Kaikorai Estuary

Fine Scale Monitoring 2017/18

Prepared
for

**Otago
Regional
Council**

**May
2018**

Cover Photo: Kaikorai Estuary lower reaches

Kaikorai Estuary muddy middle reaches facing south toward Brighton Road Bridge

Kaikorai Estuary

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Prepared for
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by

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KAIKORAI ESTUARY - EXECUTIVE SUMMARY

This report summarises the results of the first year of fine scale baseline monitoring (2017/18) of three benthic intertidal sites and three upper estuary water column sites within Kaikorai Estuary, a moderate sized, shallow, intertidal dominated (SIDE) estuary on the Otago south coast. It is one of the key estuaries in Otago Regional Council's (ORC's) long-term coastal monitoring programme. The fine scale monitoring results, risk indicator ratings, overall estuary condition, and monitoring recommendations are summarised below.

FINE SCALE MONITORING RESULTS

Benthic Intertidal Habitat Results

- There was no seagrass at any of the fine scale sites, and <5 % cover of opportunistic macroalgae, the primary indicator of benthic eutrophication, at lower and middle estuary Sites A and B and 50-70 % cover at upper estuary Site C.
- Sediment mud content ranged from 14-65 % with the lowest content at Site A nearest the ocean and highest at middle and upper estuary Sites B and C.
- Sediment oxygenation was moderate in the lower estuary (redox potential <-150 mV below 5 cm depth, Site A), and poor in middle and upper estuary sediments (redox potential <-150 mV below 0.5 cm depth, Site B and C).
- The indicators of organic enrichment (total organic carbon) and nutrient enrichment (total nitrogen and phosphorus) were at low concentrations at Site A, high at Site B and moderate at Site C.
- Trace metal concentrations were low at upper and lower sites, and moderate at mid-estuary Site B (apart from zinc, which was high).
- The estuary macroinvertebrate community index (NZ AMBI) indicated an unbalanced to impoverished community affected by elevated sediment mud, total organic carbon and nutrient concentrations and poor oxygenation, particularly at mid and upper estuary Sites B and C.

BENTHIC RISK INDICATOR RATINGS

(INDICATE RISK OF ADVERSE ECOLOGICAL IMPACTS)

🟦	Low	🟨	Moderate
⬜	Very Low	🟧	High

Kaikorai Estuary	Site Kaik A (lower)				Site Kaik B (mid)				Site Kaik C (upper)			
	2017	Yr 2	Yr 3	Yr 4	2017	Yr 2	Yr 3	Yr 4	2017	Yr 2	Yr 3	Yr 4
Sediment Mud Content	🟦				🟧				🟧			
Redox Potential (Oxygenation)	🟦				🟧				🟧			
TOC (Total Organic Carbon)	🟦				🟧				🟨			
Total Nitrogen	🟦				🟧				🟨			
Macroinvert condition (NZ AMBI)	🟨				🟨				🟨			
Metals (Cd, Cu, Cr, Hg, Ni, Pb, Zn As)	⬜				🟨				🟦			

Upper Estuary Subtidal Habitat Results

- The salinity results for the surface and bottom waters of the three subtidal sites shows that the main upper estuary channel (1.5 km stretch) was stratified with saline bottom water overlain by a freshwater-influenced, less dense, saline layer. The presence of isolated (stratified) bottom water where nutrient concentrations can build-up indicates a high potential for eutrophication symptoms to develop.
- Total nitrogen (TN), dissolved inorganic nitrogen (DIN) and total phosphorus (TP) concentrations exceeded the eutrophication thresholds of 0.33 mg TN l^{-1}, 0.07 mg DIN l^{-1} and 0.02 mg P l^{-1} in both the surface and bottom waters at all three upper estuary sites.
- Chlorophyll *a* concentrations, the primary indicator of water column eutrophication, exceeded the NZ ETI eutrophication threshold level of 16 ug l^{-1}. Bottom water at middle and upper Sites Y and Z had a high concentration (i.e. 27.1-44.4 ug l^{-1} chlorophyll *a*) while the lower Site X, and the surface waters at all three sites, had low concentrations. Also of relevance was the presence of relatively high macroalgal cover in the nearby upper estuary benthic Site C.

Kaikorai Estuary - Executive Summary (continued)

ESTUARY CONDITION AND ISSUES

Benthic Intertidal Habitat

The fine scale monitoring of representative intertidal sediments placed the estuary in a POOR state overall, with a middle and upper estuary eutrophication and sedimentation issue as well as a sediment zinc toxicity issue in the middle estuary. The former manifested as elevated muds and nutrients and poor sediment oxygenation and macroinvertebrate community condition. The NZ ETI score for Kaikorai, which integrates broad scale monitoring results, was HIGH, reflecting the presence of primary eutrophication high symptoms in the mid-upper estuary.

Upper Estuary Subtidal Habitat

Taken as a whole, the December 2017 data showed that the bottom water in the poorly flushed upper estuary channel was stratified and eutrophic, as indicated by very high chlorophyll *a* and the presence of TN, DIN and TP exceeding eutrophication threshold concentrations. However, given only one comprehensive sampling event, questions remain around likely duration, magnitude and frequency of such eutrophication symptoms. Although upper estuary bottom water stratification is a natural event in many shallow NZ estuaries, it can be exacerbated by reductions in natural river inflows (e.g. from upstream water abstraction and damming). Once established, the extent of eutrophication in the bottom layer is likely to be primarily driven by catchment nutrients, particularly nitrogen. Preliminary indications suggest that river total nitrogen concentrations would need to be much less than 0.33 mg N l^{-1} in order to minimise eutrophication symptoms in this sensitive zone of the estuary.

Overall, the findings indicate that muddiness, organic and nutrient enrichment, and toxicity (primarily in the middle and upper estuary), and upper estuary bottom-water phytoplankton blooms, are issues that require further attention. The results also indicated that the current loading regimes of nitrogen to the Kaikorai Estuary were expected to exacerbate its poor trophic state, but the degree to which current suspended sediment loads affect its sedimentation state were unknown.

RECOMMENDED MONITORING

Kaikorai Estuary has been identified by ORC as a priority for monitoring because it is a moderate sized estuary with high ecological and human use values that is situated in a developed catchment, and therefore vulnerable to excessive sedimentation, toxicity and eutrophication. In order to assess ongoing long-term trends in the condition of such estuaries, it is common practice amongst NZ Regional Councils to establish a strong baseline against which future trends can be compared. This typically comprises comprehensive broad scale habitat mapping on a 5-10 yearly cycle, targeted monitoring where specific issues are identified (e.g. opportunistic nuisance macroalgal growth), and fine scale monitoring comprising 3-4 consecutive years of baseline monitoring, followed by 5 yearly impact monitoring.

Broad scale habitat mapping and fine scale sampling has now been undertaken for 1 baseline year (December 2017). To complete the fine scale baseline in Kaikorai Estuary, it is recommended that 3 consecutive years of annual summer (i.e. Dec-Feb) fine scale monitoring of intertidal sites (including sedimentation rate measures), and water column monitoring, be undertaken in 2018, 2019 and 2020.

Upper estuary channel where subtidal water quality monitoring was undertaken, Kaikorai Estuary, 2017.

1. INTRODUCTION

Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. The Otago Regional Council's 'Regional Policy Statement and Regional Plan: Water' demonstrates the Council's determination to maintain estuaries in good condition. In the period 2005-2009 Otago Regional Council (ORC) undertook preliminary (one-off) monitoring of the condition of seven Otago estuaries in its region. In 2016, ORC began a more comprehensive long-term estuary monitoring programme designed to specifically address the key NZ estuary issues of eutrophication and sedimentation within their estuaries, as well as identifying any toxicity and habitat change issues. The estuaries currently included in the programme are; Kaikorai Estuary, Tokomairiro Estuary, Shag Estuary, Waikouaiti Estuary and Catlins Estuary.

Monitoring of the Kaikorai Estuary began with preliminary broad and fine scale monitoring undertaken in partial form in February 2001 and October 2007-08, and the first year of comprehensive baseline monitoring undertaken in December 2017.

Within NZ, the approach for monitoring estuary condition follows the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002) and the NZ Estuary Trophic Index (ETI) (Robertson et al. 2016a and b). It consists of three components as follows:

1. **Ecological Vulnerability Assessment (EVA**) of estuaries in the region to major issues (see Table 1) and appropriate monitoring design. This component has not yet been undertaken on a regional scale for Otago and hence relative vulnerabilities of their estuaries to the key issues have not been formally identified.
2. **Broad Scale Habitat Mapping (NEMP approach).** This component (see Table 1) maps the key habitats within the estuary, determines their condition, and assesses changes to these habitats over time. Broad scale intertidal mapping of Kaikorai Estuary was first undertaken in February 2001 (Robertson et al. 2002) and was repeated in October 2008 (Stewart 2008) and January 2017 (Stevens 2018).
3. **Fine Scale Monitoring (NEMP approach).** Monitoring of physical, chemical and biological indicators (see Table 1). This component, which provides detailed information on the condition of Kaikorai Estuary, was first undertaken in February 2001 (Robertson et al. 2002), and repeated in partial form in October 2007 (Stewart 2008), with the first year of baseline monitoring undertaken on 15 December 2017. This latter monitoring is the subject of this report.

To help evaluate overall estuary condition and decide on appropriate monitoring and management actions, a series of risk indicator ratings are presented and described in Section 2. The current report describes the 2017/18 fine scale results and compares them to the relevant previous findings. An overall NZ ETI score (Robertson et al. 2016a and 2016b), which integrates the 2017/18 broad scale monitoring results (Stevens 2018) to describe the estuary's current trophic status in relation to catchment-derived nutrient and sediment inputs, is presented in Section 4.3 of this report.

Kaikorai Estuary

The Kaikorai Estuary, located on the Otago south coast (Figure 1), is moderate in size (94 ha) and comprises a confined upper estuary river channel, a large centrally constricted basin, and tall sand dunes and a highly dynamic sandy beach on the exposed southern coastal margin that create a narrow (infrequently closed) entrance to the estuary. When the mouth is closed the estuary remains predominantly subtidal, but becomes largely intertidal when the mouth is open. Because the latter appears to be the prevailing physical state based on previous monitoring events, the Kaikorai Estuary operates as a microtidal (tidal range <1m) Shallow Intertidal Dominated Estuary (SIDE) type, rather than a poorly flushed coastal lagoon. The tidal estuary extends ~4 km up the valley with some of its margins lined by high-tidal saltmarsh and historically included large areas of estuary or flood plain but which have subsequently been developed for farming and other infrastructure (golf course and landfill). The greatest development has occurred on the northern and eastern sides of the estuary. The Kaikorai Estuary is listed as a regionally significant wetland area in the ORC's Regional Plan: Water, and an area of significant conservation value in the Dunedin City District Plan.

Catchment landuse is dominated by sheep grazing on high and low producing exotic grassland but it also includes significant areas of urban development and both native and exotic forest.

Because the estuary is fed by a relatively small river, the Kaikorai (mean flow ~0.46 $m^3 s^{-1}$), the main channel of the upper-mid estuary is poorly flushed during baseflows. As a consequence, this section becomes stratified with a surface layer of lighter, low salinity freshwater flowing over a layer of dense saline water. Because the dense bottom water layer is more stagnant, its water quality can deteriorate, particularly in relation to excessive inputs of nutrients (ETI nutrient load susceptibility rating of HIGH) and fine muds.

Table 1. Summary of the major environmental issues affecting most New Zealand estuaries.

1. Sediment Changes

Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays. Prior to European settlement they were dominated by sandy sediments and had low sedimentation rates (<1 mm/year). In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, New Zealand'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; and
- making the water unappealing to swimmers.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Sedimentation	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 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

2. Eutrophication

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 Key Indicators:

Issue	Recommended Indicators	Method
Eutrophication	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 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

Table 1. Summary of major environmental issues affecting New Zealand estuaries (continued).

3. Disease Risk

Runoff from farmland and human wastewater often carries a variety of disease-causing organisms or pathogens (including viruses, bacteria and protozoans) that, once discharged into the estuarine environment, can survive for some time (e.g. Stewart et al. 2008). Every time humans come into contact with seawater that has been contaminated with human and animal faeces, we expose ourselves to these organisms and risk getting sick. Human diseases linked to such organisms include gastroenteritis, salmonellosis and hepatitis A (Wade et al. 2003). Aside from serious health risks posed to humans through recreational contact and shellfish consumption, pathogen contamination can also cause economic losses due to closed commercial shellfish beds.

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Disease Risk	Shellfish and Bathing Water faecal coliforms, viruses, protozoa etc.	Bathing water and shellfish disease risk monitoring (Council or industry driven).

4. Toxic Contamination

In the last 60 years, 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 Key Indicators:

Issue	Recommended Indicators	Method
Toxins	Sediment Contaminants	Chemical analysis of heavy metals (total recoverable cadmium, chromium, copper, nickel, lead and zinc) and any other suspected contaminants in sediment samples.
	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 15cm of sediments (infauna in $0.0133m^2$ replicate cores), and on the sediment surface (epifauna in $0.25m^2$ replicate quadrats).

5. Habitat Loss

Estuaries have 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 Key Indicators:

Issue	Recommended Indicators	Method
Habitat Loss	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 substrate types.
	Sea level	Measure sea level change.
	Others e.g. Freshwater Inflows, Fish Surveys, Floodgates, Wastewater Discharges	Various survey types.

2. ESTUARY RISK INDICATOR RATINGS

The estuary monitoring approach used by Wriggle 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; Table 1), 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 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 below). 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 considering other relevant information and/or indicator results before making management decisions regarding the presence or significance of any estuary issue.
- 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 secondary ratings, primary ratings being given more weight in assessing the significance of indicator results. It is noted that many secondary 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 and overseas 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. We recommend that where a high level of risk is identified, the following steps are taken:
  - Statistical measures be used to refine indicator ratings where information is lacking.
  - 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.
  - The outputs stimulate discussion regarding what the acceptable level of risk is, and managing it.
  - The indicators and condition ratings used for the Kaikorai monitoring programme are summarised in Table 2, with detailed background notes explaining the use and justifications for each indicator presented in the NZ ETI (Robertson et al. 2016a and 2016b). 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 NZ estuaries. Work to refine and document these relationships is ongoing.

Note an overall NZ ETI score for Kaikorai Estuary, applied to describe the estuary's current trophic status in relation to catchment-derived nutrient and sediment inputs, required integration of relevant broad scale monitoring results (in this case the 2017/18 outputs; Stevens 2018), and is presented as a separate section in this report.

Summary of relevant estuary condition risk indicator ratings used in the present report.

RISK INDICATOR RATINGS / ETI BANDS (indicate risk of adverse ecological impacts)				
INDICATOR	Very Low - Band A	Low - Band B	Moderate - Band C	High - Band D
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 %	5-10 %	>10-25 %	>25 %
Macroinvertebrate Enrichment Index (NZ AMBI) ****	0 - 1.0 None to minor stress on benthic fauna	>1.0 - 2.5 Minor to moderate stress on fauna	>2.5 - 4.0 Moderate to high stress on fauna	>4.0 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 (Robertson et al. 2016b), ** Hargrave et al. (2008), ***Robertson (2018), Keeley et al. (2012), **** Robertson et al. (2015, 2016).

3. METHODS

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. 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. This is most commonly unvegetated intertidal mudflats at low-mid water (avoiding areas of significant vegetation and channels). In addition, because some estuaries, including SIDEs, also 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), synoptic water quality samples from surface and bottom waters, and subtidal sediment are commonly collected to support intertidal assessments.

Using the outputs of the broad scale habitat mapping, representative intertidal sampling sites (usually two per estuary, but varies with estuary size) are selected and samples collected and analysed for the following variables.

- Salinity, Oxygenation (Redox Potential Discontinuity depth - RPD (mV), Grain size (% mud, sand, gravel).
- Organic Matter and Nutrients: Total Organic Carbon (TOC), Total Nitrogen (TN), Total Phosphorus (TP).
- Heavy metals and metalloids: 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 the Kaikorai Estuary, three fine scale sampling sites (Figure 1), were selected in unvegetated, mid-low water habitat. The lower estuary Site A and the middle estuary Site B (Sites 1 and 2, respectively, in Stewart 2008) comprised a 30 m x 40 m area, while the upper estuary Site C (positioned ~100 m north-west of 2001 NEMP Site due to channel migration) comprised a 15 m x 20 m area. Each site was marked out and divided into 12 equal sized plots. Within each area, ten plots were selected, a random position defined within each, and sampling undertaken as described in the following sections: plots were selected, a random position defined within each, and sampling undertaken as described in the following sections:

Physical and Chemical Analyses

- At each site, average Redox Potential Discontinuity (RPD expressed in mV) depth was recorded within three representative plots using an oxidation-reduction potential (ORP) meter at 0, 1, 3, 6 and 10 cm depths below the surface.
- At each site, 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) were collected adjacent to each core for chemical analysis. All samples were kept in a chilly bin in the field before dispatch to R.J. Hill Laboratories for chemical analysis (details of lab methods and detection limits in Appendix 1):
- 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.

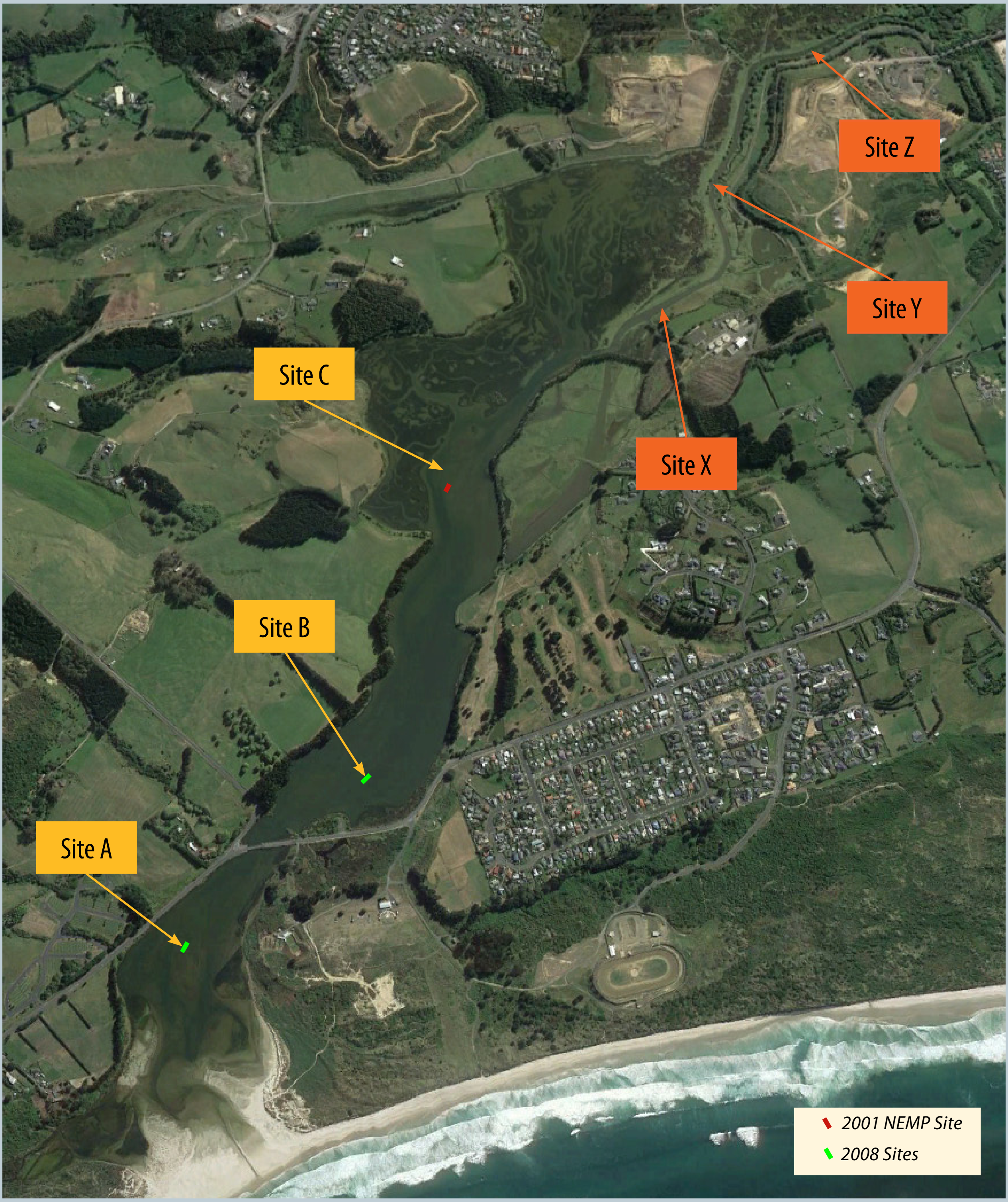

Figure 1. Location of water quality (orange) and benthic quality (yellow) monitoring sites in Kaikorai Estuary (Photo: Google).

- The samples were sorted by experienced Wriggle staff before being sent to a commercial laboratory for counting and identification (Gary Stephenson, Coastal Marine Ecology Consultants, Appendix 1).
- 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.

3. Methods (continued)

- Conspicuous epifauna visible on the sediment surface within the 15 m x 30 m sampling area were semi-quantitatively assessed based on the UK MarClim approach (MNCR 1990, Hiscock 1996, 1998). Epifauna species are identified and allocated a SACFOR abundance category based on percentage cover (Table A, Appendix 2), or by counting individual organisms >5 mm in size within quadrats placed in representative areas (Table B, Appendix 2). 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.

Upper Estuary Subtidal Water and sediment quality

Three representative sites were selected in deep main channel sections in the upper estuary where there was a potential for the estuary water to become stratified (Sites X, Y and Z respectively, see Figure 1). At each site at high tide, a YSI-Sonde (6000 series) hand-held field meter was used to directly measure and log depth, chlorophyll *a*, salinity, temperature, pH, and dissolved oxygen in upper and lower 0.5 m of the water column. At the same locations water samples were also collected with a van dorn water sampler for laboratory nutrient analyses (total N, nitrate-N, ammonia-N, dissolved reactive P and total P concentrations).

In addition, at each site secchi disc clarity was measured and one benthic sediment sample was collected using either a remotely triggered van veen grab sampler or a custom built sediment sampling hoe with telescopic handle). Once at the surface the sediment apparent Redox Potential Discontinuity (aRPD) depth was measured, and a sub-sample collected for subsequent chemical analysis for TOC, grain size, TN and TP.

- All samples were kept in a chilly bin in the field before dispatch to R.J. Hill Laboratories for chemical analysis (details of lab methods and detection limits in Appendix 1):
- Samples were tracked using standard Chain of Custody forms and results checked and transferred electronically to avoid transcription errors.

Fieldwork for this component was undertaken in Kaikorai Estuary on 12 February 2018 in order to capture prolonged low freshwater inflow conditions.

Sediment accumulation

To determine the future sedimentation rate, a simple method of measuring how much sediment builds up over a buried plate over time is used. 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. These are then measured over time (commonly annually) to assess sediment accrual.

Three sites, each with four plates (20 cm square concrete paving stones) were established in December 2017 in Kaikorai Estuary at fine scale Sites A, B and C (Figure 1), with Sites B and C representing the main middle and upper estuary deposition zone and Site A the lower estuary basin. Plates were buried deeply in the sediments where stable substrate was located and positioned 2 m apart in a linear configuration along the baseline of each fine scale site. Steel reinforcing rod was also placed horizontally next to each buried plate 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 (Appendix 2). In the future, these depths will be measured annually and, over the long-term, will provide a measure of the rate of sedimentation in the estuary.

4. RESULTS AND DISCUSSION

A summary of the results of the 2017/18 fine scale sediment (15 December 2017) and upper estuary subtidal (12 February 2018) monitoring of the Kaikorai Estuary is presented in Tables 2 and 3 with detailed results in Appendices 2 and 3. Note the estuary mouth was open to the sea during both the benthic intertidal and upper estuary subtidal surveys. Also included are the summary results of the preliminary fine scale sediment monitoring undertaken in 2001 (Robertson et al. 2002) and 2008 (Stewart 2008).

Table 2. Mean fine scale sediment physical, chemical, plant growth (*n* = 3) and macrofauna (*n* = 10) results, Kaikorai Estuary, February 2001, October 2008 and 15 December 2017. NA = not assessed.

Year Site	RPD	Salinity	TOC	Mud	Sand	Gravel	Cd****	Cr	Cu	Ni	Pb	Zn	As	Hg	TP	TN
	cm	ppt	%				mg kg^{-1}									
2017 A	3	31	0.57	14.3	85.7	<0.1	0.03	8.8	5.0	4.9	9.1	47.0	4.8	<0.02	410	633
2017 B	0	31	2.60	65.0	34.8	0.25	0.25	43.7	24.0	18.2	45.7	236.7	14.0	0.09	1076	2067
2017 C	1	30	1.38	27.2	70.5	2.3	0.10	21.0	10.3	12.8	22.3	132.3	6.2	0.03	663	1133
2008 A	>3**	NA	0.28*	7.7	92.3	<0.1	0.02	3.4	2.0	2.3	3.8	24.0	NA	NA	310	<500***
2008 B	0**	NA	2.55*	57.9	42.0	<0.1	0.25	34.0	22.0	16.0	51.0	230.0	NA	NA	1100	2500
2001 C	NA	NA	1.9*	27.0	NA	NA	0.1	11.1	3.8	5.0	0.7	17.1	NA	NA	799	1600

* 2001 and 2008 data was measured as ash-free dry weight (AFDW) and converted to TOC using the following equation (TOC = AFDW x 0.38) (Lindquist et al. 2008)

** measured visually, compared with 2017 which was measured using ORP meter. ***below detection limit (Appendix 1).

****2001 results (obtained from Cawthron Lab) were often reported above the detection limit (Appendix 1). Given that such elevated Cd levels were not recorded at the same sites in later years (post 2006) by R. J. Hill Labs with much lower detection limits, it is concluded that the Cawthron methods were inaccurate in those years.

Year Site	Seagrass Biomass and Cover	Macroalgal Biomass and Cover	Macrofauna Abundance	Macrofauna Richness
	g m^{-2} wet weight / (% cover)	g m^{-2} wet weight / (% cover)	Individuals per m^2	Species per core (0.013 m^2)
2017 A	0 (0 %)	0 (0 %)	4189	5.7
2017 B	0 (0 %)	10 (<5 %)	3357	5.2
2017 C	0 (0 %)	200 (60-70 %)	2218	0.8
2008 A	0 (0 %)	0 (0 %)	9200*	4.5*
2008 B	0 (0 %)	0 (0 %)	13775*	6*
2001 C	0 (0 %)	NA	2495	6

* *n* = 3, compared with 2001 and 2017 which were based on 10 cores samples.

Table 3. Summary of fine scale water quality results (upper water column, bottom water column and bottom sediment), Kaikorai Estuary, 12 February 2018.

Parameter	Site X		Site Y		Site Z	
	Surface	Bottom	Surface	Bottom	Surface	Bottom
Depth (m)	0.2	0.5	0.2	1.0	0.2	1.5
Temperature (degrees C)	24.5	25.6	23.0	22.7	21.0	21.0
Salinity (ppt)	4.8	16.5	1	14.3	0.5	13.6
Dissolved Oxygen (mg l^{-1})	10.1	10.8	9.7	12	10	13.2
Chlorophyll *a* (ug l^{-1})	7.1	15.2	6.2	27.1	6.3	44.4
Total N (g m^{-3})	0.9	0.8	1.1	3	0.9	1.4
Total Ammoniacal-N (g m^{-3})	0.16	0.10	0.20	0.18	0.20	0.22
Nitrate-N (g m^{-3})	0.30	0.09	0.40	0.27	0.35	0.32
Dissolved Reactive P (g m^{-3})	0.02	0.02	0.01	0.01	0.01	0.01
Total P (g m^{-3})	0.06	0.12	0.06	1.14	0.05	0.18

Bottom Sediment Site	aRPD (cm)	TOC (%)	Mud (%)	Sand (%)	Gravel (%)	TP (mg/kg)	TN (mg/kg)
Kaik Site X	0	1.0	19.3	80.5	0.2	350	800
Kaik Site Y	0	0.4	78.4	21.5	0.1	260	<500
Kaik Site Z	0	6.5	42.8	47.6	9.7	890	3800

4. Results and Discussion (continued)

Analysis and discussion of the 2017 results are presented as two main steps; firstly, the intertidal benthic habitat condition and secondly, the upper estuary water column condition. The assessment is undertaken with a focus on the key estuarine issues of muddiness (or sedimentation), eutrophication, and toxicity.

4.1 Benthic Habitat Condition

4.1.1 Muddiness (or Sedimentation)

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 below, however, preliminary sedimentation rate data will not be available until December 2018.

Sediment Mud Content

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 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). In contrast, 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 Kaikorai Estuary fine scale sites had moderate (14-65 % mud) sediment mud contents (Table 2, Figure 2).

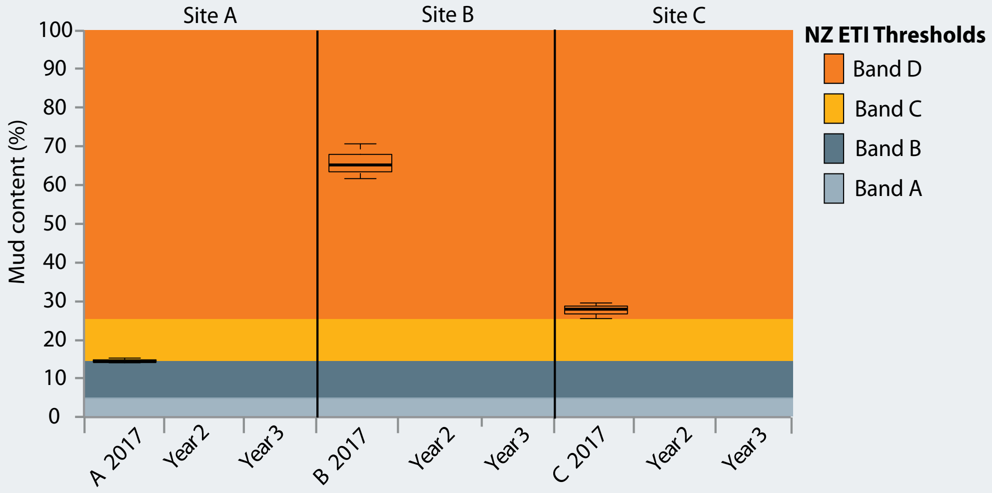

Figure 2. Mean mud content (median, interquartile range, total range, *n* = 3), Kaikorai Estuary, December 2017.

Site A (downstream) showed the sandiest sediments, primarily because of the sites proximity to ocean-derived sands which intermittently mix with catchment derived muds. Site B (middle estuary) showed the highest mud content (mean 65 % mud compared with 14 % at Site A and 27.2 % at Site C) reflecting the site's physical position in the estuary as a natural deposition zone. The overall high mud content fits the Band D rating, and indicates the following ecological conditions are likely (Robertson et al. 2016b):

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

4. Results and Discussion (continued)

4.1.2 Eutrophication

The primary variables indicating eutrophication impacts are sediment mud content, RPD depth, sediment organic matter, nitrogen and phosphorus concentrations, 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 sediment ecosystem (Robertson et al. 2016b). In addition, seagrass (*Zostera muelleri*) cover and biomass on the sediment surface is also measured when present because seagrass can mitigate or offset the negative symptoms of eutrophication and muddiness. When seagrass losses occur it provides a clear indication of a shift towards a more degraded estuary state.

Results showed a complete absence of seagrass and macroalgae at Sites A and B, and 60-70 % cover (moderate biomass ~350 g m^{-2}) of opportunistic macroalgae (*Ulva intestinalis*) and no seagrass at Site C (Figure 3). Such findings indicate low levels of eutrophication at Sites A and B and moderate at levels at Site C, and that conditions are unsuitable for high value seagrass habitat across all three sites.

Figure 3. An absence of seagrass and macroalgae in the lower (left) and moderate opportunistic macroalgal cover and no seagrass in the upper (right) Kaikorai Estuary, December 2017.

Sediment Mud Content

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, high mud contents (i.e. Sites B and C in Kaikorai) indicate sediment oxygenation is likely to be relatively poor.

Redox Potential Discontinuity (RPD)

The depth of the RPD boundary indicates the extent of oxygenation within sediments. Currently, the condition rating for redox potential is under development (Robertson et al. 2016b) pending the results of a PhD study in which redox potential (RP) measured with an ORP electrode and meter, are being assessed for a gradient of eutrophication symptoms. Initial findings indicate that the recommended NZ estuary redox potential thresholds are likely to reflect those put forward by Hargrave et al. (2008).

Figure 4 shows the redox potentials (5 depths at each site, mean of triplicate measures plotted) for the three Kaikorai Estuary sampling sites for December 2017.

4. Results and Discussion (continued)

The redox potential for Site A indicates that the upper ~5 cm sediments are sufficiently well oxygenated to support a range of sensitive taxa but below this depth poor oxygenation conditions are present (i.e. low redox <-150 mV, Band D). By contrast, Sites B and C had poorly oxygenated conditions throughout the entire 10 cm sediment profile. Such poorly oxygenated sediments are likely to only support low diversity macroinvertebrate communities dominated by tolerant taxa (see Section 4.1.4).

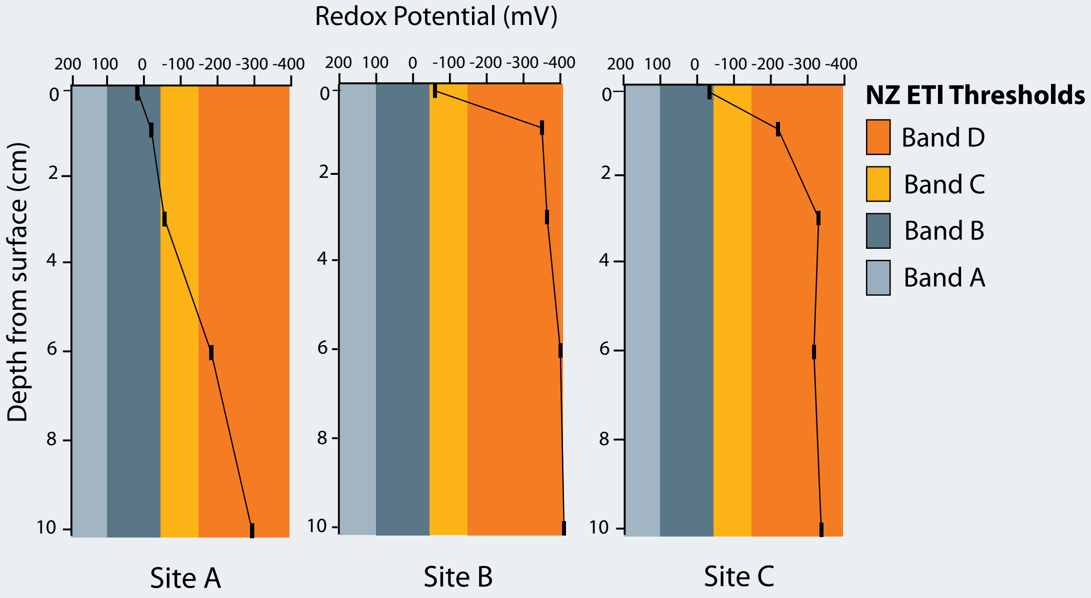

Figure 4. Mean down-core sediment Redox Potential (mV) measured at 0, 1, 3, 6 and 10 cm depths (*n* = 3), Kaikorai Estuary, December 2017.

Total Organic Carbon and Nutrients

The concentrations of sediment organic matter (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 RPD, 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 their respective loadings are exceeding the assimilative capacity of the estuary.

Results for the three benthic fine scale sites showed TOC (0.57-2.60 %) and TN (633-2067 mg kg^{-1}) were in the "low" (Site A), "moderate" (Site C) or "high" (Site B) risk indicator ratings, while TP (rating not yet developed) was relatively low at Site A (663 mg kg^{-1}) but elevated at Sites B (2067 mg kg^{-1}) and C (1133 mg kg^{-1}) (Figures 5, 6 and 7).

Synoptic fine scale monitoring results collected from relevant sites in February 2001 (Robertson et al. 2002) and October 2008 (Stewart 2008) are presented alongside the current results in Table 2. Comparisons show that 2001 results were similar to those from nearby Site C in 2017, and 2008 results were similar to those from nearby Sites A and B in 2017, indicating those parts of the estuary are unlikely to have significantly changed in terms of sediment TOC, TN and TP concentrations in the past decade. However, the 2001 and 2008 synoptic surveys have not been comprehensively assessed in the current report as they did not meet the requirements of a full baseline survey [e.g. involved one-off sampling outside of the recommended December-March summer period, in the case of the 2008 survey, used limited replication (a single composite chemistry sample and 3 macroinvertebrate replicates instead of the recommended 10), did not assess the high susceptibility upper estuary arm, and did not monitor for water column eutrophication]. In addition, the possibility that the slight (100 m) spatial offset at Site C compromised comparability over time (NEMP 2001 vs 2017/2018 survey) cannot be excluded.

4. Results and Discussion (continued)

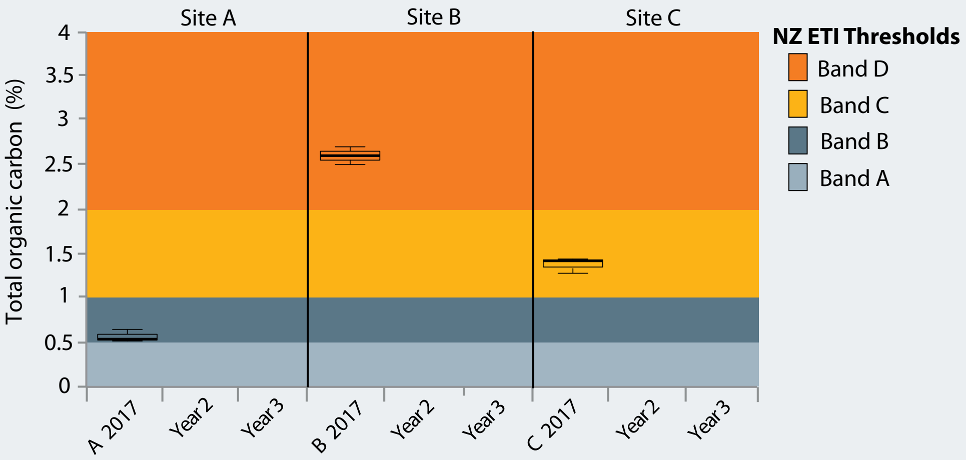

Figure 5. Sediment total organic carbon (%) (median, interquartile range, total range, *n* = 3), December 2017.

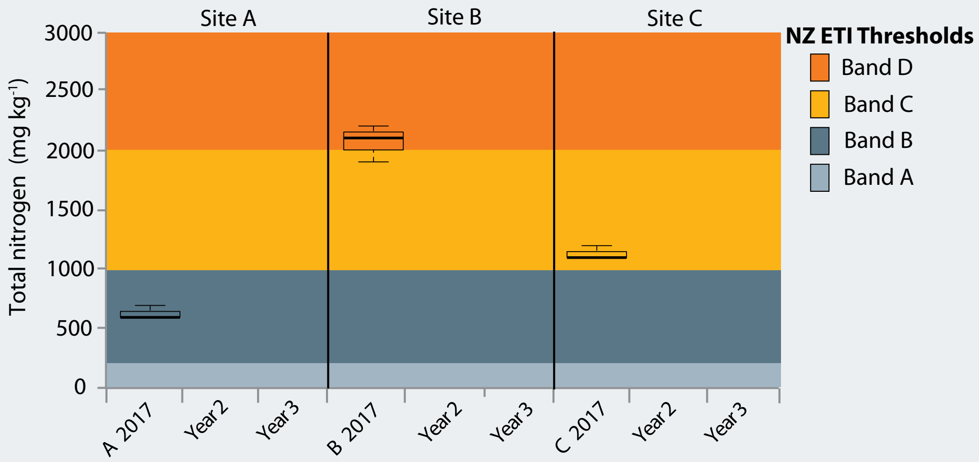

Figure 6. Sediment total nitrogen (mg kg^{-1}) (median, interquartile range, total range, *n* = 3), December 2017.

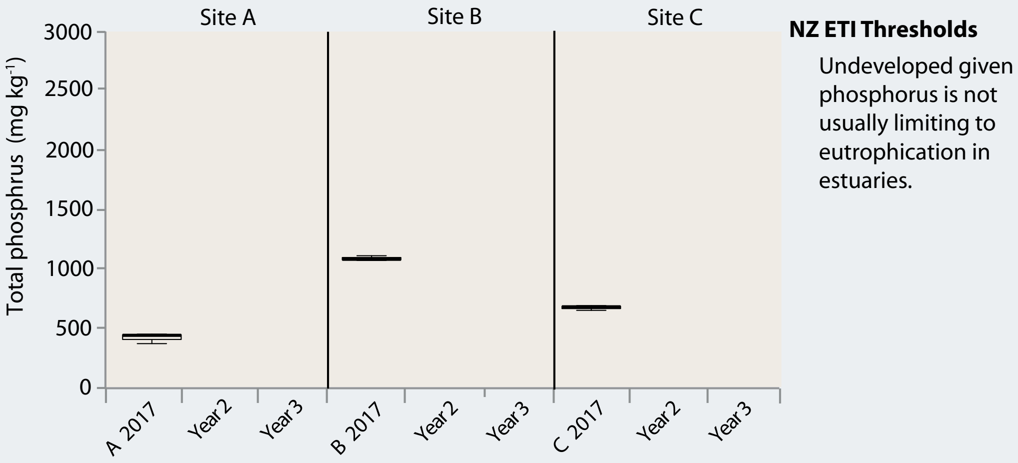

Figure 7. Sediment total phosphorus (mg kg^{-1}) (median, interquartile range, total range, *n* = 3), December 2017.

4. Results and Discussion (continued)

4.1.3 Toxicity

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.

Results for heavy metals Cd, Cr, Cu, Hg, Pb, Ni, Zn and As, used as indicators of potential toxicants, were rated “very low” to “moderate” for all parameters except for zinc which was “high” at mid-estuary Site B. With the exception of elevated zinc concentrations at Site B, all non-normalised values were below the ANZECC (2000) ISQG-Low trigger values (Table 4), and therefore indicate the toxicant indicators monitored posed no threat to aquatic life.

Table 4. Indicator toxicant results for Kaikorai Estuary (Sites A, B and C), December 2017.

Year/Site/Rep	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg
	mg/kg							
2017 A 1-4 [b]	0.03	8.3	4.8	4.7	9.0	44	4.4	<0.02
2017 A-4-8 [b]	0.03	8.4	4.8	4.8	8.6	46	4.5	<0.02
2017 A-9-10 [b]	0.04	9.6	5.4	5.1	9.7	51	5.6	<0.02
2017 B-1-4 [b]	0.26	44.0	25.0	18.1	47.0	240	14.3	0.10
2017 B-4-8 [b]	0.24	42.0	23.0	17.4	45.0	230	13.6	0.09
2017 B-9-10 [b]	0.25	45.0	24.0	19.0	45.0	240	14.1	0.09
2017 C-1-4 [b]	0.09	20.0	10.3	12.5	22.0	125	6.0	0.03
2017 C-4-8 [b]	0.10	22.0	10.6	13.2	23.0	135	6.7	0.03
2017 C-9-10 [b]	0.10	21.0	9.9	12.7	22.0	137	5.9	0.03
Condition Thresholds (ANZECC 2000 criteria, Very Low, <0.2 x ISQG Low; Low, 0.2-0.5 x ISQG Low; Moderate, 0.5 x to ISQG Low; High, >ISQG Low)								
[a] Band A Very Low Risk	<0.3	<16	<13	<4.2	<10	<40	<4	<0.03
[a] Band B Low Risk	0.3 - 0.75	16 - 40	13 - 32.5	4.2 - 10.5	10 - 25	40 - 100	4 - 10	0.03 - 0.075
[a] Band C Moderate Risk	0.75 - 1.5	40 - 80	32.5 - 65	10.5 - 21	25 - 50	100 - 200	10 - 20	0.075 - 0.15
[a] Band D High Risk	>1.5	>80	>65	>21	>50	>200	>20	>0.15
[a] ISQG-Low	1.5	80	65	21	50	200	20	0.15
[a] ISQG-High	10	370	270	52	220	410	70	1

[a] ANZECC 2000, [b] composite samples

4.1.4 Benthic Macroinvertebrate Community

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). Because they integrate recent disturbance history in the sediment, macroinvertebrate communities are therefore very effective in showing the combined effects of pollutants or stressors.

The response of macroinvertebrates to stressors in the Kaikorai Estuary will be analysed in detail once sufficient baseline monitoring data is available. This analysis will include four steps:

1. Ordination plots to enable an initial visual overview (in 2-dimensions) of the spatial and temporal structure of the macroinvertebrate community among each fine scale site over time.
2. The BIO-ENV program in the PRIMER (version 6) package will be used to evaluate and compare the relative importance of different environmental factors and their influence on the identified macrobenthic communities.
3. Assessment of species richness, abundance, diversity and major infauna groups.
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 (NZ AMBI, Robertson et al. 2015, Robertson et al. 2016).

At this stage, with only one year of monitoring data, this section of the report will present and interpret data in relation to steps 3 and 4 only.

4. Results and Discussion (continued)

Species Richness, Abundance, Diversity and Infaunal Groups

In this step, simple univariate whole community indices, i.e. species richness, abundance and diversity are presented for each site (Figure 8) and in the future when more data are available, will be used to help explain any differences between years indicated by other analyses.

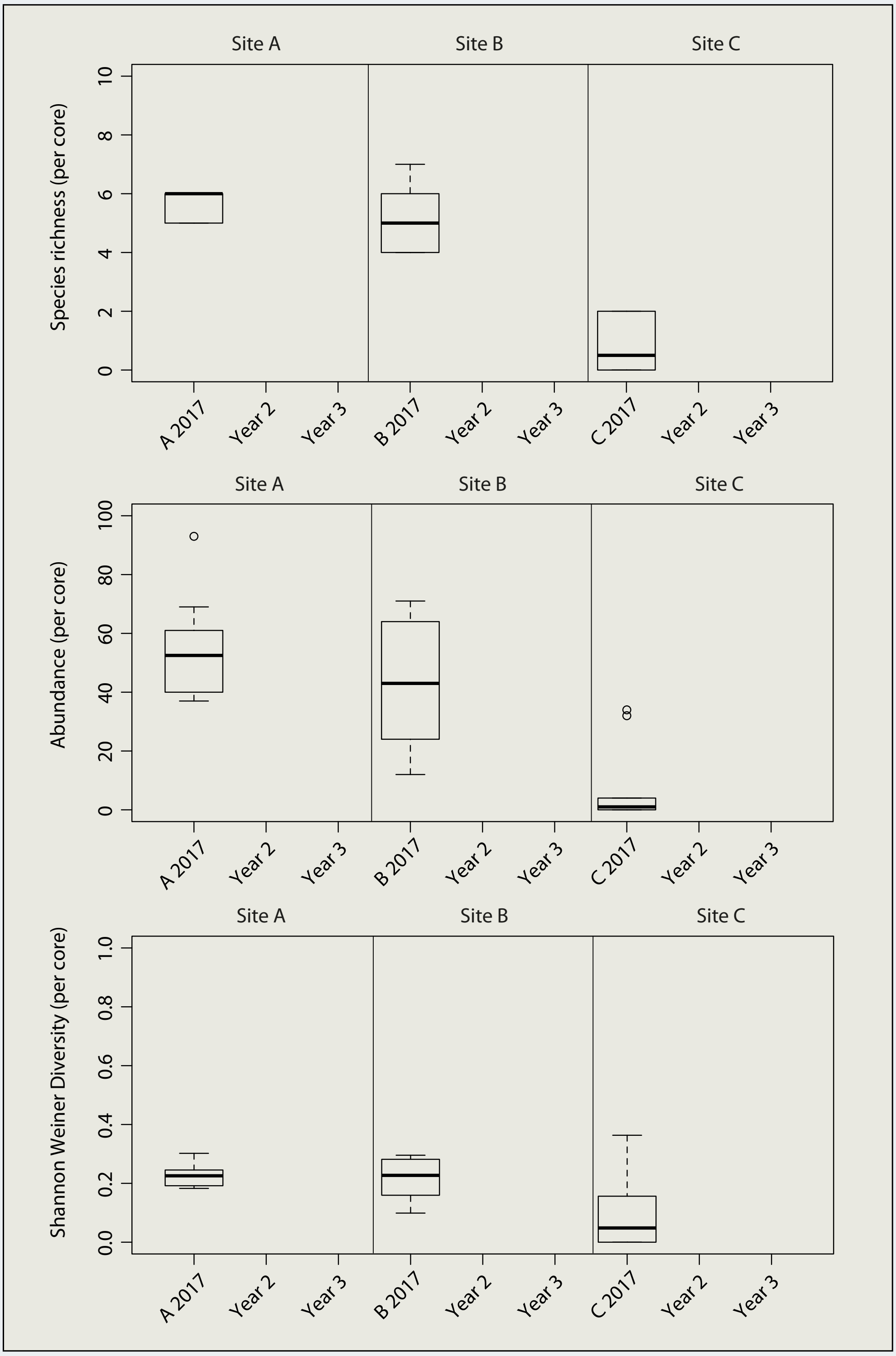

Figure 8. Boxplot showing species richness, abundance, and Shannon Diversity index per core (median, interquartile range, total range, outliers, *n* = 10) at fine-scale Sites A, B and C, Kaikorai Estuary, December 2017.

Figure 8 shows that at the lower estuary Site A and middle estuary Site B, there was relatively low mean species richness (5.2-5.7 per core), abundance (43.6-54.4 per core) and Shannon diversity (0.21-0.22 per core), similar in terms of species richness and abundance yet much less diverse than the fine scale sites in Waimea Inlet, Tasman [i.e. species richness (6-13 per core), abundance (8-83 per core) and Shannon diversity (1.4-2.4 per core) - Robertson and Stevens 2014)], but a lot lower (for all three metrics) than sites in Porirua Harbour, Wellington [i.e. species richness (10-25 per core), abundance (50-220 per core) and Shannon diversity (1.1-1.6 per core) - Robertson and Stevens 2015)]. The upper Kaikorai estuary Site C had very low species richness (0.8 per core), abundance (7.5 per core) and Shannon diversity (0.1 per core) compared to both Sites A and B in the Kaikorai. Notably, of the 10 core samples obtained from Site C, 5 were completely devoid of macroinvertebrates.

In terms of taxonomic groups present at each fine scale site, Figure 9 indicates that the macroinvertebrate community at Sites A and B comprised a mix of polychaetes and crustacea, and to a lesser extent oligochaetes, with obvious differences in abundance between sites, particularly in relation to polychaetes and crustacea. The comparatively depauperate community at Site C was dominated by crustacea which were low in abundance compared to Sites A and B. The plot also shows that bivalves (e.g. *Austrovenus stutchburyi* and anthozoa were absent from all three sites. These differences are discussed in more detail in the following sections.

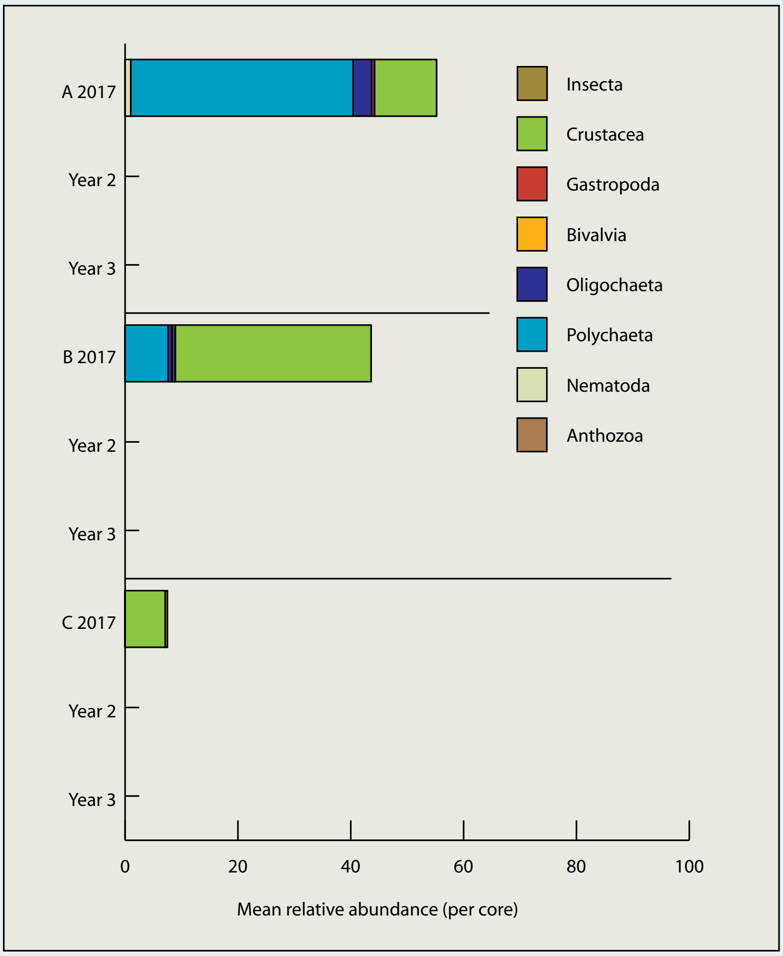

Figure 9. Mean relative abundance of major benthic macroinvertebrate groups (*n* = 10), Kaikorai Estuary, December 2017.

4. Results and Discussion (continued)

Macroinvertebrate Community in Relation to Mud and Organic Enrichment

1. Mud and Organic Enrichment Index (NZ AMBI)

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

- Integration of previously established, quantitative ecological group (EGs) classifications (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. Note 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);
- The AMBI was successfully validated (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);
- Also note the NZ AMBI index has recently undergone further optimisation to more accurately diagnose benthic health in relation to nutrient enrichment of shallow estuaries (e.g. Jacobs River Estuary) (Robertson 2018). The updated index (not used in this report) is expected to be available from September 2018 following journal publication.

For the three fine scale sites in the Kaikorai Estuary, the mean NZ (R-Hybrid NZEGs) AMBI biotic coefficients were 3.4 at Site A, 3.9 at Site B and 3.6 at Site C (Figure 10). The coefficients indicate that Sites A, B and C were in the "moderate" ecological condition categories (i.e. moderate to high stress on benthic macrofauna - community tolerant of moderate organic enrichment and elevated muds).

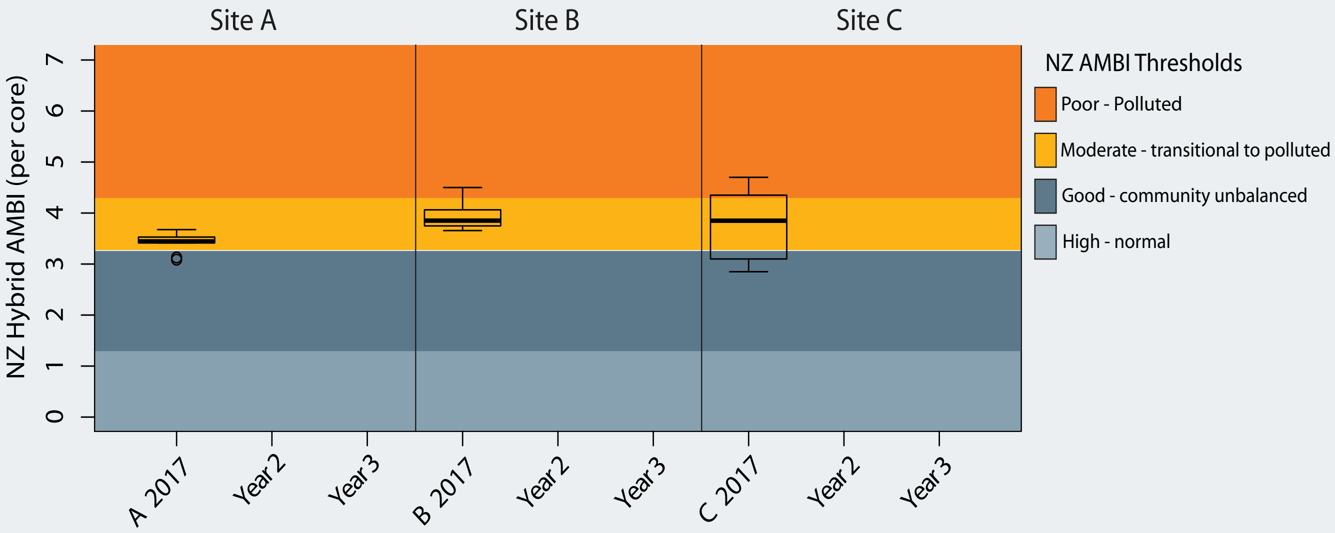

Figure 10. Benthic invertebrate NZ AMBI mud/organic enrichment tolerance rating (median, interquartile range, total range, outliers, *n* = 10), Kaikorai Estuary, December 2017. Note: Unidentified Nereididae (formerly spelled Nereidae) juveniles were retained in the NZ AMBI because their sensitivity to mud/organic enrichment and therefore EG classification has been validated for shallow NZ estuaries (Robertson et al. 2015).

2. Individual Species

To further explore the macroinvertebrate community in terms of taxa sensitivities to mud and organic enrichment, a comparison was made of the mean abundances of individual taxa within the 5 major mud/enrichment tolerance groupings (i.e. *1 = highly sensitive to (intolerant of) mud and organic enrichment; 2 = sensitive to mud and organic enrichment; 3 = widely tolerant of mud and organic enrichment; 4 = prefers muddy, organic enriched sediments; 5 = very strong preference for muddy, organic enriched sediments*) (Figures 11a and b).

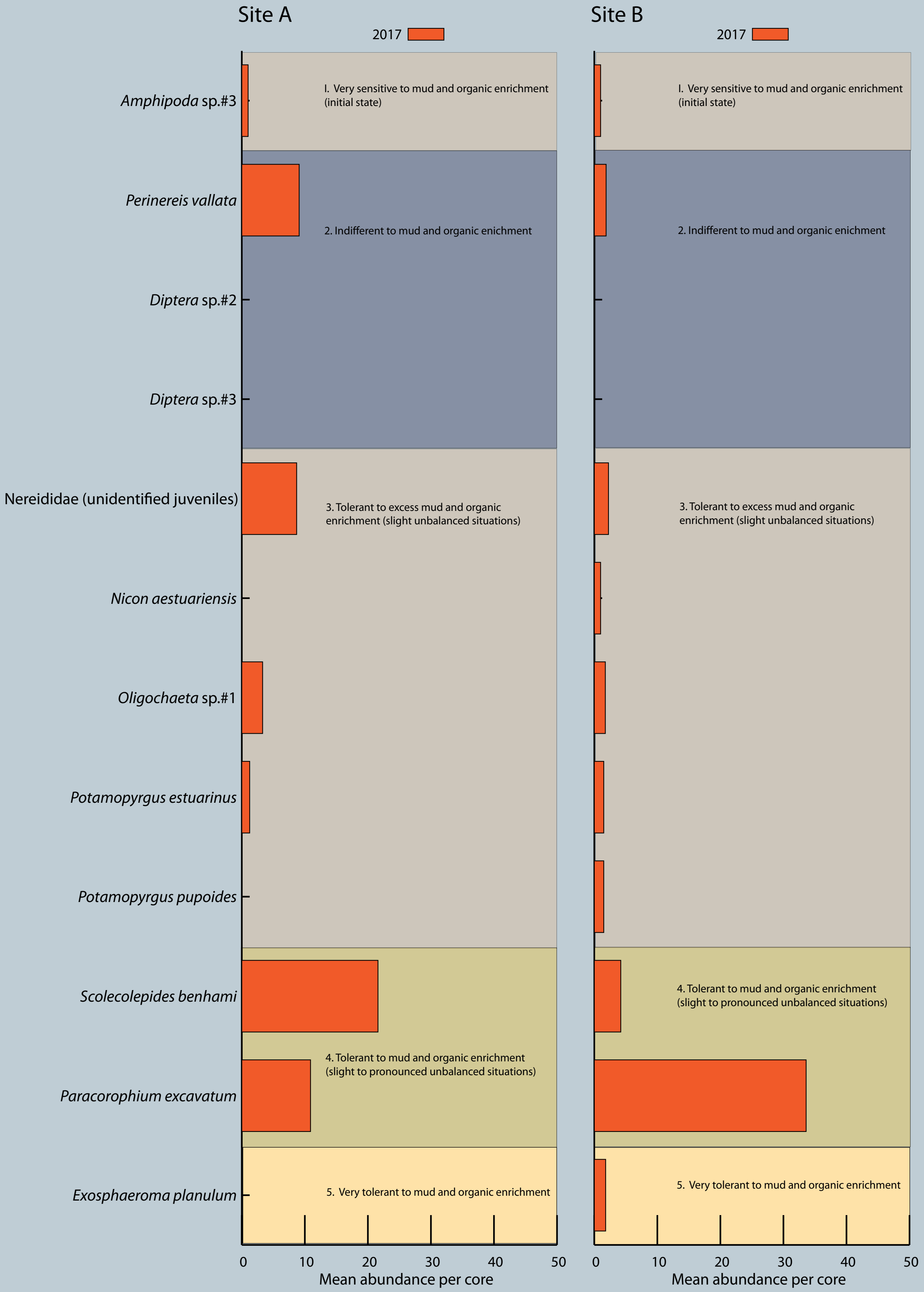

Figure 11a. Mud and organic enrichment sensitivity of macroinvertebrates, Kaikorai Estuary Sites A and B, December 2017 (see Appendix 3 for sensitivity details).

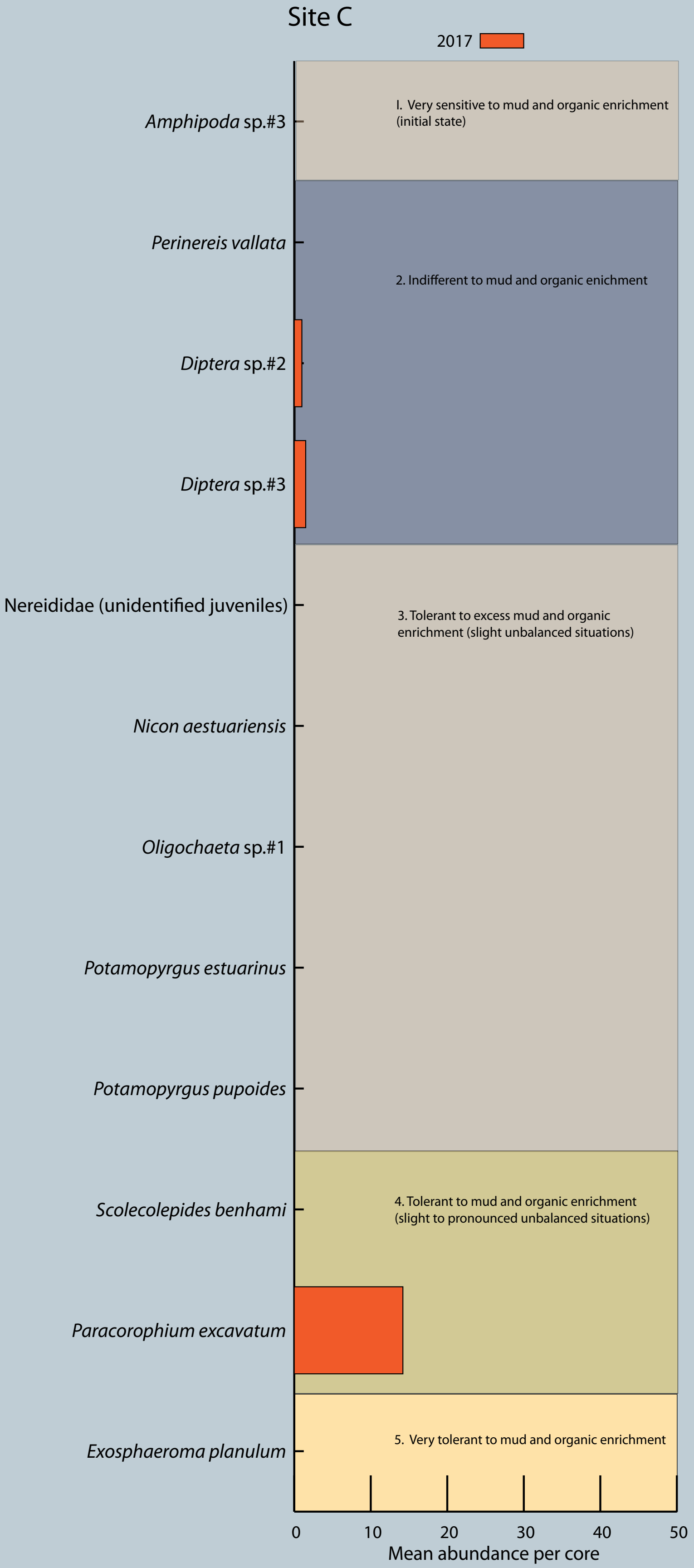

Figure 11b. Mud and organic enrichment sensitivity of macroinvertebrates, Kaikorai Estuary Site C, December 2017 (see Appendix 4 for sensitivity details).

The results in Figure 11a indicate that the majority of taxa and individuals at Sites A and B were distributed in the Group 2, 3 and 4 categories (i.e. from indifferent to tolerant of mud and organic enrichment). Group 3 and 4 organisms, which comprised approximately 70 % of the total number of taxa present at Sites A and B, included the surface deposit feeding spionid polychaete *Scolecolepides benhami*. This spionid is very tolerant of mud, fluctuating salinities, organic enrichment and toxicants (e.g. trace metals). It is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards the low water mark. Also present at Sites A and B was the tube-dwelling crustacean amphipod *Paracorophium excavatum*, which is the dominant corophioid amphipod in the South Island. *P. excavatum* is well-known as a major primary coloniser (and hence indicator) of disturbed estuarine intertidal flats (Ford et al. 1999).

The upper estuary Site C (Figure 11b) comprised only three taxa in total, two of which were dipteran flies indifferent to muddiness (Group 2) and again the tube-dwelling amphipod *P. excavatum* (Group 4).

Overall, taxa that prefer sandy, not organically enriched sediments were poorly represented across the estuary, with only one highly sensitive (Group 1) taxon, *Amphibola* sp., present at intertidal Sites A and B and none at upper Site C.

4.2 Upper Estuary Water Column Condition

Background

In SIDEs the rapid flushing time (<3 days for these estuaries) means water column phytoplankton cannot reach high concentrations before they are flushed to the sea. However, the Kaikorai has a slower flushing time (approximately 3.3 days; NIWA's CLUES database) and can experience short-periods of elevated concentrations during the occasional periods of mouth closure, and also in parts of the upper estuary during low flow-baseflow periods when inflowing freshwater flows over more saline tidal water and results in a dense isolated layer of saline bottom water that neither freshwater or tidal inflow currents are strong enough to flush out. Such isolated (or stratified) bottom water (often situated in the 1-2 m depth range) is susceptible to phytoplankton blooms, low dissolved oxygen, elevated nutrient concentrations and accumulation of fine sediment. In these situations, which vary between marine and close to freshwater salinities, a co-limiting situation between nitrogen (N) and phosphorus (P) is expected, and as a consequence any assessment of nutrient impacts should include both N and P.

Since both N and P are continually cycling between all of their major nutrient forms, an assessment of total N (TN), dissolved inorganic N (DIN) and total P (TP) is needed in order to gauge the level of N and P within an estuary and therefore its potential nutrient related health. Reliance on a single N or P fraction, e.g. inorganic N, results in inaccurate assessments, since even in a large algal bloom inorganic concentrations may be low due to the uptake by the plants (Howes et al. 2003). Based on the following literature, a TN, DIN and TP threshold concentration of approximately 0.33 mg TN l^{-1}, 0.07 mg DIN l^{-1} and 0.02 mg P l^{-1} for the appearance of advanced eutrophic conditions (high phytoplankton and low oxygen levels) for the upper estuary channel water column can be identified (see inset). It should be noted that less sensitive thresholds (e.g. 0.4 mg TN l^{-1}, 0.096 mg DIN l^{-1} and 0.025 mg TP l^{-1}) would likely apply to Kaikorai Estuary during open mouth periods, similar to those proposed for the Shag Estuary (Robertson & Stevens 2017) and Kakanui Estuary (Plew and Barr 2015). However, their applicability would first require validation against (currently unavailable) annual Kaikorai Estuary mouth open/closed status data.

Literature supporting water column TN, DIN and TP thresholds

- In Waituna Lagoon, an ICOLL in Southland, thresholds of 0.33 mg TN l^{-1} and 0.02 mg P l^{-1} have been identified to maintain a healthy rooted aquatic plant community (particularly key species like *Ruppia* spp.) (Robertson et al. 2013; Burns et al. 2000; Schallenburg et al. 2017).
- In Kakanui Estuary, an ICOLL in Otago, DIN thresholds of 0.07 mg DIN l^{-1} when the mouth is closed and 0.096 mg DIN l^{-1} when open have been proposed to limit nuisance level production of the opportunistic macroalga *Ulva* sp. (Plew and Barr 2015).
- In Horsen's Estuary, Denmark, research indicates a mean phytoplankton growing season threshold value of 0.398 mg TN l^{-1} to meet good ecological status (Hinsby et al. 2012). This research also identified a threshold for inorganic nutrients as 0.021 mg DIN l^{-1} and 0.007 mg DIP l^{-1}.

- In the US, EPA Region 1 has considered total N threshold concentrations for estuaries and coastal waters of 0.45 mg TN l^{-1} as protective of DO standards and 0.34 mg TN l^{-1} as protective for eelgrass (Latimer and Rego 2010, State of New Hampshire 2009, Benson et al. 2009).
- NZ ETI Tool 1 (Robertson et al. 2016a) cites three estuary nutrient concentration guidelines (EU Estuary guidelines OSPAR (2008) for DIN: Poor >0.63, Moderate 0.42-0.63, Good 0.28-0.42, High <0.28 mg DIN l^{-1}; ASSETS (Bricker et al. 1999) for TN (maximum dissolved surface conc): POOR >=1.0, Moderate 0.1-1.0, Low 0-0.1 mg TN l^{-1}; ANZECC (2000) Guidelines (South East Australian default trigger values): DIN 0.03, TN 0.3, TP 0.03 mg l^{-1}). Note: thresholds are generalised for multiple estuary types.

Results

The water quality results for the surface and bottom waters at three upper estuary sites in the Kaikorai Estuary (Sites X, Y and Z respectively) where susceptibility to nutrients was greatest, are presented in Table 3 (see Figure 1 for site locations). The main findings were as follows:

Water column stratification

There was minimal difference between surface and bottom water temperature, but salinity (Figure 12), chlorophyll *a* and dissolved oxygen (Figure 14) indicated stratification was occurring at all three upper estuary sites when sampled on 12 February 2018. The presence of water column stratification, and the consequent likelihood of poorly flushed bottom water, means there is a high potential for intermittent eutrophication of the upper estuary water column as discussed on the following pages.

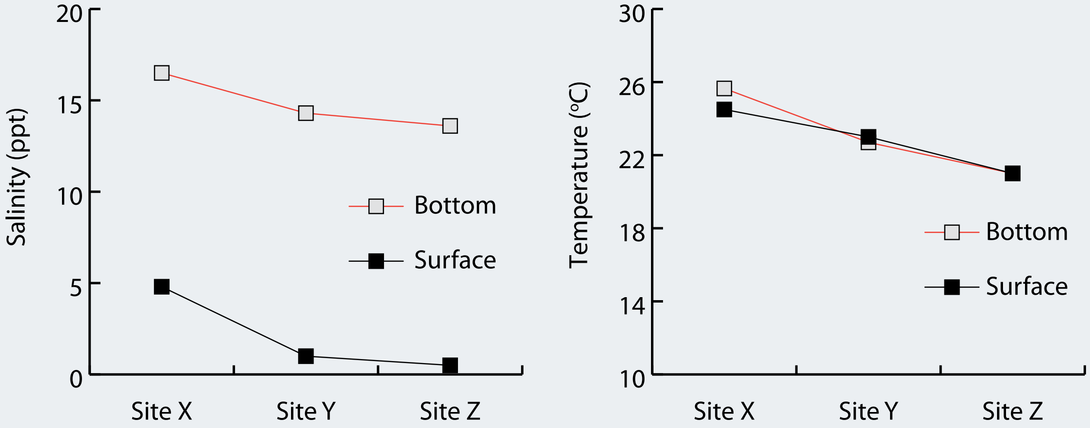

Figure 12. Salinity and temperature in surface and bottom water at three upper estuary sites, Kaikorai Estuary, February 2018.

Susceptibility to eutrophication based on water column TN, DIN and TP concentrations

Total nitrogen (TN), dissolved inorganic nitrogen (DIN) and total phosphorus (TP) concentrations in both the surface and bottom waters at all three upper estuary sites exceeded the eutrophication threshold levels of 0.33 mg TN l^{-1}, 0.07 mg DIN l^{-1} and 0.02 mg P l^{-1} (Figure 13). These plots show that TN and TP were particularly elevated at Site Y bottom water, which is likely a result of its muddier underlying sediments (Table 3). Otherwise nutrient concentrations were similar across the three sites. In addition, previous water quality data collected monthly during 2016 from surface waters at a middle estuary site (near the Brighton Road Bridge), also exceeded thresholds levels for TN, DIN and TP (2016 annual average: 0.71 mg TN l^{-1}, 0.48 mg DIN l^{-1} and 0.027 mg P l^{-1}).

Taken together, these results indicate a high likelihood of eutrophication symptoms (e.g. high chlorophyll *a* concentrations) being present in the bottom and surface waters of the upper estuary, and possibly also in the middle estuary or in the main estuary channel, particularly if the flow at the estuary mouth becomes constricted. However, in the case of the 2018 results, where data for only one discrete event were collected, the results can only be used as an early indicator of likely growing season susceptibility. To assess the susceptibility to eutrophication over the whole growing season (November-April), monthly TN, DIN and TP concentrations and appropriate biological indicator (e.g. chlorophyll *a*) data should be used.

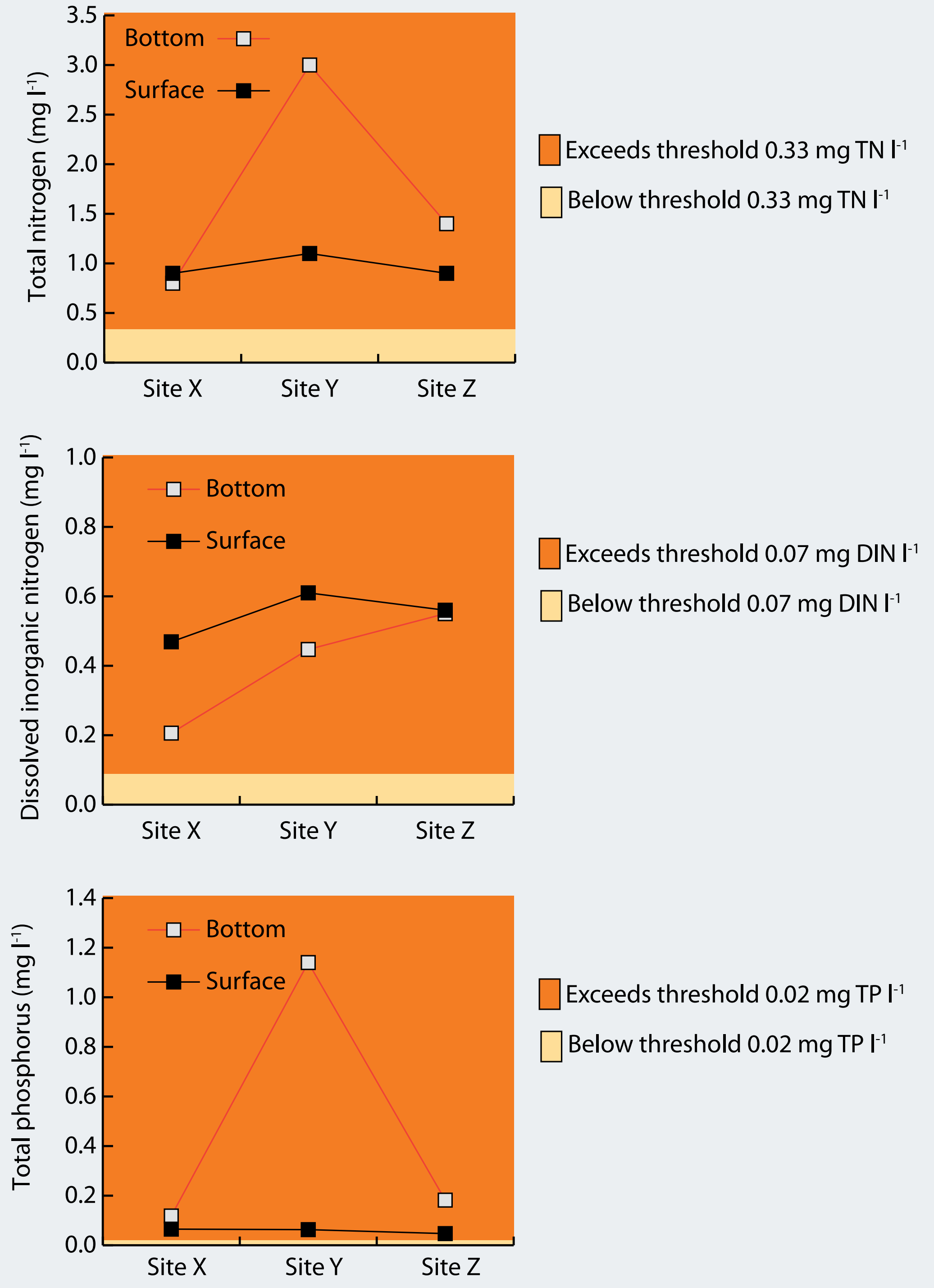

Figure 13. Total nitrogen, dissolved inorganic nitrogen and total phosphorus concentrations in surface and bottom water at upper estuary sites, Kaikorai Estuary, 12 February 2018.

Eutrophic status based on water column chlorophyll *a* and dissolved oxygen concentrations

The NZ ETI threshold for chlorophyll *a* (the primary indicator of water column eutrophication) is expressed as the 90th percentile of monthly measures collected during the growing season, and for dissolved oxygen (the main eutrophication supporting indicator), a 7 day mean. Consequently the one-off measures collected on 12 February 2018 can only be used as an indication of current condition.

Chlorophyll *a* concentrations were low in surface waters at all three upper estuary sites (<10 µg l^{-1}) (Figure 14). However, concentrations in denser saline bottom water at Site X exceeded the NZ ETI threshold level of 10 µg l^{-1}, and Site Y and Site Z exceeded threshold levels of 16 µg l^{-1} (Robertson et al. 2016b). In particular, Site Z bottom water had a very high concentration (i.e. 44 µg l^{-1} chlorophyll *a*). The same sites had super-saturated dissolved oxygen concentrations in bottom water during daylight (10.8, 12 and 13.2 mg DO l^{-1} at Sites X, Y and Z respectively), indicating a potential for depression to low levels during the night. Both these indicators highlight potential eutrophication issues in the upper estuary channel.

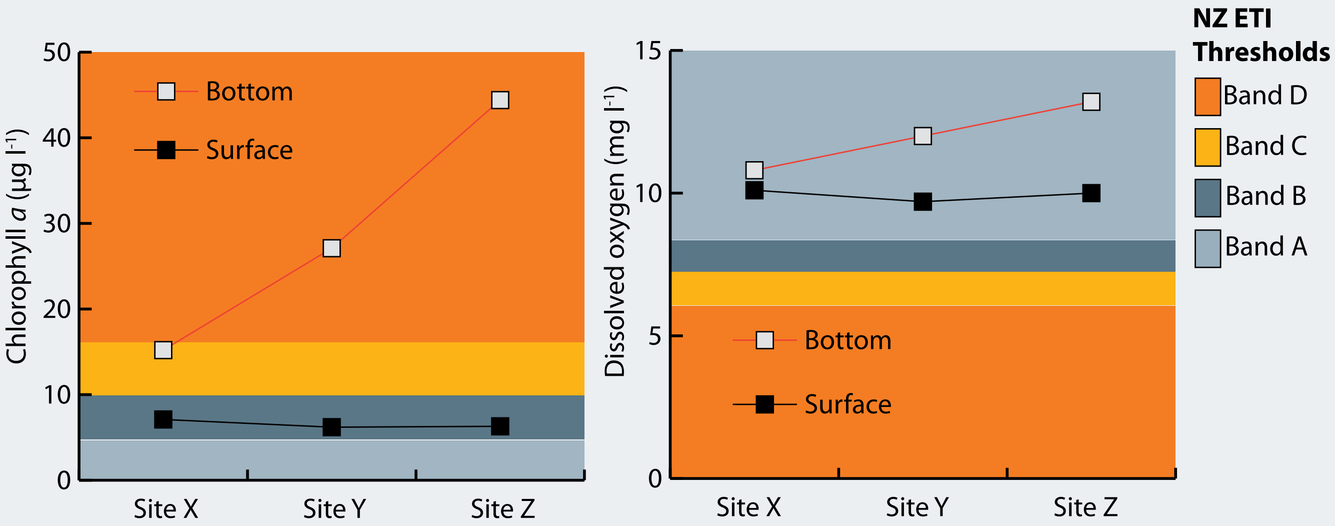

Figure 14. Chlorophyll *a* and dissolved oxygen concentrations in surface and bottom water at three upper estuary sites, Kaikorai Estuary, February 2018.

Developed pasture to upper estuary channel margins (left) and poorly flushed, nutrient/phytoplankton rich waters at upper estuary channel where sampling was undertaken (right), Kaikorai Estuary, 2018.

4.3 Estuary Trophic and Sedimentation Condition versus Catchment Loads

To provide screening-level guidance on whether managing contaminant loading to the Kaikorai Estuary from the surrounding catchment would shift the estuary towards a different ecological state (e.g. to improve its condition), the results for the most pertinent condition indicators [based on the combined fine scale (this report) and most recent broad scale (Jan 2018 - Stevens 2018) monitoring results and NZ ETI criteria (Robertson et al. 2016a,b)] are summarised in relation to estimated nitrogen (N) load[1] thresholds and sediment loads[1] in Figure 15 overleaf. Appendix 5 presents detailed background information on the indicator values and criteria used to derive an overall NZ ETI score.

In relation to catchment contaminant loads, while the NZ ETI rates the physical and nitrogen susceptibility of Kaikorai Estuary as "HIGH", its susceptibility to suspended sediment loads is unknown, which is supported by the following:

- Current estimated total N loading to the estuary (88 mg N m^{-2} d^{-1}) exceeded natural state N loads estimated by assuming a native forest land cover (70 mg N m^{-2} d^{-1} - note this estimate excludes any further attenuation by associated wetlands), and was close to critical eutrophication thresholds (100 mg N m^{-2} d^{-1}; Robertson 2018). Primary eutrophication symptoms characterised 16 % of the estuary's intertidal flats in Jan 2018 (Stevens 2018), resulting in an NZ ETI score of 0.81, Band D, a rating of "HIGH" for eutrophic symptoms. To improve sediment anoxia and potentially the health of associated macroinvertebrates, as well as possibly allow for expansion of seagrass habitat in the future, areal nitrogen loading rates should be managed below critical thresholds of 50 mg N m^{-2} d^{-1} (Robertson 2018; Robertson & Savage under review).
- The combination of current (1.0 kT SS yr^{-1}) and historic (unknown) suspended sediment loads to the estuary is predicted to cause stress to aquatic organisms (Robertson et al. 2016b), based on observed sedimentation issues (i.e. >30 % intertidal area in soft or very soft mud in 2018). However, at this stage, and without an established sediment load/estuary response threshold, it is difficult to determine the magnitude of likely ongoing sedimentation.
- 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)[2]. 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). For the Kaikorai, the CSSL/NSSL ratio was estimated to be 6 (i.e. 1.0 kT yr^{-1}/0.16 kT yr^{-1}), which indicates that the current sedimentation rate is likely to exceed the natural state sedimentation rate and therefore promote sedimentation issues in the estuary.
- It is noted that NIWA is currently researching likely natural state nitrogen and sediment loads to estuaries and will be reporting these to MfE (John Zeldis pers. comm. 2018).

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[1] Estimates of the total nitrogen load and total current state/natural state sediment load (i.e. CSSL/NSSL) for Kaikorai Estuary catchment were derived from NIWA's Catchment Land Use for Environmental Sustainability model – CLUES 10.5. CLUES is a modelling system for assessing the effects of land use change and mitigation practices on water quality (TN, TP, sediment and E. coli) and socio-economic factors for catchments (~10 km^2 and above). The basic spatial unit within CLUES is the River Environments Classification (REC2) (Snelder et al. 2010) river reach and surrounding subcatchment. CLUES couples a number of existing models within a GIS-platform, and incorporates the Landcare Research Land Cover Data Base (LCDB3) as a default land cover layer for deriving loads. Of most importance to this application of CLUES is the SPARROW component which predicts annual average stream loads of total nitrogen, total phosphorus, sediment and E. coli. It includes extensive provisions for stream routing and loss processes (storage and attenuation). This modelling procedure was originally developed by the United States Geological Survey (Smith et al. 1997) and has since been applied and modified in the New Zealand context with extensive liaison with the developers. SPARROW has been applied to nitrogen and phosphorus in Waikato (Alexander et al. 2002) and subsequently to the whole New Zealand landscape (Elliott et al. 2005). Further details on the CLUES modelling framework can be found in Semadeni-Davies et al. (2011, 2015), Woods et al. (2006), and more recently in Plew et al. (2018).

[2] 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 (Schubauer-Berigan et al. 2008).
- 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, A, 2009).

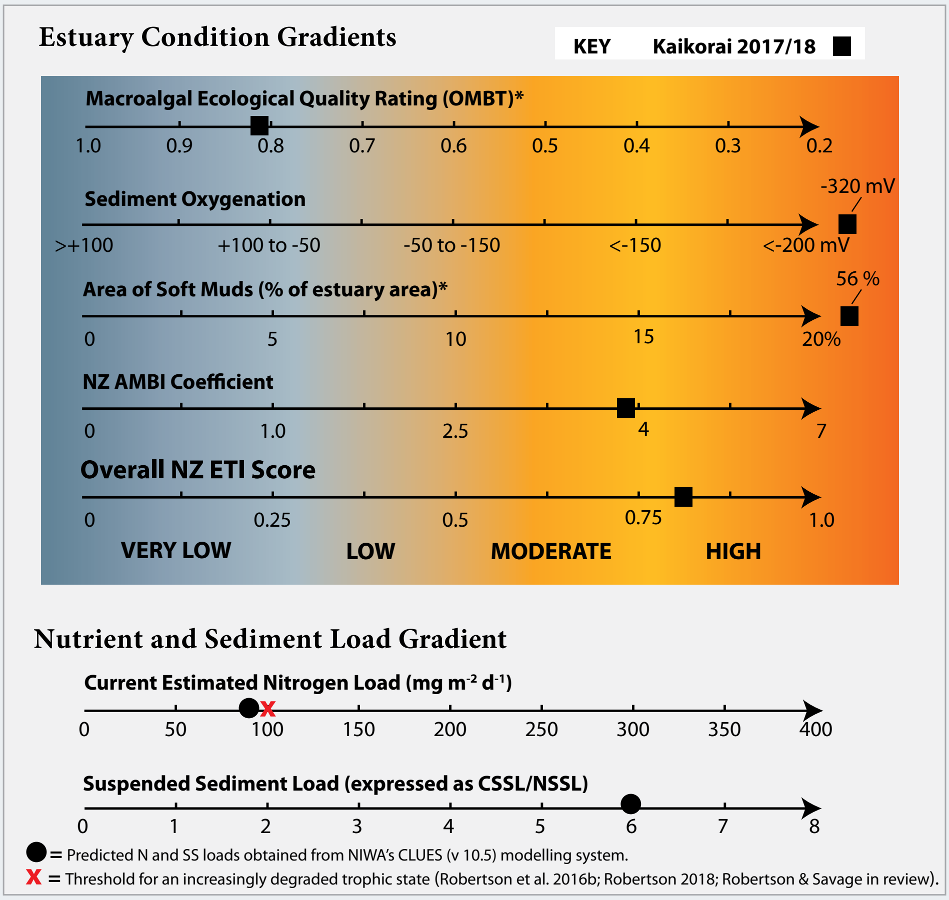

Figure 15. Indicator and NZ ETI scores, and matching catchment nitrogen and suspended sediment loading rates, Kaikorai Estuary, 2017. 'Sediment Oxygenation' expressed as mean redox potential (mV) at 1 cm depth in most impacted sediments and representing at least 10 % of estuary area. 'NZ AMBI' expressed as mean NZ AMBI score measured at 0-15 cm depth in most impacted sediments and representing at least 10% of estuary area. *based on 2018 broad scale survey findings (Stevens 2018).

5. SUMMARY AND CONCLUSIONS

Fine scale results of estuary condition for benthic intertidal and upper estuary channel monitoring sites within Kaikorai Estuary in December 2017 and February 2018, respectively, showed the following findings in relation to the key issues of sedimentation, eutrophication and toxicity:

Benthic habitat

Muddiness: The intertidal sites, chosen to represent the main lower, middle and upper estuary benthic habitats, showed a range of mud contents (14-65 % mud), with considerably muddier sediments in the estuary's main deposition zone (Site B - mean 65 % mud) and sandier sediments in the lower estuary (Site A - mean 14 % mud). The overall high mud content fits the Band D rating, and indicates a '*significant, persistent stress on a range of aquatic organisms caused by the indicator exceeding tolerance levels. A likelihood of local extinctions of keystone species and loss of ecological integrity, especially if nutrient loads are excessive*' (Robertson et al. 2016b).

Eutrophication: The results show that in December 2017 there was no seagrass or opportunistic macroalgal cover at both Sites A and B, and 60-70 % cover of opportunistic macroalgae (*Ulva intestinalis*) and no seagrass at Site C. In addition, while underlying sediments in the lower estuary (Site A) had

5. Summary and Conclusions (continued)

low organic carbon and nutrient contents compared to those in the middle and upper estuary (Sites B and C) all three regions were characterised by poor oxygenation conditions (i.e. low redox <-150 mV, Band D) in shallow surface sediments beginning below 1-5 cm depth.

The combination of moderate mud content and poor oxygenation indicates that the macroinvertebrate community would likely be dominated by mud and/or enrichment tolerant species. Such a biological response was reflected in the NZ estuary macroinvertebrate community index (the NZ Hybrid AMBI) results, mean 3.4 at Site A, 3.9 at Site B and 3.6 at Site C. These coefficients indicate a moderate-poor ecological condition category (i.e. an unbalanced type community indicative of elevated mud concentrations, possibly accompanied by organic enrichment).

Toxicity: 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, except for Zn in middle estuary (Site B) sediments, where the threat was rated as “high”. The source of the zinc to the muddy sediments of Site B is potentially derived from a combination of historical and modern catchment sources.

Upper estuary subtidal habitat

Eutrophication: Taken as a whole, the February 2018 water quality data showed that an approximate 1.5 km stretch of the upper estuary bottom water and underlying substrata was eutrophic at the time of sampling, as indicated by chlorophyll *a* and TN, DIN and TP all exceeding the eutrophication threshold concentrations (Figure 16).

However, given only one comprehensive sampling event, questions remain around the likely duration, magnitude and frequency of such eutrophication symptoms. Furthermore, it should be noted that the present results, obtained when the estuary mouth was open, do not reflect eutrophication related conditions under a closed mouth situation (i.e. potentially worse case scenario with regard to the estuary’s capacity to flush nutrients before they cause problems).

Based on expert opinion, the bottom water stratification and accompanying eutrophication likely manifest as cycles that gradually increase in intensity towards the end of the cycle, with the cycles being broken by intermittent high flow events that disrupt the stratification and flush phytoplankton and nutrients into the main body of the estuary and out to sea. The magnitude of the blooms will likely depend on the duration between flood events, with nuisance conditions increasing as time between floods increases.

Although upper estuary bottom water stratification is a natural event in many shallow NZ estuaries, it can be exacerbated by reductions in natural river inflows (e.g. from upstream water abstraction and damming). Once established, the extent of eutrophication in the bottom layer is likely to be primarily driven by catchment nutrients, particularly nitrogen. Preliminary indications suggest that river total nutrient inputs concentrations would need to be much less than 0.33 mg TN l^{-1}, 0.07 mg DIN l^{-1} and 0.02 mg TP l^{-1} in order to minimise eutrophication symptoms in the sensitive upper channel of the estuary.

In terms of risk to estuarine ecology from this cyclical degradation of the upper estuary bottom water layer, the likely main threats would be to benthic macroinvertebrates, fish and birds primarily through associated loss of functional habitat.

Comparison with 2001 and 2008 results

A comparison of the 2001 (Robertson et al. 2002) and 2008 (Stewart 2008) and 2017 results was possible for some indicators. Comparisons show that 2001 results were similar to those from nearby Site C in 2017, and 2008 results were similar to those from nearby Sites A and B in 2017, indicating those parts of the estuary are unlikely to have changed significantly in terms of sediment TOC, TN and TP concentrations over the past decade. Macroinvertebrate communities, on the other hand, were considerably less abundant and had fewer species present at Sites B and C in 2017 compared to 2001 and 2008, indicating a potential loss of the ecosystem functionality that macroinvertebrates provide during that period. However, these temporal trends should be considered with caution, as the 2001 and 2008 synoptic surveys did not meet the requirements of a full baseline survey [e.g. involved one-off sampling outside of the recommended December-March summer period, in the case of the 2008 survey used limited replication (a single composite chemistry sample and 3 macroinvertebrate replicates instead of the recommended 10), did not assess the high susceptibility upper estuary arm, and did not monitor for water column eutrophication]. In addition, the possibility that the slight (100 m) spatial offset at Site C compromised comparability over time (NEMP 2001 vs 2017/2018 survey) cannot be excluded.

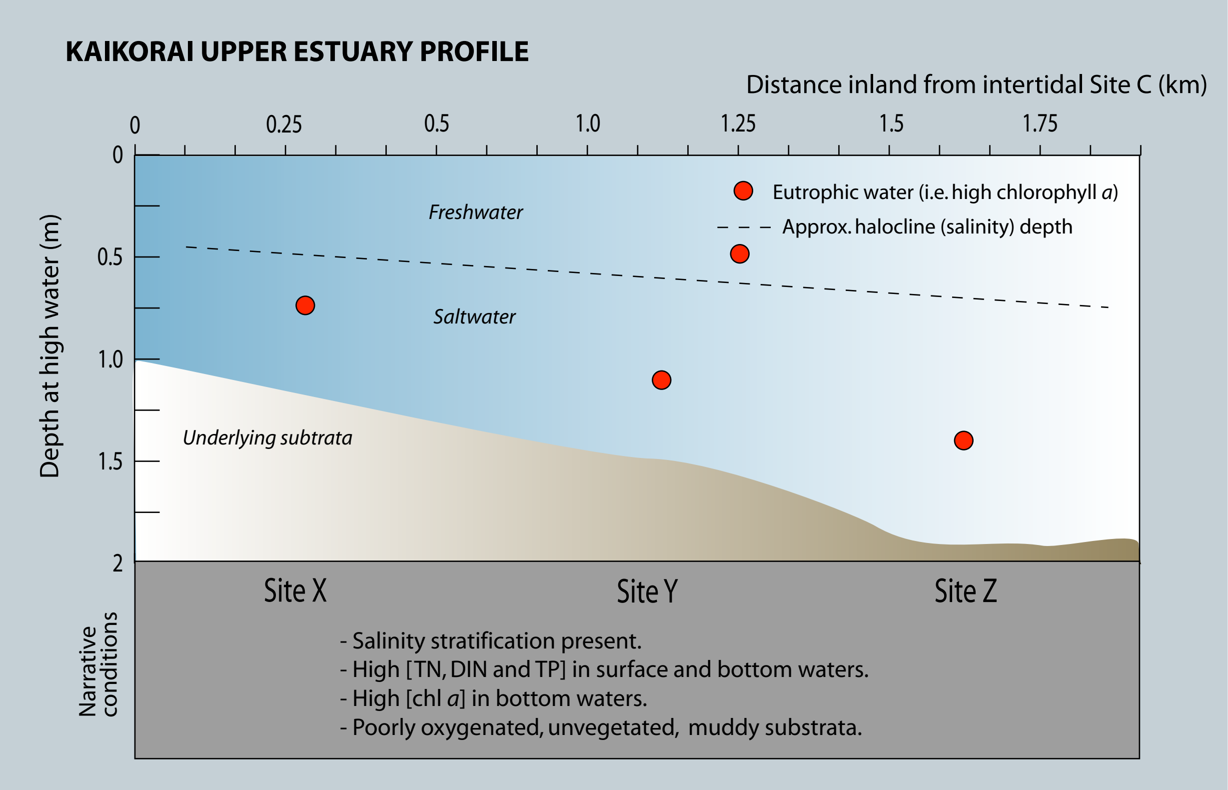

Figure 16. Generalised longitudinal profile (sea to river) of maximum water depth (at high water), salinity and chlorophyll *a*, and underlying substrata type at three upper estuary channel locations, Kaikorai Estuary, 12 February 2018.

Overview

In overview, the results for the two habitat types assessed, i.e. the intertidal benthic habitat throughout the estuary and the upper estuary water column, were as follows:

- The benthic intertidal results placed the estuary in a POOR state overall, with a middle and upper estuary eutrophication and sedimentation issue as well as a sediment zinc toxicity issue in the middle estuary. The former manifested as elevated muds and nutrients and poor sediment oxygenation and macroinvertebrate community condition.
- The upper estuary water column results showed an approximate 1.5 km stretch of the upper estuary bottom water to be expressing eutrophic symptoms (i.e. chlorophyll *a,* TN, DIN and TP levels all exceeded established eutrophication thresholds).

Finally, in order to assess the potential of the estuary for eutrophication and sedimentation issues, the current estimated nitrogen and sediment loads to the estuary were compared with existing thresholds for expression of problems. The results showed that, although the current estimated nitrogen loading (88 mg N m^{-2} d^{-1}) to the estuary was below the threshold for the expression of eutrophic conditions (Robertson 2018), the ETI score, which integrated the 2017/18 broad scale monitoring results (Stevens 2018), of 0.81, Band D, indicated a high degree of eutrophic symptoms. To improve sediment anoxia and potentially the health of associated macroinvertebrates, as well as possibly allow for expansion of seagrass habitat in the future, areal nitrogen loading rates should be managed below critical thresholds of 50 mg N m^{-2} d^{-1} (Robertson 2018; Robertson & Savage under review). Also, based on the elevated area of soft mud habitat in the estuary, it is apparent that the combination of current and historic suspended sediment loads to the estuary is predicted to cause moderate stress to aquatic organisms. However, because quantitative sediment load versus sedimentation thresholds have yet to be developed for NZ estuaries, the issue of ongoing sedimentation rates in the estuary is more difficult to predict.

6. MONITORING

Monitoring

Kaikorai Estuary has been identified by ORC as a priority for monitoring because it is a moderate sized estuary with high ecological and human use values that is situated in a developed catchment, and therefore vulnerable to excessive sedimentation and eutrophication. As a consequence, it is a key part of ORC's coastal monitoring programme being undertaken throughout the Otago region. Broad scale habitat mapping and fine scale sampling has now been undertaken for 1 baseline year (December 2017).

In order to assess ongoing long-term trends in the condition of such estuaries, it is common practice amongst NZ Regional Councils to establish a strong baseline against which future trends can be compared. This typically comprises comprehensive broad scale habitat mapping on a 5-10 yearly cycle, targeted annual monitoring where specific issues are identified (e.g. opportunistic nuisance macroalgal growth), and fine scale monitoring comprising 3-4 consecutive years of baseline monitoring, followed by 5 yearly impact monitoring.

The present report addresses the fine scale component of the long term programme. The recommendation for ongoing monitoring to meet this requirement for the Kaikorai Estuary is as follows:

Fine Scale Monitoring

To complete the fine scale baseline in Kaikorai Estuary it is recommended that the remaining 3 consecutive years of annual summer (i.e. December-February) fine scale monitoring of intertidal sites (including sedimentation rate measures), be undertaken in 2018, 2019 and 2020 (preferably during a summer, low flow period).

To fully characterise the potential for upper estuary stratification and eutrophication, it is recommended that water column monitoring of the upper to mid estuary be undertaken during a summer, prolonged low flow period in 2018. It is envisaged that this should include sampling of surface and bottom water at 5-6 sites in the main channel of the estuary.

To characterise the potential for excessive sedimentation, it is recommended that sedimentation rates be assessed annually, using the appropriately placed sediment plates deployed in 2017, and the areal extent of muddy sediments be assessed at 5-10 yearly intervals (the latter assessed in broad scale monitoring).

Broad Scale Habitat Mapping

Refer to Stevens (2018) for associated long-term broad scale habitat monitoring recommendations.

7. ACKNOWLEDGEMENTS

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APPENDIX 1. DETAILS ON ANALYTICAL METHODS

Indicator	Laboratory	Method	Detection Limit
Infauna Sorting and ID	CMES	Coastal Marine Ecology Consultants (Gary Stephenson) *	N/A
Grain Size	R.J Hill	Wet sieving, gravimetric (calculation by difference).	0.1 g 100^{-g} dry wgt
Total Organic Carbon	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	0.05g 100^{-g} dry wgt
Total recoverable cadmium	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.01 mg kg^{-1} dry wgt
Total recoverable chromium	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg kg^{-1} dry wgt
Total recoverable copper	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg kg^{-1} dry wgt
Total recoverable nickel	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.2 mg kg^{-1} dry wgt
Total recoverable lead	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.04 mg kg^{-1} dry wgt
Total recoverable zinc	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	0.4 mg kg^{-1} dry wgt
Total recoverable mercury	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	<0.27 mg kg^{-1} dry wgt
Total recoverable arsenic	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	<10 mg kg^{-1} dry wgt
Total recoverable phosphorus	R.J Hill	Nitric/hydrochloric acid digestion, ICP-MS (low level) USEPA 200.2.	40 mg kg^{-1} dry wgt
Total nitrogen	R.J Hill	Catalytic combustion, separation, thermal conductivity detector (Elementary Analyser).	500 mg kg^{-1} dry wgt
Dry Matter (Env)	R.J. Hill	Dried at 103 °C (removes 3-5 % more water than air dry)	

* Coastal Marine Ecology Consultants (established in 1990) specialises in coastal soft-shore and inner continental shelf soft-bottom benthic ecology. Principal, Gary Stephenson (BSc Zoology) has worked as a marine biologist for more than 25 years, including 13 years with the former New Zealand Oceanographic Institute, DSIR. Coastal Marine Ecology Consultants holds an extensive reference collection of macroinvertebrates from estuaries and soft-shores throughout New Zealand. New material is compared with these to maintain consistency in identifications, and where necessary specimens are referred to taxonomists in organisations such as NIWA and Te Papa Tongarewa Museum of New Zealand for identification or cross-checking.

Water Quality Indicator	Laboratory	Method	Detection Limit
Filtration, Unpreserved	R.J Hill	Sample filtration through 0.45 μm membrane filter.	-
Total Kjeldahl Digestion	R.J Hill	Sulphuric acid digestion with copper sulphate catalyst.	-
Total Phosphorus Digestion	R.J Hill	Acid persulphate digestion.	-
Total Nitrogen	R.J Hill	Calculation: TKN + Nitrate-N + Nitrite-N. Please note: Default Detection Limit of 0.05 g m^{-3} is only attainable when the TKN has been determined using a trace method utilising duplicate analyses. In cases where the Detection Limit for TKN is 0.10 g m^{-3}, the Default Detection Limit for Total Nitrogen will be 0.11 g m^{-3}.	0.05 g m^{-3}
Total Ammoniacal-N	R.J Hill	Saline, filtered sample. Phenol/hypochlorite colorimetry. Discrete Analyser. (NH4-N = NH4+-N + NH3-N). APHA 4500- NH3 F (modified from manual analysis) 22nd ed. 2012.	0.010 g m^{-3}
Nitrite-N	R.J Hill	Saline sample. Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO3- I 22nd ed. 2012 (modified).	0.002 g m^{-3}
Nitrate-N	R.J Hill	Calculation: (Nitrate-N + Nitrite-N) - NO2N. In-House.	0.0010 g m^{-3}
Nitrate-N + Nitrite-N	R.J Hill	Saline sample. Total oxidised nitrogen. Automated cadmium reduction, Flow injection analyser. APHA 4500-NO3- I 22nd ed. 2012 (modified).	0.002 g m^{-3}
Total Kjeldahl Nitrogen (TKN)	R.J Hill	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser. APHA 4500-Norg D. (modified) 4500 NH3 F (modified) 22nd ed. 2012.	0.10 g m^{-3}
Dissolved Reactive Phosphorus	R.J Hill	Filtered sample. Molybdenum blue colorimetry. Discrete Analyser. APHA 4500-P E (modified from manual analysis) 22nd ed. 2012.	0.004 g m^{-3}
Total Phosphorus	R.J Hill	Total phosphorus digestion, ascorbic acid colorimetry. Discrete Analyser. APHA 4500-P B & E (modified from manual analysis) 22nd ed. 2012. Also modified to include the use of a reductant to eliminate interference from arsenic present in the sample. NWASCA, Water & soil Miscellaneous Publication No. 38, 1982.	0.004 g m^{-3}

APPENDIX 2. 2017/18 DETAILED RESULTS

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

A. PERCENTAGE 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%.

B. DENSITY SCALES

SACFOR size class				Density				
i	ii	iii	iv	0.25 m^2	1.0 m^2	10 m^2	100 m^2	1,000 m^2
<1 cm	1-3 cm	3-15 cm	>15 cm	(50x50 cm)	(100x100 cm)	(3.16x3.16 m)	(10x10 m)	(31.6x31.6 m)
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

Appendix 2. 2017/18 Detailed Results (continued)

Kaikorai Estuary fine scale site boundaries

Kaikorai Site A	1	2	3	4
NZTM E	1397488	1397513	1397532	1397510
NZTM N	4910644	4910635	4910668	4910687
Kaikorai Site C	1	2	3	4
NZTM E	1398215	1398203	1398175	1398186
NZTM N	4911923	4911894	4911903	4911938

Kaikorai Site B	1	2	3	4
NZTM EAST	1397985	1398011	1397996	1397964
NZTM NORTH	4911045	4911066	4911088	4911060

Fine scale station locations, Kaikorai Estuary, 15 December 2017

Kaikorai Site A	1	2	3	4	5	6	7	8	9	10
NZTM E	1397496	1397501	1397505	1397510	1397518	1397514	1397510	1397506	1397512	1397517
NZTM N	4910649	4910658	4910667	4910675	4910671	4910663	4910655	4910646	4910644	4910652
Kaikorai Site B	1	2	3	4	5	6	7	8	9	10
NZTM E	1397986	1397992	1397997	1398003	1397998	1397992	1397985	1397980	1397975	1397979
NZTM N	4911051	4911056	4911060	4911064	4911073	4911068	4911064	4911058	4911061	4911068
Kaikorai Site C	1	2	3	4	5	6	7	8	9	10
NZTM E	1398207	1398204	1398200	1398199	1398199	1398195	1398193	1398190	1398182	1398184
NZTM N	4911923	4911916	4911909	4911901	4911926	4911920	4911913	4911904	4911907	4911915

Kaikorai Estuary sediment plate and peg locations and depth of plate (mm) below surface

Site A Sed Plates (Firm Muddy Sand)	NZTM E	NZTM N	Height/Depth (mm) Dec 2017
Peg 1 (0 m)	1397532	4910669	
Plate 1 (2 m)	1397531	4910670	119
Plate 2 (4 m)	1397529	4910671	126
Peg 2 (5 m)	1397528	4910672	
Plate 3 (6 m)	1397527	4910673	86
Plate 4 (8 m)	1397526	4910674	94
Peg 3 (10 m)	1397525	4910675	
Site C Sed Plates (Firm Muddy Sand)	NZTM E	NZTM N	Height/Depth (mm) Dec 2017
Peg 1 (0 m)	1398174	4911903	
Plate 1 (2 m)	1398173	4911904	63
Plate 2 (4 m)	1398171	4911905	61
Peg 2 (5 m)	1398170	4911906	
Plate 3 (6 m)	1398169	4911907	77
Plate 4 (8 m)	1398168	4911908	96
Peg 3 (10 m)	1398167	4911909	

Site B Sed Plates (Soft Mud)	NZTM East	NZTM North	Height/Depth (mm) Dec 2017
Peg 1 (0 m)	1397964	4911060	
Plate 1 (2 m)	1397962	4911061	112
Plate 2 (4 m)	1397961	4911063	121
Peg 2 (5 m)	1397960	4911064	
Plate 3 (6 m)	1397959	4911065	98
Plate 4 (8 m)	1397958	4911066	103
Peg 3 (10 m)	1397957	4911067	

Upper estuary water quality and subtidal sediment site locations, Kaikorai Estuary, 12 February 2018

Kaikorai	**Site X (lower)**	**Site Y (mid)**	**Site Z (upper)**
NZTM E	1398478	1398930	1399041
NZTM N	4912219	4912507	4913157

Appendix 2. 2017/18 Detailed Results (continued)

Sediment Redox Potential (mV) profiles at fine scale sites ($n = 3$), Kaikorai Estuary, 15 December 2017

Year/Site	Redox Potential (mV) / Depth														
	0 cm			-1 cm			-3 cm			-6 cm			-10 cm		
2017 A	18	22	45	-20	-43	-47	-56	-67	-65	-183	-154	-173	-294	-275	-264
2017 B	-60	-76	-46	-350	-345	-337	-364	-382	-372	-400	-413	-407	-410	-426	-402
2017 C	-34	-26	-29	-220	-218	-227	-330	-317	-324	-317	-346	-319	-337	-334	-331

Physical and chemical results for fine scale Sites A, B and C, Kaikorai Estuary, 15 December 2017

Year/Site/Rep	RPD	Salinity	TOC	Mud	Sand	Gravel	Cd	Cr	Cu	Ni	Pb	Zn	As	Hg	TP	TN
	cm	ppt	%				mg/kg									
2017 A 1-4 [b]	3	31	0.52	13.8	86.1	<0.1	0.03	8.3	4.8	4.7	9.0	44.0	4.4	<0.02	360	600
2017 A-4-8 [b]	3	31	0.54	14.1	86.0	<0.1	0.03	8.4	4.8	4.8	8.6	46.0	4.5	<0.02	430	600
2017 A-9-10 [b]	3	31	0.65	15	85.0	<0.1	0.04	9.6	5.4	5.1	9.7	51.0	5.6	<0.02	440	700
2017 B-1-4 [b]	0	31	2.7	64.4	35.5	0.1	0.26	44.0	25.0	18.1	47.0	240.0	14.3	0.10	1060	2200
2017 B-4-8 [b]	0	31	2.6	69.8	30.1	<0.1	0.24	42.0	23.0	17.4	45.0	230.0	13.6	0.09	1070	2100
2017 B-9-10 [b]	0	31	2.5	60.9	38.7	0.4	0.25	45.0	24.0	19.0	45.0	240.0	14.1	0.09	1100	1900
2017 C-1-4 [b]	1	30	1.44	27.5	70.3	2.3	0.10	20.0	10.3	12.5	22.0	125.0	6.0	0.03	640	1200
2017 C-4-8 [b]	1	30	1.42	29.1	67.2	3.8	0.10	22.0	10.6	13.2	23.0	135.0	6.7	0.03	680	1100
2017 C-9-10 [b]	1	30	1.28	25.1	74.1	0.8	0.10	21.0	9.9	12.7	22.0	137.0	5.9	0.03	670	1100
ISQG-Low [a]	-	-	-	-	-	-	1.5	80	65	21	50	200	20	0.15	-	-
ISQG-High [a]	-	-	-	-	-	-	10	370	270	52	220	410	70	1	-	-

[a] ANZECC 2000. [b] composite samples.

Water quality results for upper estuary Sites X, Y and Z, Kaikorai Estuary, 12 February 2018

Parameter	Units	Kaikorai Site X (surface)	Kaikorai Site X (bottom)	Kaikorai Site Y (surface)	Kaikorai Site Y (bottom)	Kaikorai Site Z (surface)	Kaikorai Site Z (bottom)
Depth	m	0.2	0.5	0.2	1	0.2	1.5
Temperature	degrees C	24.5	25.6	23.0	22.7	21.0	21.0
Salinity	ppt	4.8	16.5	1.0	14.3	0.5	13.6
Dissolved Oxygen	mg l^{-1}	10.1	10.8	9.7	12.0	10.0	13.2
Chlorophyll *a*	mg m^{-3}	7.1	15.2	6.2	27.1	6.3	44.4
Total Nitrogen	g m^{-3}	0.9	0.8	1.1	3.0	0.9	1.4
Total Ammoniacal-N	g m^{-3}	0.1	0.1	0.2	0.2	0.2	0.2
Nitrite-N	g m^{-3}	0.01	0.01	0.01	0.01	0.01	0.01
Nitrate-N	g m^{-3}	0.3	0.1	0.4	0.3	0.4	0.3
Nitrate-N + Nitrite-N	g m^{-3}	0.3	0.1	0.4	0.3	0.4	0.3
Total Kjeldahl Nitrogen (TKN)	g m^{-3}	0.6	0.7	0.7	2.8	0.6	1.1
Dissolved Reactive Phosphorus	g m^{-3}	0.02	0.02	0.02	0.01	0.02	0.02
Total Phosphorus	g m^{-3}	0.06	0.11	0.06	1.14	0.04	0.18

Sediment quality results for subtidal Sites X, Y and Z, Kaikorai Estuary, 12 February 2018

Year/Site	TOC	Mud	Sand	Gravel	TN	TP
	%				mg kg^{-1}	
Kaikorai SED X 2018	0.9	19.3	80.5	0.2	800	350
Kaikorai SED Y 2018	0.3	78.4	21.5	0.1	<500	260
Kaikorai SED Z 2018	6.5	42.8	47.6	9.7	3800	890

Appendix 2. 2017/18 Detailed Results (continued)

Epifauna abundance and macroalgal cover at fine scale sites, Kaikorai Estuary, 15 December 2017

Group	Family	Species	Common name	Scale	Class	A	B	C
Gastropod snail	Amphibolidae	*Amphibola crenata*	Mud-flat snail	#	ii	R	-	-
Green algae	Ulvaceae	*Ulva intestinalis*	Gutweed or grass kelp	%	ii	-	-	A

Seagrass (*Zostera muelleri*) and macroalgal cover and biomass at fine scale sites, Kaikorai Estuary, 15 December 2017

Year/Site	Seagrass Biomass (g m^{-2} wet weight) and Cover (%)	Macroalgal Biomass (g m^{-2} wet weight) and Cover (%)
2017 A	0 (0%)	0 (0 %)
2017 B	0 (0%)	0 (0 %)
2017 C	0 (0%)	200 (60-70 %)

Infauna results* for fine scale Sites A, B and C, Kaikorai Estuary, 15 December 2017

Infauna (numbers per 0.01327 m² core)

Group	Species	NZ Hyb AMBI*	A-01	A-02	A-03	A-04	A-05	A-06	A-07	A-08	A-09	A-10	B-01	B-02	B-03	B-04	B-05	B-06	B-07	B-08	B-09	B-10
Nematoda	Nematoda	NA	1	1																		
Polychaeta	Nereididae (unidentified juveniles)	3	1	6	8	16	14	8	11	4	10	9	4	2	1	1			4	1	2	3
	Nicon aestuariensis	3																			1	
	Perinereis vallata	2	17	10	17	19	5	7	6	2	5	3	1	1	1		3	2	4	1		2
	Scolecolepides benhami	4	15	19	24	13	26	23	14	29	25	28	1	4	3	3	3	2	8	9	5	4
Oligochaeta	*Oligochaeta* sp.#1	3	2	7	4	5	5	2	1	4	1	2		3			1		1	2		
Gastropoda	*Potamopyrgus estuarinus*	3				2	1	1				1			1			2				
	Potamopyrgus pupoides	3											2	1								
Crustacea	*Amphipoda* sp.#3	1									1		1								1	
	Exosphaeroma planulum	5											2	3	1	1					2	
	Paracorophium excavatum	4	1	9	40	3	2	2	6	1	27	18	13	52	29	7	64	10	47	48	25	41
Insecta	*Diptera* sp.#2	2																				
	Diptera sp.#3	2																				
Total individuals in sample			37	52	93	58	53	43	38	40	69	61	24	66	36	12	71	16	64	61	36	50
Total number of species in sample			6	6	5	6	6	6	5	5	6	6	7	7	6	4	4	4	5	5	6	4

Group	Species	NZ Hyb AMBI*	C-01	C-02	C-03	C-04	C-05	C-06	C-07	C-08	C-09	C-10
Nematoda	Nematoda	NA										
Polychaeta	Nereididae (unidentified juveniles)	3										
	Nicon aestuariensis	3										
	Perinereis vallata	2										
	Scolecolepides benhami	4										
Oligochaeta	*Oligochaeta* sp.#1	3										
Gastropoda	*Potamopyrgus estuarinus*	3										
	Potamopyrgus pupoides	3										
Crustacea	*Amphipoda* sp.#3	1										
	Exosphaeroma planulum	5										
	Paracorophium excavatum	4	1		3	34					1	32
Insecta	*Diptera* sp.#2	2	1									
	Diptera sp.#3	2			1						2	
Total individuals in sample			2	0	4	34	0	0	0	0	3	32
Total number of species in sample			2	0	2	1	0	0	0	0	2	1

*sourced from Robertson et al. 2015, 2016

APPENDIX 3. INFAUNA CHARACTERISTICS

Group and Species		NZ Hyb AMBI Gp*	Details
Polychaeta	*Nicon aestuariensis*	3	A nereid (ragworm) that is tolerant of freshwater and is a surface deposit feeding omnivore. Prefers to live in moderate mud content sediments.
	Nereididae	3	Active, omnivorous worms, usually green or brown in colour. There are a large number of New Zealand nereids. Rarely dominant in numbers compared to other polychaetes, but they are conspicuous due to their large size and vigorous movement. Nereids are found in many habitats. The tube-dwelling nereid polychaete *Nereis diversicolor* is usually found in the innermost parts of estuaries and fjords in different types of sediment, but it prefers silty sediments with a high content of organic matter. Blood, intestinal wall and intestinal fluid of this species catalyzed sulfide oxidation, which means it is tolerant of elevated sulphide concentrations.
	Perinereis vallata	2	An intertidal soft shore nereid (common and very active, omnivorous worms). Prefers mud/sand sediments. Prey items for fish and birds. Sensitive to large increases in sedimentation.
	Scolecolepides benhami	4	A spionid, surface deposit feeder. Is rarely absent in sandy/mud estuaries, often occurring in a dense zone high on the shore, although large adults tend to occur further down towards low water mark. A close relative, the larger *Scolecolepides freemani* occurs upstream in some rivers, usually in sticky mud in near freshwater conditions. e.g. Waihopai Arm, New River Estuary.
Oligochaeta	*Oligochaeta* sp. 1	3	Segmented worms - deposit feeders. Classified as very pollution tolerant (e.g. Tubificid worms) although there are some less tolerant species.
Gastropoda	*Potamopyrgus* sp.	3	Endemic to NZ. Small snail that can live in freshwater as well as brackish conditions. In estuaries *P. antipodarum* can tolerate up to 17-24 % salinity. Shell varies in colour (gray, light to dark brown). Feeds on decomposing animal and plant matter, bacteria, and algae. Intolerant of anoxic surface muds but can tolerate organically enriched conditions. Tolerant of muds. Populations in saline conditions produce fewer offspring, grow more slowly, and undergo longer gestation periods. *Potamopyrgus estuarinus* is a small estuarine snail, requiring brackish conditions for survival. Intolerant of anoxic surface muds. Tolerant of muds and organic enrichment.
Crustacea	*Paracorophium excavatum*	4	A tube-dwelling corophioid amphipod. Two species in NZ, *Paracorophium excavatum* and *Paracorophium lucasi* and both are endemic to NZ. *P. lucasi* occurs on both sides of the North Island, but also in the Nelson area of the South Island. *P. excavatum* has been found mainly in east coast habitats of both the South and North Islands. Sensitive to metals. Also very strong mud preference.
	Exosphaeroma planulum	5	Small seaweed dwelling isopod. Highly tolerant of muds and organic enrichment.
	Amphipoda sp.#3	1	An unidentified amphipod.
Insecta	*Diptera* sp.#2	2	Fly or midge larvae - species unknown.
	Diptera sp.#3	2	An unknown dipteran or fly larvae.
Nematoda	*Nematoda* sp.	NA	Small unsegmented roundworms. Very common. Feed on a range of materials. Common inhabitant of muddy sands. Many are so small that they are not collected in the 0.5 mm mesh sieve. Generally reside in the upper 2.5 cm of sediment. Intolerant of anoxic conditions.

* NZ AMBI Biotic Index sensitivity groupings sourced from Robertson et al. (2015) and nationally validated in Robertson et al. (2016).
1 = highly sensitive to (intolerant of) mud and organic enrichment;
2 = sensitive to mud and organic enrichment;
3 = widely tolerant of mud and organic enrichment;
4 = prefers muddy, organic enriched sediments;
5 = very strong preference for muddy, organic enriched sediments.

APPENDIX 4. NZ ESTUARY TROPHIC INDEX

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 ETI score becomes. Where established ratings are not yet incorporated into the NIWA ETI online calculator they are included via spreadsheet calculator.

The indicators used to derive an ETI score and determine current trophic and sedimentation state for the Kaikorai Estuary (as presented in Figure 15) are presented below using the most recent broad scale monitoring results (Stevens 2018) and fine scale monitoring results (this report).

The input values used in the online calculator are presented on the following page.

ETI Tool 1 rates the physical and nutrient load susceptibility of Kaikorai Estuary as "HIGH".

ETI Tool 2 online calculator scores the estuary 0.81, Band D, a rating of "HIGH" for eutrophic symptoms.

ETI SCORING SUMMARY FOR KAIKORAI ESTUARY, DECEMBER 2017.			NIWA online calculator	Spreadsheet calculator
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*	0.9	0.9
	Macroalgal Gross Nuisance Zone (GNA) %	% Gross Nuisance Area (GNA)/Estuary Area*	16	16
	Macroalgal GNA Ha	Ha Gross Nuisance Area (GNA)*	12.8	12.8
Optional	Phytoplankton biomass	Chl *a* (summer 90 pctl, mg m^{-3})	25***	25***
	Cyanobacteria (if issue identified) - NOTE 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**	-320	-320
		% of estuary with Redox Potential <-150 mV at 3 cm or aRPD <1 cm*		21
		Ha of estuary with Redox Potential <-150 mV at 3 cm or aRPD <1 cm*		17
	Sediment Total Organic Carbon	Mean TOC (%) measured at 0-2 cm depth in most impacted sediments and representing at least 10 % of estuary area**	2.6	2.6
	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**	2066	2066
	Macroinvertebrates	Mean AMBI score measured at 0-15 cm depth in most impacted sediments and representing at least 10 % of estuary area**	3.9	3.9
Optional	Muddy sediment	% estuary area with soft mud (>25 % mud content)*	0.56	0.56
	Sedimentation rate	Ratio of Mean estimated annual Current State Sediment Load (CSSL) relative to mean annual Natural State Sediemnt Load (NSSL)		6.0
	Dissolved Oxygen	1 day instantaneous minimum of water column measured from representative areas of estuary water column (including likely worst case condtions) (mg m^{-3})	4.6	4.6
		NZ ETI Score	**0.81**	**0.81**

* Based on 2018 broad scale findings (Stevens 2018).

** Based on 2018 fine scale findings (this report).

*** Measurements from >1 m depth in the upper estuary collected on 16/2/18 were 20-30 mg m^{-3}, surface water concentrations throughout the estuary were 5-7 mg m^{-3}. Phytoplankton is not recommended for use as primary indicator to derive the ETI score in SIDE estuaries and was not used in calculating the ETI scores presented.

Appendix 4. NZ Estuary Trophic Index (Continued)

Input values used in the NZ ETI online calculator (May 2018). See the NIWA online tool metadata spreadsheets for full explanation of terms and abbreviations. Refer to Stevens (2018) for 'Input Value' background/rationale.

NZ ETI Tool 1 Input details	**Calculator Headings**	**Unit**	**Input Value**
Estuary Number	Est_no		1060
Estuary Name	Est_name		Kaikorai Stream
Regional Council	Reg_Council		ORC
Island	Island		South Island
NZCHS geomorphic code	NZCHS_code		6C
NZCHS geomorphic class	NZCHS_class		Tidal river mouth (bar. enc.)
ETI Class	ETI_class		SIDE
Latitude	LAT	decimal degrees	-45.93689584
Longitude	LON	decimal degrees	170.3907738
Freshwater inflow	Qf	m3/s	0.46
Annual river total nitrogen loading	TNriver	T/yr	30.08*
Annual river total phosphorus loading	TPriver	T/yr	2.28*
Volume	V	m3	1645000
Tidal Prism	P	m3	1544500
Return flow fraction	b	unitless	NA
ACExR fitted exponent	A	unitless	-0.32
ACExR fitted constant	B	unitless	123.2
Ratio NO3	R_NO3	unitless	0.63
Ratio DRP	R_DRP	unitless	0.73
Ocean salinity	OceanSalinity_mean	ppt	34.40
Ocean nitrate concentration	NOcean	mg/m3	72.83
Ocean DRP concentration	POcean	mg/m3	15.92
Intertidal area	Intertidal	%	86
Typical closure length	Tl	days	NA
ICOE class	isICOE	one of: TRUE, FALSE	TRUE
Closure length	closure_length	one of: days, months	days
Estuary Area	est_area_m2	m2	940000
Mean depth	mean_depth	m	1.75
Tidal height	tidal_height	m	1.6826
Low tide area	LOWTIDEest_area_m2	m2	134000
Low tide mean depth	LOWTIDEmean_depth	m	0.75
Low tide volume	LOWTIDEvolume	m3	100500

NZ ETI Tool 2 Input details			
Name of estuary	estuary_name		
Phytoplankton Biomass (Chlorophyll a)	CHLA	mg/m3	0
Macroalgal GNA	macroalgae_GNA_ha	ha	12.8
Macroalgal GNA/Estuary Area	macroalgae_GNA_percent	%	16
Opportunistic Macroalgae	macroalgae_EQR	OMBT EQR	0.9
Dissolved Oxygen (DO)	DO	mg/m3	4.6
Sediment Redox Potential (RP)	REDOX	mV	-320
Total Organic Carbon (TOC)	TOC	%	2.6
Total Nitrogen (TN)	TN	mg/kg	2066
Macroinvertebrates	AMBI	NZ AMBI	3.9
Area of soft mud	soft_mud	Proportion	0.56
Estuary type	estuary_type		SIDE
ICOE status	isICOE	TRUE/FALSE	TRUE

* Loads calculated using CLUES v10.5.