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Kaikorai Estuary

Broad Scale Habitat Mapping 2018

Prepared for

Otago Regional Council

June 2018

Cover Photo: Kaikorai Estuary, view over herbfields in the upper estuary, February 2018.


Lower Kaikorai Estuary

Kaikorai Estuary

Broad Scale Habitat Mapping 2018

Prepared for
Otago Regional Council

by

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RECOMMENDED CITATION:
Stevens, L.M. 2018. Kaikorai Estuary: Broad Scale Habitat Mapping 2018. Report prepared by Wriggle Coastal Management for Otago Regional Council. 30p.

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KAIKORAI ESTUARY - EXECUTIVE SUMMARY

Kaikorai Estuary is an extensively modified, moderate sized (94ha), microtidal, shallow (mean depth ~1.5m at high water), tidal lagoon type estuary located at Dunedin, Otago. The mouth is nearly always open but occasionally closes for short periods and often has a constricted tidal mouth, and the upper estuary is at times poorly flushed, stratified and susceptible to phytoplankton blooms. Mouth constriction, reclamation and causeways in the lower reaches of the estuary have contributed to the central estuary becoming dominated by muddy sediments in poor condition. The catchment is dominated by pasture (48%) and urban areas (21%). Kaikorai is one of the key estuaries in Otago Regional Council's (ORC's) long-term coastal monitoring programme. This report presents the results of the February 2018 broad scale estuary habitat mapping with broad scale monitoring results, overall estuary condition and issues, and monitoring recommendations summarised below.

BROAD SCALE RESULTS

- Intertidal flats comprised 50% of the estuary, saltmarsh 36%, and subtidal waters 14%.
- Intertidal substrates (outside of saltmarsh) were dominated by firm sand (27%), firm mud (24%) and very soft mud (28%), with smaller areas of firm muddy sand (8%), firm sandy mud (5%), soft mud (4%), and mobile sand (4%).
- Sediment mud content measured within mud habitat was moderate-high (17-62%).
- No significant opportunistic macroalgal growth was present, an Ecological Quality Rating of "HIGH", however, phytoplankton concentrations were high, particularly in stratified upper estuary areas.
- Large parts of the estuary were adversely impacted by gross eutrophic zones and areas with low sediment oxygenation.
- Saltmarsh cover was relatively extensive 34ha (42% of the intertidal area) and was dominated by herbfields (85%).
- The 200m terrestrial margin was 44% pasture or unmaintained grassland with 34% densely vegetated buffer zone.

ESTUARY CONDITION AND ISSUES

In relation to the key issues addressed by the broad scale monitoring (i.e. muddiness, eutrophication, and habitat modification), the 2018 broad scale mapping results show that the estuary supported a variety of substrate types, extensive areas of saltmarsh, but no seagrass. It was expressing symptoms of excessive muddiness, and a high level of eutrophication with extensive gross eutrophic zones with soft muds and poor sediment oxygenation high phytoplankton concentrations, but no nuisance macroalgal growths present.

Historically, there has been significant modification and loss of estuary saltmarsh (estimated at ~100ha overall) and the 200m terrestrial buffer is now dominated by a mix of industrial activities, roading and grassland.

The combined results place the estuary in a MODERATE state overall in relation to ecological health, with an ETI score of 0.81, Band D, reflecting a high degree of eutrophic symptoms. The most degraded intertidal conditions were in the relatively sheltered central basin of the estuary.

RECOMMENDED MONITORING

Kaikorai Estuary has been identified by ORC as a priority for monitoring because it is a moderate sized estuary with moderate-high ecological and human use values that is situated in a developed catchment, and therefore vulnerable to excessive sedimentation and eutrophication. Broad scale habitat mapping, in conjunction with fine scale monitoring (including sedimentation rate monitoring), provides valuable information on current estuary condition and trends over time. The following broad scale monitoring recommendations are proposed by Wriggle for consideration by ORC.

To characterise any issues of change in habitat (e.g. saltmarsh area, soft mud extent), it is recommended that broad scale habitat mapping be undertaken at 10 yearly intervals (next scheduled for 2028) unless obvious changes are observed in the interim, that sediment plates to monitor annual sediment accrual be installed at three additional sites in key deposition zones in the estuary, and that macroalgae and phytoplankton be assessed 5 yearly.

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 2005-2008 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 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 the Shag, Waikouaiti, Catlins, Tokomairiro and Kaikorai estuaries.

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. Preliminary broad scale intertidal mapping of Kaikorai Estuary has been undertaken in 2001 (Robertson et al. 2002) and 2007 (Stewart 2008) with a comprehensive survey undertaken in February 2018 (Stevens 2018). This latter monitoring is the subject of this report.
3. **Fine Scale Monitoring (NEMP approach).** Monitoring of physical, chemical and biological indicators (see Table 1). This component, which provides detailed information on sediment condition, was undertaken in a partial form in 2001 (Robertson et al. 2002) and 2007 (Stewart 2008), with the first year of comprehensive baseline monitoring undertaken in Dec. 2017 (Robertson and Robertson 2018).

Report Structure: The current report presents an overview of key estuary issues in NZ and recommended monitoring indicators (Section 1). This is followed by risk indicator ratings (Section 2) and the sampling methods (Section 3) used in this broad scale assessment. Summarised broad scale results of the February 2018 field sampling are then presented and discussed (Section 4) for the following:

Sediment types - particularly muddiness, Sediment oxygenation, Macroalgae and Phytoplankton, Gross Eutrophic Zones (GEZs), Saltmarsh vegetation, and the 200m terrestrial margin surrounding the estuary.

To help the reader interpret the findings, results are related to relevant risk indicator ratings to facilitate the assessment of overall estuary condition (summarised in Section 5), and to guide monitoring recommendations (Section 6).

KAIKORAI ESTUARY

Situated at the mouth of the Kaikorai Stream (mean flow ~0.46 $m^3.s^{-1}$), Kaikorai Estuary drains a 55km^2 catchment containing high producing exotic pastures (43%) and urban areas (21%). The estuary is a 94ha shallow, intertidal dominated (SIDE) estuary (Figure 1) that discharges to the Pacific Ocean via a broad embayment at Waldronville, South Dunedin, Otago. The mouth is nearly always open but experiences occasional closures and often has a constricted tidal mouth. The impact of sand bar formation and periodic mouth closure has led to rapid siltation within the estuary, limiting the tidal input of water such that the estuary can now be categorised as microtidal (tidal range <1m) with fast moving currents confined to the main channels. The estuary is dominated by shallow mudflat habitat which acts as an extremely good trap for both marine and land-sourced sediments, and at low water, almost the entire estuary is less than 70cm deep (Robertson et al. 2002). Large parts of the central estuary are excessively muddy and highly enriched. Because the estuary is fed by relatively small streams, the main channel of the upper estuary is poorly flushed during baseflows. As a consequence, deeper sections can become stratified with a surface layer of lighter, low salinity freshwater flowing over a layer of dense saline water and making the estuary susceptible to phytoplankton blooms (ETI nutrient load susceptibility rating of HIGH).

Ecologically, habitat diversity is moderate and although large areas remain in saltmarsh (42% of estuary), this is dominated by low-lying herbfields. The unvegetated tidal flats have a macrofaunal assemblage dominated by small, short-lived 'opportunistic' species (tolerant to organic enrichment and freshwater) such as chironomids, oligochaetes and amphipods, almost certainly reflecting the fact that the estuary is prone to prolonged periods of lowered salinities at times of mouth constriction. The estuary provides habitat for a large variety of bird species, particularly waterfowl, gulls and waders and including the threatened black billed gull. Most of the natural vegetated margin and extensive areas of saltmarsh have been lost through historical drainage and reclamation for urban and industrial use and grazing. Despite these changes, Kaikorai Estuary is valued for its cultural, spiritual, scientific and aesthetic appeal, and ecological biodiversity.

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 (Black et al. 2013). 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 2007, 2010, 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 of fine sediments 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
Sediment Changes	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 storm-water 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, polychlo-rinated 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 pollut-ants, 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.

Figure 1. Kaikorai Estuary, showing main estuary zones and fine scale monitoring sites.

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, "indicator ratings" have been proposed that assign a condition band (e.g. very good, good, moderate, poor) based on specific indicators of intertidal estuary condition (see Table 2 below). Each condition rating is designed to be used in combination with relevant information and other indicator ratings, and under expert guidance, to assess overall estuarine condition in relation to key issues, and make monitoring and management recommendations. When interpreting indicator results we emphasise:

- The importance of taking into account other relevant information and/or indicator results before making management decisions regarding the presence or significance of any estuary issue e.g. community aspirations, cost/benefit considerations.
- That rating and ranking systems can easily mask or oversimplify results. For instance, significant changes can occur within the same condition band, but small changes near the edge of the band may shift the rating to the next band.
- Most issues will have a mix of primary and supporting indicators, primary indicators being given more weight in assessing the significance of results. It is noted that many supporting estuary indicators will be monitored under other programmes and can be used if primary indicators reflect a significant risk exists, or if risk profiles have changed over time.
- Ratings have been established in many cases using statistical measures based on NZ estuary data and presented in the NZ estuary Trophic Index (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 experience monitoring estuaries throughout NZ. Our hope is that where a high level of risk is identified, the following steps are taken:
    1. Statistical measures be used to refine indicator ratings where information is lacking.
    2. Issues identified as having a high likelihood of causing a significant change in ecological condition (either positive or negative), trigger intensive, targeted investigations to appropriately characterise the extent of the issue.
    3. The outputs stimulate discussion regarding what an acceptable level of risk is, and how it should best be managed.

The indicators and interim risk ratings used for the Kaikorai Estuary broad scale monitoring programme are summarised in Table 2, with supporting notes explaining the use and justifications for each indicator in Appendix 2. The basis underpinning most of the ratings is the observed correlation between an indicator and the presence of degraded estuary conditions from a range of tidal lagoon and tidal river estuaries throughout NZ. Work to refine and document these relationships is ongoing.

Table 2. Summary of estuary condition risk indicator ratings used in broad scale assessments.

RISK INDICATOR RATINGS / ETI BANDS* (indicate risk of adverse ecological impacts)					
BROAD AND FINE SCALE INDICATORS		Very Low - Band A	Low - Band B	Moderate - Band C	High - Band D
Soft mud (% of unvegetated intertidal substrate)		<1%	1-5%	>5-15%	>15%
Sediment Mud Content (% mud)		<5%	5-10%	>10-25%	>25%
Apparent Redox Potential Discontinuity (aRPD)**		Unreliable	Unreliable	0.5-2cm	<0.5cm
Redox Potential (RP mV) upper 3cm***		>+100mV	+100 to -50mV	-50 to -150mV	<-150mV
Sediment Oxygenation (aRPD <0.5cm or RP@3cm <-150mV)*		<0.5ha or <1%	0.5-5ha or 1-5%	6-20ha or >5-10%	>20ha or >10%
Macroalgal Ecological Quality Rating (OMBT)		≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	0.0 - <0.4
Phytoplankton Biomass (chl-a 90th percentile)		<2ug/l	5-10ug/l	>10-16ug/l	>16ug/l
Seagrass (% change from baseline)		<5% decrease	5%-10% decrease	>10-20% decrease	>20% decrease
Gross Eutrophic Zones (ha or % of intertidal area)		<0.5ha or <1%	0.5-5ha or 1-5%	6-20ha or >5-10%	>20ha or >10%
Saltmarsh Extent (% of intertidal area)		>20%	>10-20%	>5-10%	0-5%
Supporting indicator	**Extent** (% remaining from est. natural state)	>80-100%	>60-80%	>40-60%	<40%
Vegetated 200m Terrestrial Margin		>80-100%	>50-80%	>25-50%	<25%
Percent Change from Monitored Baseline		<5%	5-10%	>10-20%	>20%
NZ ETI score*		0-0.25	0.25-0.50	0.50-0.75	0.75-1.0

*NZ ETI (Robertson et al. 2016b), **Hargrave et al. (2008), ***Robertson (PhD in prep.), Keeley et al. (2012). See NOTES in Appendix 2 for further information.

3. METHODS

Broad-scale mapping is a method for describing habitat types based on the dominant surface features present (e.g. substrate: mud, sand, cobble, rock; or vegetation: macrophyte, macroalgae, rushland, etc). It follows the NEMP approach originally described for use in NZ estuaries by Robertson et al. (2002) with a combination of detailed ground-truthing of aerial photography and GIS-based digital mapping from photography to record the primary habitat features present. Appendix 1 lists the definitions used to classify substrate and saltmarsh vegetation. Very simply, the method involves:

- Obtaining aerial photos of the estuary for recording dominant habitat features.
- Carrying out field identification and mapping (i.e. ground-truthing) using laminated aerial photos.
- Digitising ground-truthed features evident on aerial photographs into GIS layers (e.g. ArcMap).

The georeferenced spatial habitat maps provide a robust baseline of key indicators that are used with risk ratings to assess estuary condition in response to common stressors, and assess future change.

Estuary boundaries were set seaward from an imaginary line closing the mouth to the upper extent of saline intrusion (i.e. where ocean derived salts during average annual low flow are <0.5ppt). For the current study, LINZ rectified colour aerial photos (~0.25m/pixel resolution) flown in 2014/15 were sourced from ESRI online, laminated (scale of 1:3,000), and used by experienced scientists who walked the area in February 2018 to ground-truth the spatial extent of dominant vegetation and substrate types. From representative broad scale substrate classes, 6 grain size samples were analysed to validate substrate classifications (Figure 3, Table 5). When present, macroalgae and seagrass patches were mapped to the nearest 5% using a 6 category percent cover rating scale as a guide to describe density (see Figure 2). Notes on sampling, resolution and accuracy are presented in Appendix 3.

If present, macroalgae is further assessed by identifying patches of comparable growth, and enumerating each patch by measuring:

- % cover of opportunistic macroalgae (the spatial extent and density of algal cover providing an early warning of eutrophication issues).
- macroalgal biomass (wet weight) (providing a direct measure of areas of excessive growth).
- extent of algal entrainment in sediment (highlighting where nuisance condition have a high potential for establishing and persisting).
- gross eutrophic zones (highlighting significant sediment degradation by measuring where there is a combined presence of high algal cover or biomass, low sediment oxygenation, and soft muds).

Where macroalgal cover exceeds 5% of the Available Intertidal Habitat (AIH), a modified Opportunistic Macroalgal Blooming Tool (OMBT) is used to rate macroalgal condition. The OMBT, described in detail in WDF-UKTAG (2014), is a 5 part multimetric index that produces an overall Ecological Quality Rating (EQR) ranging from 0 (major disturbance) to 1 (minimally disturbed) and which is placed within overall quality status threshold bands (i.e. bad, poor, good, moderate, high). This integrated index provides a comprehensive measure of the combined influence of macroalgal growth and distribution.

Broad scale habitat features were digitised into ArcMap 10.5 shapefiles using a Wacom Cintiq21UX drawing tablet, and combined with field notes and georeferenced photographs, to produce habitat maps showing the dominant cover of: substrate, macroalgae (e.g. *Ulva, Gracilaria* - when present), seagrass, saltmarsh vegetation, and the 200m wide terrestrial margin vegetation/landuse. These broad scale results are summarised in Section 4, with the supporting GIS files (supplied as a separate electronic output) providing a much more detailed data set designed for easy interrogation to address specific monitoring and management questions.

Figure 2. Visual rating scale for percentage cover estimates of macroalgae (top) and seagrass (bottom).

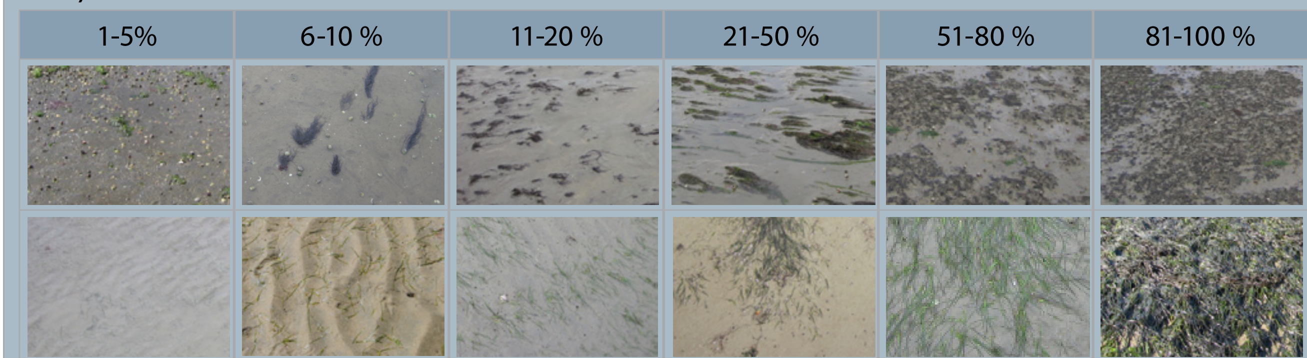


Figure 3. Kaikorai Estuary - mapped estuary extent showing ground-truthing coverage, field photos and location of fine scale sites and grain size samples used to validate substrate classifications.

4. RESULTS AND DISCUSSION

4.1. BROAD SCALE MAPPING SUMMARY

The 2018 broad scale habitat mapping ground-truthed and mapped all intertidal substrate and vegetation including the dominant land cover of the 200m terrestrial margin, with the dominant estuary features summarised in Table 3. The estuary comprises an enclosed tidal estuary dominated by intertidal flats (50%) and saltmarsh (36%) that is located predominantly within sheltered tidal flats in the central and upper estuary. 14% of the estuary remained subtidal at low tide. There was no intertidal seagrass or dense (>50% cover) opportunistic macroalgae. The dominant land cover of the 200m wide terrestrial margin was grassland (44%). 34% remained densely vegetated and 21% was urban. The supporting GIS files underlying this written report provide a detailed spatial record of the key features present throughout the estuary. These are intended as the primary supporting tool to help the Council address a wide suite of estuary issues and management needs, and to act as a baseline to assess future change.

In the following sections, various factors related to each of the key habitats in the estuary (e.g. area of soft mud) are used in conjunction with risk ratings to assess key estuary issues of sedimentation, eutrophication, and habitat modification.

Table 3. Summary of dominant broad scale features, Kaikorai Estuary, 2018.

Dominant Estuary Feature		2018		
		ha	% of intertidal area	% of total estuary area
1.	Intertidal flats (excluding saltmarsh)	47.0	58.2	49.9
2.	Saltmarsh	33.8	41.8	35.9
3.	Subtidal waters	13.4	-	14.2
Total Estuary		**94.2**		**100%**
4.	200m wide densely vegetated Terrestrial Margin (e.g. scrub, shrub, forest)			34%

While broad scale mapping of the estuary was undertaken in 2001 (Robertson et al. 2002) and 2007 (Stewart 2008), only high level comparisons could be made with the current results due to variability in the way features were previously classified, and limitations with the accuracy of the 2001 and 2007 GIS files.

4.2. INTERTIDAL SUBSTRATE

Results (summarised in Table 4 and Figure 4) show intertidal substrate comprised three major sediment types located in distinct parts of the estuary. The lower estuary was dominated by sands, the central estuary by soft and very soft mud, and the central to upper estuary (where most saltmarsh was located) by firm mud. Artificial boulder fields, cobble and gravel habitat was relatively scarce (<1%) and located along the edge of reclaimed estuary margins.

Table 4. Summary of dominant intertidal substrate, Kaikorai Estuary, 2018.

Dominant Substrate	Within Saltmarsh		Intertidal Flats		Total Estuary	
	Ha	%	Ha	%	Ha	%
Boulder field man-made			0.3	0.7	0.3	0.4
Cobble field or Gravel field			0.05	0.1	0.05	0.1
Mobile sand			2.1	4.4	2.1	2.6
Firm sand	0.7	2.0	12.6	26.9	13.3	16.5
Firm muddy sand	4.5	13.3	3.5	7.5	8.0	9.9
Firm sandy mud	0.3	0.7	2.3	4.9	2.5	3.2
Firm mud	28.0	82.9	11.1	23.6	39.1	48.4
Soft mud	0.4	1.1	2.1	4.4	2.4	3.0
Very soft mud			12.9	27.5	12.9	16.0
Grand Total	**33.8**	**100**	**47.0**	**100**	**80.8**	**100**

Tidal exchange in the lower estuary provides good flushing and maintains this part of the estuary in a sandy condition both through the deposition of marine sands and the flushing and export of terrestrial derived muddy sediments from the estuary to the coast. Migration of the river channel as it crosses the coastal delta also contributes to the export of fine muds from the lower estuary by eroding deposited muds. Further upstream, past modification of the estuary has had a major influence on the retention of fine sediment. In particular, the construction of the causeway and bridge on Brighton Road has constrained tidal exchange in the central estuary and created a large settling basin that facilitates the deposition and retention of catchment derived sediment, particularly fine muds. Consequently this area is very muddy and in relatively poor condition (see following section). In the upper estuary, extensive reclamation, diversion of the flow channel, and drainage of wetlands and saltmarsh has resulted in a large reduction in estuary area estimated at ~100ha. The loss of saltmarsh, particularly rushland which is a very effective sediment trap, has greatly reduced the estuary's capacity to assimilate sediment inputs, while channelisation and drainage has reduced the areas previously regularly inundated by tidal flows leaving the sediments relatively dry and firm. In the absence of seawater flows to these areas, previously intertidal saltmarsh areas have become terrestrial.

4.3. EXTENT OF SOFT MUD

Where soil erosion from catchment disturbance exceeds the assimilative capacity of an estuary, adverse estuary impacts are expected from increased muddiness and turbidity, shallowing, increased nutrients, increased organic matter degradation by anoxic processes (e.g. sulphide production), increased contaminant concentrations (where fine muds provide a sink for catchment contaminants like heavy metals), and alterations to saltmarsh, seagrass, fish and invertebrate communities. In particular, multiple studies have shown estuarine macroinvertebrate communities to be adversely affected by mud accumulation, both through direct and indirect mechanisms including: declining sediment oxygenation, smothering, and compromisation of feeding habits (e.g. see Mannino and Montagna 1997; Rakocinski et al. 1997; Peeters et al. 2000; Norkko et al. 2002; Ellis et al. 2002; Thrush et al. 2003; Lohrer et al. 2004; Sakamaki and Nishimura 2009; Wehkamp and Fischer 2012; Robertson 2013).

Because of such consequences, three key measures are commonly used to assess soft mud:

i. **Horizontal extent** (area of soft mud) - broad scale indicator (see rating in Table 2).

ii. **Vertical buildup** (sedimentation rate) - fine scale assessment using sediment plates (or retrospectively through historical coring). Ratings are currently under development as part of national ANZECC guidelines.

iii. **Sediment mud content** - fine scale indicator - recommended guideline is no increase from established baseline.

The area (horizontal extent) of intertidal soft mud outside of saltmarsh areas is the primary sediment indicator used in the current broad scale report, with sediment mud content ("muddiness") a supporting indicator. Sediment plates have been established at three fine scale sites (see Robertson and Robertson 2018 for details) to monitor sediment accrual. The plates are primarily to help understand potential changes in the biological community at these sites, with only site B within the primary deposition zone of the estuary.

Figure 4 and Table 4 show that of the intertidal area not supporting saltmarsh, soft or very soft muds covered 15ha (32%), and firm muds covered 11.ha (24%), a risk rating of HIGH. The mud content measured in representative areas of firm and soft mud was 17-26% and 54-65% in very soft muds, supporting risk indicator ratings of MODERATE to HIGH respectively (Table 5).

Soft muds were concentrated in the central estuary where mud settlement is facilitated by the Brighton Road causeway and, to a lesser extent, salinity driven flocculation. Within the dominant sandy substrate of the estuary, grain size reflected a LOW risk rating (1-14% mud content).

The 2018 soft mud extent (15ha soft muds and 11.1ha firm muds) was significantly more than the 6.3ha reported in 2001 (Robertson et al. 2002), and comparable to the 39.5ha reported in 2007 (Stewart 2008), considering that the latter figure includes mud from subtidal areas. The results indicate that there was a significant increase in soft muds in the estuary between 1999 and 2007, and the data indicate that there has been little change from 2007 to 2018.

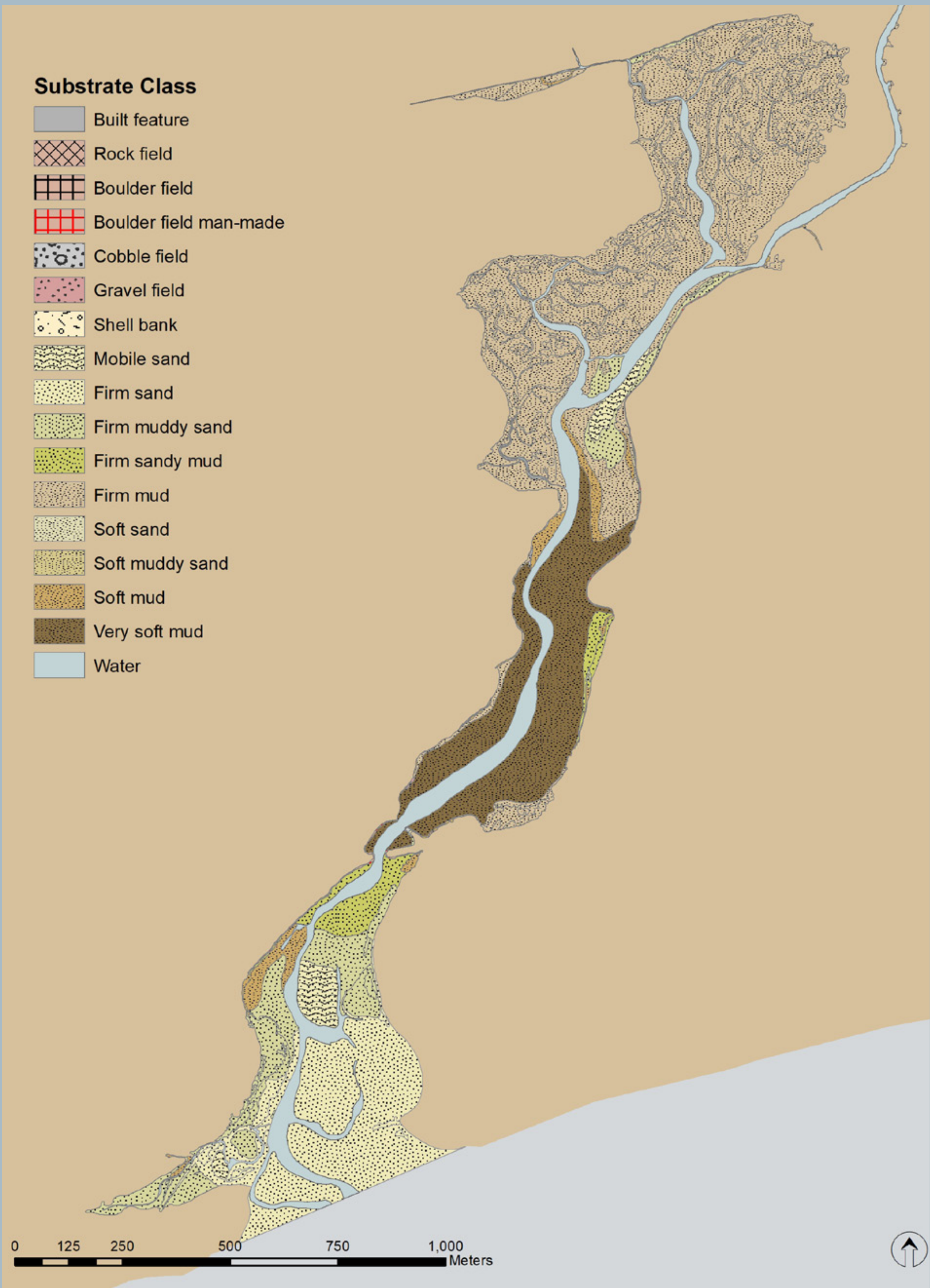


Figure 4. Map of dominant intertidal substrate types - Kaikorai Estuary, Feb. 2018.

Table 5. Grain size and RPD results from representative sediments, Kaikorai Estuary, 2018.

Broad Scale Classification	Site #	% mud	% sand	% gravel	aRPD cm	RP@3cm	NZTM East	NZTM North
Firm Sand	1	1	99	0	>5	27	1397440	4910154
Firm Muddy Sand	6	3	97	0	>5	-32	1398526	4912280
	FS A*	14	85	0	na	-63	1397488	4910644
Firm Sandy Mud	5	17	81	2	3	-137	1398285	4911701
	2	21	79	0	0.5	-128	1397771	4910882
Soft Mud	FS C*	27	71	2	na	-324	1398175	4911903
Very Soft Mud	4	54	46	0	0.5	-131	1398216	4911648
	3	61	39	0	0.5	-315	1397837	4910971
	FS B*	65	35	0	na	-373	1397985	4911045

See Figure 3 for site locations. *Data sourced from Robertson and Robertson (2018) FS=Fine Scale, na=not assessed.

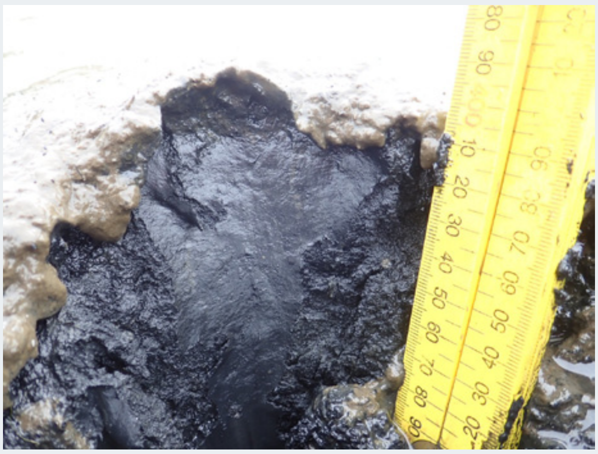
4.4. SEDIMENT OXYGENATION

The primary indicators used to assess sediment oxygenation are apparent Redox Potential Discontinuity (aRPD) depth and Redox Potential (RPmV) measured at 3cm. These indicators were measured at representative sites throughout the dominant sand and mud substrate types. From these measurements, broad boundaries have been drawn of estuary zones where sediment oxygen is depleted to the extent that adverse impacts to macrofauna (sediment and surface dwelling animals) are expected (Figure 5). Because macrofauna are used as an indicator of ecological impacts to other taxa, it is expected that these zones will also be exerting adverse impacts on associated higher trophic communities including birds and fish.

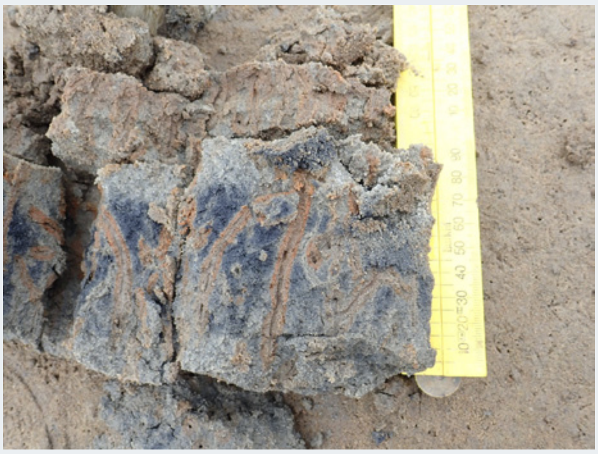
These results show that there is a large part (17.2ha 21%) of the total intertidal area identified as having depleted sediment oxygen, a NZ ETI risk rating of HIGH. This was largely confined to soft and very soft muds located in the upper tidal range of the main settlement basin in the central estuary. Sediments in this area had a high level of organic enrichment and exhibited strong hydrogen sulphide (rotten egg) odours indicating anaerobic degradation was occurring.

Elsewhere the majority of the estuary sediments are well to moderately well oxygenated and appeared in good (healthy) ecological condition, with the aRPD depth at 2-5cm and the RP above -150mV at 3cm in most sand dominated sediments in the lower estuary and among saltmarsh where oxygen exchange through plant roots contributed to good but variable sediment oxygenation.

Sediment oxygenation was not recorded outside of fine scale sites in 2001 or 2007 so the broad scale patterns of sediment oxygenation cannot be determined from these earlier studies.



Very thin layer of oxygenated sediment overlying highly anoxic muds in the central estuary.



Well oxygenated sands in the lower estuary. Note the worm tubes facilitating oxygen penetration deep into sediments.

4.5. OPPORTUNISTIC MACROALGAE

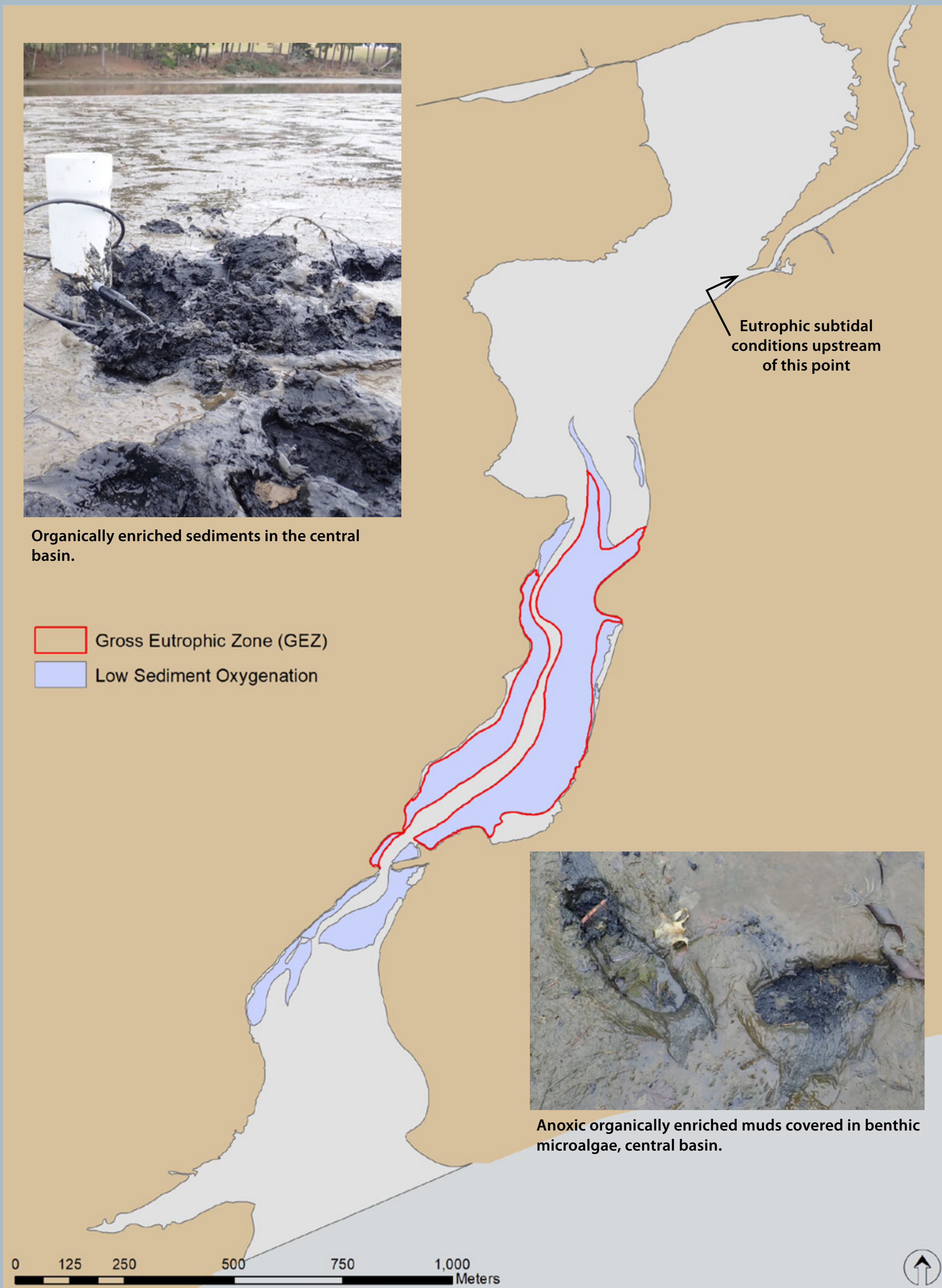
Opportunistic macroalgae are a primary symptom of estuary eutrophication. They are highly effective at utilising excess nitrogen enabling them to out-compete other seaweed species and, at nuisance levels, can form mats on the estuary surface which adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and saltmarsh. Macroalgae that becomes detached can also accumulate and decay in subtidal areas and on shorelines causing oxygen depletion and nuisance odours and conditions. The greater the density, persistence, and extent of macroalgal entrainment within sediments, the greater the subsequent impacts.

The Opportunistic Macroalgal Blooming Tool (OMBT) rates estuaries from 0 (reflecting major disturbance) to 1 (pristine condition). Because Kaikorai Estuary supported <5% opportunistic macroalgal cover within the Available Intertidal Habitat (AIH), the OMBT requires no further enumeration of macroalgal cover. The density and overall quality status is scored as HIGH and it has been given an Ecological Quality Rating (EQR) score of 0.9, a risk rating of LOW - Section 2, Table 2. However, Robertson and Robertson (2018) reports a 60-70% cover of intertidal macroalgae (*Ulva*) from fine scale Site C in Dec. 2017, although the extent throughout the estuary is not reported. Stewart (2008) recorded 5ha of microalgal growth in the middle estuary in 2007. The absence of macroalgal growth in mid-Feb. 2018 may reflect recent flood scouring of the estuary following an intense rainfall event on 1 Feb 2018 that caused the Kaikorai Stream to flood (>70mm rainfall in 24 hours resulting in state of emergency being declared). The available data indicate seasonal blooms of macroalgae in the estuary are likely. Also the absence of macroalgae at the time of the current survey does not mean the estuary is not expressing eutrophication symptoms.

Because the mouth of the estuary is at times constricted and there are deeper parts of the upper estuary known to stratify, phytoplankton blooms are likely to be an issue in subtidal parts of the estuary if catchment nutrients and sediments accumulate and do not get flushed out to sea. This component is more thoroughly addressed in the fine scale report (Robertson and Robertson 2018). Synoptic sampling undertaken to support the broad scale mapping on 16 February 2018 recorded chl-a concentrations throughout the estuary surface water of 5-7mg/m^3 (an ETI rating of Band B - Moderate), with chl-a concentrations increasing significantly with depth in the upper estuary e.g. 0.5m deep: 10-12mg/m^3 (ETI Band C - High) and >1m deep: 20-30mg/m^3 (ETI Band D - Very High). These deeper waters were stratified with buoyant fresh water trapping eutrophic high salinity waters on the bottom of the estuary. This stratification was present despite the very significant rainfall event on 1 Feb 2018 (see above). These high chl-a concentrations, while a 1 day snapshot shortly after a significant flood event, show that deeper parts of the subtidal estuary are adversely impacted by elevated phytoplankton growth and that phytoplankton can very quickly reach problem densities despite recent flushing. Under prolonged low flow summer conditions, these conditions will get progressively worse and can be expected to have a significant adverse effect on the biological health of the estuary. Current nutrient and sediment loadings to the estuary in relation to both natural state/reference conditions and recommended guidelines will be assessed in detail in Robertson and Robertson (2018).

4.6. GROSS EUTROPHIC ZONES (GEZ)

Gross eutrophic conditions occur when sediments exhibit combined symptoms of a high mud content, a shallow apparent Redox Potential Discontinuity (aRPD) depth, elevated nutrient and total organic carbon concentrations, displacement of invertebrates sensitive to organic enrichment, and high algal growth. Persistent and extensive areas of gross nuisance conditions should not be present in short residence time estuaries, and their presence provides a clear signal that the assimilative capacity of the estuary is being exceeded. Results show that a large part (12.8ha, 16%) of the total intertidal area in Kaikorai Estuary exhibited gross eutrophic conditions, a NZ ETI risk rating of HIGH. These conditions were most extensive in the central estuary immediately upstream of the Brighton Road bridge. The constricted water exchange through the relatively narrow bridge has created a large area where organic matter and fine sediment has accumulated on the tidal flats. This has resulted in very poor sediment conditions supporting extensive microalgal growth. Further, there is strong evidence that much of the subtidal area in the confined upper estuary Kaikorai Stream channel is eutrophic and degraded with high organic enrichment, poor sediment condition and low clarity.



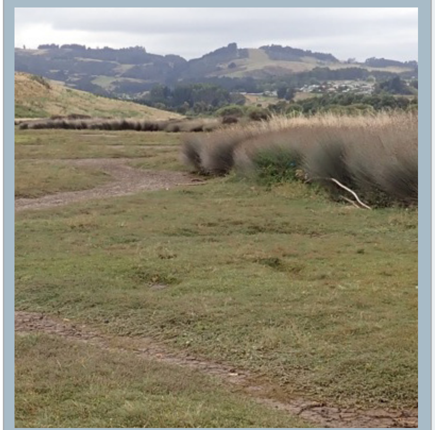
Organically enriched sediments in the central basin.

Anoxic organically enriched muds covered in benthic microalgae, central basin.

Figure 5. Map of Gross Eutrophic Zones and areas with low sediment oxygenation - Kaikorai Estuary, Feb. 2018.

4.7. SALTMARSH

Old fence line running though herbfield in the upper estuary.



Transition from estuarine herbfield to jointed wire rush to terrestrial tall fescue in the upper estuary.

Saltmarsh (vegetation able to tolerate saline conditions where terrestrial plants are unable to survive) is important as it is highly productive, naturally filters and assimilates sediment and nutrients, acts as a buffer that protects against introduced grasses and weeds, and provides an important habitat for a variety of species including fish and birds. Saltmarsh generally has the most dense cover in the sheltered and more strongly freshwater influenced upper estuary, and relatively sparse cover in the lower more exposed and saltwater dominated parts of the estuary. The lower extent of saltmarsh growth is limited for most species to above the height of mean high water neap (MHWN).

The primary measure to assess saltmarsh condition is the percent cover of the intertidal area. Table 6 and Figure 6 summarise the 2018 results and show saltmarsh was present across 33.8ha (42%) of the intertidal estuary area, a risk indicator rating of VERY LOW. Saltmarsh was dominated by herbfields (85%) which were located in extensive beds in the upper estuary. Primrose was the dominant cover, commonly mixed with remuremu, glasswort, bachelor's button and shore leptinella. Introduced weeds and grasses were common in the upper tidal range, particularly where drainage channels have been modified, but generally did not encroach into the herbfields significantly. There were small areas dominated by rushland (jointed wirerush - 2.4ha, 7%), predominantly in pockets near the terrestrial fringe in the upper estuary, as well as in the upper reaches of the sheltered arm near the estuary entrance (Figure 6). Elsewhere channelling of the main river, or steep edges to reclaimed or drained estuary margins, restricted saltmarsh to a relatively narrow strip along the upper tidal reaches.

A supporting measure also applied is saltmarsh loss compared to estimated natural state cover. While the historical extent of the estuary has not been mapped as part of the current work, it is evident that extensive areas in the upper estuary have been historically drained and converted to pasture or reclaimed. It is estimated that ~100ha of saltmarsh has been lost from the estuary, a supporting risk rating of HIGH.

The combined overall risk rating has been assessed as LOW recognising that while historical losses have been significant, saltmarsh, particularly herbfields, remain a significant feature of the estuary and further reclamation and drainage is unlikely.

Sedgeland and herbfield in the lower estuary looking toward the entrance.

Herbfield and saltmarsh ribbonwood along the Brighton Road margin.

Jointed wire rush.

Herbfield adjacent to rushland in the lower estuary.

Table 6. Summary of dominant saltmarsh cover, Kaikorai Estuary, 2018.

Saltmarsh Class, Dominant and subdominant species	Ha	%
Estuarine Shrub	0.4	1.3
Plagianthus divaricatus (Saltmarsh ribbonwood)		
Apodasmia similis (Jointed wirerush)		
Festuca arundinacea (Tall fescue)	0.3	
Festuca arundinacea (Tall fescue)		
Apodasmia similis (Jointed wirerush)	0.2	
Grassland	0.6	1.7
Festuca arundinacea (Tall fescue)	0.4	
Apodasmia similis (Jointed wirerush)		
Ficinia (Isolepis) nodosa (Knobby clubrush)	0.2	
Duneland	0.4	1.2
Ammophila arenaria (Marram grass)	0.1	
Festuca arundinacea (Tall fescue)	0.3	
Sedgeland	1.4	4.1
Schoenoplectus pungens (Three-square)	0.7	
Selliera radicans (Remuremu)		
Samolus repens (Primrose)	0.7	
Rushland	2.4	7.0
Apodasmia similis (Jointed wirerush)	1.1	
Festuca arundinacea (Tall fescue)		
Ficinia (Isolepis) nodosa (Knobby clubrush)	0.03	
Plagianthus divaricatus (Saltmarsh ribbonwood)	0.03	
Festuca arundinacea (Tall fescue)	0.5	
Phormium tenax (New Zealand flax)	0.7	
Samolus repens (Primrose)		
Selliera radicans (Remuremu)	0.04	
Schoenoplectus pungens (Three-square)	0.03	
Herbfield	28.6	84.7
Leptinella dioica (Shore Leptinella)		
Selliera radicans (Remuremu)		
Samolus repens (Primrose)	0.1	
Samolus repens (Primrose)	0.1	
Selliera radicans (Remuremu)	0.01	
Cotula coronopifolia (Bachelor's button)	0.3	
Festuca arundinacea (Tall fescue)	0.1	
Leptinella dioica (Shore Leptinella)	0.3	
Sarcocornia quinqueflora (Glasswort)	1.2	
Sarcocornia quinqueflora (Glasswort)		
Selliera radicans (Remuremu)		
Samolus repens (Primrose)	0.7	
Selliera radicans (Remuremu)		
Isolepis cernua (Slender clubrush)		
Cotula coronopifolia (Bachelor's button)	0.03	
Samolus repens (Primrose)	0.2	
Apodasmia similis (Jointed wirerush)	0.3	
Isolepis cernua (Slender clubrush)	0.0	
Leptinella dioica (Shore Leptinella)	24.7	
Sarcocornia quinqueflora (Glasswort)	0.1	
Schoenoplectus pungens (Three-square)	0.3	
Grand Total	**33.8**	100

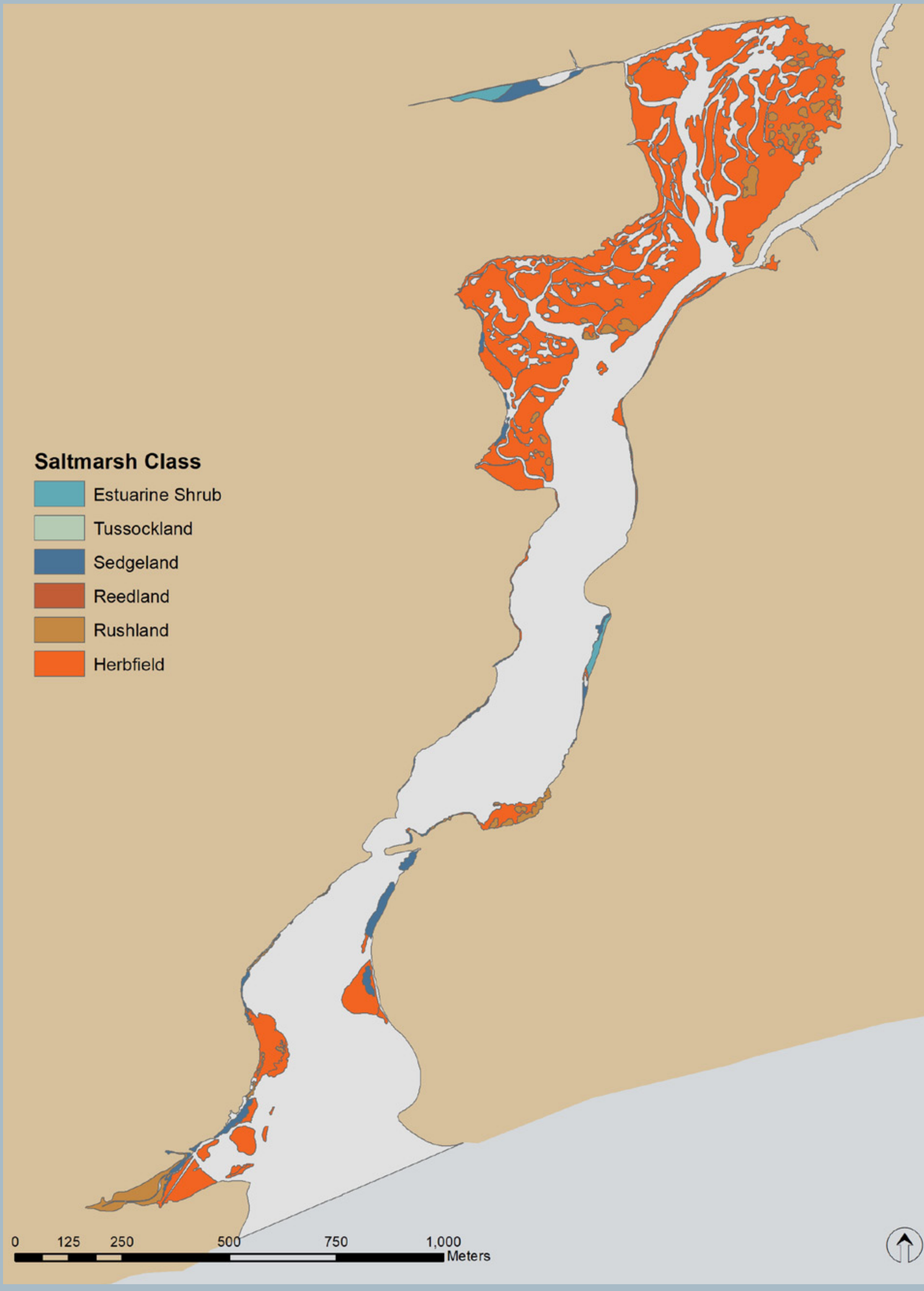
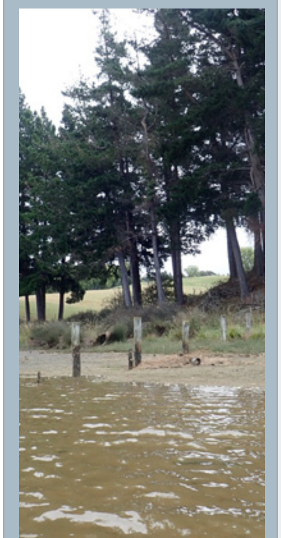


Figure 6. Map of dominant saltmarsh cover - Kaikorai Estuary, Feb. 2018.

4.8. 200m TERRESTRIAL MARGIN

Narrow strip of tall fescue and saltmarsh ribbonwood along the reclaimed margin of the central estuary.



Narrow strip of pine trees in front of pasture in the central estuary.

Like saltmarsh, a densely vegetated terrestrial margin filters and assimilates sediment and nutrients, acts as an important buffer that protects against introduced grasses and weeds, is an important habitat for a variety of species, provides shade to help moderate stream temperature fluctuations, and improves estuary biodiversity. The results of the 200m terrestrial margin mapping of the estuary (Table 7 and Figure 7) showed:

- 34% was densely vegetated, a risk indicator rating of MODERATE.
- 44% was pasture or unmaintained grassland, including amenity areas.
- 22% had been developed (residential, industrial, road).

At a catchment-wide scale, a similar pattern is evident with 48% of the catchment in high producing grassland, 21% urban, 10% native scrub/forest and 8% exotic forest. Only 0.1% of the catchment is freshwater wetland (Figure 8).

The 200m terrestrial margin estuary margin has been significantly modified historically, primarily through extensive reclamation and drainage for conversion to pasture, channelisation and armouring for flood control, industrial purposes including sewage treatment works and two landfills, Island Park golf course and residential development. Consequently there are now extensive physical barriers preventing the natural expansion of saltmarsh in response to sea level rise. However, there are extensive areas of rushland and grassland along the tidal margins of the upper estuary. Before being drained, this was previously estuarine habitat but despite now being terrestrial, it retains important wildlife values by providing a buffer against localised sediment and nutrient inputs, and offering potential areas where improved natural ecological connectivity between the estuary and surrounding natural habitats could be developed.

Table 7. Summary of 200m terrestrial margin land cover, Kaikorai Estuary, 2018.

Class	Dominant features	Percentage
Forest	Mixed native and exotic trees including forestry, windbreaks and amenity plantings. Scrub vegetation dominated by *Ulex europaeus* (Gorse), *Pteridium esculentum* (Bracken fern) and *Cytisus scoparius* (Broom).	5.5
Scrub/Forest		5.5
Scrub		9.6
Grassland	Pasture, un-maintained grassland and recreational/amenity areas.	43.8
Duneland	Small area of *Ammophila arenaria* (Marram grass) at the coast.	5.5
Rushland	Predominantly in the upper estuary adjacent to Kaikorai Stream.	8.0
Industrial	Green Island landfill and waste water treatment plant.	14.4
Residential	Waldronville, Green Island.	4.2
Artificial substrate	Primarily roading and small areas of rock wall around reclamations.	2.9
Water	Ponds and river.	0.5
Total		**100**

Channelised upper estuary with terrestrial grasses growing to the water edge.

Reclaimed estuary margin planted in pine trees.

Figure 7. Map of 200m Terrestrial Margin - Dominant Land Cover, Kaikorai Estuary, Feb. 2018.

LCDB4 (2012)	%	LCDB4 (2012)	%
Broadleaved Indigenous Hardwoods	4.1	Low Producing Grassland	0.5
Built-up Area (settlement)	20.4	Manuka and/or Kanuka	4.4
Deciduous Hardwoods	0.4	Mixed Exotic Shrubland	1.2
Exotic Forest	6.8	Sand or Gravel	0.1
Flaxland	0.0	Surface Mine or Dump	1.1
Forest - Harvested	1.6	Transport Infrastructure	0.4
Gorse and/or Broom	5.8	Urban Parkland/Open Space	2.3
Herbaceous Freshwater Vegetation	0.1		
Herbaceous Saline Vegetation	1.2		
High Producing Exotic Grassland	48.3		
Indigenous Forest	1.0		
Lake or Pond	0.3		

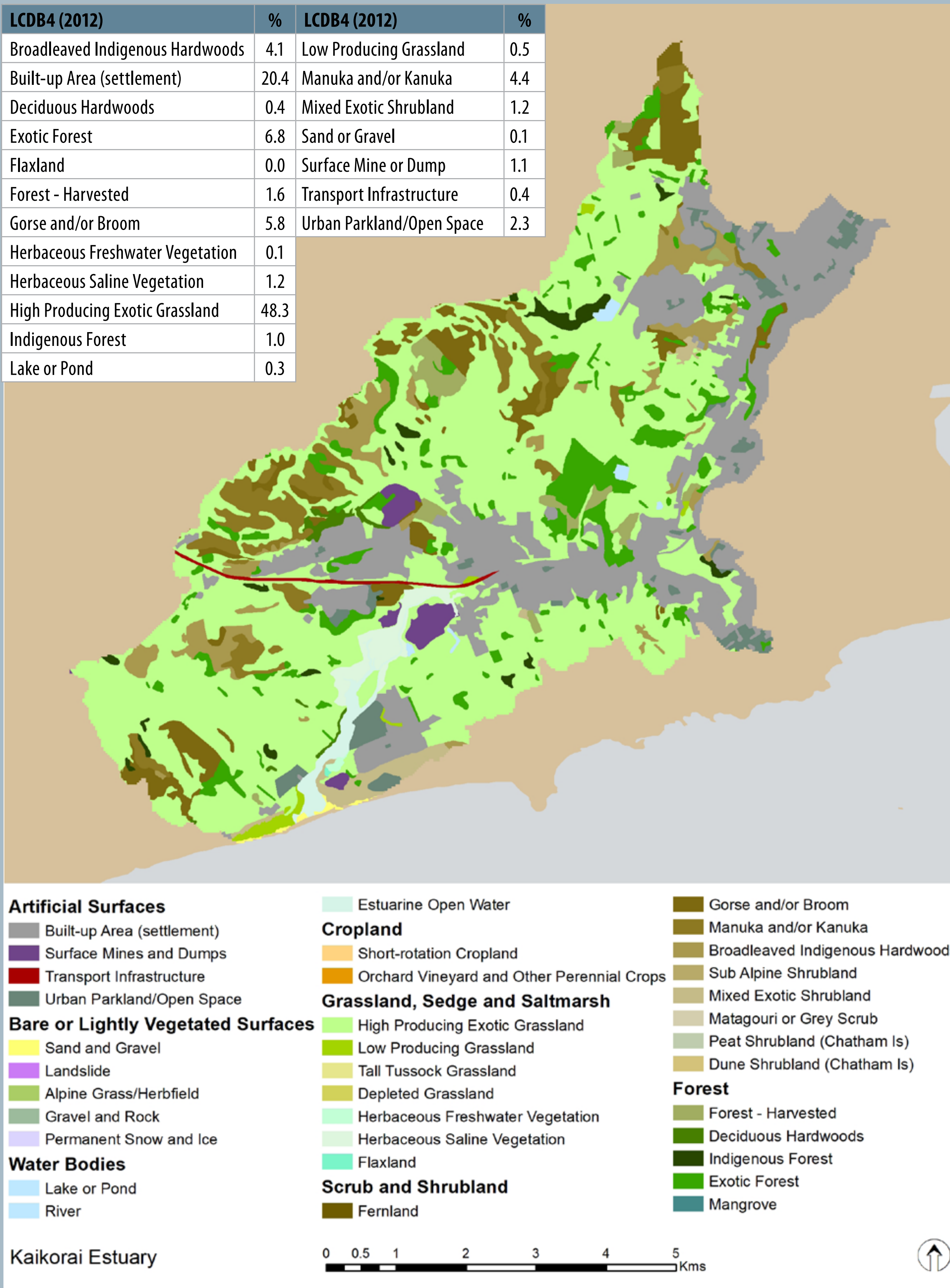


Figure 8. Summary of Catchment Land Cover (LCDB4 2012), Kaikorai Estuary.

5. SUMMARY

Broad scale habitat mapping undertaken in February 2018, combined with ecological indicator ratings in relation to the key estuary stressors (i.e. muddiness, eutrophication and habitat modification) have been used to assess overall estuary condition.

Muddiness

Soft or very soft muds covered 15ha (31.9%) of the intertidal area, a risk indicator rating of HIGH. Soft muds were concentrated in the central estuary where mud settlement is facilitated by the presence of the Brighton Road causeway and, to a lesser extent, salinity driven flocculation. 27.5% of the estuary had a mud content measured in representative areas of 54-62%, an ETI rating of HIGH. To inform the broad scale report recommendations, the current state/natural state sediment load (CSSL/NSSL) ratio and the mean annual rate of sediment deposition have been estimated. The CSSL/NSSL ratio is estimated as >6, an ETI rating of HIGH, and the mean annual rate of sediment deposition as 1.0mm/yr (assuming 80% of estimated sediment load retained in estuary, sediment density of 1.2, and all sediment is deposited on mud dominated intertidal substrate and subtidal habitat within the estuary), a rating of LOW. See Robertson and Robertson (2018) for detail on the data sources, methods and calculations used to derive these parameters.

Within the dominant sandy substrate of the lower and central estuary, grain size reflected a LOW risk rating (1-8% mud content). Associated with the presence of muds, 17ha (21%) of the intertidal area (including saltmarsh) had sediment oxygenation depleted to a level where adverse impacts to macrofauna (sediment and surface dwelling animals) are expected, an ETI rating of HIGH.

Eutrophication

Key broad scale indicators used to assess eutrophic expression in the estuary are primary productivity through macroalgal growth and phytoplankton (fuelled by nutrient inputs to the estuary), and supporting indicators of sediment muddiness, oxygenation, and the presence of gross eutrophic zones (a combined presence of dense algal growth, muds and poor sediment oxygenation). Fine scale indicators, reported in Robertson and Robertson (2018) include sediment organic content, nutrients, macroinvertebrates, and mud content.

The Opportunistic Macroalgal Blooming Tool EQR score was 0.9, a risk rating of LOW although this may reflect macroalgal being scouring from the estuary during a flood 2 weeks prior to sampling. High chl-a concentrations indicate that both the water column, and particularly deeper parts of the subtidal upper estuary, are adversely impacted by elevated phytoplankton growth which can very quickly reach problem levels. In addition, a large part (12.8ha 16%) of the total intertidal area exhibited gross eutrophic conditions, a risk indicator rating of HIGH. The total nitrogen (TN) areal load, not including point source discharges from the catchment, is estimated as ~80mgTN/m^2/d, which is getting close to the 100mgTN/m^2/d threshold where eutrophic symptoms commonly occur in open SIDE estuaries in NZ (Robertson et al. 2016a). Because point source nutrient inputs are not included in the above, and because the mouth of Kaikorai Estuary is often constricted and is therefore more sensitive to nutrient inputs than open SIDEs, the estuary is likely to be above the threshold where eutrophication problems are expected to occur for much of the time.

The above results highlight that a significant part of the estuary is currently eutrophic, that nutrient inputs to the estuary are sufficient to fuel nuisance algal growths, and that at times of prolonged low flows or mouth constriction parts of the estuary will quickly shift to a more degraded state.

The expected nutrient and sediment loads that relate to specific states of ecological condition, and the susceptibility of Kaikorai Estuary under various nutrient and fine sediment loads (reflecting good, moderate and poor condition) are to be described in detail in Robertson and Robertson (2018) with the results used to provide guidance on what changes to sediment and nutrient loads would be required to shift the estuary towards a different ecological state (e.g. to improve its condition).

Habitat modification

Despite significant historical saltmarsh losses (estimated at ~100ha in total), extensive herbfield-and rushland remained in the estuary (33ha, 42% of the intertidal area). The presence of such a large area of saltmarsh is very positive, a risk indicator of VERY LOW. The 200m terrestrial margin had been highly modified although 34% supported a densely vegetated buffer of rushland, scrub and forest, with 44% in pasture or grassland and 22% developed (residential/road), a risk indicator of HIGH. The estuary supported no high value intertidal seagrass beds.

5. SUMMARY (CONTINUED)

Comparison with previous results

It is difficult to compare the current results directly with the preliminary assessments undertaken in 2001 and 2007 due to variability in the features included and accuracy of the mapping. However there appears to have been a significant increase in soft muds in the estuary between 2001 and 2007, with little change from 2007 to 2018. There appears to have been no significant change in the extent of herbfield dominated saltmarsh since 2001, a very positive sign. Future monitoring will determine if these results reflect ongoing trends in broad scale estuary features.

6. CONCLUSION

The combined results place the estuary in a MODERATE state overall in relation to broad scale ecological features. Extensive areas of saltmarsh remain in good condition but there are sediment muddiness issues evident in the relatively sheltered central basin, and eutrophication issues apparent through the presence of large areas of enriched and oxygen depleted sediments and high phytoplankton concentrations in the upper estuary.

The NZ Estuary Trophic Index (ETI) score has been calculated using available broad scale and fine scale indicators (details summarised in Appendix 5). The ETI score for Kaikorai Estuary was 0.81, Band D, reflecting a high degree of eutrophic symptoms.

7. MONITORING RECOMMENDATIONS

Kaikorai Estuary is a moderate sized estuary situated in a developed catchment with moderate-high ecological and human use values. It is vulnerable to excessive sedimentation and eutrophication and has been identified as a priority for monitoring within ORC's coastal monitoring programme. The present report addresses the broad scale component of the long term programme. The recommendation for ongoing broad scale monitoring is as follows:

Broad Scale Habitat Mapping

To characterise any issues of change in habitat (e.g. saltmarsh area, soft mud extent, GEZ's, sediment oxygen depletion), it is recommended that broad scale habitat mapping be undertaken at 10 yearly intervals (next scheduled for 2028) unless obvious changes are observed in the interim.

Although predicted sedimentation rates are not excessive, the extensive areas of soft mud in the estuary highlight sediment issues are widespread in the middle estuary. In order to monitor the long term effectiveness of catchment management initiatives and potential changes in the estuary, it is recommended that sediment plates be established at three additional sites in the key middle estuary deposition zone to monitor annual sediment accrual.

Because the estuary is expressing strong symptoms of eutrophication and is close to the nutrient threshold where eutrophic symptoms commonly occur, it is recommended that broad scale assessment of macroalgae and phytoplankton be undertaken 5 yearly. In addition, it is recommended that the dominant sources of nutrients to the estuary be defined and assessed regarding whether it is possible to mitigate inputs to a level the estuary can better assimilate.

There is also much to be gained from simple initiatives to improve the quality and amenity of the estuary through enhancing public access, encouraging the re-establishment of native saltmarsh and terrestrial margin vegetation, and limiting the input of litter to the estuary.

8. ACKNOWLEDGEMENTS

This survey and report has been undertaken with the support and assistance of Rachel Ozanne (Coastal Scientist, ORC). Her review of this report was much appreciated. The review of this report by John Zeldis (NIWA) was also much appreciated. I am also very grateful to Sally O'Neill for help with the field sampling and reporting.

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APPENDIX 1. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS.

Vegetation was classified using an interpretation of the Atkinson (1985) system, whereby dominant plant species were coded by using the two first letters of their Latin genus and species names e.g. marram grass, *Ammophila arenaria*, was coded as Amar. An indication of dominance is provided by the use of ( ) to distinguish subdominant species e.g. Amar(Caed) indicates that marram grass was dominant over ice plant (*Carpobrotus edulis*). The use of ( ) is not always based on percentage cover, but the subjective observation of which vegetation is the dominant or subdominant species within the patch. A measure of vegetation height can be derived from its structural class (e.g. rushland, scrub, forest).

Forest: Woody vegetation in which the cover of trees and shrubs in the canopy is >80% and in which tree cover exceeds that of shrubs. Trees are woody plants ≥10 cm diameter at breast height (dbh). Tree ferns ≥10cm dbh are treated as trees. Commonly sub-grouped into native, exotic or mixed forest.

Treeland: Cover of trees in the canopy is 20-80%. Trees are woody plants >10cm dbh. Commonly sub-grouped into native, exotic or mixed treeland.

Scrub: Cover of shrubs and trees in the canopy is >80% and in which shrub cover exceeds that of trees (c.f. FOREST). Shrubs are woody plants <10 cm dbh. Commonly sub-grouped into native, exotic or mixed scrub.

Shrubland: Cover of shrubs in the canopy is 20-80%. Shrubs are woody plants <10 cm dbh. Commonly sub-grouped into native, exotic or mixed shrubland.

Tussockland: Vegetation in which the cover of tussock in the canopy is 20-100% and in which the tussock cover exceeds that of any other growth form or bare ground. Tussock includes all grasses, sedges, rushes, and other herbaceous plants with linear leaves (or linear non-woody stems) that are densely clumped and >100 cm height. Examples of the growth form occur in all species of *Cortaderia, Gahnia,* and *Phormium*, and in some species of *Chionochloa, Poa, Festuca, Rytidosperma, Cyperus, Carex, Uncinia, Juncus, Astelia, Aciphylla,* and *Celmisia*.

Duneland: Vegetated sand dunes in which the cover of vegetation in the canopy (commonly Spinifex, Pingao or Marram grass) is 20-100% and in which the vegetation cover exceeds that of any other growth form or bare ground.

Grassland: Vegetation in which the cover of grass (excluding tussock-grasses) in the canopy is 20-100%, and in which the grass cover exceeds that of any other growth form or bare ground.

Sedgeland: Vegetation in which the cover of sedges (excluding tussock-sedges and reed-forming sedges) in the canopy is 20-100% and in which the sedge cover exceeds that of any other growth form or bare ground. "Sedges have edges." Sedges vary from grass by feeling the stem. If the stem is flat or rounded, it's probably a grass or a reed, if the stem is clearly triangular, it's a sedge. Sedges include many species of *Carex, Uncinia,* and *Scirpus*.

Rushland: Vegetation in which the cover of rushes (excluding tussock-rushes) in the canopy is 20-100% and where rush cover exceeds that of any other growth form or bare ground. A tall grasslike, often hollow-stemmed plant, included in rushland are some species of *Juncus* and all species of *Leptocarpus*.

Reedland: Vegetation in which the cover of reeds in the canopy is 20-100% and in which the reed cover exceeds that of any other growth form or open water. Reeds are herbaceous plants growing in standing or slowly-running water that have tall, slender, erect, unbranched leaves or culms that are either round and hollow – somewhat like a soda straw, or have a very spongy pith. Unlike grasses or sedges, reed flowers will each bear six tiny petal-like structures. Examples include *Typha, Bolboschoenus, Scirpus lacutris, Eleocharis sphacelata,* and *Baumea articulata*.

Cushionfield: Vegetation in which the cover of cushion plants in the canopy is 20-100% and in which the cushion-plant cover exceeds that of any other growth form or bare ground. Cushion plants include herbaceous, semi-woody and woody plants with short densely packed branches and closely spaced leaves that together form dense hemispherical cushions.

Herbfield: Vegetation in which the cover of herbs in the canopy is 20-100% and where herb cover exceeds that of any other growth form or bare ground. Herbs include all herbaceous and low-growing semi-woody plants that are not separated as ferns, tussocks, grasses, sedges, rushes, reeds, cushion plants, mosses or lichens.

Lichenfield: Vegetation in which the cover of lichens in the canopy is 20-100% and where lichen cover exceeds that of any other growth form or bare ground.

Introduced weeds: Vegetation in which the cover of introduced weeds in the canopy is 20-100% and in which the weed cover exceeds that of any other growth form or bare ground.

Seagrass meadows: Seagrasses are the sole marine representatives of the Angiospermae. They all belong to the order Helobiae, in two families: Potamogetonaceae and Hydrocharitaceae. Although they may occasionally be exposed to the air, they are predominantly submerged, and their flowers are usually pollinated underwater. A notable feature of all seagrass plants is the extensive underground root/rhizome system which anchors them to their substrate. Seagrasses are commonly found in shallow coastal marine locations, salt-marshes and estuaries and is mapped separately to the substrates they overlie.

Macroalgal bed: Algae are relatively simple plants that live in freshwater or saltwater environments. In the marine environment, they are often called seaweeds. Although they contain cholorophyll, they differ from many other plants by their lack of vascular tissues (roots, stems, and leaves). Many familiar algae fall into three major divisions: Chlorophyta (green algae), Rhodophyta (red algae), and Phaeophyta (brown algae). Macroalgae are algae observable without using a microscope. Macroalgal density, biomass and entrainment are classified and mapped separately to the substrates they overlie.

Cliff: A steep face of land which exceeds the area covered by any one class of plant growth-form. Cliffs are named from the dominant substrate type when unvegetated or the leading plant species when plant cover is ≥1%.

Rock field: Land in which the area of residual rock exceeds the area covered by any one class of plant growth-form. They are named from the leading plant species when plant cover is ≥1%.

Boulder field: Land in which the area of unconsolidated boulders (>200mm diam.) exceeds the area covered by any one class of plant growth-form. Boulder fields are named from the leading plant species when plant cover is ≥1%.

Cobble field: Land in which the area of unconsolidated cobbles (20-200 mm diam.) exceeds the area covered by any one class of plant growth-form. Cobble fields are named from the leading plant species when plant cover is ≥1%.

Gravel field: Land in which the area of unconsolidated gravel (2-20 mm diameter) exceeds the area covered by any one class of plant growth-form. Gravel fields are named from the leading plant species when plant cover is ≥1%.

Mobile sand: Granular beach sand characterised by a rippled surface layer from strong tidal or wind-generated currents. Often forms bars and beaches.

Firm or soft sand: Sand flats may be mud-like in appearance but are granular when rubbed between the fingers and no conspicuous fines are evident when sediment is disturbed e.g. a mud content <1%. Classified as firm sand if an adult sinks <2 cm or soft sand if an adult sinks >2 cm.

Firm muddy sand: A sand/mud mixture dominated by sand with a moderate mud fraction (e.g. 1-10%), the mud fraction conspicuous only when sediment is mixed in water. The sediment appears brown, and may have a black anaerobic layer below. From a distance appears visually similar to firm sandy mud, firm or soft mud, and very soft mud. When walking you'll sink 0-2 cm. Granular when rubbed between the fingers.

Firm sandy mud: A sand/mud mixture dominated by sand with an elevated mud fraction (e.g. 10-25%), the mud fraction visually conspicuous when walking on it. The surface appears brown, and may have a black anaerobic layer below. From a distance appears visually similar to firm muddy sand, firm or soft mud, and very soft mud. When walking you'll sink 0-2 cm. Granular when rubbed between the fingers, but with a smoother consistency than firm muddy sand.

Firm or soft mud: A mixture of mud and sand where mud is a major component (e.g. >25% mud). Sediment rubbed between the fingers retains a granular component but is primarily smooth/silken. The surface appears grey or brown, and may have a black anaerobic layer below. From a distance appears visually similar to firm muddy sand, firm sandy mud, and very soft mud. Classified as firm mud if an adult sinks <5 cm (usually if sediments are dried out or another component e.g. gravel prevents sinking) or soft mud if an adult sinks >5 cm.

Very soft mud: A mixture of mud and sand where mud is the major component (e.g. >50% mud), the surface appears brown, and may have a black anaerobic layer below. When walking you'll sink >5 cm unless another component e.g. gravel prevents sinking. From a distance appears visually similar to firm muddy sand, firm sandy mud, and firm or soft mud. Sediment rubbed between the fingers may retain a slight granular component but is primarily smooth/silken.

Cockle bed /Mussel reef/ Oyster reef: Area that is dominated by both live and dead cockle shells, or one or more mussel or oyster species respectively.

Sabellid field: Area that is dominated by raised beds of sabellid polychaete tubes.

Shell bank: Area that is dominated by dead shells.

Artificial structures: Introduced natural or man-made materials that modify the environment. Includes rip-rap, rock walls, wharf piles, bridge supports, walkways, boat ramps, sand replenishment, groynes, flood control banks, stopgates.

APPENDIX 2. NOTES SUPPORTING RISK INDICATOR RATINGS (TABLE 2)

NOTES to Table 2: See Robertson et al. (2016a, 2016b) for further information supporting these ratings.

Soft Mud Percent Cover. Soft mud (>25% mud content) has been shown to result in a degraded macroinvertebrate community (Robertson et al. 2015, 2016), and excessive mud decreases water clarity, lowers biodiversity and affects aesthetics and access. Because estuaries are a sink for sediments, the presence of large areas of soft mud is likely to lead to major and detrimental ecological changes that could be very difficult to reverse. In particular, its presence indicates where changes in land management may be needed. If an estuary is suspected of being an outlier (e.g. has >25% mud content but substrate remains firm to walk on), it is recommended that the initial broad scale assessment be followed by particle grain size analyses of relevant areas to determine the extent of the estuary with sediment mud contents >25%.

Sedimentation Mud Content. Below mud contents of 20-30% sediments are relatively incohesive and firm to walk on. Above this, they become sticky and cohesive and are associated with a significant shift in the macroinvertebrate assemblage to a lower diversity community tolerant of muds. This is particularly pronounced if elevated mud contents are contiguous with elevated total organic carbon concentrations, which typically increase with mud content, as do the concentrations of sediment bound nutrients and heavy metals. Consequently, muddy sediments are often poorly oxygenated, nutrient rich, and on intertidal flats of estuaries can be overlain with dense opportunistic macroalgal blooms. High mud contents also contribute to poor water clarity through ready resuspension of fine muds, impacting on seagrass, birds, fish and aesthetic values.

apparent Redox Potential Discontinuity (aRPD). aRPD depth, the transition between oxygenated sediments near the surface and deeper anoxic sediments, is a primary estuary condition indicator as it is a direct measure of whether nutrient and organic enrichment exceeds levels causing nuisance (anoxic) conditions. Knowing if the aRPD is close to the surface is important for two main reasons:

1. As the aRPD layer gets close to the surface, a "tipping point" is reached where the pool of sediment nutrients (which can be large), suddenly becomes available to fuel algal blooms and to worsen sediment conditions.
2. Anoxic sediments contain toxic sulphides and support very little aquatic life.

In sandy porous sediments, the aRPD layer is usually relatively deep (>3cm) and is maintained primarily by current or wave action that pumps oxygenated water into the sediments. In finer silt/clay sediments, physical diffusion limits oxygen penetration to <1cm (Jørgensen and Revsbech 1985) unless bioturbation by infauna oxygenates the sediments. The tendency for sediments to become anoxic is much greater if the sediments are muddy.

Redox Potential (Eh). For meter approaches, Eh measurements represent a composite of multiple redox equilibria measured at the surface of a redox potential electrode coupled to a millivolt meter (Rosenberg et al. 2001) (often called an ORP meter) and reflects a system's tendency to receive or donate electrons. The electrode is inserted to different depths into the sediment and the extent of reducing conditions at each depth recorded (RPD is the depth at which the redox potential is ~0mV, Fenchel and Riedl 1970, Revsbech et al. 1980, Birchenough et al. 2012, Hunting et al. 2012). The Eh rating bands reflect the presence of healthy macrofauna communities in sediments below the aRPD depth.

Gross Eutrophic Conditions. Gross eutrophic conditions occur when sediments exhibit combined symptoms of: a high mud content, a shallow apparent Redox Potential Discontinuity (aRPD) depth, elevated nutrient and total organic carbon concentrations, displacement of invertebrates sensitive to organic enrichment, and high macroalgal growth (>50% cover). Persistent and extensive areas of gross nuisance conditions should not be present in short residence time estuaries, and their presence provides a clear signal that the assimilative capacity of the estuary is being exceeded. Consequently, the actual area exhibiting nuisance conditions, rather than the % of an estuary affected, is the primary condition indicator. Natural deposition and settlement areas, often in the upper estuary where flocculation at the freshwater/saltwater interface occurs, are commonly first affected. The gross eutrophic condition rating is based on the area affected by the combined presence of poorly oxygenated and muddy sediments, and a dense (>50%) macroalgal cover.

Opportunistic Macroalgae. The presence of opportunistic macroalgae is a primary indicator of estuary eutrophication, and when combined with gross eutrophic conditions (see previous) can cause significant adverse ecological impacts that are very difficult to reverse. Thresholds used to assess this indicator are derived from the OMBT (see Section 3), with results combined with those of other indicators to determine overall condition.

Seagrass. Seagrass (*Zostera muelleri*) grows in soft sediments in most NZ estuaries. It is widely acknowledged that the presence of healthy seagrass beds enhances estuary biodiversity and particularly improves benthic ecology (Nelson 2009). Though tolerant of a wide range of conditions, it is seldom found above mean sea level (MSL), and is vulnerable to fine sediments in the water column and sediment quality (particularly if there is a lack of oxygen and production of sulphide), rapid sediment deposition, excessive macroalgal growth, high nutrient concentrations, and reclamation. Decreases in seagrass extent is likely to indicate an increase in these types of pressures.

Saltmarsh. Saltmarshes have high biodiversity, are amongst the most productive habitats on earth, and have strong aesthetic appeal. They are sensitive to a wide range of pressures including land reclamation, margin development, flow regulation, sea level rise, grazing, wastewater contaminants, and weed invasion. Most NZ estuarine saltmarsh grows in the upper estuary margins above mean high water neap (MHWN) tide where vegetation stabilises fine sediment transported by tidal flows. Saltmarsh zonation is commonly evident, resulting from the combined influence of factors including salinity, inundation period, elevation, wave exposure, and sediment type. Highest saltmarsh diversity is generally present above mean high water spring (MHWS) tide where a variety of salt tolerant species grow including scrub, sedge, tussock, grass, reed, rush and herb fields. Between MHWS and MHWN, saltmarsh is commonly dominated by relatively low diversity rushland and herbfields. Below this, the MHWN to MSL range is commonly unvegetated or limited to either mangroves or *Spartina*, the latter being able to grow to MLWN. Further work is required to develop a comprehensive saltmarsh metric for NZ. As an interim measure, the % of the intertidal area comprising saltmarsh is used to indicate saltmarsh condition. A supporting metric is also proposed of % loss from Estimated Natural State Cover. This assumes that a reduction in natural state saltmarsh cover corresponds to a reduction in ecological services and habitat values. The interim risk ratings proposed for these ratings are Very Low=>80-100%, Low=>60-80%, Moderate=>40-60%, and High=<40%. The "early warning trigger" for initiating management action/further investigation is a trend of a decreasing saltmarsh area.

Vegetated Margin. The presence of a terrestrial margin dominated by a dense assemblage of scrub/shrub and forest vegetation acts as an important buffer between developed areas and the saltmarsh and estuary. This buffer is sensitive to a wide range of pressures including land reclamation, margin development, flow regulation, sea level rise, grazing, wastewater contaminants, and weed invasion. It protects the estuary against introduced weeds and grasses, naturally filters sediments and nutrients, and provides valuable ecological habitat. Reduction in the vegetated terrestrial buffer around the estuary is likely to result in a decline in estuary quality. The "early warning trigger" for initiating management action is <50% of the estuary with a densely vegetated margin.

Change from Baseline Condition. Where natural state conditions for high value habitat of seagrass, saltmarsh, and densely vegetated terrestrial margin are unknown it is proposed that % change from the first measured baseline condition be used to determine trends in estuary condition. It is assumed that increases in such habitat are desirable (i.e. represent a Very Low risk rating), and decreases are undesirable. For decreases, the interim risk ratings proposed are: Very Low=<5%, Low=>5-10%, Moderate=>10-20%, and High=>20%. For indicators of degraded habitat e.g. extent of soft mud or gross eutrophic conditions, the same interim risk rating bands are proposed, but are applied to increases in extent.

APPENDIX 3. NOTES ON SAMPLING, RESOLUTION AND ACCURACY

Sediment sampling and analysis

Grain size samples were collected from representative mud and sand habitats (to validate substrate classifications) by sampling a composite of the top 20mm of sediment (approx. 250gms in total) using a plastic trowel. Samples were placed inside a numbered plastic bag, refrigerated within 4 hours of sample collection before being frozen and sent to R.J. Hill Laboratories for grain size analysis (% mud, sand, gravel). Details of lab methods and detection limits are presented in Appendix 4. Samples were tracked using standard Chain of Custody forms and results were checked and transferred electronically to avoid transcription errors.

In addition, at selected sampling sites redox potential (RP) was measured with an oxidation-reduction potential meter at 0, 1, 3, 5 and 10cm depths below the substrate surface, and the aRPD depth and substrate type recorded. These results have been used to generate broad scale maps showing areas where sediment oxygenation is depleted to the extent that adverse impacts to macrofauna (sediment and surface dwelling animals) are expected i.e. where RPD at 3cm <-150mV or aRPD <1cm (Robertson et al. 2016b).

Sampling resolution and accuracy

Estimates of error for different measurements have been made based on the field data collected to date. Initial broad scale mapping is intended to provide a rapid overview of estuary condition based on the mapping of features visible on aerial photographs, supported by ground-truthing to validate the visible features. The accuracy of mapping is therefore primarily determined by the resolution of the available photos, and secondarily by the extent of groundtruthing. In most instances features with readily defined edges such as saltmarsh beds, rockfields etc. can be accurately mapped to within 1-2m of their boundaries. The largest area for potential error is where boundaries are not readily visible on photographs e.g. where firm muddy sands transition to soft muds. These boundaries require field validation. Extensive mapping experience has shown that it is possible to define such boundaries to within ±10m where they have been thoroughly ground-truthed using NEMP classifications. Because broad scale mapping necessitates the grouping of variable and non-uniform patches (which introduces a certain amount of variation) overall broad scale accuracy is unlikely to exceed ±10% for boundaries not readily visible on photographs.

Where initial broad scale mapping results indicate a need for greater resolution of boundaries (e.g. to increase certainty about the extent of soft mud areas), or to define changes within NEMP categories (e.g. to define the mud content within firm muddy sand habitat), then issue-specific approaches are recommended. The former includes more widespread ground-truthing, and the latter uses transect or grid based grain size sampling.

For specific broad scale seagrass and macroalgae features that are spatially and temporally variable, the overall spatial extent, and boundaries between different percentage cover and density areas, are considered accurate to within ±10m where they have been thoroughly ground-truthed using NEMP classifications. Accuracy declines when assessed remotely e.g. from aerial photographs, and particularly so when assessing lower density (<50%) cover which is commonly not visible on aerial coverages. As previously, the most accurate measures are obtained with increasing field time (and cost).

Within mapped boundaries, broad scale estimates of percentage cover and density, due to the grouping of variable and non-uniform patches, are considered accurate to ±10%. These however can be assessed to a much higher degree of accuracy using fine scale quadrat based approaches such as the OMBT. Accuracy can also be increased by applying fine scale approaches estuary-wide if a very high degree of accuracy is considered important.

For the OMBT, a methodology for calculating a measure of the confidence of class (CofC), has been developed (Davey, 2009) that defines the specific accuracy of the measures undertaken. Called CAPTAIN ('Confidence And Precision Tool Aids aNalysis') it calculates CofC at three levels: i. metric, ii. survey (single sampling event), and iii. water body over the reporting period (potentially several surveys).

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Certificate of Analysis

SPv1

Client:	Salt Ecology Limited	**Lab No:**	1926974
Contact:	Leigh Stevens	**Date Received:**	17-Feb-2018
	C/- Salt Ecology Limited	**Date Reported:**	28-Mar-2018
	21 Mount Vernon Place	**Quote No:**	90442
	Washington Valley	**Order No:**	
	Nelson 7010	**Client Reference:**	Kaikorai Estuary
		Submitted By:	Leigh Stevens

Sample Type: Sediment

Sample Name:		Kaikorai 1 14-Feb-2018	Kaikorai 2 14-Feb-2018	Kaikorai 3 14-Feb-2018	Kaikorai 4 14-Feb-2018	Kaikorai 5 14-Feb-2018
Lab Number:		1926974.1	1926974.2	1926974.3	1926974.4	1926974.5
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	80	70	50	56	76
3 Grain Sizes Profile						
Fraction >/= 2 mm*	g/100g dry wt	< 0.1	< 0.1	0.4	0.2	1.9
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	99.1	78.5	38.6	45.8	81.4
Fraction < 63 µm*	g/100g dry wt	0.9	21.4	61.0	54.0	16.6

Sample Name:		Kaikorai 6 14-Feb-2018				
Lab Number:		1926974.6				
Individual Tests						
Dry Matter of Sieved Sample	g/100g as rcvd	78	-	-	-	-
3 Grain Sizes Profile						
Fraction >/= 2 mm*	g/100g dry wt	< 0.1	-	-	-	-
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	97.0	-	-	-	-
Fraction < 63 µm*	g/100g dry wt	3.0	-	-	-	-

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Sample No
Individual Tests			
Dry Matter for Grainsize samples	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-6
3 Grain Sizes Profile*		0.1 g/100g dry wt	1-6
3 Grain Sizes Profile			
Fraction >/= 2 mm*	Wet sieving with dispersant, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-6
Fraction < 2 mm, >/= 63 µm*	Wet sieving using dispersant, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-6
Fraction < 63 µm*	Wet sieving with dispersant, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-6

APPENDIX 4. ANALYTICAL METHODS AND RESULTS

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

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

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

Graham Corban MSc Tech (Hons)
Client Services Manager - Environmental

APPENDIX 5. 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. 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. Because the default values in the ETI database have been sourced from high level national data with limited field validation e.g. the Coastal Explorer database, key inputs such as estuary area, depth, volume, tidal prism and flow have been updated using specific estuary measurements and field observations.

The indicators used to derive an ETI score for the estuary are presented below using the broad scale monitoring results (this report) and fine scale monitoring results (Robertson and Robertson 2018). 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. This is driven primarily by the extensive areas of GEZ in the middle estuary.

ETI scoring summary for Kaikorai Estuary, February 2018.				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	OMBT EQR	shallow inter-tidal	0.9	0.9
	Macroalgal GEZ %	% Gross Eutrophic Zone (GEZ)/Estuary Area		16	16
	Macroalgal GEZ Ha	Ha Gross Eutrophic Zone (GEZ)		12.8	12.8
Optional	Phytoplankton biomass	Chl- a (summer 90 pctl, mg/m^3)	water column	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 1cm depth in most impacted sediments and representing at least 10% of estuary area	shallow inter-tidal	-320	-320
		% of estuary with Redox Potential <-150mV at 3cm or aRPD <1cm			21
		Ha of estuary with Redox Potential <-150mV at 3cm or aRPD <1cm			17
	Sediment Total Organic Carbon	Mean TOC (%) measured at 0-2cm depth in most impacted sediments and representing at least 10% of estuary area		2.6#	2.6#
	Sediment Total Nitrogen	Mean TN (mg/kg) measured at 0-2cm depth in most impacted sediments and representing at least 10% of estuary area		2066#	2066#
	Macroinvertebrates	Mean AMBI score measured at 0-15cm depth in most impacted sediments and representing at least 10% of estuary area		3.8#	3.8#
Optional Indicators	Muddy sediment	Proportion of estuary area with >25% mud content	shallow inter-tidal	0.56	0.56
	Sedimentation Rate	Ratio of mean annual Current State Sediment Load (CSSL) relative to mean annual Natural State (NSSL)			6.0#
	Dissolved oxygen	1 day instantaneous minimum of water column measured from representative areas of estuary water column (including likely worst case conditions) ($mg.m^3$)	water column	4.6	4.6
NZ ETI Score				**0.81**	**0.81**

*Measurements from >1m depth in the upper estuary collected on 16/2/18 were 20-30mg/m^3, surface water concentrations throughout the estuary were 5-7mg/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.

Data from fine scale site B, Dec 2017 - source Robertson and Robertson (2018).

APPENDIX 5. NZ ESTUARY TROPHIC INDEX

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.

NZ ETI Tool 1 Input details	Calculator Heading	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 (barrier beach enclosed)
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	29.424
Annual river total phosphorus loading	TPriver	T/yr	1.853
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	123.21
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	72.84
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	1.68
Estuary Area at low tide	LOWTIDEest_area_m2	m2	134000
Mean depth at low tide	LOWTIDEmean_depth	m	0.75
Estuary volume at low tide	LOWTIDEvolume	m3	100500

NZ ETI Tool 2 Input details			
Name of estuary	estuary_name		Kaikorai Estuary 2018
Phytoplankton Biomass	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	3.8
Area of soft mud	soft_mud	Proportion	0.56
Estuary type	estuary_type		SIDE
ICOE status	isICOE	TRUE/FALSE	TRUE