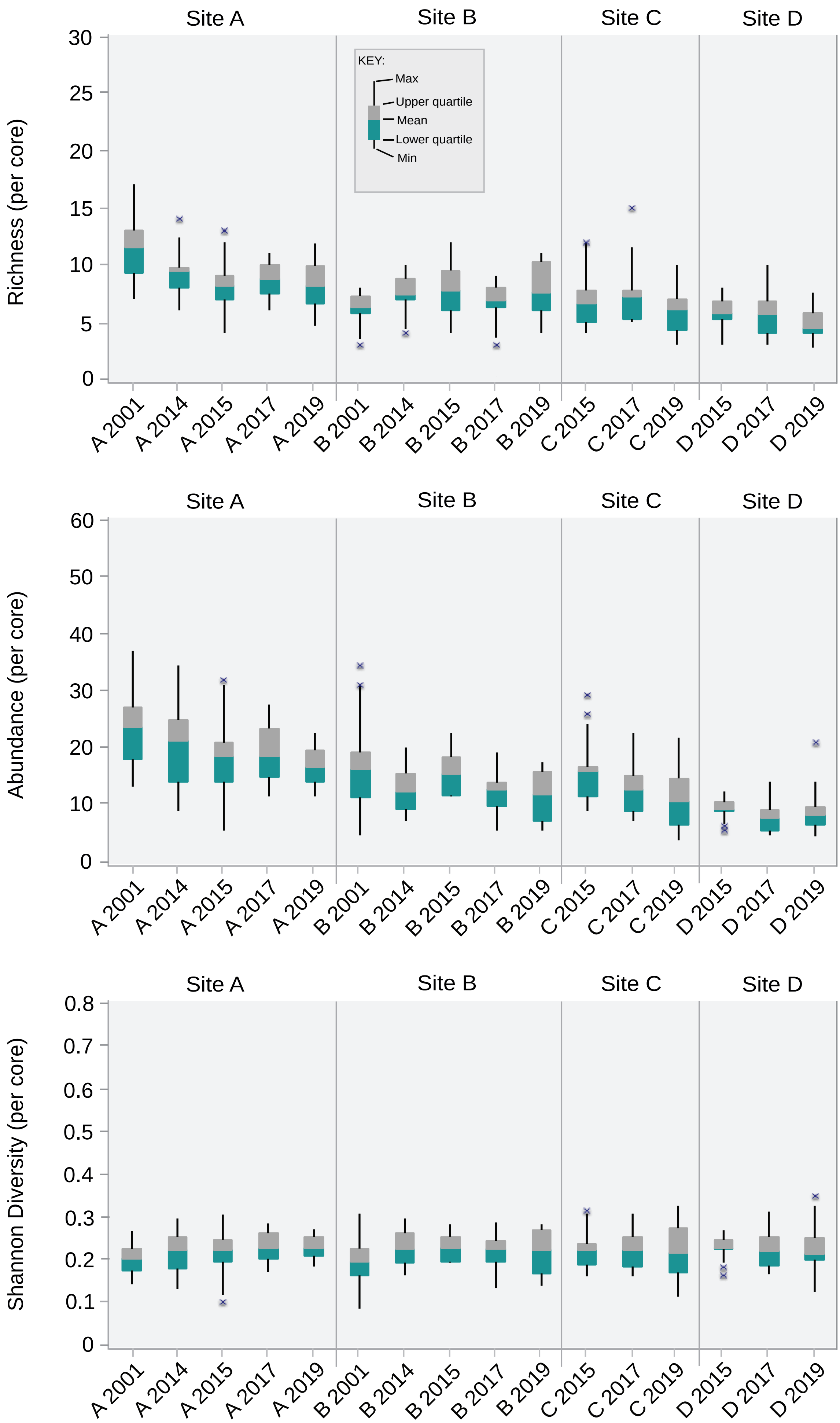


Figure 7. Mean richness (no. of taxa), abundance, and Shannon diversity, *n* = 10, Havelock Estuary, 2001, 2014-19.

A. Mud and Organic Enrichment Index (NZ AMBI)

This step is undertaken by using the NZ AMBI (detailed methodological information available in Robertson et al. 2015, 2016), a benthic macroinvertebrate index based on the international AMBI approach (Borja et al. 2000) which includes several modifications to strengthen its responsiveness to anthropogenic stressors, specifically mud and organic enrichment, as follows:

- Integration of previously established, quantitative ecological group (EGs) classifications (Robertson 2013; Robertson et al. 2015). Note the NZ AMBI coefficients presented in this report reflect the hybrid model amalgamating local EGs (Robertson et al. 2015) supplemented with standard international EGs from the AMBI list (Borja et al. 2000);
- Addition of a meaningful macrofaunal component (taxa richness), which means the index now accounts for changes in the number of taxa and thereby diversity, rather than their abundance only. The richness-integrated NZ AMBI is presented herein, which has been validated (through international peer-review) for inclusion into the standard abundance-weighted coefficient (Robertson et al. 2016);
- Derivation of thresholds that delineated benthic condition along primary estuarine stressor gradients (in this case, sediment mud and total organic carbon contents);
- Successful validation (R^2 values >0.5 for mud, and >0.4 for total organic carbon) for use in shallow estuaries New Zealand-wide, and further validated in a recent national-scale study (Berthelsen et al. 2018);
- Finally, the index has recently undergone further optimisation to more accurately diagnose benthic health in relation to nutrient enrichment of shallow estuaries (e.g. Havelock Estuary) (Robertson 2018). The updated index (not used in this report) is expected to be available in the near future following journal publication.

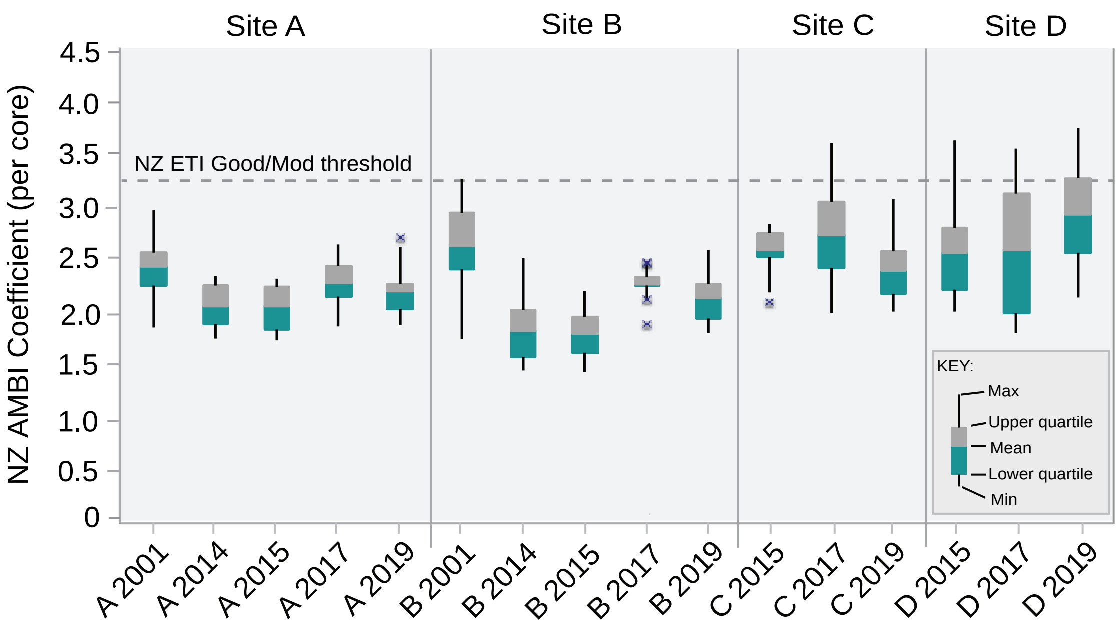


Figure 8. Mean NZ (RI-Hyrbid) AMBI scores (*n* = 10), Havelock Estuary, 2001, and baseline (2014-19) years.

The mean NZ (RI-Hybrid) AMBI coefficients for Havelock Estuary in 2019 were; 2.2, 2.1, 2.4 and 2.9 at Sites A, B, C and D, respectively (Table 4, Figure 8). These results, and those from previous years, all fit within the "good" ecological condition category (i.e. a "normal to slightly unbalanced" type macroinvertebrate community), with no instances of mean scores breaching the moderate or poor categories, reflecting the low sediment enrichment relative to muddiness at the middle-lower intertidal flats where monitoring sites are located.

B. Taxonomic Groups and Individual Taxa

This step compares the structure of the macrofaunal community within each site, firstly in terms of their general taxonomic grouping and secondly in terms of individual taxa. The aim of this step is to identify the taxa that are responsible for any observed macrofaunal differences between the sites and/or deviation from expected results (e.g. NZ AMBI scores), and to hypothesize on potential reasons based on their individual sensitivity to measured stressors, in this case mud and organic enrichment.

Broad taxonomic groupings (Figure 9) provide insight into the diversity of the dominant intertidal habitat in Havelock Estuary. A range of taxonomic groups were present at fine scale sites in 2019. While communities were uniformly dominated by polychaeta and bivalvia, they also comprised a mix of anthozoa, crustacea and gastropoda and to a lesser extent, nemertea, nematoda and sipuncula, with only small differences in abundance between sites. Similar groups and abundances were represented at each site in previous years, including 2001.

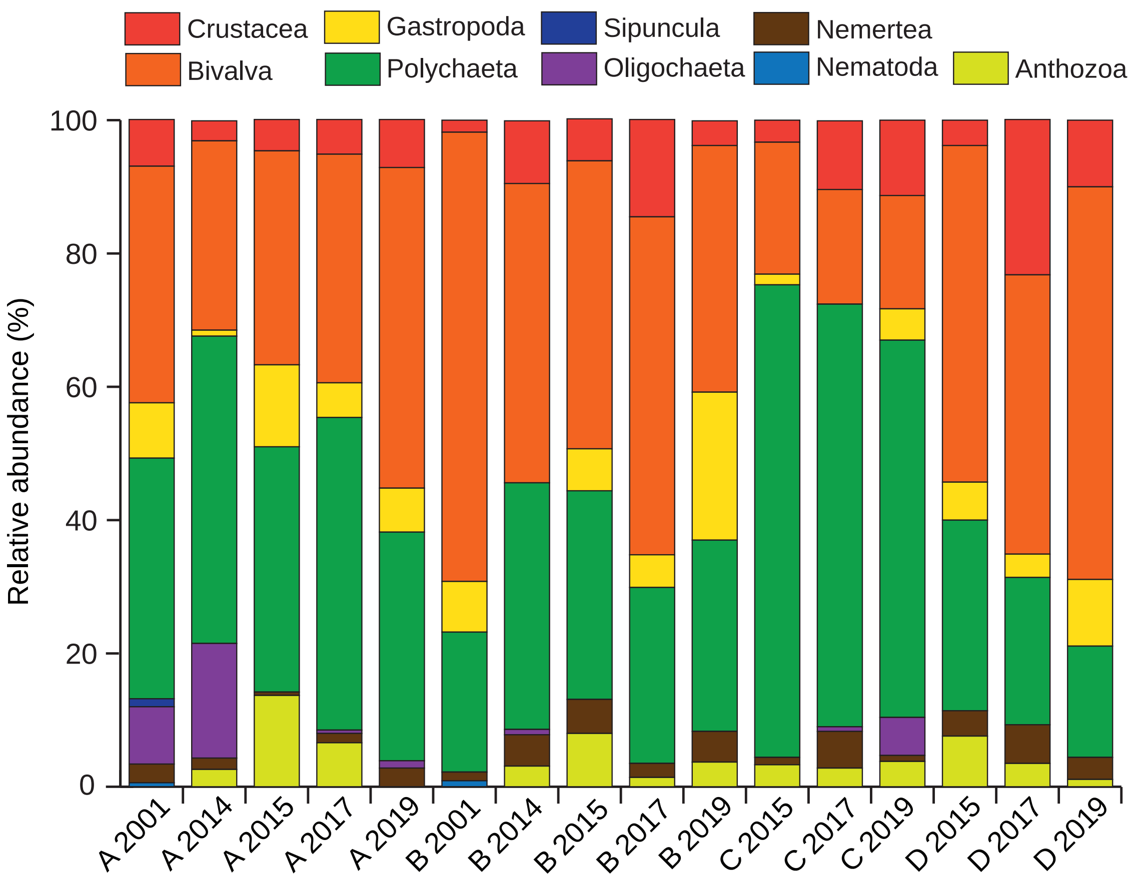


Figure 9. Relative abundance of major taxonomic groups across fine scale sites, Havelock Estuary, 2001, and baseline (2014-19) years.

Table 5 shows a comparison of the 2019 mean richness and abundances of taxa among each of the 5 major mud/enrichment tolerance groupings (i.e. from Group 1 "highly sensitive to mud/organic enrichment" through to Group 5 "1st-order opportunistic taxa with a very strong preference for muddy, organically enriched sediments"; Robertson 2013, Robertson et al. 2015). The macroinvertebrate community in 2019 was generally dominated at Sites A, B, C and D by taxa either sensitive to or widely tolerant of mud and organic enrichment (i.e. Groups 2 and 3), with only a few taxa (at relatively low abundances) belonging to either the highly sensitivity Group 1 or higher tolerance Groups 4 and 5. The low number of taxa belonging to these latter groups directly reflects the sedimentary conditions, with elevated mud contents limiting the presence of highly sensitive Group 1 and low levels of organic enrichment limiting the presence of the more tolerant Group 4 and 5 taxa.

Table 5. Summary of mud and organic enrichment sensitivity groupings, January 2019, Havelock Estuary. Pre-2019 data presented in Appendix C.

NZ AMBI (Mud/Organic Enrichment Tolerance) Group	Site A		Site B		Site C		Site D	
	Rich-ness	Abun-dance	Rich-ness	Abun-dance	Rich-ness	Abun-dance	Rich-ness	Abun-dance
1. Highly sensitive to (intolerant of) mud and organic enrichment	2	0.3	2	0.4	1	1.0	0	0.0
2. Sensitive to mud and organic enrichment	11	3.6	9	5.5	6	2.5	6	1.4
3. Widely tolerant of mud and organic enrichment	9	3.4	7	3.0	10	3.8	6	2.9
4. Prefers muddy, organically enriched sediments	0	0.0	2	0.4	0	0.0	2	3.3
5. Very strong preference for muddy, organically enriched sediments	1	0.4	0	0.0	1	0.2	1	0.2

Table 6 breakdowns the dominant taxa present at each monitoring site in 2019. The two most dominant organisms were as follows:

- At Sites A, B, C and to a lesser extent D, the common bivalve cockle, *Austrovenus stutchburyi*, was the most abundant organism, as was the case in previous years including 2001 (Sites A and B only). Reasons for its dominance/persistence, and despite the elevated mud contents (i.e. cockles tolerate mud content up to 85% with an optimum range of 0-10% (Group 2), but are sensitive to long term exposure to high levels of mud), may include each site's relative proximity to the main channel enhancing food supply and perhaps regulating the magnitude of sediment deposited and the frequency of delivery, both important factors limiting cockle distributions in intertidal estuaries (Thrush et al. 2003; Gibbs and Hewitt 2004). Furthermore, a recent experiment conducted in nearby Delawere Inlet, Nelson, also revealed the capacity for cockles to resurface after significant, high frequency sediment deposition events (Barrett et al. 2017). While sediments used in the experiments were dominated by sands with only 4-8% mud content, the present results support such an ability even in mud-impacted estuaries (i.e. significant intertidal area with >20% mud content) like Havelock;
- Also prolific at Sites A, B and C was the head-down deposit feeding polychaete worm, *Heteromastus filiformis.* It is widely mud and enrichment-tolerant (Group 3), but with a sulphide sensitivity cannot tolerate excessively enriched situations, which is consistent with the observation that sediments at these sites had low organic content and no distinctive sulphide odour. *H. filiformis* was also present at these sites in baseline years and 2001 and at Site D in 2017 but, for reasons unknown, not 2015 or 2019.

A diverse range of feeding types were represented among communities, but the majority of the dominant taxa (other than primarily suspension feeding cockles) across all four sites were surface and/or sub-surface deposit feeders (Table 6). Deposit feeders are particularly important in maintaining healthy/functional estuarine ecosystems, because by actively bioturbating (reworking) sediments they provide an effective removal pathway for excess nutrients and/or organic material thereby limiting eutrophication impacts. Other feeding groups present but at relatively low abundances included infaunal suspension-feeders (e.g. *Macomona liliana*), surface suspension-feeders (e.g. *Austrominius modestus*), and microalgal/detrital grazers (e.g. *Diloma subrostratum, Amphibola crenata*).

Overall, these results demonstrate that while sediment muddiness was clearly limiting the number and abundance of highly sensitive (Group 1) organisms with a preference for sandy environments, macrofaunal communities at the monitoring sites appeared to be in a relatively diverse and healthy state, a NZ ETI condition rating of good, reflecting the absence of advanced eutrophication symptoms and trace metal toxicity from that part of the estuary in 2019. However, overall richness and abundance was low when compared to relatively pristine (non-impacted) NZ SIDEs (e.g. Freshwater Estuary, Stewart Island), so results must be viewed in that context, and the potential for rapid decline due to the elevated susceptibility of mud-dominated estuaries to eutrophication impacts considered.

Table 6. General description and feeding type of the dominant sediment-dwelling macrofauna, January 2019, Havelock Estuary.

Site	Dominant	Feeding type	Description	Primary Sub-dominant	Feeding type	Description	Secondary Sub-dominant	Feeding type	Description
A	*Austrovenus stutchburyi (Group 2)*	Filter and deposit feeder	*A. stutchburyi* is a common suspension feeding bivalve that lives a few cm from the sediment surface at mid-low water situations and has an important and often critical functional role as active bio-engineers. It can improve water quality, stabilise sediments, oxygenate sediments, and can provide critical-habitat, both as living bivalve beds and through the accumulation of biogenic shell debris that can support highly diverse benthic assemblages (Lohrer et al. 2004, Thrush et al. 2006).Although cockles are often found in mud concentrations greater than 10%, the evidence suggests that they struggle. Small cockles are an important part of the diet of some wading bird species including South Island and variable oystercatchers, bar-tailed godwits, and Caspian and white-fronted terns.	*Heteromastus filiformis (Group 3)*	Infaunal deposit feeder	Small sized capitellid polychaete. A sub-surface, deposit-feeder that lives throughout the sediment to depths of 15 cm, and prefers a muddy-sand substrate. Shows a preference for areas of moderate organic enrichment as other members of this polychaete group do. Mitochondrial sulfide oxidation, which is sensitive to high concentrations of sulfide and cyanide, has been demonstrated in this species.	*Edwardsia* sp. *(Group 2)*	Filter and deposit feeder	A tiny elongate anemone adapted for burrowing; colour very variable, usually 16 tentacles but up to 24, pale buff or orange in colour. Fairly common throughout New Zealand. Prefers sandy sediments with low-moderate mud. Intolerant of anoxic conditions.
B	*Austrovenus stutchburyi (Group 2)*	Filter and deposit feeder		*Heteromastus filiformis (Group 3)*	Infaunal deposit feeder		Phoxocephalidae *(Group 2)*	Deposit feeder	A family of gammarid amphipods. Common example is *Waitangi* sp. which is a strong sand preference organism.
C	*Austrovenus stutchburyi (Group 2)*	Filter and deposit feeder		*Heteromastus filiformis (Group 3)*	Infaunal deposit feeder		Maldanidae *(Group 1)*	Deposit feeder	Bamboo worms are large, blunt-ended, cylindrical polychaete worms and feed as bulk consumers of sediment using a balloon-like proboscis. Most bamboo worms live below the surface in flimsy sediment tubes. They process copious amounts of sediment and deposit it in earthworm-like surface casts.
D	*Arthritica bifurca (Group 4)*	Infaunal deposit feeder	Arthritica is a small sedentary deposit feeding bivalve that lives greater than 2 cm deep in the muds. Arthritica tolerates a sediment mud content of up to 75% with an optimum range of 20-60%. Its abundance fluctuates considerably (Halliday and Cummings 2012) with peaks generally in January.	*Austrovenus stutchburyi (Group 2)*	Filter and deposit feeder		*Nicon aestuariensis (Group 3)*	Omnivorous deposit feeder	Nicon (ragworm) is a surface deposit feeding nereid worm that is tolerant of freshwater that prefers to live in moderate mud content sediments.

4 Summary

Fine scale results of estuary condition for benthic intertidal sites within Havelock Estuary in January 2019, combined with risk indicator ratings, and supported by previous results (Table 7), showed the following findings in relation to the key issues of sedimentation, eutrophication and toxicity:

Sedimentation (Muddiness)

The four intertidal sites, chosen to represent the main middle-lower estuary benthic habitat, showed moderate-high average mud contents (18.5-60.6% mud), with sandier sediments at Site B (closest to main channel) and muddier sediments at Sites A, C and D. Ecologically, the overall high mud content fits the NZ ETI Band D condition rating, and indicates the following conditions are likely: *'Significant, persistent stress on a range of aquatic organisms caused by dissolved oxygen exceeding tolerance levels. Likelihood of local extinctions of keystone species and loss of ecological integrity'* (Robertson et al. 2016b). In addition, average sedimentation rates (measured at fine scale sites and two upper estuary sites) over the past 3-5 years have generally indicated moderate accrual (>2-5 mm yr^{-1}), yielding an across-site average of 2.7 mm yr^{-1}, with greater infilling occurring in the upper Eastern Arm of the estuary (mean increase of 6.5 mm yr^{-1} at Site F since 2017).

Table 7. Summary of overall fine scale risk indicator ratings for Havelock Estuary, baseline years (2014-19), and narrative changes from 2001 survey. *na* = not applicable.

Estuary Issue	Indicator	Risk indicator rating[1]					Narrative change since 2001
		2001	Baseline years				
			2014	2015	2017	2019	
Sedimentation	Sediment mud content (% mud)	Mod-High	Mod-High	Mod-High	Mod-High	Mod-High	No notable change
Eutrophication	Apparent Redox Potential Discontinuity (aRPD)	*na*	Moderate	Moderate	Moderate	Moderate	Not applicable
Eutrophication	Redox Potential (mV) upper 3cm***	*na*	*na*	*na*	High	High	Not applicable
Eutrophication	Total Organic Carbon (TOC)	Moderate	Low	Low-Mod	Low-Mod	Low-Mod	No notable change
Eutrophication	Total Nitrogen (TN)	Very Low-Low	Very Low-Low	Low-Mod	Low-Mod	Low-Mod	No notable change
Sedimentation/ Eutrophication	Macroinvertebrate Condition Index (NZ-Hybrid RI-AMBI)	Low	Low	Low	Low	Low	No notable change
Toxic Contamination	Trace Metals[2]	Low	Low	Low	Low	Low	No notable change

[1] 2001 and 2014 ratings based on data from Sites A and B only; post-2014 ratings based on data from Sites A, B, C and D.
[2] All below ANZEEC Low Trigger Limit except for naturally elevated Nickel concentrations that were below the High Trigger Limit.

Eutrophication

The results show that in January 2019 eutrophication condition/risk was moderate, based on generally low macroalgal cover (<10 % cover of opportunistic macroalgae), an absence of seagrass, and underlying muddy sediments low in organic carbon and nutrient contents with moderate-poor oxygenation (i.e. low redox <-150 mV below 1 cm depth).

Toxic contamination

Indicators of sediment toxicants [heavy metals (Cd, Cr, Cu, Pb, Hg, Ni, Zn and As)] were at concentrations that were not expected to pose toxicity threats to aquatic life. Nickel, while likely from a natural source, was elevated at several sites but did not exceed the ISQG high toxicity limit (ANZECC 2000) and therefore does not require further investigation of factors controlling bioavailability.

Macroinvertebrate community condition

The combination of predominantly high mud content, moderate-poor oxygenation, but low enrichment and trace metal toxicity indicates that the macroinvertebrate community would likely be dominated by taxa widely tolerant of mud, with fewer highly sensitive/tolerant taxa. Such a biological response was reflected in the NZ estuary macroinvertebrate community index (NZ AMBI) results, coefficients of which indicate a good ecological condition (i.e. minor to moderate stress on benthic macrofauna - community tolerant of slight organic enrichment and moderate muds).

While such results provide a somewhat positive sign with regard to the current state of macrofaunal communities in main intertidal basin of Havelock Estuary, studies on other NZ SIDE type estuaries indicate that mud-dominated benthic environments are more susceptible to eutrophication impacts, and consequent macrofaunal decline. This, coupled with recent evidence of advanced eutrophication symptoms, albeit localised, in the estuary (Robertson 2019), and given catchment-derived nutrient (total nitrogen) inputs are close to critical thresholds (Robertson 2018), conditions in adjacent regions of the estuary (e.g. at fine scale sites) could quickly deteriorate and result in macrofaunal thresholds being breached in the short-medium term.

In addition, overall macrofaunal richness (no. of taxa) and abundance was relatively low when compared to relatively pristine (non-impacted) NZ SIDEs (e.g. Freshwater Estuary, Stewart Island), so results must be viewed in that context, and the potential for rapid decline due to the elevated susceptibility of mud-dominated estuaries to eutrophication impacts considered.

Baseline comparison with 2001 results

A comparison of the 2001 (Robertson et al. 2001) and baseline results show that 2001 benthic physicochemical results were similar to those from fine scale sites in 2019 and previous baseline years, indicating Havelock's main intertidal basin was unlikely to have significantly changed in terms of sediment mud, TOC, TN, TP, and trace metal concentrations in the past almost two decades. Based on NZ AMBI scores, macroinvertebrate communities, which consisted of a broad range of taxonomic and functional groupings, were in "good" condition in baseline years and 2001. However, in the absence of a full baseline dataset (i.e. the 2001 fine scale survey data represented only a single-year sampling event rather than sampling over a recommended 3-4 consecutive year period), these temporal trends should be considered with caution. Future monitoring will determine if results reflect ongoing trends in fine scale estuary conditions.

5 Conclusions

Based on the combined results from the January 2019 fine scale survey, Havelock Estuary's main intertidal basin is considered to be in a moderate-poor state in relation to sedimentation, eutrophication and trace metal toxicity, the poor status reflecting an ongoing sediment muddiness issue and uniform absence of high-value seagrass habitat. Macroinvertebrate communities are relatively impaired but appear to be in a relatively good (functional and diverse) condition. In terms of nutrient-induced disturbance, the current results, when combined with 2019 broad scale monitoring outputs, yield a NZ Estuary Trophic Index (NZ ETI) score of 0.67 (summarised in Appendix F), indicating that the estuary overall is expressing moderate symptoms of eutrophication.

6 Monitoring Recommendations

Havelock Estuary has been identified by MDC as a priority for monitoring because it is a large sized estuary with moderate-high ecological and human use values that is situated in a developed catchment, and therefore vulnerable to a range of stressors including sedimentation, eutrophication and toxic contamination. Fine scale monitoring (including sedimentation rate monitoring), in conjunction with broad scale habitat mapping, provides valuable information on current estuary condition and trends over time. The following fine scale monitoring recommendations are proposed by Robertson Environmental Ltd for consideration by MDC:

- Because the estuary is expressing moderate symptoms of eutrophication as well as an ongoing muddiess issue, fine scale conditions could quickly deteriorate in the short-medium term, particularly given that catchment-derived nitrogen inputs are close to critical thresholds. It is therefore recommended that macroinvertebrates and eutrophication-related indicators (e.g. sediment [TOC, TN, mud], redox) be monitored annually at high susceptibility Sites C and D (next recommended in 2020), with comprehensive fine scale monitoring undertaken every 5 years (next recommended in 2024);
- Sediment muddiness remains a priority issue in the estuary. It is therefore recommended that existing sediment plate depths be measured annually, and a single composite sediment sample be analysed for grain size at each site;
- Broad scale monitoring recommendations are presented in Robertson (2019).

In terms of management, given the ongoing sedimentation issue and more recent establishment of gross eutrophic conditions, albeit localised, in the estuary, previous recommendations (e.g. Stevens and Robertson 2014) are reiterated for the prioritised development of catchment nutrient and sediment guideline criteria to derive thresholds protecting against adverse sediment and nutrient impacts. To provide more robust catchment load estimates, it is recommended that future river total nitrogen and suspended sediment load sampling be undertaken during representative lowflow, baseflow and floodflow periods. This would enable local calibration of modelled load estimates thereby strengthening their usefulness for associated management initiatives.

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8 Limitations

This document does not include any assessment or consideration of ecological conditions within the subtidal environment of Havelock Estuary, and all physicochemical and biological sampling was carried out at a site-specific scale only. Regarding the latter, from a technical perspective, the benthic environment outside of areas sampled may present substantial uncertainty. It is a heterogeneous, complex environment, in which small surface features or changes in geologic conditions can have substantial impacts on associated physicochemical conditions and biology. Robertson Environmental's professional opinions are based on its professional judgement, experience, and training. These opinions are also based upon data derived from the monitoring and analysis described in this document, with the support of relevant national standards (e.g. NZ ETI; Robertson et al. 2016a,b). It is possible that additional testing and analyses might produce different results and/or different opinions. Should additional information become available, this report should be updated accordingly. Robertson Environmental Ltd has relied upon information provided by the MDC to inform parts of this document, some of which has not been fully verified by Robertson Environmental Ltd. In particular, the 2001 (Sites A and B only) survey data were not comprehensively assessed in this current report because (1) they did not meet the requirements of a full (3-4 consecutive years) baseline survey (i.e. involved one-off sampling >13 years ago) and (2) sampling effort differed between 2001 and baseline years (i.e. sample *n* was not consistent). Therefore any inferences based on associations between baseline and 2001 datasets should be considered with particular caution. This document may be transmitted, reproduced or disseminated only in its entirety.

Appendix A:

Major Issues Facing NZ Estuaries

Eutrophication is a process that adversely affects the high value biological components of an estuary, in particular through the increased growth, primary production and biomass of phytoplankton, macroalgae (or both); loss of seagrass, changes in the balance of organisms; and water quality degradation. The consequences of eutrophication are undesirable if they appreciably degrade ecosystem health and/or the sustainable provision of goods and services (Ferriera et al. 2011). Susceptibility of an estuary to eutrophication is controlled by factors related to hydrodynamics, physical conditions and biological processes (National Research Council, 2000) and hence is generally estuary-type specific. However, the general consensus is that, subject to available light, excessive nutrient input causes growth and accumulation of opportunistic fast growing primary producers (i.e. phytoplankton and opportunistic red or green macroalgae and/or epiphytes - Painting et al. 2007). In nutrient-rich estuaries, the relative abundance of each of these primary producer groups is largely dependent on flushing, proximity to the nutrient source, and light availability. Notably, phytoplankton blooms are generally not a major problem in well flushed estuaries (Valiela et al. 1997), and hence are not common in the majority of NZ estuaries. Of greater concern are the mass blooms of green and red macroalgae, mainly of the genera *Cladophora, Ulva, and Gracilaria* which are now widespread on intertidal flats and shallow subtidal areas of nutrient-enriched New Zealand estuaries. They present a significant nuisance problem, especially when loose mats accumulate on shorelines and decompose, both within the estuary and adjacent coastal areas. Blooms also have major ecological impacts on water and sediment quality (e.g. reduced clarity, physical smothering, lack of oxygen), affecting or displacing the animals that live there (Anderson et al. 2002, Valiela et al. 1997).

Recommended Indicator(s)	Method
Macroalgal Cover/Biomass	Broad scale mapping - macroalgal cover/biomass over time.
Phytoplankton (water column)	Chlorophyll a concentration (water column).
Sediment Organic and Nutrient Enrichment	Chemical analysis of sediment total nitrogen, total phosphorus, and total organic carbon concentrations.
Water Column Nutrients	Chemical analysis of various forms of N and P (water column).
Redox Profile	Redox potential discontinuity profile (RPD) using visual method (i.e. apparent Redox Potential Depth - aRPD) and/or redox probe. Note: Total Sulphur is also currently under trial.
Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15 cm of sediments (infauna in 0.0133 m^2 replicate cores), and on the sediment surface (epifauna in 0.25 m^2 replicate quadrats).

Sedimentary changes influence the ecology of estuaries. Because they are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays. Prior to European settlement they were most likely dominated by sandy sediments and had low sedimentation rates (e.g. <1 mm/year). In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, NZ's estuaries have begun to infill rapidly with fine sediments. Today, average sedimentation rates in our estuaries are typically 10 times or more higher than before humans arrived (e.g. see Abrahim 2005, Gibb and Cox 2009, Robertson and Stevens 2007a, 2010b, and Swales and Hume 1995). Soil erosion and sedimentation can also contribute to turbid conditions and poor water quality, particularly in shallow, wind-exposed estuaries where re-suspension is common. These changes to water and sediment result in negative impacts to estuarine ecology that are difficult to reverse. They include:

- habitat loss such as the infilling of saltmarsh and tidal flats;
- prevention of sunlight from reaching aquatic vegetation such as seagrass meadows;
- increased toxicity and eutrophication by binding toxic contaminants (e.g. heavy metals and hydrocarbons) and nutrients;
- a shift towards mud-tolerant benthic organisms which often means a loss of sensitive shellfish (e.g. pipi) and other filter feeders;
- making the water unappealing to swimmers.

Recommended Indicators	Method
Soft Mud Area	GIS Based Broad scale mapping - estimates the area and change in soft mud habitat over time.
Seagrass Area/Biomass	GIS Based Broad scale mapping - estimates the area and change in seagrass habitat over time.
Saltmarsh Area	GIS Based Broad scale mapping - estimates the area and change in saltmarsh habitat over time.
Mud Content	Grain size - estimates the % mud content of sediment.
Water Clarity/Turbidity	Secchi disc water clarity or turbidity.
Sediment Toxicants	Sediment heavy metal concentrations (see toxicity section).
Sedimentation Rate	Fine scale measurement of sediment infilling rate (e.g. using sediment plates).
Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15 cm of sediments (infauna in 0.0133 m^2 replicate cores), and on the sediment surface (epifauna in 0.25 m^2 replicate quadrats).

Habitat Loss impacts estuaries and their many different types of high value habitats including shellfish beds, seagrass meadows, saltmarshes (rushlands, herbfields, reedlands etc.), tidal flats, forested wetlands, beaches, river deltas, and rocky shores. The continued health and biodiversity of estuarine systems depends on the maintenance of high-quality habitat. Loss of such habitat negatively affects fisheries, animal populations, filtering of water pollutants, and the ability of shorelines to resist storm-related erosion. Within New Zealand, habitat degradation or loss is common-place with the major causes being sea level rise, population pressures on margins, dredging, drainage, reclamation, pest and weed invasion, reduced flows (damming and irrigation), over-fishing, polluted runoff, and wastewater discharges (IPCC 2007 and 2013, Kennish 2002).

Recommended Indicators	Method
Saltmarsh Area	Broad scale mapping - estimates the area and change in saltmarsh habitat over time.
Seagrass Area	Broad scale mapping - estimates the area and change in seagrass habitat over time.
Vegetated Terrestrial Buffer	Broad scale mapping - estimates the area and change in buffer habitat over time.
Shellfish Area	Broad scale mapping - estimates the area and change in shellfish habitat over time.
Unvegetated Habitat Area	Broad scale mapping - estimates the area and change in unvegetated habitat over time, broken down into the different substrata types.
Sea level	Measure sea level change.
Others e.g. Freshwater Inflows, Fish Surveys, Floodgates, Wastewater Discharges	Various survey types.

Toxic Contamination has become an issue in the last 60 years, as NZ has seen a huge range of synthetic chemicals introduced to the coastal environment through urban and agricultural stormwater runoff, groundwater contamination, industrial discharges, oil spills, antifouling agents, leaching from boat hulls, and air pollution. Many of them are toxic even in minute concentrations, and of particular concern are polycyclic aromatic hydrocarbons (PAHs), heavy metals, polychlorinated biphenyls (PCBs), endocrine disrupting compounds, and pesticides. When they enter estuaries these chemicals collect in sediments and bio-accumulate in fish and shellfish, causing health risks to marine life and humans. In addition, natural toxins can be released by macroalgae and phytoplankton, often causing mass closures of shellfish beds, potentially hindering the supply of food resources, as well as introducing economic implications for people depending on various shellfish stocks for their income. For example, in 1993, a nationwide closure of shellfish harvesting was instigated in NZ after 180 cases of human illness following the consumption of various shellfish contaminated by a toxic dinoflagellate, which also lead to wide-spread fish and shellfish deaths (de Salas et al. 2005). Decay of organic matter in estuaries (e.g. macroalgal blooms) can also cause the production of sulphides and ammonia at concentrations exceeding ecotoxicity thresholds.

Recommended Indicators	Method
Shellfish and Bathing Water faecal coliforms, viruses, protozoa etc.	Bathing water and shellfish disease risk monitoring. Note disease risk indicators on the Marlborough coast are assessed separately in MDC's recreational water quality monitoring programme.
Biota Contaminants	Chemical analysis of suspected contaminants in body of at-risk biota (e.g. fish, shellfish).
Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15 cm of sediments (infauna in 0.0133 m^2 replicate cores), and on the sediment surface (epifauna in 0.25 m^2 replicate quadrats).

Appendix B:

Support Information (Table 1)

The estuary monitoring approach used by Robertson Environmental Ltd has been established to provide a defensible, cost-effective way to help quickly identify the likely presence of the predominant issues affecting NZ estuaries (i.e. eutrophication, sedimentation, disease risk, toxicity and habitat change; Appendix A), and to assess changes in the long term condition of estuarine systems. The design is based on the use of primary indicators that have a documented strong relationship with water and/or sediment quality.

In order to facilitate this assessment process, "risk indicator ratings" have also been proposed that assign a relative level of risk (e.g. very low, low, moderate, high) of specific indicators adversely affecting intertidal estuary condition (see Table 1). Each risk indicator rating is designed to be used in combination with relevant information and other risk indicator ratings, and under expert guidance, to assess overall estuarine condition in relation to key issues, and make monitoring and management recommendations. When interpreting risk indicator results we emphasise:

- The importance of taking into account other relevant information and/or indicator results before making management decisions regarding the presence or significance of any estuary issue e.g. community aspirations, cost/benefit considerations;
- That rating and ranking systems can easily mask or oversimplify results. For instance, large changes can occur within the same risk category, but small changes near the edge of one risk category may shift the rating to the next risk level;
- Most issues will have a mix of primary and supporting indicators, primary indicators being given more weight in assessing the significance of results. It is noted that many supporting estuary indicators will be monitored under other programmes and can be used if primary indicators reflect a significant risk exists, or if risk profiles have changed over time;
- Ratings have been established in many cases using statistical measures based on NZ estuary data and presented in the NZ Estuary Trophic Index (NZ ETI; Robertson et al. 2016a and 2016b). However, where such data is lacking, or has yet to be processed, ratings have been established using professional judgement, based on our experience from monitoring numerous NZ estuaries. Our hope is that where a high level of risk is identified, the following steps are taken:

    1. Statistical measures be used to refine indicator ratings where information is lacking;
    2. Issues identified as having a high likelihood of causing a significant change in ecological condition (either positive or negative), trigger intensive, targeted investigations to appropriately characterise the extent of the issue; and
    3. The outputs stimulate discussion regarding what an acceptable level of risk is, and how it should best be managed.

Supporting notes explaining the use and justifications for each rating indicator are presented below. The basis underpinning most of the ratings is the observed correlation between an indicator and the presence of degraded estuary conditions from a range of tidal lagoon and tidal river estuaries throughout NZ. Work to refine and document these relationships is ongoing. See Robertson et al. (2016a, 2016b) and Robertson (2018) for further information supporting these ratings.

Appendix C:

Detailed Field Results

2019 Fine Scale Site Boundaries									
Havelock Site A	1	2	3	4	**Havelock Site B**	1	2	3	4
NZTM EAST	1664422	1664446	1664418	1664395	NZTM EAST	1664816	1664847	1664873	1664842
NZTM NORTH	5430910	5430965	5430977	5430921	NZTM NORTH	5430902	5430850	5430865	5430917
Havelock Site C	1	2	3	4	**Havelock Site D**	1	2	3	4
NZTM EAST	1664292	1664287	1664226	1664231	NZTM EAST	1664946	1664970	1664997	1664971
NZTM NORTH	5430909	5430937	5430930	5430901	NZTM NORTH	5430919	5430865	5430831	5430937

2019 Fine Scale Sample Station Locations										
Havelock Site A	1	2	3	4	5	6	7	8	9	10
NZTM EAST	1664433	1664421	1664414	1664411	1664402	1664405	1664412	1664419	1664407	1664400
NZTM NORTH	5430958	5430939	5430919	5430913	5430918	5430928	5430948	5430963	5430965	5430945
Havelock Site B	1	2	3	4	5	6	7	8	9	10
NZTM EAST	1664842	1664834	1664826	1664822	1664834	1664840	1664849	1664854	1664861	1664855
NZTM NORTH	5430859	5430878	5430894	5430906	5430908	5430896	5430877	5430863	5430868	5430884
Havelock Site C	1	2	3	4	5	6	7	8	9	10
NZTM EAST	1664289	1664275	1664257	1664241	1664240	1664256	1664274	1664287	1664285	1664272
NZTM NORTH	5430909	5430909	5430908	5430908	5430915	5430919	5430919	5430921	5430931	5430929
Havelock Site D	1	2	3	4	5	6	7	8	9	10
NZTM EAST	1664969	1664963	1664958	1664955	1664965	1664971	1664975	1664982	1664991	1664985
NZTM NORTH	5430872	5430891	5430907	5430919	5430921	5430908	5430893	5430877	5430884	5430898

Down-core redox potential (mV) and aRPD depth (cm) for Havelock Estuary fine scale sites, 25-26 January 2019, *n* = 3.

Year/Site	Replicate	Redox Potential (mV)				
		0 cm (surface)	-1 cm	-3 cm	-6 cm	-10 cm
2019 A	1	-18	-220	-263	-368	-418
	2	-2	-207	-273	-372	-407
	3	10	-226	-254	-379	-419
	Mean	-3	-218	-263	-373	-415
2019 B	1	-27	-232	-324	-379	-394
	2	-84	-234	-327	-382	-396
	3	-67	-237	-334	-397	-384
	Mean	-59	-234	-328	-386	-391
2019 C	1	-86	-247	-287	-274	-268
	2	-104	-256	-258	-294	-284
	3	-147	-274	-296	-271	-254
	Mean	-112	-259	-280	-280	-269
2019 D	1	-98	-228	-267	-321	-324
	2	-101	-233	-274	-327	-323
	3	-92	-216	-261	-331	-344
	Mean	-97	-226	-267	-326	-330

Physical and chemical results, Havelock Estuary, 2019. - Refer to Appendix D for raw laboratory outputs and detection limits.

		aRPD	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg	TN	TP
Year/Site	Reps[b]	cm	ppt	%				mg kg^{-1}									
2019 A1	1-4	1.0	30-34	0.58	27.3	72.0	0.7	0.05	51.0	10.2	39.0	5.8	45	4.1	0.04	700	410
2019 A2	4-8	1.0	30-34	0.55	27.6	70.1	2.3	0.04	50.0	10.8	40.0	5.8	43	3.9	0.04	600	400
2019 A3	9-10	1.0	30-34	0.62	31.2	64.7	4.1	0.04	53.0	10.8	42.0	5.9	45	4.1	0.04	600	390
2019 B1	1-4	1.0	30-34	0.26	17.2	82.6	0.2	0.02	16.9	5.9	13.6	3.6	23	1.5	<0.02[c]	<500[c]	210
2019 B2	4-8	1.0	30-34	0.21	19.7	80.0	0.4	0.02	18.0	5.4	15.6	3.3	22	1.4	<0.02[c]	<500[c]	192
2019 B3	9-10	1.0	30-34	0.24	18.7	81.1	0.1	0.02	16.2	5.4	12.9	3.3	21	1.3	<0.02[c]	<500[c]	177
2019 C1	1-4	0.5	30-34	1.25	61.0	39.1	<0.1	0.04	66.0	14.8	51.0	7.6	49	4.1	0.06	1100	420
2019 C2	4-8	0.5	30-34	1.30	59.0	41.0	<0.1	0.04	68.0	15.6	53.0	8.0	51	4.8	0.07	1100	430
2019 C3	9-10	0.5	30-34	1.19	61.7	38.3	<0.1	0.04	66.0	14.9	52.0	7.8	49	4.3	0.05	1000	420
2019 D1	1-4	0.5	30-34	0.67	45.3	53.1	1.7	0.03	23.0	8.7	17.3	4.9	30	2.5	<0.02[c]	700	310
2019 D2	4-8	0.5	30-34	0.86	51.8	48.0	0.1	0.03	26.0	10.6	19.6	6.0	35	3.0	<0.02[c]	700	360
2019 D3	9-10	0.5	30-34	0.73	50.9	48.0	1.1	0.03	23.0	10.2	18.0	5.3	32	2.6	0.02	600	330
ISQG-Low[a]		-	-	-	-	-	-	1.5	80	65	21	50	200	20	0.15	-	-
ISQG-High[a]		-	-	-	-	-	-	10	370	270	52	220	410	70	1	-	-
Baseline Average		-	-	-	-	-	-	0.04	40.9	12.9	34.4	6.1	39	3.7	0.04	-	-
NZ ETI Category								Very Low	Low	Very Low	High	Very Low	Very Low	Very Low	Low		

a ANZECC 2000.
b composite macrofuanal samples.
c below detection limit (Appendix D). Note: All fine scale sites including this data (i.e. Sites B and D) have been excluded from all relevant aspects (Section 3.4) of this report.

Expanded grain size (7) results, Havelock Estuary fine scale and sediment plate sites, 2019.							
Year/Site	Gravel	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Mud (silt and clay)
	≥2 mm	<2 mm, ≥1 mm	<1 mm, ≥500 µm	<500 µm, ≥250 µm	<250 µm, ≥125 µm	<125 µm, ≥63 µm	<63 µm
2019 A1	0.7	2.2	8.6	19.4	24.1	17.7	27.3
2019 A2	2.3	1.8	7.7	20.3	24.3	16.0	27.6
2019 A3	4.1	1.9	6.9	16.3	19.7	19.9	31.2
2019 B1	0.2	0.2	0.3	0.5	15.5	66.1	17.2
2019 B2	0.4	0.2	0.3	0.6	15.4	63.5	19.7
2019 B3	0.1	0.1	0.2	0.5	17.3	63.0	18.7
2019 C1	<0.1	0.3	0.7	2.3	5.9	29.9	61.0
2019 C2	<0.1	<0.1	0.5	1.9	5.9	32.7	59.0
2019 C3	<0.1	<0.1	0.4	2.0	5.7	30.2	61.7
2019 D1	1.7	0.2	0.4	0.6	1.6	50.3	45.3
2019 D2	0.1	0.2	0.4	0.6	1.4	45.4	51.8
2019 D3	1.1	0.3	0.5	1.0	10.9	35.3	50.9
SP-A1	2.1	1.7	7.2	16.8	23.6	17.4	31.3
SP-B1	2.5	0.1	0.2	0.7	16.1	60.1	20.3
SP-C1	<0.1	0.2	0.8	3.3	7.6	32.4	55.6
SP-D1	0.2	0.3	0.4	0.8	2.1	51.0	45.4
SP-E1	<0.1	0.5	1.7	5.8	6.2	7.6	78.1
SP-F1	0.1	0.6	1.7	5.2	8.1	11.0	73.2

Sediment plate locations and depth of plate (mm) below surface							
Site A Plates	NZTM E	NZTM N	Peg Height/Plate Depth (mm)				
			28/3/14	19/3/15	29/3/17	26/1/19	
Peg 1			+150				SM - Soft Mud
Plate 1 @2 m	1664438	5430967	-186	-185	-191	-205	
Plate 2 @4 m	1664436	5430967	-142	-143	-151	-163	
Peg 2			+150				
Plate 3 @6 m	1664434	5430968	-131	-130	-142	-150	
Plate 4 @8 m	1664431	5430969	-143	-144	-145	-167	
Peg 3			+150				
Site B Plates	NZTM E	NZTM N	28/3/14	19/3/15	29/3/17	26/1/19	
Peg 1			+150				FMS/SM - Firm Muddy Sand/Soft Mud
Plate 1 @2 m	1664844	5430850	-138	-147	-144	-150	
Plate 2 @4 m	1664845	5430852	-154	-165	-158	-165	
Peg 2			+150				
Plate 3 @6 m	1664846	5430853	-166	-176	-175	-190	
Plate 4 @8 m	1664849	5430855	-149	-159	-156	-166	
Peg 3			+150				
Site C Plates	NZTM E	NZTM N	28/3/14	19/3/15	29/3/17	26/1/19	
Peg 1	1664287	5430937		+150			VSM - Very Soft Mud
Plate 1 @2 m	1664290	5430909		-93	-98	-100	
Plate 2 @4 m	1664288	5430908		-85	-91	-89	
Peg 2	1664287	5430909		+150			
Plate 3 @6 m	1664285	5430909		-98	-92	-102	
Plate 4 @8 m	1664283	5430909		-97	-91	-91	
Peg 3	1664281	5430908		+150			
Site D Plates	NZTM E	NZTM N	28/3/14	19/3/15	29/3/17	26/1/19	
Peg 1	1664970	5430865		+150			VSM - Very Soft Mud
Plate 1 @2 m	1664972	5430865		-93	-103	-117	
Plate 2 @4 m	1664974	5430867		-85	-74	-93	
Peg 2	1664975	5430868		+150			
Plate 3 @6 m	1664975	5430868		-98	-68	-77	
Plate 4 @8 m	1664978	5430870		-97	-53	-60	
Peg 3	1664978	5430870		+150			
Site E Plates	NZTM E	NZTM N	28/3/14	19/3/15	29/3/17	26/1/19	
Peg 1	1663894	5430726			+100		VSM - Very Soft Mud
Plate 1 @2 m	1663892	5430725			-53	-70	
Plate 2 @4 m	1663890	5430725			-62	-75	
Peg 2	1663889	5430724			+100		
Plate 3 @6 m	1663888	5430724			-49	-67	
Plate 4 @8 m	1663886	5430724			-39	-42	
Peg 3	1663883	5430724			+100		
Site F Plates	NZTM E	NZTM N	28/3/14	19/3/15	29/3/17	26/1/19	
Peg 1	1664016	5430692			+100		VSM - Very Soft Mud
Plate 1 @2 m	1664014	5430692			-57	-72	
Plate 2 @4 m	1664013	5430693			-46	-63	
Peg 2	1664011	5430692			+100		
Plate 3 @6 m	1664009	5430693			-58	-80	
Plate 4 @8 m	1664008	5430693			-56	-80	
Peg 3	1664006	5430694			+100		

Note sediment plate depth measurements for Sites E and F in 2017 are indicative baseline depths only which were recorded during site establishment, and should not be used in estimates of sedimentation rate until supported by additional site measurements.

Raw macrofaunal data, Site A, Havelock Estuary, 2019.												
Group	Taxa	NZ (Hybrid RI) AMBI EG	Rep									
			A01	A02	A03	A04	A05	A06	A07	A08	A09	A10
Polychaeta	*Aonides trifida*	1						1			1	
Polychaeta	Maldanidae	1										
Polychaeta	*Orbinia papillosa*	1										
Polychaeta	*Scoloplos cylindrifer*	1					1					
Gastropoda	*Zeacumantus lutulentus*	2		1				1				
Amphipoda	*Amphipoda* spp.	2										
Crustacea	*Austrominius modestus*	2			1					1	3	
Bivalvia	*Austrovenus stutchburyi**	2	8	10	11	7	10	7	6	8	4	10
Polychaeta	*Boccardia* sp.	2	1									
Crustacea	Copepoda	2							1			
Bivalvia	*Cyclomactra ovata*	2					1			1		
Anthozoa	*Edwardsia* sp.	2	2		4	1	1			1		
Bivalvia	*Leptomya retiaria retiaria***	2										
Bivalvia	*Macomona liliana*	2			1	1	1		1			
Gastropoda	*Notoacmea helmsi*	2						1				
Polychaeta	*Perinereis vallata*	2										1
Amphipoda	Phoxocephalidae	2			1							
Bivalvia	*Theora lubrica*	3										
Gastropoda	*Amphibola crenata****	3					2		1		2	
Gastropoda	*Cominella glandiformis*	3	1	1						2		
Crustacea	*Halicarcinus whitei*	3			1				1			1
Polychaeta	*Heteromastus filiformis*	3	3	1	5	9	5	5	3	10	3	4
Nemertea	Nemertea	3				1	1		2			1
Polychaeta	Nereidae (juvenile)****	3	1	1		1	1			1		
Polychaeta	*Nicon aestuariensis*	3			1							
Oligochaeta	Oligochaeta	3							2			
Polychaeta	Paraonidae	3							3			
Polychaeta	*Pectinaria australis*	3										
Bivalvia	*Arthritica bifurca*	4										
Polychaeta	*Scolecolepides benhami*	4										
Crustacea	*Hemiplax hirtipes*	5						1	1	2		
Crustacea	*Alpheus* sp.	NA										
		Total individuals in sample	16	14	25	20	23	16	21	26	13	17
		Total species in sample	9	8	10	7	12	8	13	12	7	7

*several size classes lumped. **NZ AMBI EG based on expert judgement.
***Juveniles removed from NZ AMBI calculations as per Borja & Muxika (2005).
****Unidentified Nereididae (formerly spelled Nereidae) juveniles were retained in the NZ AMBI because their sensitivity to mud/organic enrichment and therefore EG classification has been validated for shallow NZ estuaries (Robertson et al. 2015).

Raw macrofaunal data, Site B, Havelock Estuary, 2019.												
Group	Taxa	NZ (Hybrid RI) AMBI EG	Rep									
			B01	B02	B03	B04	B05	B06	B07	B08	B09	B10
Polychaeta	*Aonides trifida*	1										
Polychaeta	Maldanidae	1			1	1			1			
Polychaeta	*Orbinia papillosa*	1					1					
Polychaeta	*Scoloplos cylindrifer*	1										
Gastropoda	*Zeacumantus lutulentus*	2	1			1	3	1	1			
Amphipoda	*Amphipoda* spp.	2						1	1			2
Crustacea	*Austrominius modestus*	2					1					
Bivalvia	*Austrovenus stutchburyi**	2		10	5	2	4	1	1	1	3	4
Polychaeta	*Boccardia* sp.	2										
Crustacea	Copepoda	2										
Bivalvia	*Cyclomactra ovata*	2										
Anthozoa	*Edwardsia* sp.	2	1									
Bivalvia	*Leptomya retiaria retiaria***	2				1						
Bivalvia	*Macomona liliana*	2				1		2	2		1	
Gastropoda	*Notoacmea helmsi*	2				1	2		1			
Polychaeta	*Perinereis vallata*	2										
Amphipoda	Phoxocephalidae	2		3	5	4	1	2	3	3	1	4
Bivalvia	*Theora lubrica*	3										
Gastropoda	*Amphibola crenata****	3			1	3	2		1			
Gastropoda	*Cominella glandiformis*	3		1		3			1			
Crustacea	*Halicarcinus whitei*	3	1		1							1
Polychaeta	*Heteromastus filiformis*	3	1	1	2	2			3	1	1	3
Nemertea	Nemertea	3	1	1		1	1			1		
Polychaeta	Nereidae (juvenile)****	3		2			1			1		2
Polychaeta	*Nicon aestuariensis*	3										
Oligochaeta	Oligochaeta	3										
Polychaeta	Paraonidae	3		1	2		1		1			
Polychaeta	*Pectinaria australis*	3										
Bivalvia	*Arthritica bifurca*	4			1			1				
Polychaeta	*Scolecolepides benhami*	4					1			1		
Crustacea	*Hemiplax hirtipes*	5										
Crustacea	*Alpheus* sp.	NA										
		Total individuals in sample	6	19	18	20	18	8	16	8	6	16
		Total species in sample	6	9	10	11	13	6	11	6	5	7

*several size classes lumped. **NZ AMBI EG based on expert judgement.
***Juveniles removed from NZ AMBI calculations as per Borja & Muxika (2005).
****Unidentified Nereididae (formerly spelled Nereidae) juveniles were retained in the NZ AMBI because their sensitivity to mud/organic enrichment and therefore EG classification has been validated for shallow NZ estuaries (Robertson et al. 2015).

Raw macrofaunal data, Site C, Havelock Estuary, 2019.

Group	Taxa	NZ (Hybrid RI) AMBI EG	Rep									
			C01	C02	C03	C04	C05	C06	C07	C08	C09	C10
Polychaeta	*Aonides trifida*	1										
Polychaeta	Maldanidae	1						1		1		8
Polychaeta	*Orbinia papillosa*	1										
Polychaeta	*Scoloplos cylindrifer*	1										
Gastropoda	*Zeacumantus lutulentus*	2										
Amphipoda	*Amphipoda* spp.	2		2	1					1		
Crustacea	*Austrominius modestus*	2								1		
Bivalvia	*Austrovenus stutchburyi**	2	3				2	4		2	3	1
Polychaeta	*Boccardia* sp.	2										
Crustacea	Copepoda	2								1		
Bivalvia	*Cyclomactra ovata*	2										
Anthozoa	*Edwardsia* sp.	2										
Bivalvia	*Leptomya retiaria retiaria***	2										
Bivalvia	*Macomona liliana*	2							1			
Gastropoda	*Notoacmea helmsi*	2										
Polychaeta	*Perinereis vallata*	2										
Amphipoda	Phoxocephalidae	2		1	5	2	2	2	1	1	1	
Bivalvia	*Theora lubrica*	3				1					1	
Gastropoda	*Amphibola crenata****	3					2			3		
Gastropoda	*Cominella glandiformis*	3										
Crustacea	*Halicarcinus whitei*	3		2				1	1			3
Polychaeta	*Heteromastus filiformis*	3		4				8	3	1		4
Nemertea	Nemertea	3							1			
Polychaeta	Nereidae (juvenile)****	3	2	1	1				1			1
Polychaeta	*Nicon aestuariensis*	3	1			1		1		1		
Oligochaeta	Oligochaeta	3									1	5
Polychaeta	Paraonidae	3		10	2		1			1		1
Polychaeta	*Pectinaria australis*	3		1	1		1	1				1
Bivalvia	*Arthritica bifurca*	4										
Polychaeta	*Scolecolepides benhami*	4										
Crustacea	*Hemiplax hirtipes*	5	1				1					
Crustacea	*Alpheus* sp.	NA										1
		Total individuals in sample	7	21	10	4	9	18	8	13	6	25
		Total species in sample	5	7	5	3	7	9	6	11	5	9

*several size classes lumped. **NZ AMBI EG based on expert judgement.
***Juveniles removed from NZ AMBI calculations as per Borja & Muxika (2005).
****Unidentified Nereididae (formerly spelled Nereidae) juveniles were retained in the NZ AMBI because their sensitivity to mud/organic enrichment and therefore EG classification has been validated for shallow NZ estuaries (Robertson et al. 2015).

Raw macrofaunal data, Site D, Havelock Estuary, 2019.												
Group	Taxa	NZ (Hybrid RI) AMBI EG	Rep									
			D01	D02	D03	D04	D05	D06	D07	D08	D09	D10
Polychaeta	*Aonides trifida*	1										
Polychaeta	Maldanidae	1										
Polychaeta	*Orbinia papillosa*	1										
Polychaeta	*Scoloplos cylindrifer*	1										
Gastropoda	*Zeacumantus lutulentus*	2										
Amphipoda	*Amphipoda* spp.	2									1	
Crustacea	*Austrominius modestus*	2				3					1	
Bivalvia	*Austrovenus stutchburyi**	2			1	3	1	3	3	1	3	4
Polychaeta	*Boccardia* sp.	2										
Crustacea	Copepoda	2										
Bivalvia	*Cyclomactra ovata*	2										
Anthozoa	*Edwardsia* sp.	2										
Bivalvia	*Leptomya retiaria retiaria***	2						1				
Bivalvia	*Macomona liliana*	2		1								
Gastropoda	*Notoacmea helmsi*	2										
Polychaeta	*Perinereis vallata*	2										
Amphipoda	Phoxocephalidae	2				1	2					
Bivalvia	*Theora lubrica*	3										
Gastropoda	*Amphibola crenata****	3		1	1	1	2					2
Gastropoda	*Cominella glandiformis*	3										2
Crustacea	*Halicarcinus whitei*	3		1							1	1
Polychaeta	*Heteromastus filiformis*	3										
Nemertea	Nemertea	3	1			1				1		
Polychaeta	Nereidae (juvenile)****	3		1						2		1
Polychaeta	*Nicon aestuariensis*	3				2	1	2	3	1	1	
Oligochaeta	Oligochaeta	3										
Polychaeta	Paraonidae	3										
Polychaeta	*Pectinaria australis*	3										
Bivalvia	*Arthritica bifurca*	4		4	1		18	5		2	2	
Polychaeta	*Scolecolepides benhami*	4								1		
Crustacea	*Hemiplax hirtipes*	5			1				1			
Crustacea	*Alpheus* sp.	NA										
		Total individuals in sample	1	8	4	11	24	11	7	8	9	10
		Total species in sample	1	5	4	8	5	5	4	6	6	7

*several size classes lumped. **NZ AMBI EG based on expert judgement.
***Juveniles removed from NZ AMBI calculations as per Borja & Muxika (2005).
****Unidentified Nereididae (formerly spelled Nereidae) juveniles were retained in the NZ AMBI because their sensitivity to mud/organic enrichment and therefore EG classification has been validated for shallow NZ estuaries (Robertson et al. 2015).

Epifauna (surface-dwelling animals) - SACFOR Percentage Cover and Density Scales (after Marine Nature Conservation Review - MNCR).

Table A. % Cover	Growth Form	
	i. Crust/ Meadow	ii. Massive/ Turf
>80	S	-
40-79	A	S
20-39	C	A
10-19	F	C
5-9	O	F
1-4	R	O
<1	-	R

SACFOR Category
S = Super Abundant
A = Abundant
C = Common
F = Frequent
O = Occasional
R = Rare

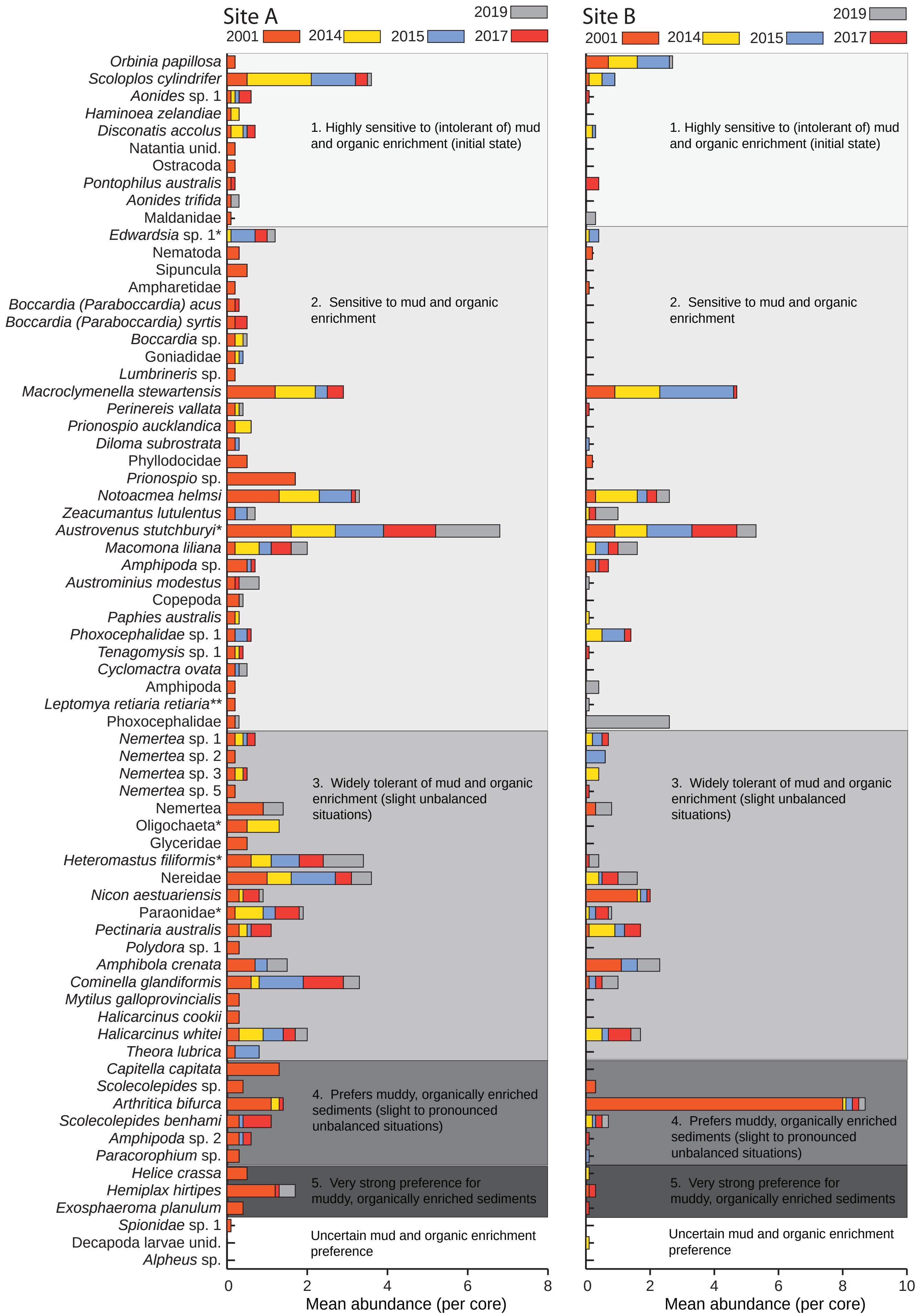
- Whenever percentage cover can be estimated for an attached species, it should be used in preference to the density scale.
- The massive/turf percentage cover scale should be used for all species except those classified under crust/ meadow.
- Where two or more layers exist, for instance foliose algae overgrowing crustose algae, total percentage cover can be over 100%.

Table B. Density Scales								
SACFOR size class				Density				
i	ii	iii	iv	0.25 m^2 (50x50 cm)	1.0 m^2 (100x100 cm)	10 m^2 (3.16x3.16 m)	100 m^2 (10x10 m)	1,000 m^2 (31.6x31.6 m)
<1 cm	1-3 cm	3-15 cm	>15 cm					
S	-	-	-	>2500	>10,000			
A	S	-	-	250-2500	1000-9999	>10,000		
C	A	S	-	25-249	100-999	1000-9999	>10,000	
F	C	A	S	3-24	10-99	100-999	1000-9999	>10,000
O	F	C	A	1-2	1-9	10-99	100-999	1000-9999
R	O	F	C			1-9	10-99	100-999
-	R	O	F				1-9	10-99
-	-	R	O					1-9
-	-	-	R					<1

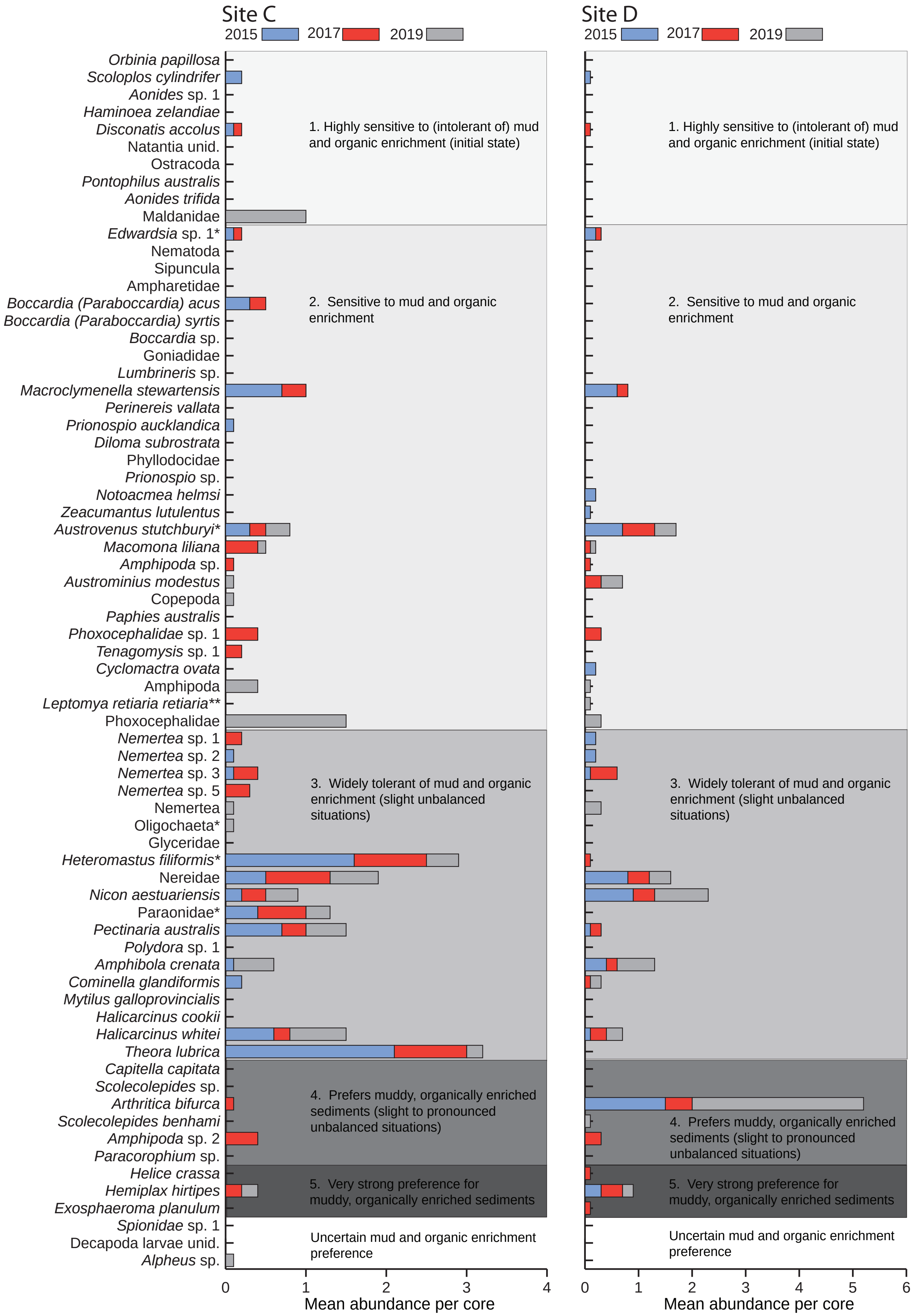
Epifauna and macroalgal cover (0.25 m^2 quadrats), Havelock Estuary Sites A, B, C, and D, 25-26 January 2019, *n* = 3.

Group	Family	Species	Common name	Scale	Class	A	B	C	D
Topshells	Amphibolidae	*Amphibola crenata*	Mudflat snail	#	ii	A	A	A	A
	Buccinidae	*Cominella glandiformis*	Mudflat whelk	#	ii	O	C	O	O
	Batillariidae	*Zeacumantus lutulentus*	Spire shell	#	ii	C	C	O	O
Red algae	Gracilariaceae	*Gracilaria chilensis*	Gracilaria weed	%	ii	O	O	O	O
Green algae	Ulvaceae	*Ulva lactuca*	Sea lettuce	%	ii	R	R	R	R

Mud and organic enrichment sensitivity of macroinvertebrates, Havelock Estuary, Sites A and B.
*denotes taxa for which abundance data for each year has been reduced by a scale factor of 5 to allow for graphical representation/interpretation of temporal differences in abundance among sensitivity groupings.



Mud and organic enrichment sensitivity of macroinvertebrates, Havelock Estuary, Sites C and D.
*denotes taxa for which abundance data for each year has been reduced by a scale factor of 5 to allow for graphical representation/interpretation of temporal differences in abundance among sensitivity groupings.



Appendix D:

Analytical Results

Hill Laboratories
TRIED, TESTED AND TRUSTED

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Hamilton 3240 New Zealand

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Certificate of Analysis

Client:	Robertson Environmental	**Lab No:**	2137591 SPv1
Contact:	Ben Robertson	**Date Received:**	07-Mar-2019
	C/- Robertson Environmental	**Date Reported:**	04-Apr-2019
	108 Glen Road	**Quote No:**	96814
	RD 1	**Order No:**	
	Nelson 7071	**Client Reference:**	Havelock Estuary - Marlborough
		Submitted By:	Ben Robertson

Sample Type: Sediment

Sample Name:		HAVFS_A-1 24-Jan-2019 5:00 pm	HAVFS_A-2 24-Jan-2019 5:00 pm	HAVFS_A-3 24-Jan-2019 5:00 pm	HAVFS_B-1 24-Jan-2019 5:00 pm	HAVFS_B-2 24-Jan-2019 5:00 pm
Lab Number:		2137591.1	2137591.2	2137591.3	2137591.4	2137591.5
Individual Tests						
Total Recoverable Phosphorus	mg/kg dry wt	410	400	390	210	192
Total Nitrogen*	g/100g dry wt	0.07	0.06	0.06	< 0.05	< 0.05
Total Organic Carbon*	g/100g dry wt	0.58	0.55	0.62	0.26	0.21
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg						
Total Recoverable Arsenic	mg/kg dry wt	4.1	3.9	4.1	1.5	1.4
Total Recoverable Cadmium	mg/kg dry wt	0.050	0.041	0.042	0.021	0.021
Total Recoverable Chromium	mg/kg dry wt	51	50	53	16.9	18.0
Total Recoverable Copper	mg/kg dry wt	10.2	10.8	10.8	5.9	5.4
Total Recoverable Lead	mg/kg dry wt	5.8	5.8	5.9	3.6	3.3
Total Recoverable Mercury	mg/kg dry wt	0.04	0.04	0.04	< 0.02	< 0.02
Total Recoverable Nickel	mg/kg dry wt	39	40	42	13.6	15.6
Total Recoverable Zinc	mg/kg dry wt	45	43	45	23	22
7 Grain Sizes Profile						
Dry Matter of Sieved Sample	g/100g as rcvd	76	74	73	76	76
Fraction >/= 2 mm*	g/100g dry wt	0.7	2.3	4.1	0.2	0.4
Fraction < 2 mm, >/= 1 mm*	g/100g dry wt	2.2	1.8	1.9	0.2	0.2
Fraction < 1 mm, >/= 500 µm*	g/100g dry wt	8.6	7.7	6.9	0.3	0.3
Fraction < 500 µm, >/= 250 µm*	g/100g dry wt	19.4	20.3	16.3	0.5	0.6
Fraction < 250 µm, >/= 125 µm*	g/100g dry wt	24.1	24.3	19.7	15.5	15.4
Fraction < 125 µm, >/= 63 µm*	g/100g dry wt	17.7	16.0	19.9	66.1	63.5
Fraction < 63 µm*	g/100g dry wt	27.3	27.6	31.2	17.2	19.7

Sample Name:		HAVFS_B-3 24-Jan-2019 5:00 pm	HAVFS_C-1 24-Jan-2019 5:00 pm	HAVFS_C-2 24-Jan-2019 5:00 pm	HAVFS_C-3 24-Jan-2019 5:00 pm	HAVFS_D-1 24-Jan-2019 5:00 pm
Lab Number:		2137591.6	2137591.7	2137591.8	2137591.9	2137591.10
Individual Tests						
Total Recoverable Phosphorus	mg/kg dry wt	177	420	430	420	310
Total Nitrogen*	g/100g dry wt	< 0.05	0.11	0.11	0.10	0.07
Total Organic Carbon*	g/100g dry wt	0.24	1.25	1.30	1.19	0.67
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg						
Total Recoverable Arsenic	mg/kg dry wt	1.3	4.1	4.8	4.3	2.5
Total Recoverable Cadmium	mg/kg dry wt	0.019	0.045	0.044	0.039	0.026
Total Recoverable Chromium	mg/kg dry wt	16.2	66	68	66	23
Total Recoverable Copper	mg/kg dry wt	5.4	14.8	15.6	14.9	8.7
Total Recoverable Lead	mg/kg dry wt	3.3	7.6	8.0	7.8	4.9
Total Recoverable Mercury	mg/kg dry wt	< 0.02	0.06	0.07	0.05	< 0.02
Total Recoverable Nickel	mg/kg dry wt	12.9	51	53	52	17.3

Sample Type: Sediment

Sample Name:		HAVFS_B-3 24-Jan-2019 5:00 pm	HAVFS_C-1 24-Jan-2019 5:00 pm	HAVFS_C-2 24-Jan-2019 5:00 pm	HAVFS_C-3 24-Jan-2019 5:00 pm	HAVFS_D-1 24-Jan-2019 5:00 pm
Lab Number:		2137591.6	2137591.7	2137591.8	2137591.9	2137591.10
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg						
Total Recoverable Zinc	mg/kg dry wt	21	49	51	49	30
7 Grain Sizes Profile						
Dry Matter of Sieved Sample	g/100g as rcvd	76	61	62	61	73
Fraction >/= 2 mm*	g/100g dry wt	0.1	< 0.1	< 0.1	< 0.1	1.7
Fraction < 2 mm, >/= 1 mm*	g/100g dry wt	0.1	0.3	< 0.1	< 0.1	0.2
Fraction < 1 mm, >/= 500 µm*	g/100g dry wt	0.2	0.7	0.5	0.4	0.4
Fraction < 500 µm, >/= 250 µm*	g/100g dry wt	0.5	2.3	1.9	2.0	0.6
Fraction < 250 µm, >/= 125 µm*	g/100g dry wt	17.3	5.9	5.9	5.7	1.6
Fraction < 125 µm, >/= 63 µm*	g/100g dry wt	63.0	29.9	32.7	30.2	50.3
Fraction < 63 µm*	g/100g dry wt	18.7	61.0	59.0	61.7	45.3

Sample Name:		HAVFS_D-2 24-Jan-2019 5:00 pm	HAVFS_D-3 24-Jan-2019 5:00 pm	HAVSP-A 24-Jan-2019 5:00 pm	HAVSP-B 24-Jan-2019 5:00 pm	HAVSP-C 24-Jan-2019 5:00 pm
Lab Number:		2137591.11	2137591.12	2137591.13	2137591.14	2137591.15
Individual Tests						
Total Recoverable Phosphorus	mg/kg dry wt	360	330	-	-	-
Total Nitrogen*	g/100g dry wt	0.07	0.06	-	-	-
Total Organic Carbon*	g/100g dry wt	0.86	0.73	-	-	-
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg						
Total Recoverable Arsenic	mg/kg dry wt	3.0	2.6	-	-	-
Total Recoverable Cadmium	mg/kg dry wt	0.035	0.031	-	-	-
Total Recoverable Chromium	mg/kg dry wt	26	23	-	-	-
Total Recoverable Copper	mg/kg dry wt	10.6	10.2	-	-	-
Total Recoverable Lead	mg/kg dry wt	6.0	5.3	-	-	-
Total Recoverable Mercury	mg/kg dry wt	< 0.02	0.02	-	-	-
Total Recoverable Nickel	mg/kg dry wt	19.6	18.0	-	-	-
Total Recoverable Zinc	mg/kg dry wt	35	32	-	-	-
7 Grain Sizes Profile						
Dry Matter of Sieved Sample	g/100g as rcvd	71	72	70	75	63
Fraction >/= 2 mm*	g/100g dry wt	0.1	1.1	2.1	2.5	< 0.1
Fraction < 2 mm, >/= 1 mm*	g/100g dry wt	0.2	0.3	1.7	0.1	0.2
Fraction < 1 mm, >/= 500 µm*	g/100g dry wt	0.4	0.5	7.2	0.2	0.8
Fraction < 500 µm, >/= 250 µm*	g/100g dry wt	0.6	1.0	16.8	0.7	3.3
Fraction < 250 µm, >/= 125 µm*	g/100g dry wt	1.4	10.9	23.6	16.1	7.6
Fraction < 125 µm, >/= 63 µm*	g/100g dry wt	45.4	35.3	17.4	60.1	32.4
Fraction < 63 µm*	g/100g dry wt	51.8	50.9	31.3	20.3	55.6

Sample Name:		HAVSP-D 24-Jan-2019 5:00 pm	HAVSP-E 24-Jan-2019 5:00 pm	HAVSP-F 24-Jan-2019 5:00 pm	HAVBS_GS-1 26-Jan-2019 6:00 pm	HAVBS_GS-2 26-Jan-2019 6:00 pm
Lab Number:		2137591.16	2137591.17	2137591.18	2137591.19	2137591.20
7 Grain Sizes Profile						
Dry Matter of Sieved Sample	g/100g as rcvd	73	60	61	75	60
Fraction >/= 2 mm*	g/100g dry wt	0.2	< 0.1	0.1	5.1	1.0
Fraction < 2 mm, >/= 1 mm*	g/100g dry wt	0.3	0.5	0.6	0.4	1.2
Fraction < 1 mm, >/= 500 µm*	g/100g dry wt	0.4	1.7	1.7	3.0	2.6
Fraction < 500 µm, >/= 250 µm*	g/100g dry wt	0.8	5.8	5.2	42.2	4.9
Fraction < 250 µm, >/= 125 µm*	g/100g dry wt	2.1	6.2	8.1	33.9	8.1
Fraction < 125 µm, >/= 63 µm*	g/100g dry wt	51.0	7.6	11.0	3.3	9.5
Fraction < 63 µm*	g/100g dry wt	45.4	78.1	73.2	12.1	72.7

Sample Name:		HAVBS_GS-3 26-Jan-2019 6:00 pm	HAVBS_GS-4 26-Jan-2019 6:00 pm	HAVBS_GS-5 26-Jan-2019 6:00 pm	HAVBS_GS-6 26-Jan-2019 6:00 pm	HAVBS_GS-7 26-Jan-2019 6:00 pm
Lab Number:		2137591.21	2137591.22	2137591.23	2137591.24	2137591.25

Sample Type: Sediment						
Sample Name:		HAVBS_GS-3 26-Jan-2019 6:00 pm	HAVBS_GS-4 26-Jan-2019 6:00 pm	HAVBS_GS-5 26-Jan-2019 6:00 pm	HAVBS_GS-6 26-Jan-2019 6:00 pm	HAVBS_GS-7 26-Jan-2019 6:00 pm
Lab Number:		2137591.21	2137591.22	2137591.23	2137591.24	2137591.25
7 Grain Sizes Profile						
Dry Matter of Sieved Sample	g/100g as rcvd	62	52	55	62	79
Fraction >/= 2 mm*	g/100g dry wt	0.5	0.1	< 0.1	< 0.1	4.7
Fraction < 2 mm, >/= 1 mm*	g/100g dry wt	1.4	0.2	0.2	0.2	3.1
Fraction < 1 mm, >/= 500 µm*	g/100g dry wt	4.1	0.6	0.5	0.3	10.9
Fraction < 500 µm, >/= 250 µm*	g/100g dry wt	15.2	1.3	1.2	0.5	33.7
Fraction < 250 µm, >/= 125 µm*	g/100g dry wt	19.1	1.4	1.1	1.2	26.4
Fraction < 125 µm, >/= 63 µm*	g/100g dry wt	8.0	5.1	4.2	11.1	9.2
Fraction < 63 µm*	g/100g dry wt	51.7	91.3	92.8	86.6	12.1

Sample Name:		HAVBS_GS-8 26-Jan-2019 6:00 pm	HAVBS_GS-9 26-Jan-2019 6:00 pm			
Lab Number:		2137591.26	2137591.27			
7 Grain Sizes Profile						
Dry Matter of Sieved Sample	g/100g as rcvd	76	72	-	-	-
Fraction >/= 2 mm*	g/100g dry wt	2.4	6.2	-	-	-
Fraction < 2 mm, >/= 1 mm*	g/100g dry wt	1.2	5.3	-	-	-
Fraction < 1 mm, >/= 500 µm*	g/100g dry wt	5.8	10.8	-	-	-
Fraction < 500 µm, >/= 250 µm*	g/100g dry wt	33.8	20.1	-	-	-
Fraction < 250 µm, >/= 125 µm*	g/100g dry wt	29.2	13.0	-	-	-
Fraction < 125 µm, >/= 63 µm*	g/100g dry wt	13.2	10.1	-	-	-
Fraction < 63 µm*	g/100g dry wt	14.3	34.6	-	-	-

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%.	-	1-12
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%.	-	1-12
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	1-12
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	1-12
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-12
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	1-12
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	1-12
7 Grain Sizes Profile			
Dry Matter for Grainsize samples	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-27
Fraction >/= 2 mm*	Wet sieving with dispersant, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-27
Fraction < 2 mm, >/= 1 mm*	Wet sieving using dispersant, 2.00 mm and 1.00 mm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-27
Fraction < 1 mm, >/= 500 µm*	Wet sieving using dispersant, 1.00 mm and 500 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-27
Fraction < 500 µm, >/= 250 µm*	Wet sieving using dispersant, 500 µm and 250 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-27
Fraction < 250 µm, >/= 125 µm*	Wet sieving using dispersant, 250 µm and 125 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-27
Fraction < 125 µm, >/= 63 µm*	Wet sieving using dispersant, 125 µm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-27

Sample Type: Sediment			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Fraction < 63 µm*	Wet sieving with dispersant, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-27

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

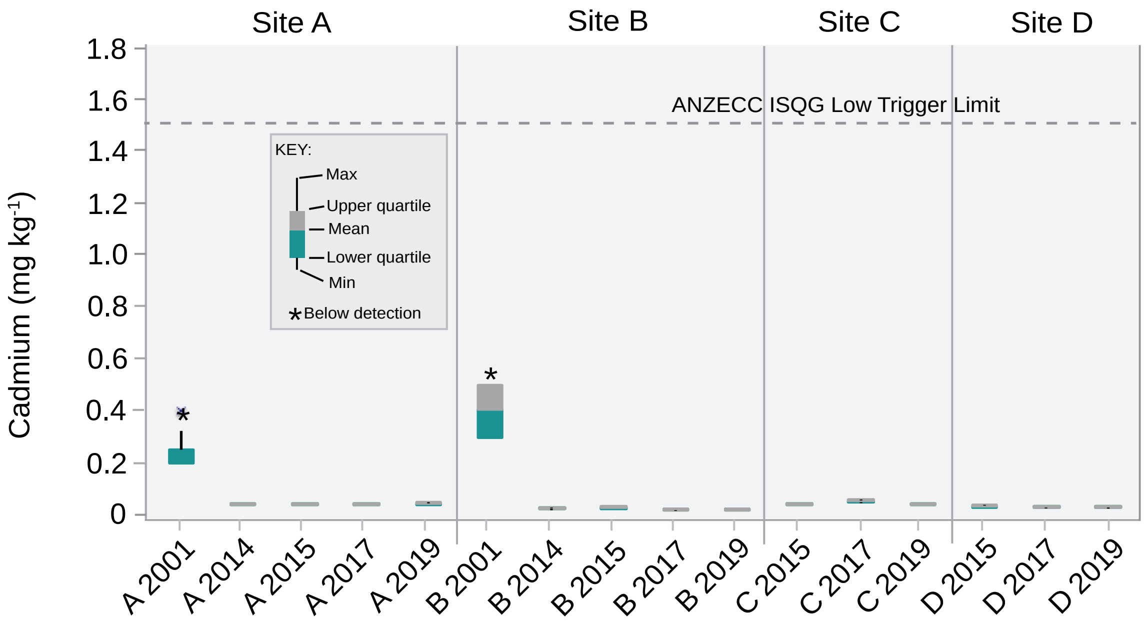
Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.

This certificate of analysis must not be reproduced, except in full, without the written consent of the signatory.

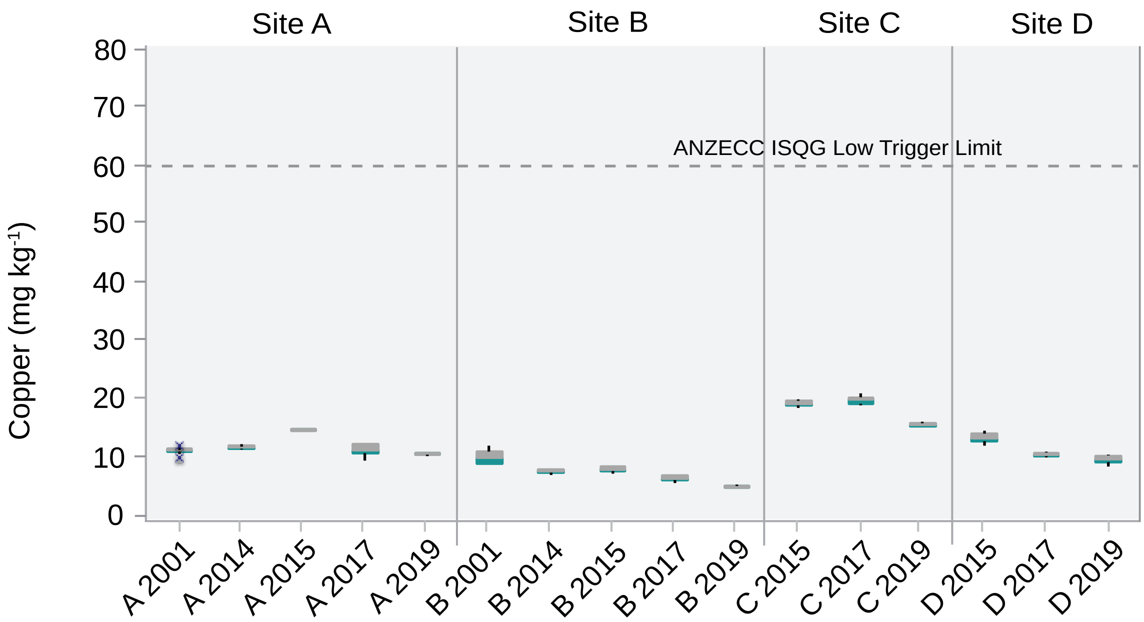
Carole Rodgers-Carroll BA, NZCS
Client Services Manager - Environmental

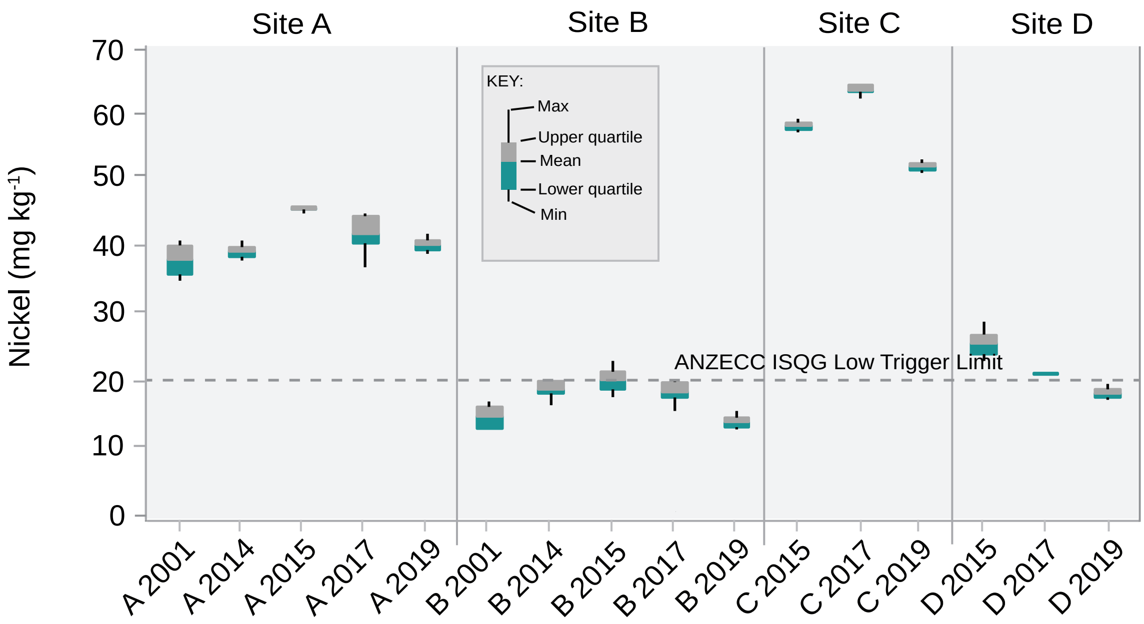
Appendix E:

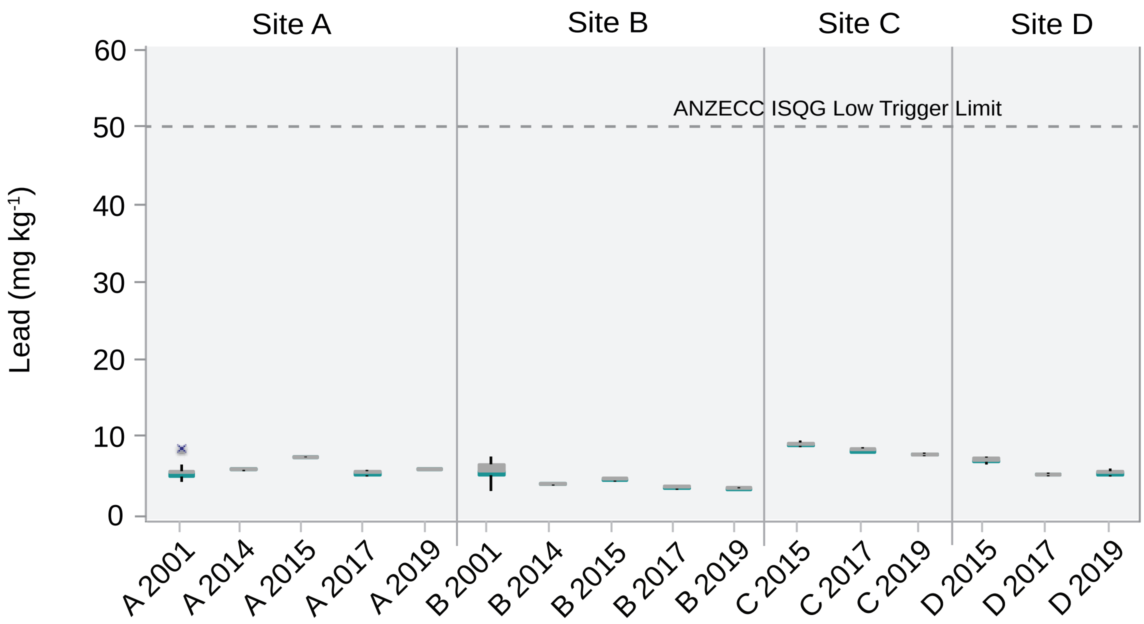
Sediment Trace Metals

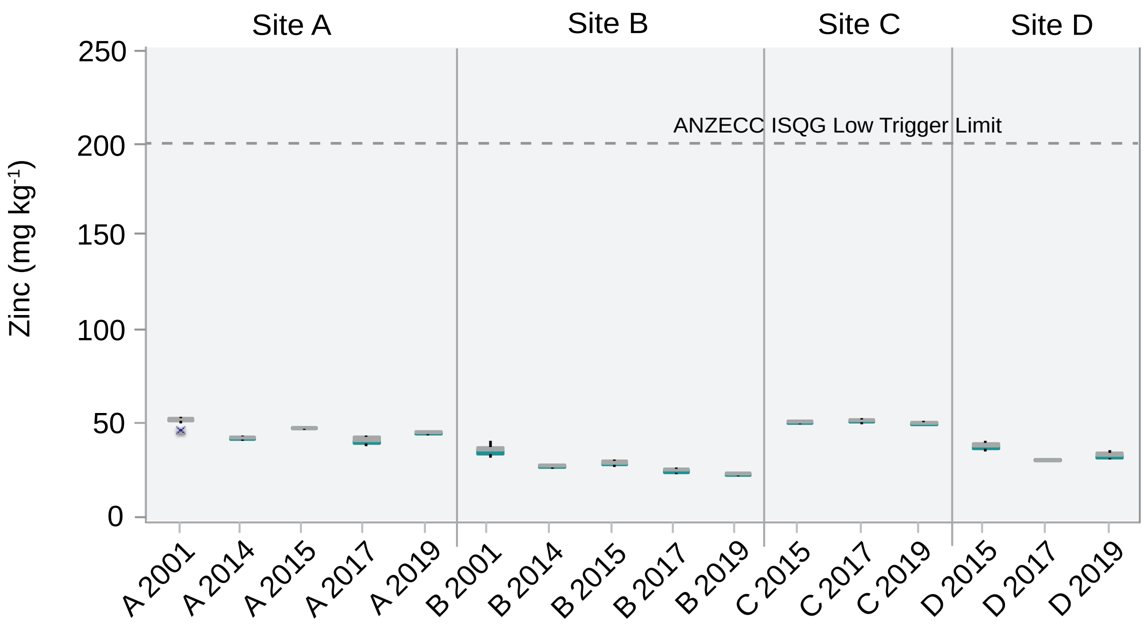

Site A
Site B
Site C
Site D
Cadmium (mg kg-1)
ANZECC ISQG Low Trigger Limit
KEY:
Max
Upper quartile
Mean
Lower quartile
Min
* Below detection
A 2001
A 2014
A 2015
A 2017
A 2019
B 2001
B 2014
B 2015
B 2017
B 2019
C 2015
C 2017
C 2019
D 2015
D 2017
D 2019

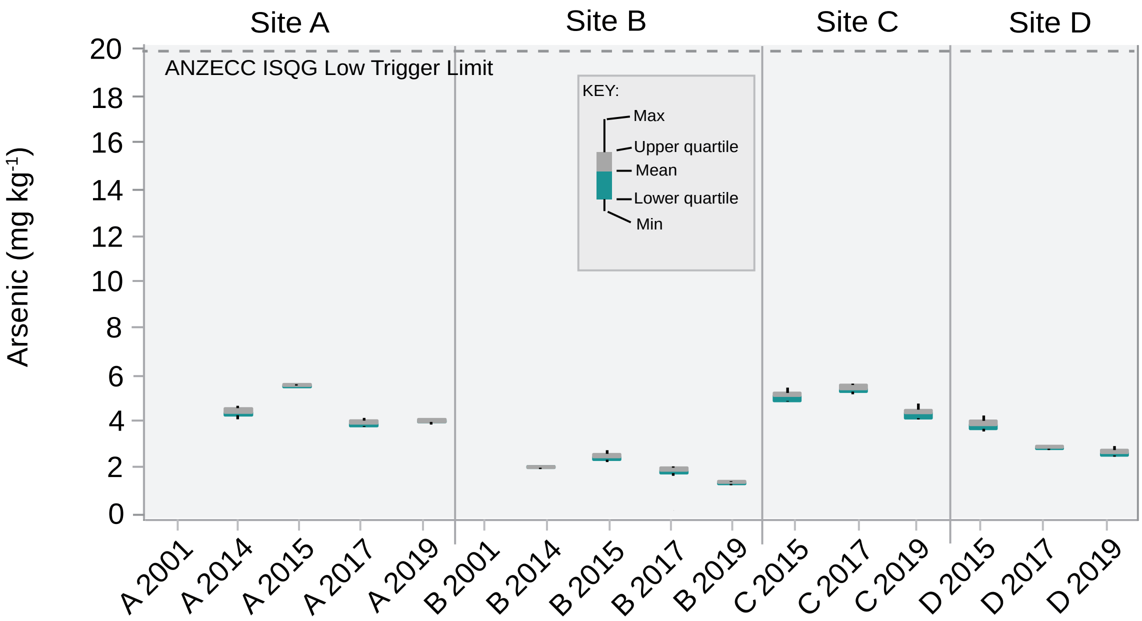

Site A
Site B
Site C
Site D
Chromium (mg kg-1)
ANZECC ISQG Low Trigger Limit
A 2001
A 2014
A 2015
A 2017
A 2019
B 2001
B 2014
B 2015
B 2017
B 2019
C 2015
C 2017
C 2019
D 2015
D 2017
D 2019

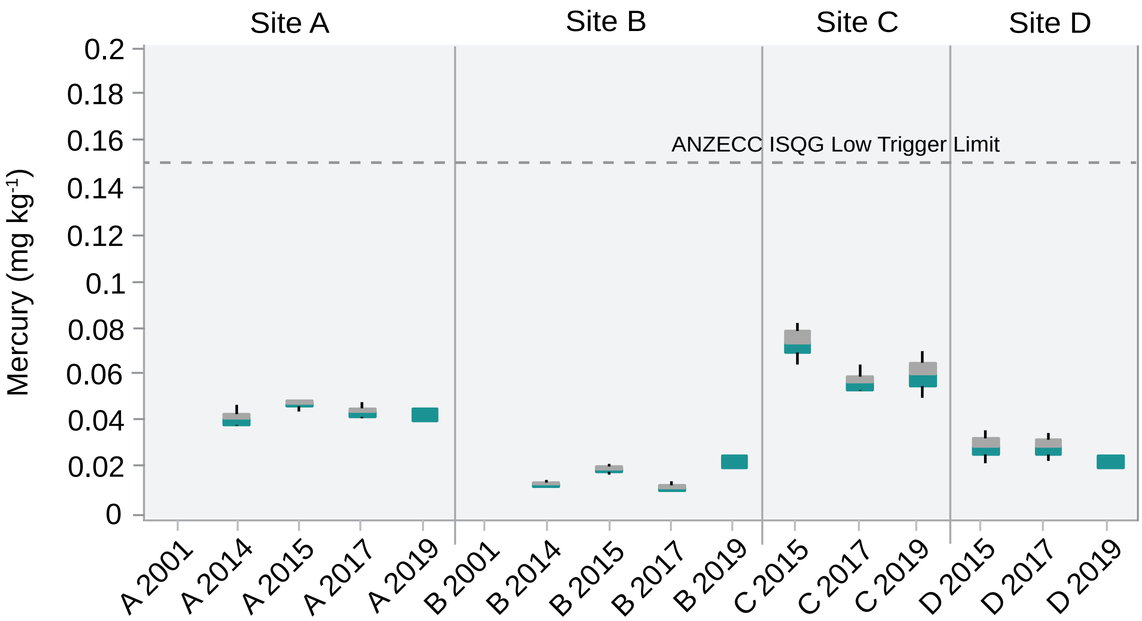

Site A
Site B
Site C
Site D
Copper (mg kg-1)
ANZECC ISQG Low Trigger Limit
A 2001
A 2014
A 2015
A 2017
A 2019
B 2001
B 2014
B 2015
B 2017
B 2019
C 2015
C 2017
C 2019
D 2015
D 2017
D 2019


Site A
Site B
Site C
Site D
Nickel (mg kg-1)
KEY:
Max
Upper quartile
Mean
Lower quartile
Min
ANZECC ISQG Low Trigger Limit
A 2001
A 2014
A 2015
A 2017
A 2019
B 2001
B 2014
B 2015
B 2017
B 2019
C 2015
C 2017
C 2019
D 2015
D 2017
D 2019


Site A
Site B
Site C
Site D
Lead (mg kg-1)
ANZECC ISQG Low Trigger Limit
A 2001
A 2014
A 2015
A 2017
A 2019
B 2001
B 2014
B 2015
B 2017
B 2019
C 2015
C 2017
C 2019
D 2015
D 2017
D 2019


Site A
Site B
Site C
Site D
Zinc (mg kg-1)
ANZECC ISQG Low Trigger Limit
A 2001
A 2014
A 2015
A 2017
A 2019
B 2001
B 2014
B 2015
B 2017
B 2019
C 2015
C 2017
C 2019
D 2015
D 2017
D 2019


Site A
Site B
Site C
Site D
ANZECC ISQG Low Trigger Limit
KEY:
Max
Upper quartile
Mean
Lower quartile
Min
Arsenic (mg kg-1)
20
18
16
14
12
10
8
6
4
2
0
A 2001
A 2014
A 2015
A 2017
A 2019
B 2001
B 2014
B 2015
B 2017
B 2019
C 2015
C 2017
C 2019
D 2015
D 2017
D 2019


Site A
Site B
Site C
Site D
ANZECC ISQG Low Trigger Limit
Mercury (mg kg-1)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
A 2001
A 2014
A 2015
A 2017
A 2019
B 2001
B 2014
B 2015
B 2017
B 2019
C 2015
C 2017
C 2019
D 2015
D 2017
D 2019

Appendix F:

Sediment Loads & NZ ETI Results Summary

Catchment-derived sediment load predictions:

Currently, there is insufficient information to identify robust sedimentation susceptibility thresholds for NZ estuaries, but in order to provide a tentative desktop estimate of the potential for ongoing sedimentation, the magnitude of modelled estimates of the Current State Sediment load (CSSL) can be compared with estimates of the historic Natural State Sediment Load (NSSL). The NSSL can be estimated by assuming a native forest land cover and the presence of sufficient catchment wetlands to retain 50 % of the load. In effect, such a ratio of CSSL/NSSL indicates whether appropriate soil conservation practices are currently undertaken in the catchment (e.g. a high ratio indicating further effort is required). Natural state sediment loads (NSSL) were estimated with all landuse set at native forest cover and corrected for wetland attenuation. Final NSSL = NFL x NSWA where NFL is Native forest load (kt yr^{-1}) and NSWA is the estimated natural state wetland attenuation for suspended sediment. In this case, NSWA is estimated as 0.5, indicating a mean wetland removal efficiency of ~50%. This assumption is based on the following study results:

- A wetland complex, draining suburban catchments in Wisconsin USA, attenuated ~71%, 21%, and 13% of the annual loads of SS, TP and TN respectively over a four year period (Kreiling et al., 2013).
- Previous studies in New Zealand (McKergow et al. 2007; Tanner et al. 2010) and around the world (Kadlec & Wallace 2009; Mitsch & Grosslink 2007) have identified the need for wetland areas of 1-5% of the contributing catchment to provide reasonable levels of nutrient attenuation in humid-climate agricultural landscapes. Depending on the specific attributes of suspended solids, smaller wetland areas in the range of 0.1-1% of contributing catchment can often achieve satisfactory suspended sediment removal.
- The average stormwater suspended sediment removal efficiency for a large number of both NZ and international wetlands showed a mean of 58% (International BMP Database 2007, as presented in Semadeni-Davies 2009).

For the Havelock Estuary, the chosen CSSL/NSSL ratio thresholds were as follows: low 1-1.1, moderate 1.1-2, high 2-5, very high >5. Catchment sediment load estimates were derived from the NIWA CLUES modelling system[1]. The load threshold ratings were then combined (using the matrix below) with ratings for the likelihood of sediment trapping based on the assumption that high susceptibility SIDEs estuaries are physically susceptible to fine sediment accumulation.

[1] CSSL estimated using CLUES (default setting of REC2 and LCBB3 (2008/2009) land cover), NSSL estimated by setting CLUES land cover to native forest, with a further 50% reduction applied in line with the points above.

	Current State Sediment Load (CSSL)/Natural State Sediment Load (NSSL)			
Estuary Category	CSSL = 1 to 1.1 x NSSL	CSSL = 1.1 to 2 x NSSL	CSSL = 2 to 5 x NSSL	CSSL > 5 x NSSL
SIDEs with extensive areas of poorly flushed habitat	Very Low Susceptibility	Low Susceptibility	Moderate Susceptibility	High Susceptibility

NZ ETI calculation and outputs:

The NZ ETI (Robertson et al. 2016a,b) is designed to enable the consistent assessment of estuary state in relation to nutrient enrichment, and also includes assessment criteria for sediment muddiness issues. An integrated online calculator is available [https://shiny.niwa.co.nz/Estuaries-Screening-Tool-1/] to calculate estuary physical and nutrient load susceptibility (primarily based on catchment nutrient loads combined with mixing and dilution in the estuary), as well as trophic expression based on key estuary indicators [https://shiny.niwa.co.nz/Estuaries-Screening-Tool-2/]. The more indicators included, the more robust the NZ ETI score becomes. Where established ratings are not yet incorporated into the NIWA NZ ETI online calculator they are included via spreadsheet calculator. The indicators used to derive an NZ ETI score and determine trophic state for the Havelock Estuary at the time the 2019 monitoring was undertaken (26th-29th January) are presented below using both the fine scale monitoring results (Robertson 2019) and broad scale monitoring results (this report). The input values used in the online calculator are presented overleaf. NZ ETI Tool 1 rates the physical and nutrient load susceptibility of Havelock Estuary as moderate. NZ ETI Tool 2 online calculator scores the estuary 0.67, Band C, a rating of moderate. This is driven primarily by the presence of GEZ in localised regions and a more widespread sediment muddiness/ poor oxygenation problem.

NZ ETI scoring summary for Havelock Estuary, January 2019.			
Primary Symptom Indicators for Shallow Intertidal Dominated Estuaries (At least 1 primary symptom indicator required)			Primary symptom value
Required	Opportunistic Macroalgae	Macroalgal Ecological Quality - Opportunistic Macroalgal Blooming Tool (OMBT) coefficient*	0.4
	Macroalgal Gross Nuisance Zone (GNA) %	% Gross Nuisance Area (GNA)/Estuary Area*	2.9
	Macroalgal GNA (ha)	Gross Nuisance Area (GNA) (ha)*	16.0
Optional	Phytoplankton biomass	Chl a (summer 90 pctl, mg m^{-3})	-
	Cyanobacteria (if issue identified) - NOTE NZ ETI rating not yet developed		-
Supporting Indicators for Shallow Intertidal Dominated Estuaries (Must include a minimum of 1 required indicator)			Supporting Indicator Value
Required indicators	Sediment Oxygenation	Mean Redox Potential (mV) at 1 cm depth in most impacted sediments and representing at least 10% of estuary area**	-268.0
		% of estuary with Redox Potential <-150 mV at 3 cm or aRPD <1 cm*	53.0
		Ha of estuary with Redox Potential <-150 mV at 3 cm or aRPD <1 cm*	194.6
	Sediment Total Organic Carbon	Mean TOC (%) measured at 0-2 cm depth in most impacted sediments and representing at least 10% of estuary area**	1.2
	Sediment Total Nitrogen	Mean TN (mg kg^{-1}) measured at 0-2 cm depth in most impacted sediments and representing at least 10% of estuary area**	100.0
	Macroinvertebrates	Mean NZ AMBI score measured at 0-15 cm depth in most impacted sediments and representing at least 10% of estuary area**	2.4
Optional	Muddy sediment	% estuary area with soft mud (>25 % mud content)*	70.7
	Sedimentation rate	Ratio of Mean estimated annual Current State Sediment Load (CSSL) relative to mean annual Natural State Sediment Load (NSSL)	2.5
	Dissolved Oxygen	1 day instantaneous minimum of water column measured from representative areas of estuary water column (including likely worst case conditions) (mg m^{-3})	-
		Overall NZ ETI Score	**0.67**
			Moderate

* Based on 2019 broad scale findings (Robertson 2019).
** Based on 2019 fine scale findings (this report).
***Sediment loads estimated from NIWA's CLUES modelling system.

Input values used in the NZ ETI online calculator (April 2019). See the NIWA online tool metadata spreadsheets for full explanation of terms and abbreviations.

NZ ETI Tool 1 Input details	Calculator Headings	Unit	Input Value
Estuary Number	Est_no		11222
Estuary Name	Est_name		Havelock Estuary
Regional Council	Reg_Council		MDC
Island	Island		South Island
NZCHS geomorphic code	NZCHS_code		9
NZCHS geomorphic class	NZCHS_class		Deep drowned valley
ETI Class	ETI_class		SIDE
Latitude	LAT	decimal degrees	-41.1659
Longitude	LON	decimal degrees	173.46
Freshwater inflow	Qf	m3/s	48.7
Annual river total nitrogen loading	TNriver	T/yr	426.5*
Annual river total phosphorus loading	TPriver	T/yr	112.1*
Volume	V	m3	24000000
Tidal Prism	P	m3	11246995
Return flow fraction	b	unitless	NA
ACExR fitted exponent	A	unitless	-0.55
ACExR fitted constant	B	unitless	128.23
Ratio NO3	R_NO3	unitless	0.86
Ratio DRP	R_DRP	unitless	0.79
Ocean salinity	OceanSalinity_mean	ppt	34.82
Ocean nitrate concentration	NOcean	mg/m3	16.30
Ocean DRP concentration	POcean	mg/m3	7.65
Intertidal area	Intertidal	%	71.00
Typical closure length	Tl	days	NA
ICOE class	isICOE	one of: TRUE, FALSE	FALSE
Closure length	closure_length	one of: days, months	days
Estuary Area	est_area_m2	m2	8007000
Mean depth	mean_depth	m	3
Tidal height	tidal_height	m	2.2

NZ ETI Tool 2 Input details			
Name of estuary	estuary_name		
Phytoplankton Biomass (Chlorophyll a)	CHLA	mg/m3	NA
Macroalgal GNA	macroalgae_GNA_ha	ha	16
Macroalgal GNA/Estuary Area	macroalgae_GNA_percent	%	2.9
Opportunistic Macroalgae	macroalgae_EQR	OMBT EQR	0.41
Dissolved Oxygen (DO)	DO	mg/m3	NA
Sediment Redox Potential (RP)	REDOX	mV	-268
Total Organic Carbon (TOC)	TOC	%	1.2
Total Nitrogen (TN)	TN	mg/kg	100
Macroinvertebrates	NZ AMBI	NZ Hybrid RI AMBI	2.4
Area of soft mud	soft_mud	Proportion	0.7
Estuary type	estuary_type		SIDE
ICOE status	isICOE	TRUE/FALSE	FALSE

* Loads derived using CLUES Model.

Appendix G:

Supporting Notes - PCO Analysis

Explanatory notes for Principal Coordinate Ordination (PCO) plots (Figure 7a,b,c):

These plots show the relationship among samples in terms of similarity in macroinvertebrate community composition at fine scale sites, for the sampling period 2001 and 2014 (Sites A and B), 2015, 2017 and 2019 (Sites A, B, C and D). The plot shows the macrofaunal samples (*n* = 12 in 2001 and *n* = 10 in subsequent years) for sites in each year, and is based on Bray Curtis dissimilarity and square root transformed data. The approach involves an unconstrained multivariate data analysis method, in this case principle coordinates analysis (PCO) using PERMANOVA version 1.0.5 (PRIMER-e v6.1.15). The analysis plots the site and abundance data for each species as points on a distance-based matrix (a scatterplot ordination diagram). Points clustered together are considered similar, with the distance between points and clusters reflecting the extent of the differences. The interpretation of the ordination diagram depends on how good a representation it is of actual dissimilarities (i.e. how much of the variation in the data matrix is explained by the first two PCO axes). For the present plots, the cumulative variation explained was 30-60%, indicating a relatively good representation of the abundance matrix.

The environmental vector overlays (*n* = 10 in 2001, and 3 post-2001 for each variable), based on Spearman correlations, show preliminary exploratory information on the strength of environmental variables, with their relative influence on the structure of macrofaunal communities proportional to their length in relation to the outer circle.

Appendix H:

Field Photographs

Photo 1-3: Sparse macroalgae (*Gracilaria chilensis* and *Ulva* spp.) and epifauna (e.g. highly abundant mud snail, *Amphibola crenata*) associated with muddy, moderate-poorly oxygenated substrata, conditions common among intertidal flats in the middle-lower estuary where fine scale sites are located.

Photo 4-7: Representative samples indicative of relatively shallow (0.5-1 cm) apparent Redox Potential Discontinuity (aRPD) depths at each fine scale site in 2019.

Photo 8-9: Sampling equipment used to measure down-core (0-10 cm) redox potential (mV), a proxy for sediment oxygenation, at each fine scale site, Havelock Estuary, 2019.

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