coastalmanagement

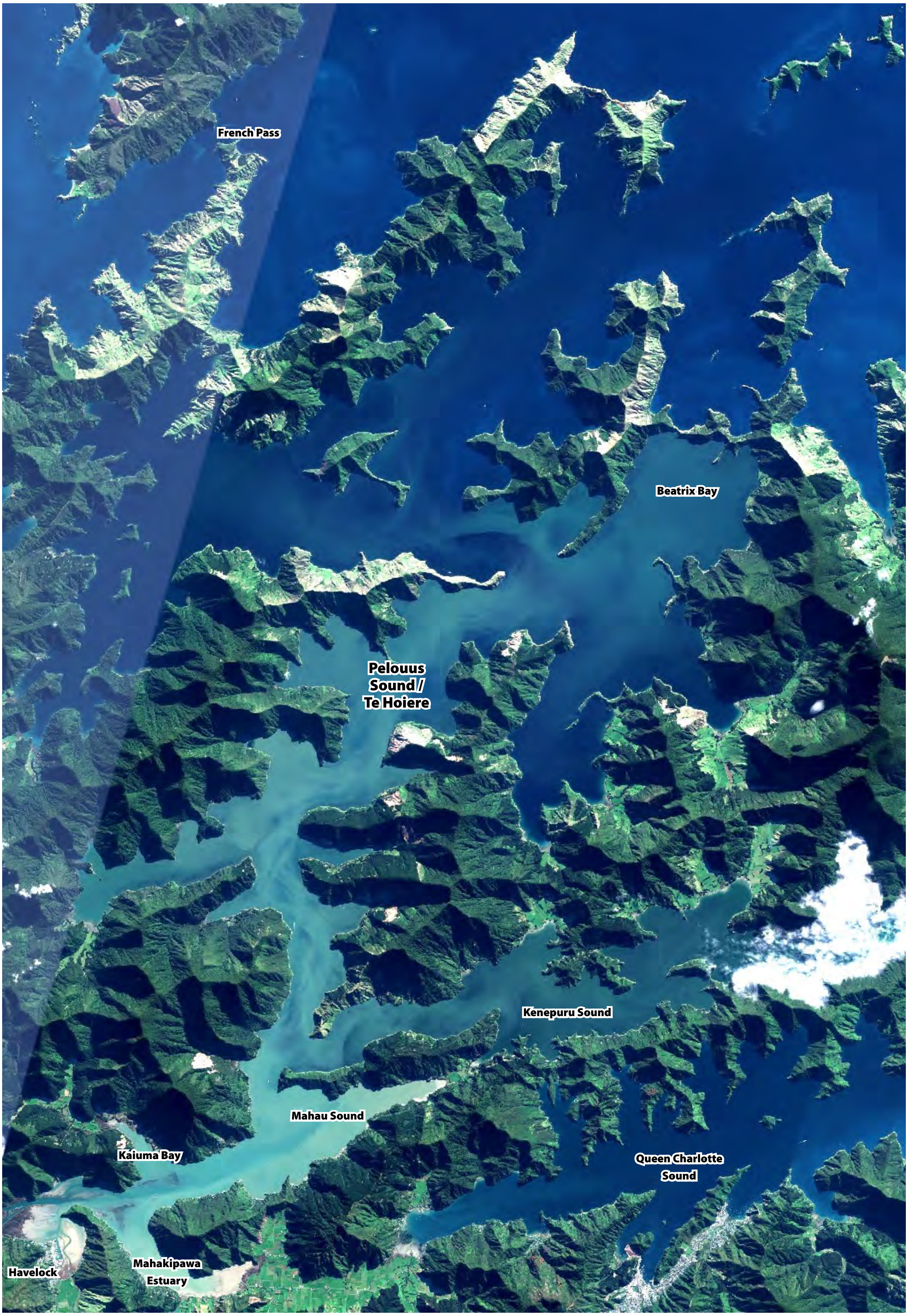
Kaiuma Estuary

Broad Scale Habitat Mapping 2017

Prepared for

Marlborough District Council

May 2017



Above Photo: Pelorus Sound, 21 May 2017. Source: European Space Agency ESA Sentinel-2. Provided to MDC by Ben Knight, Cawthron. Note extensive sediment plume extending from Havelock to the outer reaches of Pelorus Sound.

Cover Photo: Kaiuma Estuary, view over the main channel toward the head of the estuary, March 2017.

Intertidal rushland at the head of Kaiuma Estuary, March 2017

Kaiuma Estuary

Broad Scale Habitat Mapping 2017

Prepared for
Marlborough District Council

by

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All photos by Wriggle except where noted otherwise.

KAIUMA ESTUARY - EXECUTIVE SUMMARY

Kaiuma Estuary is a relatively unmodified, moderate sized (90ha), macrotidal (>1.6m spring tidal range), shallow (mean depth ~1m at high water), well-flushed (residence time <1 day), seawater-dominated, tidal lagoon type estuary located in Pelorus Sound, Marlborough. It is a shallow elongate bay with a wide unrestricted tidal opening, fed by several small streams. The catchment is dominated by native scrub and forest (74%). It is one of the key estuaries in Marlborough Regional Council's (MDC's) long-term coastal monitoring programme. This report presents the results of the March 2017 broad scale estuary habitat mapping with monitoring results, overall estuary condition and issues, and monitoring recommendations summarised below.

BROAD SCALE RESULTS

- Intertidal flats comprised 46% of the estuary, saltmarsh 13%, and subtidal waters 41%.
- Intertidal substrates were dominated by very soft mud (72%) and cobble (28%), with <1% dominant cover of gravel field, firm mud and oyster reef. The extremely high soft mud extent has a risk rating of HIGH.
- Sediment mud content measured within mud habitat was extremely high (75%-95%), a risk rating of HIGH.
- Opportunistic macroalgal growth was sparse overall (<5%), had an Ecological Quality Rating of "very good", and no gross eutrophic zones were present, a risk rating of LOW.
- Seagrass (*Zostera muelleri*) was found in one area only, covered 0.03% of the estuary, and was under stress from fine mud deposition. Due to the small extent and mud stress, it was given a risk rating of HIGH.
- Saltmarsh cover was relatively extensive 11.4ha (22% of the intertidal area), a risk rating of LOW. It was dominated by rushland (71%) and herbfields (24%).
- The 200m terrestrial margin was 67% densely vegetated (47% native scrub/forest and 20% plantation forest), a risk rating of LOW. Note land use changes, particularly forest harvesting, will significantly increase this risk rating.

ESTUARY CONDITION AND ISSUES

In relation to the key issues addressed by the broad scale monitoring (i.e. muddiness, eutrophication, and habitat modification), the 2017 broad scale mapping results show that the estuary supported a limited variety of substrate types dominated by very soft mud, one very small area of high value seagrass, and extensive areas of saltmarsh. It was expressing symptoms of excessive muddiness, a low level of eutrophication, with relatively limited historical habitat modification.

The combined results place the estuary in a "MODERATE" state overall in relation to ecological health. Fine sediment issues were most evident in the lower tidal reaches of the estuary and, given Kaiuma has a relatively unmodified catchment, are likely sourced from outside the immediate catchment (e.g. from the Kaituna or Pelorus catchments).

RECOMMENDED MONITORING AND MANAGEMENT

Kaiuma Estuary has been identified by MDC as a priority for monitoring because it is a moderate sized estuary with high ecological and human use values situated in a relatively undeveloped catchment, but vulnerable to external pressures from excessive sedimentation and, to a much lesser extent, eutrophication. The following monitoring recommendations are proposed by Wriggle for consideration by MDC:

To characterise any issues of changes in habitat (e.g. soft mud extent, saltmarsh or seagrass area), it is recommended that broad scale habitat mapping be undertaken at 5-10 yearly intervals (next scheduled for consideration in 2022), unless obvious changes are observed in the interim.

To characterise ongoing sediment deposition, it is recommended that sedimentation rate be assessed annually, using sediment plates established as part of the current work.

The large spatial extent and high mud content of sediments suggest that management actions (e.g. improved land-use controls for managing sediment losses from contributing land-uses) are required to minimise ongoing sedimentation and limit further ecological deterioration. An effective reduction in sediment inputs will likely facilitate a decrease in estuary muddiness, and improvement in estuary health, over time. A priority would be to identify the source of the excessive sediment inputs apparent in the estuary and target management actions to reduce them. Once management actions are in place, it is recommended that a robust multi-year fine scale monitoring baseline be established against which future improvements in estuary condition can be assessed.

1. INTRODUCTION

Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. These objectives, along with understanding change in condition/trends, are key objectives of Marlborough District Council's State of the Environment estuary monitoring programme. Recently, Marlborough District Council (MDC) prepared a coastal monitoring strategy which established priorities for a long-term coastal and estuarine monitoring programme (Tiernan 2012). The assessment identified Kaiuma Estuary as a priority for monitoring.

The estuary monitoring process consists of three components developed from the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002) as follows:

1. **Ecological Vulnerability Assessment** (EVA) of estuaries in the region to major issues (see Table 1) and appropriate monitoring design. To date, neither estuary specific nor region-wide EVAs have been undertaken for the Marlborough region and therefore the vulnerability of Kaiuma Estuary to issues has not yet been fully assessed. However, recent reports have documented selected ecologically significant marine sites in Marlborough (Davidson et al. 2011).
2. **Broad Scale Habitat Mapping** (NEMP approach). This component (see Table 1) documents the key habitats within the estuary, and changes to these habitats over time. The current report focuses on detailed broad scale habitat mapping undertaken in March 2017 to assess the current state of the estuary.
3. **Fine Scale Monitoring** (NEMP approach). Monitoring of physical, chemical and biological indicators (see Table 1). This component, which provides detailed information on estuary condition has yet to be undertaken.

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 results of the field sampling are then presented and discussed (Section 4) for the following:

- Broad scale mapping of estuary sediment types.
- Broad scale mapping of macroalgal beds (i.e. *Ulva* (sea lettuce), *Gracilaria*).
- Broad scale mapping of seagrass (*Zostera muelleri*).
- Broad scale mapping of saltmarsh vegetation.
- Broad scale mapping of 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 and management recommendations (Sections 6 and 7 respectively).

Kaiuma Bay, located 8.5km by sea from Havelock, is a shallow elongate bay (~175ha) located within the upper Pelorus Sound, a 43km long, deep, subtidally dominated estuary (DSDE), 435km^2 in size. The upper 90ha of Kaiuma Bay is classified as a shallow intertidally dominated estuary (SIDE), a relatively rare estuary type in the Marlborough Sounds.

A previous assessment of Kaiuma Estuary (Davidson 2005) reported ~12ha of saltmarsh habitat dominated by the rushland and herbfield. Seagrass (*Zostera muelleri*) was recorded in the estuary, but the introduced invasive cord grass *Spartina* was not. Intertidal substrate was dominated by pebble, cobbles and small areas of mud, and adjacent to the estuary was 1.6ha of coastal, tidal wetland forest, and 3.8ha of coastal forest. These tidal wetland forest areas have been protected as Department of Conservation Scenic Reserves and because within the Marlborough Sounds there are relatively few extensive intertidal estuarine habitats, and even less supporting estuary-wetland forest sequences, Kaiuma Estuary therefore represents an important area of relatively high ecological value with a recognised conservation status. This has been further enhanced by the establishment of a recreation reserve along the entire foreshore area of the estuary, much with an established walking path. The popular Nydia Bay track also starts/ends at Kaiuma Bay.

The land area on the south eastern entrance to the bay has been identified within the Marlborough Sounds Resource Management Plan as being of Outstanding Landscape Value. This Outstanding Landscape Area includes part of the Sounds Residential subdivision and also lies within the "working" environment of the Sounds where marine farming, traditional pastoral farming and forestry are being practiced. A cluster of early Māori and European archaeological sites are recorded from in and around Kaiuma Bay, and during pre European times the area formed an important walking / trading route between Motueka (Tasman Bay) and the Wairau Valley (Blenheim).

Consents for residential subdivision have been granted and housing and related infrastructure are currently (2017) being developed along much of the eastern shoreline including a small marina and launching facility. Forestry (*Pinus radiata*) harvesting is underway on the western side of the estuary, with pastoral farming near the head of the estuary. A 10ha marine farm is located in the centre of the bay comprising fixed racks for Pacific oyster spat collection.

An assessment by Davidson (2015) as part of marine farm consent application U150588 identified significant sedimentation of the estuary with the likely source from the Pelorus River and Havelock Estuary (Kaituna River) catchments rather than the immediate catchment surrounding the estuary. The applicant indicated that the majority of the influx of sediment has occurred since 2012.

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

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Toxins	Sediment Contaminants	Chemical analysis of heavy metals (total recoverable cadmium, chromium, copper, nickel, lead and zinc) and any other suspected contaminants in sediment samples.
	Biota Contaminants	Chemical analysis of suspected contaminants in body of at-risk biota (e.g. fish, shellfish).
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

5. Habitat Loss

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

Recommended Key Indicators:

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

Figure 1. Location of Kaiuma Estuary, Pelorus Sound, Marlborough.

2. ESTUARY RISK INDICATOR RATINGS

The estuary monitoring approach used by Wriggle has been established to provide a defensible, cost-effective way to help quickly identify the likely presence of the predominant issues affecting NZ estuaries (i.e. eutrophication, sedimentation, disease risk, toxicity and habitat change; Table 1), and to assess changes in the long term condition of estuarine systems. The design is based on the use of primary indicators that have a documented strong relationship with water or sediment quality.

In order to facilitate this assessment process, "risk indicator ratings" have also been proposed that assign a relative level of risk (e.g. very low, low, moderate, high) of specific indicators adversely affecting intertidal estuary condition (see Table 2 below). Each risk indicator rating is designed to be used in combination with relevant information and other risk indicator ratings, and under expert guidance, to assess overall estuarine condition in relation to key issues, and make monitoring and management recommendations. When interpreting risk indicator results we emphasise:

- The importance of taking into account other relevant information and/or indicator results before making management decisions regarding the presence or significance of any estuary issue e.g. community aspirations, cost/benefit considerations.
- That rating and ranking systems can easily mask or oversimplify results. For instance, large changes can occur within the same risk category, but small changes near the edge of one risk category may shift the rating to the next risk level.
- Most issues will have a mix of primary and supporting indicators, primary indicators being given more weight in assessing the significance of results. It is noted that many supporting estuary indicators will be monitored under other programmes and can be used if primary indicators reflect a significant risk exists, or if risk profiles have changed over time.
- Ratings have been established in many cases using statistical measures based on NZ estuary data and presented in the NZ Estuary Trophic Index (NZ ETI; Robertson et al. 2016a and 2016b). However, where such data is lacking, or has yet to be processed, ratings have been established using professional judgement, based on our experience from monitoring numerous NZ estuaries. Our hope is that where a high level of risk is identified, the following steps are taken:
    1. Statistical measures be used to refine indicator ratings where information is lacking.
    2. Issues identified as having a high likelihood of causing a significant change in ecological condition (either positive or negative), trigger intensive, targeted investigations to appropriately characterise the extent of the issue.
    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 Kaiuma Estuary broad scale monitoring programme are summarised in Table 2, with supporting notes explaining the use and justifications for each indicator on the following page. 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 the present report.

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
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*	Band A (0-0.25)	Band B (0.25-0.50)	Band C (0.50-0.75)	Band D (0.75-1.0)

* NZ ETI (Robertson et al. 2016b), ** Hargrave et al. (2008), ***B.P. 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 indicators to assess estuary condition in response to common stressors, and assess future change.

Estuary boundaries were set from seaward as defined in the MDC work brief 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 March 2017 to ground-truth the spatial extent of dominant vegetation and substrate types. From representative broad scale substrate classes, 5 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.

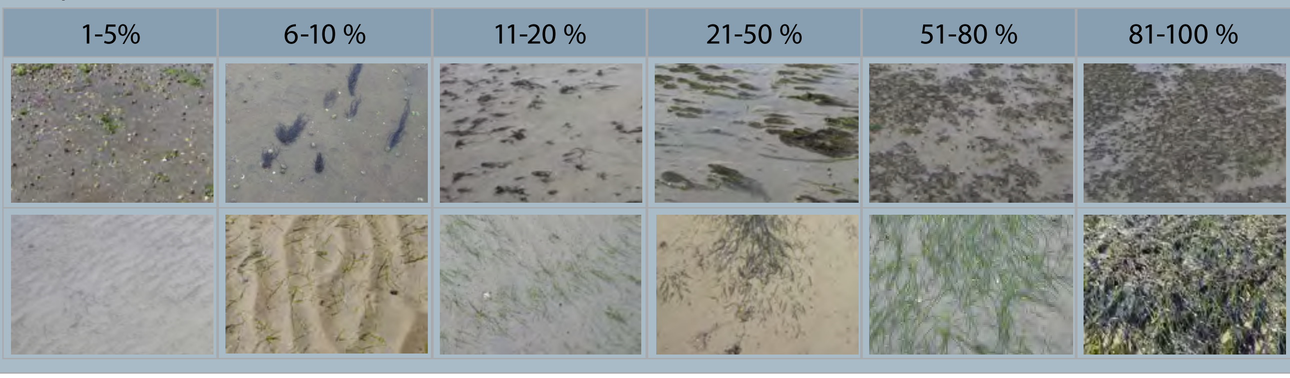
Macroalgae, if present is further assessed by identifying patches of comparable growth, and enumerating each patch by measuring:

- % cover of opportunistic macroalgae (the spatial extent and density of algal cover providing an early warning of eutrophication issues).
- macroalgal biomass (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).

A modified Opportunistic Macroalgal Blooming Tool (OMBT) is then used to rate macroalgal condition. The OMBT, described in detail in Robertson et al. (2016b), 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) (Table 2, Appendix 2). 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*), seagrass, saltmarsh vegetation, and the 200m wide terrestrial margin vegetation/landuse (Figure 4). 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).



To determine the future sedimentation rate, a simple method of measuring how much sediment builds up over a buried plate over time is used. Once a plate has been buried and levelled, probes are pushed into the sediment until they hit the plate and the penetration depth is measured. A number of measurements on each plate are averaged to account for irregular sediment surfaces, and a number of plates are buried to account for small scale variance. These are then measured over time (commonly annually) to assess sediment accrual.

Two sites, each with four plates (20cm square concrete paving stones) were established in March 2017 in Kaiuma Estuary in unvegetated intertidal deposition areas where fine muds accumulate. Plates were buried deeply in the sediments where stable substrate was located and positioned 2m apart in a linear configuration along a marked transect. Wooden pegs were used to mark the start, middle and end of each transect (0m, 5m and 10m respectively). To ensure plate stability, steel waratahs (0.8 or 1.6m long) were driven into the sediments until firm substrate was encountered beneath the plates, and the plates placed on these. Steel reinforcing rod was also placed horizontally next to buried plates to enable relocation with a metal detector.

The GPS positions of each plate were logged, and the depth from the undisturbed mud surface to the top of the sediment plate recorded (Appendix 5). In the future, these depths will be measured annually and, over the long term, will provide a measure of the rate of sedimentation in the estuary.

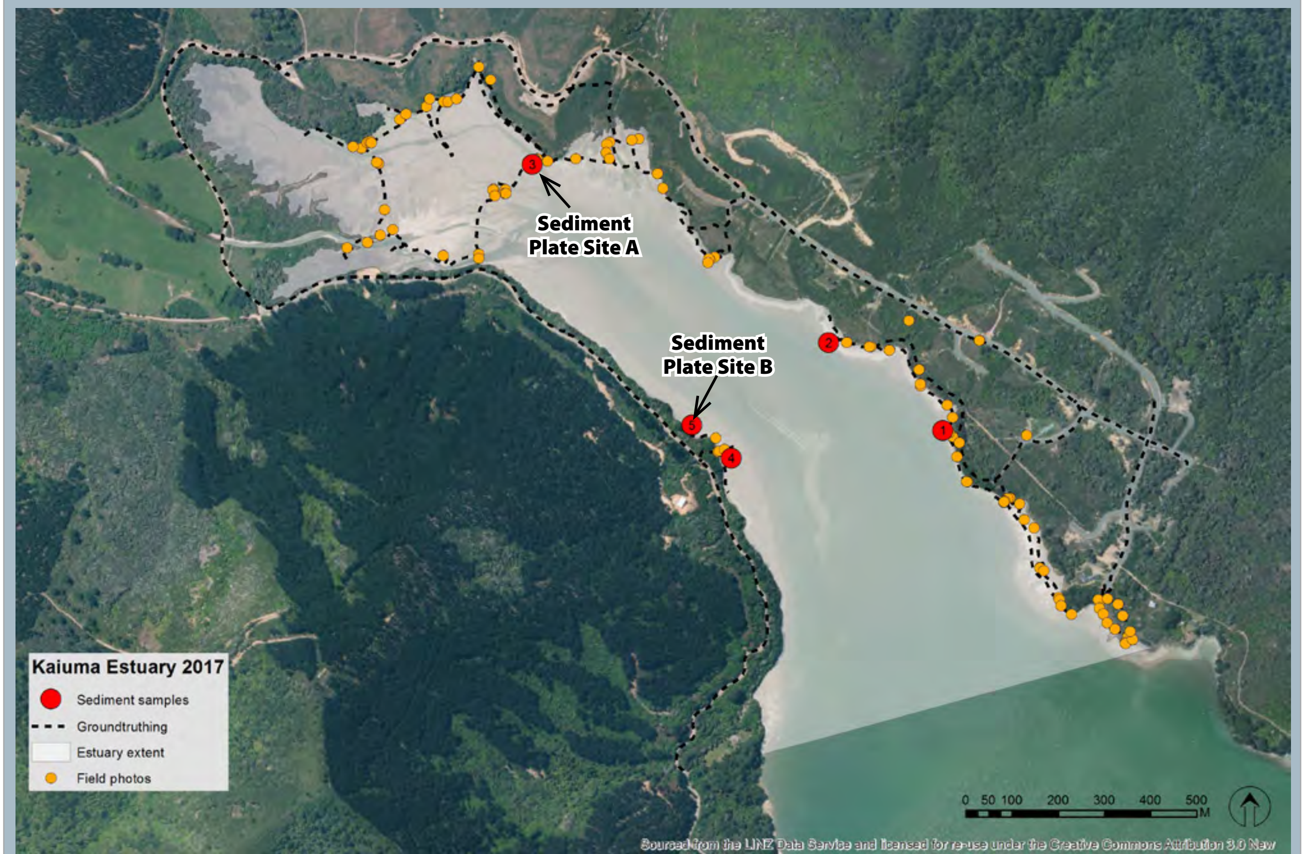


Figure 3. Kaiuma Estuary - mapped estuary extent showing ground-truthing coverage, field photos, location of grain size samples used to validate substrate classifications, and sedimentation rate monitoring sites.

4. RESULTS AND DISCUSSION

4.0. BROAD SCALE MAPPING SUMMARY

The 2017 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 six dominant estuary features summarised in Table 3 and shown in Figure 4. The estuary comprises an enclosed tidal estuary with a large subtidal component (41%), extensive unvegetated intertidal flats (46%) and saltmarsh (13%) located predominantly at the head of the estuary and in a narrow fringing strip along the eastern margin. Intertidal seagrass (<1%) was very sparse, and no dense (>50% cover) opportunistic macroalgae was observed. The 200m wide terrestrial margin was dominated by dense vegetation (67%) and grassland (26%). 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 these key habitats (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 in Kaiuma Estuary, 2017.

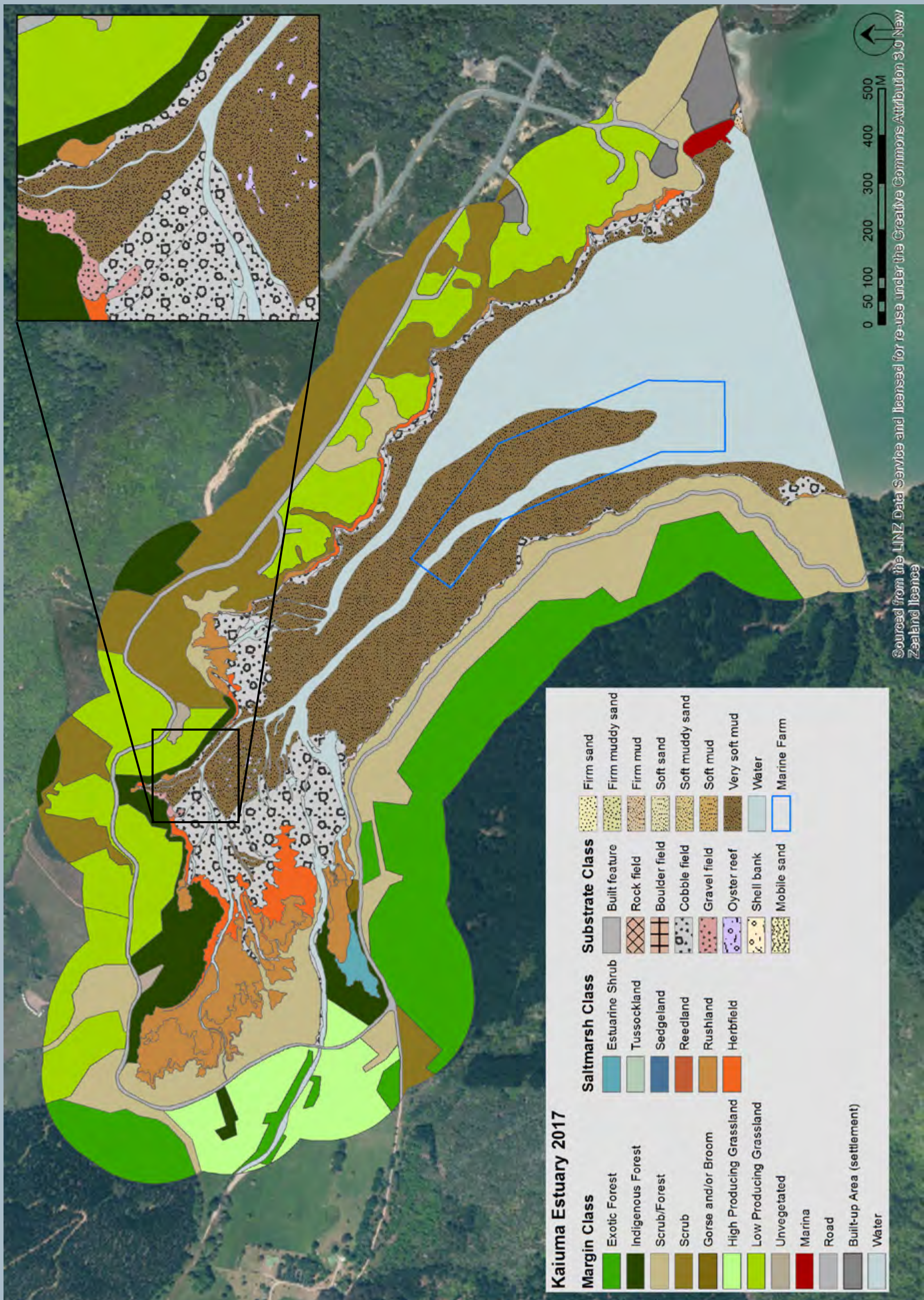
Dominant Estuary Feature		2017		
		ha	% intertidal	% estuary
1.	Intertidal flats (excluding saltmarsh)	41.4	78.4	46.3
2.	Opportunistic macroalgal beds (>50% cover) [on intertidal flats]	-	-	-
3.	Seagrass (>20% cover) [on intertidal flats]	0.02	0.03	0.02
4.	Saltmarsh	11.4	21.6	12.7
5.	Subtidal waters	36.7		41.0
Total Estuary		**89.5**		**100**
6.	200m wide Terrestrial Margin - % densely vegetated (e.g. scrub, shrub, forest)			67%

4.1. INTERTIDAL SUBSTRATE (EXCLUDING SALTMARSH)

Results (summarised in Table 4 and Figure 6) show intertidal substrate (excluding saltmarsh) was dominated by very soft mud (72%) and cobble field (28%). Gravel, firm mud, and oyster reef were minor components (<1% combined). A strong pattern of substrate zonation was present with cobbles dominating the upper shoreline, and very soft muds dominating the lower shoreline. The very soft muds on the lower shoreline overlaid buried cobble fields and commonly supported a subdominant cover of Pacific oysters. Across the mid shore, cobble was the dominant surface cover, but infilling of interstitial spaces with fine muds was widespread. This zonation was likely maintained by regular tidal and wave action mobilising fine material from the upper shore which subsequently settled in the more sheltered lower shore. Within vegetated areas, substrate among herbfields was predominantly cobble and gravel dominated, while substrate among rushland was firm mud/muddy sand dominated.

Table 4. Summary of dominant intertidal substrate, Kaiuma Estuary, 2017.

Dominant Substrate	Ha	%	Comments
Cobble field	11.4	27.5	Upper estuary stream channels and deltas, and upper tidal margins
Gravel field	0.1	0.2	Sheltered upper estuary margins
Oyster reef	0.1	0.2	On cobble in the low tide zone, and on upper estuary very soft muds
Firm mud	0.05	0.1	Small pockets in the main basin and near the entrance
Very soft mud	29.8	72.0	Throughout the lower tidal zone (and extensive subtidally)
Grand Total	**96.6**	**100**	



Note: this combined figure is intended primarily to illustrate the comprehensive mapping undertaken in the estuary. Sub-components are presented separately on the following pages for ease of interpretation, with GIS files also provided for interactive exploration of the data.

Figure 4. Overview of terrestrial margin and mapped intertidal saltmarsh and substrate (with example illustrating higher resolution GIS detail) - Kaiuma Estuary, March 2017.

4.2. 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 is the primary sediment indicator used in the current broad scale report, with sediment mud content a supporting indicator. Sediment plates have been established at two fine scale sites and baseline measures taken, to enable future monitoring of vertical buildup (see Section 3, Figure 3, and Appendix 5 for details).

Figure 6 and Table 4 shows that very soft muds covered 29.8ha (72%) of the intertidal area and Table 5 shows that the mud content measured in representative areas to be 75-95%, both at the upper end of the HIGH risk indicator rating category, and also high in a national context (Figure 5). In 2005 Kaiuma Estuary was a pebble and cobble dominated estuary with only small areas of mud (Davidson 2005) but, 10 years later Davidson (2015) reported a very large influx of fine sediment (mud), with anecdotal evidence that the majority had deposited since 2012. The extremely high muddiness recorded in the current survey, including extensive infilling of cobble interstitial spaces with fine mud, therefore appears to be a recent change from the more natural cobble dominated state of the estuary.

In terms of the likely source of sediment, aerial photos do not indicate any significant land cover changes in the Kaiuma catchment around 2012 when muddiness increases in the estuary were reported. This suggests sediment from outside the Kaiuma catchment may be the dominant source of recently deposited mud. If so, this is most likely to come from nearby upstream catchments (i.e. Kaituna and Pelorus Rivers) with sediment retention in Kaiuma Estuary facilitated by the presence of sheltered deposition zones, reduced current flows, trapping within marine farm structures (10ha of intertidal oyster racks) and, to a lesser extent, salinity driven flocculation and the presence of oyster reefs.

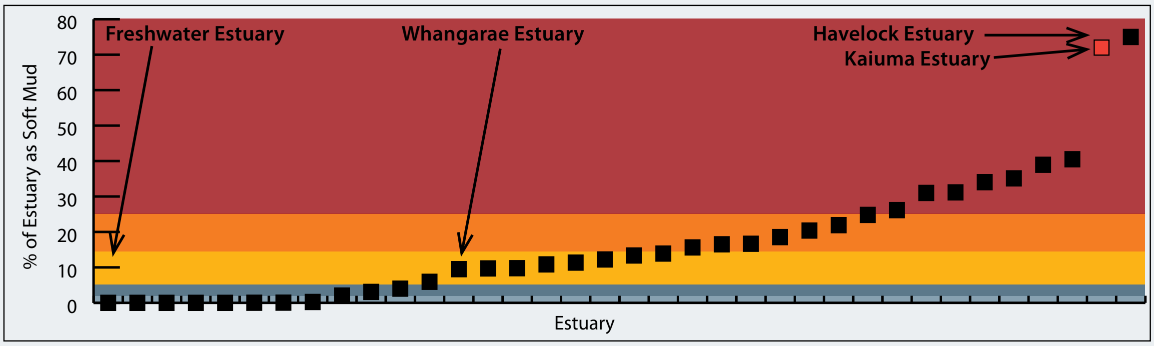


Figure 5. Percentage of estuary with soft mud habitat for 35 typical NZ tidal lagoon and delta estuaries. **(intertidal dominated, shallow, residence time <3 days - data from Wriggle monitoring reports 2006-2017 and Robertson et al. 2002).**

Table 5. Grain size results from representative sediments, Kaiuma Estuary, 2017.

Site #	% mud	% sand	% gravel
1	92.3	7.6	< 0.1
2	91.8	8.0	0.3
3	75.1	24.7	0.2
4	87.9	11.9	0.2
5	94.8	5.1	<0.1

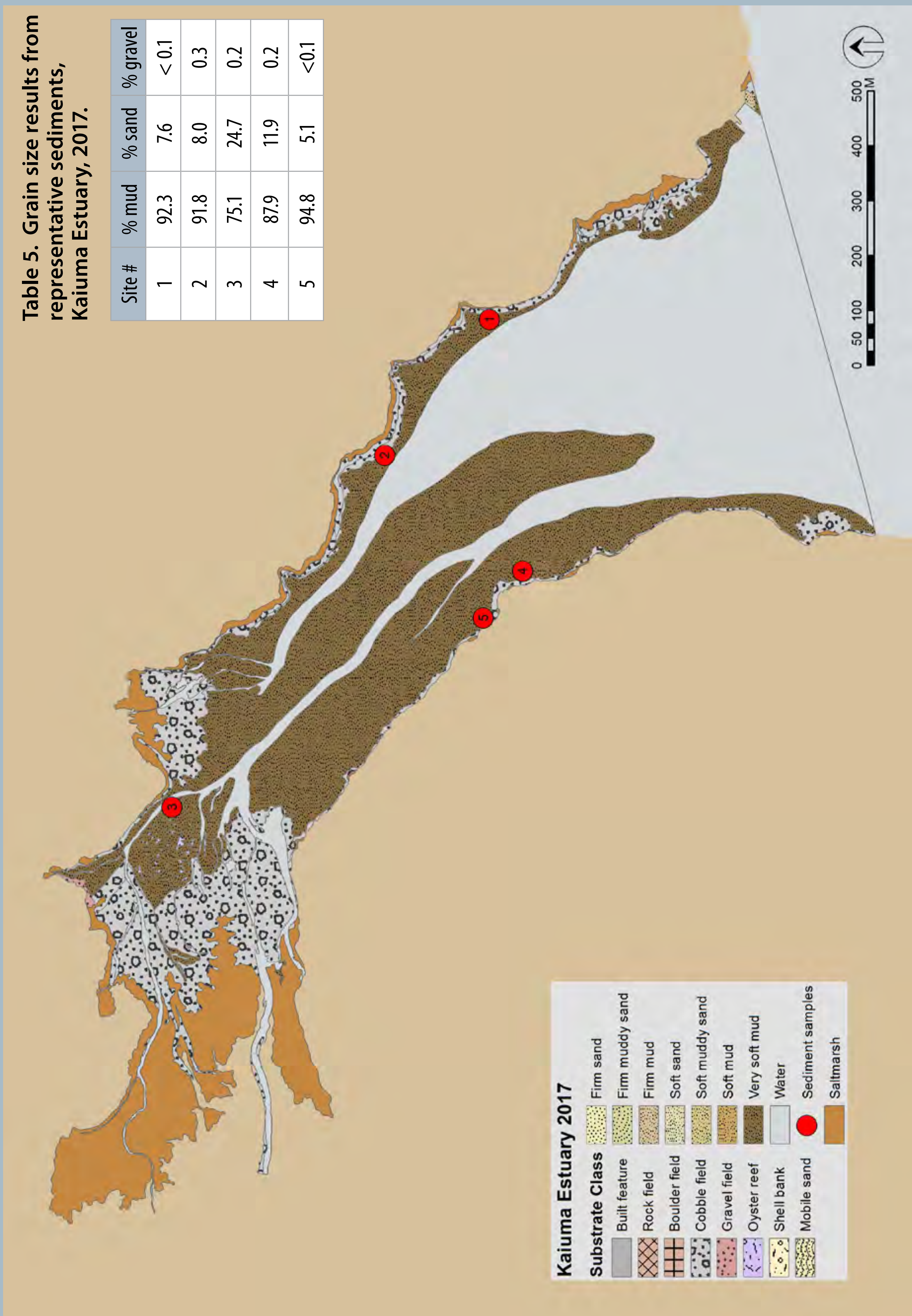


Figure 6. Map of dominant intertidal substrate types - Kaiuma Estuary, March 2017.

Clean cobbles and gravels in the head of the estuary near stream deltas in the upper estuary.

Mud coated cobbles and boulders with Pacific oysters in the lower estuary.

Oyster reefs growing within very soft muds seaward of cobble deltas in the upper estuary.

4. RESULTS AND DISCUSSION (CONTINUED)


Extensive low shore mud flats flanking and overlying cobble habitat.


Mud coated cobbles and boulders in the lower estuary (left). Marina development (right).

Marina development involving sediment scraping (see also above right photo) and reclamation.

4.3. SEDIMENT OXYGENATION

The primary indicators used to assess sediment oxygenation are aRPD depth and RP measured at 3cm. These indicators were measured at representative sites throughout the dominant sand and mud substrate types, and from a range of sites with variable macroalgal cover and biomass. 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 7). 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.

The broad scale field measurements found sand and gravel dominated sediments to be generally well oxygenated with the aRPD depth at 2-5cm. However, the majority of the estuary sediments (29.9ha, 56% of the total intertidal area) were dominated by fine sediments with a very high mud content. There was no visually distinct aRPD boundary in the very soft muds but the measured RP was consistently below -150mV at 1cm, a NZ ETI risk rating of "HIGH"

The absence of a distinct aRPD boundary has been consistently observed in estuaries that have a high mud content, tightly packed interstitial spaces (that limit tidal and atmospheric oxygenation), and relatively low organic contents in the sediment e.g. Havelock Estuary, Waimea Inlet, Moutere Inlet. Within Kaiuma Estuary, these conditions were widespread throughout the soft and very soft mud habitats located predominantly in the lower tidal range.

4.4. 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.

If the estuary supports <5% opportunistic macroalgal cover within the Available Intertidal Habitat (AIH), overall quality status is reported as HIGH with no further sampling required. If there is >5% cover, opportunistic macroalgal growth is assessed by mapping the spatial spread and density in the AIH, and calculating an OMBT "Ecological Quality Rating" (EQR) (WFD UKTAG, 2014). Intertidal macroalgal cover was very low in March 2017 (<1%), and consequently the macroalgae quality status is HIGH, and the risk rating LOW. No further enumeration is required.

4.5. SEAGRASS

Seagrass (*Zostera muelleri*) beds are important ecologically because they enhance primary production and nutrient cycling, stabilise sediments, elevate biodiversity, and provide nursery and feeding grounds for a range of invertebrates and fish. Though tolerant of a wide range of conditions, seagrass is vulnerable to excessive nutrients, fine sediments in the water column, and sediment quality (particularly if there is a lack of oxygen and production of sulphides).

Figure 8 shows the only location where intertidal seagrass was observed in the estuary (0.02ha). It was present at a very low density and appeared to be under stress from fine mud deposition. Seagrass change in the estuary cannot be quantified as while Davidson (2005) reported its presence in the estuary, no details were provided on its location and extent at that time.

In the absence of any comprehensive rating of seagrass extent within NZ estuaries, which can be highly variable in the extent of seagrass that they support, changes from a documented baseline currently represent the most reliable method for monitoring seagrass extent and assessing change. The current study has provided a high resolution GIS map of seagrass extent for this purpose, with an interim risk rating of HIGH applied because of the small area and high stress from mud. A reduction is mud inputs to the estuary is needed before seagrass recovery is likely.

Figure 7. Map of areas with low sediment oxygenation - Kaiuma Estuary, March 2017.

Figure 8. Map of intertidal seagrass (*Zostera muelleri*) - Kaiuma Estuary, March 2017.

4. RESULTS AND DISCUSSION (CONTINUED)

4.6. SALTMARSH

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, with the lower extent of saltmarsh growth 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 9 summarise the 2017 results and show saltmarsh was present across 11.4ha (22%) of the intertidal estuary area, a risk indicator rating of LOW. Saltmarsh was dominated by rushland (71%) with a relatively even spread of searush and jointed wire rush located predominantly in extensive beds in the head of the estuary, and also in narrow strips and as isolated beds along the edges. Herbfields (24%) were also prominent, commonly growing seaward of the rushland beds and also as a subdominant cover among rushland. Primrose and remuremu were the dominant species, and formed a dense turf community among gravel beds, with glasswort (*Sarcocornia quinqueflora*) relatively rare. Saltmarsh ribbonwood (5%) was the other dominant class in the upper estuary. The introduced invasive cord grass (*Spartina)* was not observed. Page 18 presents photos of representative saltmarsh growing throughout the estuary.

A supporting measure also applied is saltmarsh loss compared to estimated natural state cover. While the historical extent of the estuary has not been specifically mapped as part of the current work, it appears relatively unmodified other than a small upper estuary area historically drained and converted to pasture, and recent marina development in the lower estuary. It is estimated that <20% of saltmarsh has been lost from the estuary, a supporting risk rating of VERY LOW. The combined overall risk rating was assessed as LOW recognising that saltmarsh remains a significant and relatively unmodified feature of the estuary.

Table 6. Summary of dominant saltmarsh cover, Kaiuma Estuary, 2017.

Class	Dominant Species	Subdominant species	Area (ha)	Percentage
Estuarine Shrub			**0.6**	**5.0**
	Plagianthus divaricatus (Saltmarsh ribbonwood)	*Apodasmia similis (Jointed wirerush)*	0.6	5.0
Rushland			**8.1**	**71.3**
	Apodasmia similis (Jointed wirerush)		1.2	10.3
		Apodasmia similis (Jointed wirerush)	0.01	0.1
		Juncus kraussii (Searush)	1.9	16.3
		Plagianthus divaricatus (Saltmarsh ribbonwood)	0.3	2.8
	Juncus kraussii (Searush)		3.2	28.0
		Apodasmia similis (Jointed wirerush)	1.1	9.4
		Festuca arundinacea (Tall fescue)	0.0	0.1
		Samolus repens (Primrose)	0.1	1.1
		Selliera radicans (Remuremu)	0.4	3.1
Herbfield			**2.7**	**23.7**
	Samolus repens (Primrose)		0.2	1.6
		Juncus kraussii (Searush)	0.1	0.8
		Selliera radicans (Remuremu)	0.8	7.1
	Selliera radicans (Remuremu)	*Samolus repens (Primrose)*	1.6	14.2
Total (Ha)			**11.4**	**100**

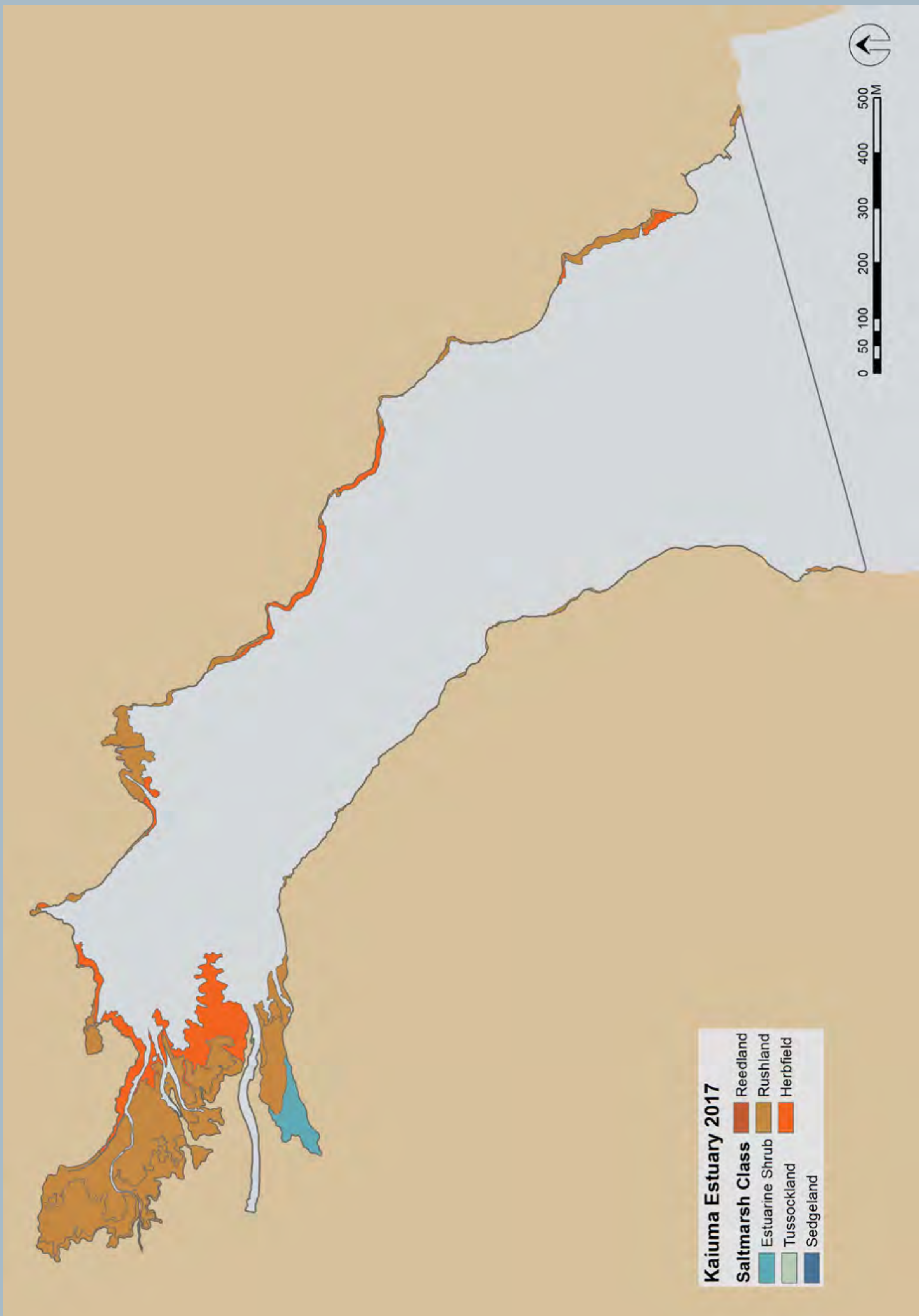


Figure 9. Map of dominant saltmarsh cover - Kaiuma Estuary, March 2017.

Saltmarsh ribbonwood (left) and jointed wire rush (right) dominated areas in the head of the estuary.

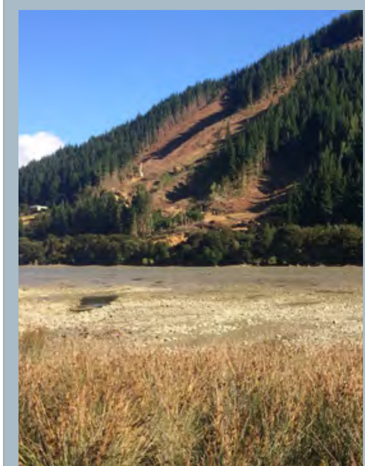
Searush growing on cobble habitat in the upper tidal range.

Herbfields in front of rushland in sheltered upper arms of the estuary near streams.

Herbfields in cobble and gravel and cobble habitat, and as a subdominant cover to rushland.

4.7. 200m TERRESTRIAL MARGIN

Native forest growing to the estuary edge.



Forest harvesting on steep hillsides adjacent to the estuary, March 2017.

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, Figure 10) showed:

- 67% was densely vegetated (47% native scrub/forest and 20% plantation forest).
- 26% was grassland (20% unmaintained grassland and 6% high producing pasture).
- 6% was developed (road, residential, marina).

Steep land surrounding the estuary has limited the modification of estuary margins, although there have been localised historical impacts related to road construction and pasture development. Residential development of much of the eastern estuary margin will change land cover but is not likely to significantly impact the estuary directly. This is partly due to the presence of a recreation reserve (predominately native scrub/forest) that runs along the shoreline around much of the estuary. This buffers the estuary from the proposed developments, facilitates human connectivity to the estuary, and is enabling community pest trapping initiatives along these easily accessed areas.

The relatively intact vegetative 200m terrestrial margin has a risk indicator rating of LOW and its ecological value is significantly enhanced by the estuary adjoining stands of protected terrestrial native forest. This helps buffer the estuary against stressors like localised sediment and nutrient inputs and introduced weeds, and supports regionally rare ecological connectivity between the estuary and surrounding natural habitats.

The relatively intact terrestrial margin is also reflected in the wider catchment with 73% of the catchment indigenous native forest and scrub, 20% exotic forest, 6% high producing grassland, and 1% developed settlements (Figure 11 - source LCDB4, 2012). The high cover of native forest and scrub is a strong factor mitigating against adverse effects commonly associated with elevated inputs of sediment, nutrients and pathogens from farming and forestry activities. Harvesting of exotic forestry on the steep hillsides in the lower catchment surrounding the estuary represents the highest current risk to the estuary.

Table 7. Summary of 200m terrestrial margin land cover, Kaiuma Estuary, 2017.

Class	Dominant features	Percentage
Exotic Forest	Commercial forestry *Pinus radiata* (Pine tree)	19.8
Native Forest	Protected coastal forest at the head of the estuary	2.9
Scrub and Forest	Mixed native and exotic trees predominantly in narrow strips near the estuary margin. Common species include beech, rimu, kanuka, manuka, gorse, broom, pine trees.	26.9
Scrub		17.0
Pasture	Developed pasture at the head of the estuary and grassland present along much of the eastern side (pending residential development)	6.1
Grassland		20.3
Marina	Intertidal development underway in the lower east of the estuary	0.4
Residential	Developed housing - many sections currently awaiting development	1.6
Built feature	Roads	4.3
Total		**100**

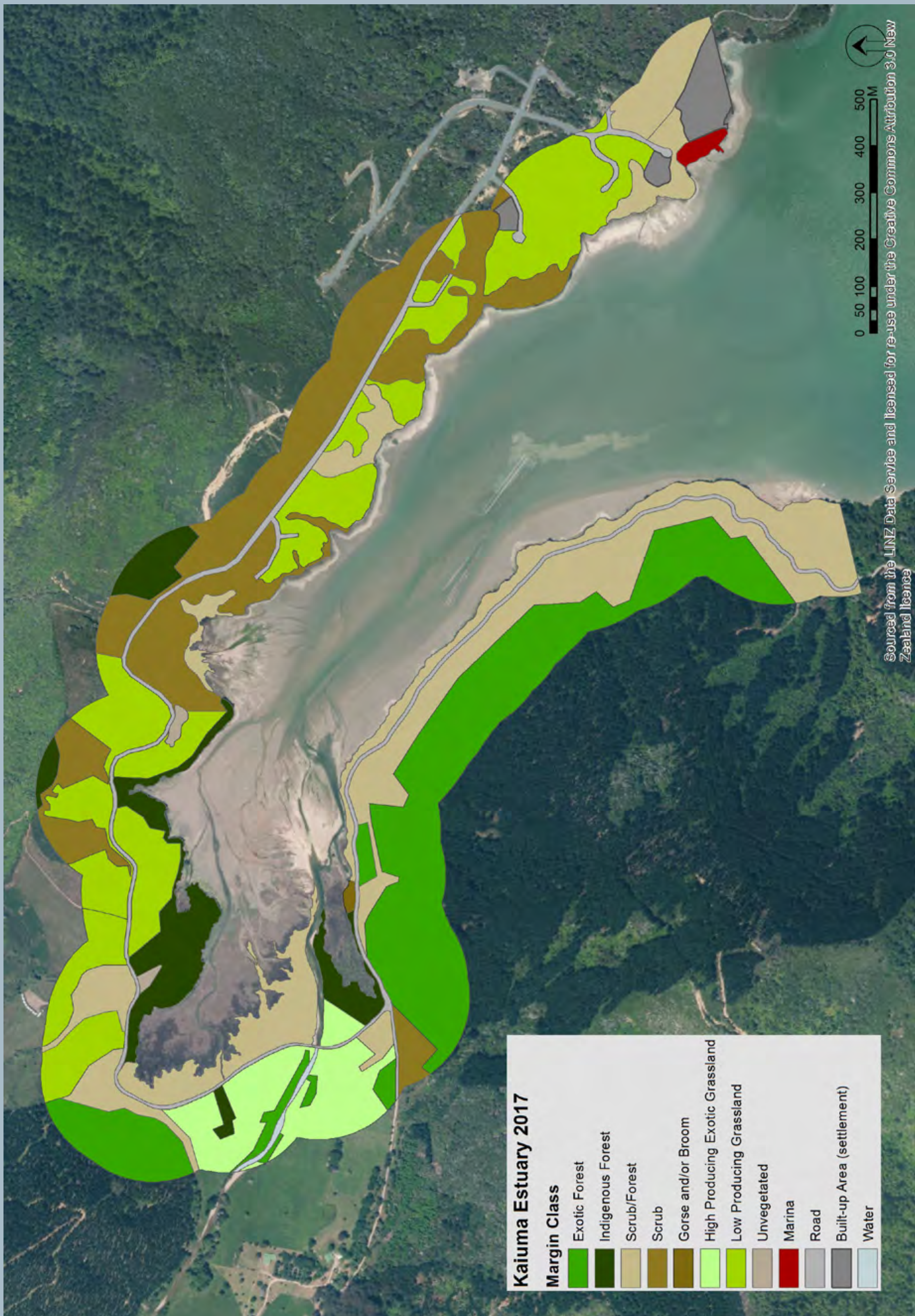


Figure 10. Map of 200m Terrestrial Margin - Dominant Land Cover, Kaiuma Estuary, March 2017.

LCDB3 (2012)	%
Exotic Forest	19.5
Indigenous Forest	59.3
Broadleaved Indigenous Hardwoods	5.8
Manuka and/or Kanuka	7.6
High Producing Exotic Grassland	6.1
Low Producing Grassland	0.2
Built-up Area (settlement)	1.0
Unvegetated	0.5

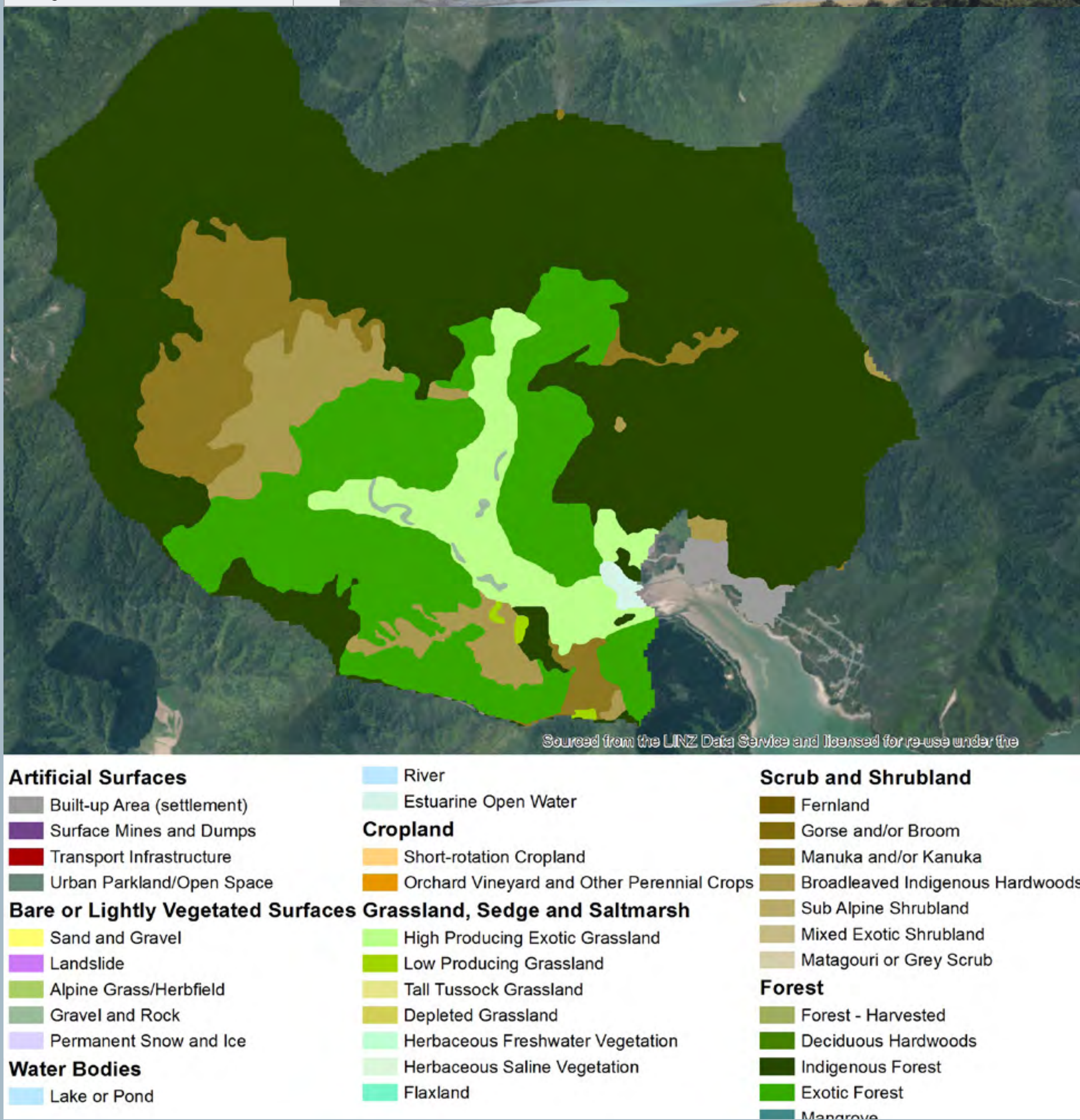


Figure 11. Summary of Catchment Land Cover (LCDB3 2012), Kaiuma Estuary.

4.8. NZ ESTUARY TROPHIC INDEX

The recently developed 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. A key part of the ETI output has been the development of an integrated calculator that enables easy calculation of 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.

From the current broad scale monitoring (this report) Table 8 presents the indicators used to derive an ETI score for the estuary. The physical and nutrient load susceptibility of Kaiuma Estuary has been determined as "MODERATE" based on catchment estimates of nutrient loads derived from NIWAs CLUES model, estuary characteristics sourced from the Coastal Explorer database, and ecological value. The overall ETI score for the estuary is 0.43, a risk rating of LOW for eutrophic symptoms, with high muddiness of the estuary the main driver of the score.

Table 8. Primary and supporting indicator values used to calculate an ETI score for Kaiuma Estuary, March 2017.

	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	1
Required	Macroalgal GEZ/Estuary Area	% Gross Eutrophic Zone (GEZ)	shallow inter-tidal	0
Required	Macroalgal GEZ	Ha Gross Eutrophic Zone (GEZ)	shallow inter-tidal	0
Optional	Phytoplankton biomass	Chl- a (summer 90 pctl, mg/m^3)	water column	-
Optional	Cyanobacteria (if issue identified)		water column	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	-275mV
Required Indicators	Sediment Oxygenation	% of estuary with Redox Potential <-150mV at 3cm	shallow inter-tidal	56%
Required Indicators	Sediment Oxygenation	Ha of estuary with Redox Potential <-150mV at 3cm	shallow inter-tidal	30
Required Indicators	Sediment Oxygenation	% of estuary with apparent Redox Potential Depth <1cm	shallow inter-tidal	-
Required Indicators	Sediment Total Organic Carbon	Mean TOC (%) measured at 0-2cm depth in most impacted sediments and representing at least 10% of estuary area	shallow inter-tidal	-
Required Indicators	Sediment Total Nitrogen	Mean TN (mg/kg) measured at 0-2cm depth in most impacted sediments and representing at least 10% of estuary area	shallow inter-tidal	-
Required Indicators	Macroinvertebrates	Mean AMBI score measured at 0-15cm depth in most impacted sediments and representing at least 10% of estuary area	shallow inter-tidal	-
Required Indicators	Macroinvertebrates	% of estuary with AMBI >4.3	shallow inter-tidal	not yet developed
Required Indicators	Macroinvertebrates	TBI (if toxicity an issue)	shallow inter-tidal	not yet developed
Optional Indicators	Dissolved oxygen	7 day mean, 7 day mean minimum, 1 day minimum (mg/m^3)	water column	not yet developed
Optional Indicators	TN and TP concentration	mg/l - 7 day mean, 7 day mean minimum, 1 day minimum	water column	not yet developed
Optional Indicators	Water Clarity	Secchi or black disc (m)	water column	not yet developed
Optional Indicators	Sediment Sulphur	Requires development	shallow inter-tidal	not yet developed
Optional Indicators	Soft mud	% estuary area with soft mud (>25% mud content)	shallow inter-tidal	72%
Optional Indicators	Soft mud	% mud content (mean of whole estuary area)	shallow inter-tidal	not yet developed
Optional Indicators	Sedimentation Rate	Ratio of current annual mean relative to Natural Sed. Rate (NSR)	shallow inter-tidal	-
Optional Indicators	Sedimentation Rate	% Estuary Area with Sedimentation Rate >5xNSR	shallow inter-tidal	baseline estab.
Optional Indicators	SAV (Seagrass)	Extent (% of ENSC)	all habitat	-
Optional Indicators	SAV (Seagrass)	% change from measured baseline	all habitat	baseline estab.
NZ ETI Score				**0.43**

5. SUMMARY AND CONCLUSIONS

Broad scale habitat mapping undertaken in March 2017, combined with ecological risk 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 29.8ha (72%) of the intertidal area, a risk indicator rating of HIGH, and had a mud content measured in representative areas of 75-92%, a supporting risk indicator rating of HIGH. 29.9ha (56% 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 risk indicator rating of HIGH. Soft muds were concentrated in the lower tidal reaches of the estuary where mud settlement is thought to predominantly reflect the presence of sheltered deposition zones, reduced current flows, trapping within marine farm structures (10ha of intertidal oyster racks) and, to a lesser extent, salinity driven flocculation and the presence of oyster reefs.

Eutrophication

The NZ ETI (Robertson et al 2016a,b) combines a range of broad and fine scale indicators to provide an overall assessment of eutrophic expression in an estuary, including primary productivity through macroalgal growth and phytoplankton, and supporting indicators of sediment muddiness, oxygenation, organic content, nutrients, macroinvertebrates, and the presence of gross eutrophic zones (a combined presence of dense macroalgal growth, muds and poor sediment oxygenation). The overall ETI score for Kaiuma Estuary in March 2017 was 0.43, a risk rating of LOW for eutrophic symptoms.

Habitat modification

Historical losses of saltmarsh appear low (<20%) and extensive rushland and herbfield-dominated saltmarsh remained in the estuary (11.4ha, 22% of the intertidal area). The estuary supported one very small seagrass bed (0.02ha, 0.03%) which was clearly stressed from fine mud deposition. The 200m terrestrial margin had a relatively large densely vegetated buffer - 47% native scrub and forest, 20% plantation forest. Other land cover comprised 20% unmaintained grassland, 6% pasture, and 6% developed (road, residential/marina). The wider catchment was dominated by indigenous native forest and scrub (73%), exotic forest (20%), high producing grassland (6%), with 1% developed settlements.

Comparison with previous results

Davidson (2005) and (2015) provide limited data on the previous state of estuary habitat. While features were not spatially mapped and therefore cannot be directly compared, it indicates there has been a significant increase in estuary muddiness since 2006, and particularly since 2012. Saltmarsh appears similar, while seagrass is likely to have declined. Future monitoring will determine if these results reflect ongoing trends in broad scale features of the estuary.

The combined results place the estuary in a "MODERATE" state overall in relation to ecological health driven by the very widespread cover and highly muddy sediments that dominate the estuary, an absence of eutrophication issues, and historically small losses of estuary saltmarsh and the densely vegetated terrestrial margin.

6. MONITORING AND MANAGEMENT

Kaiuma Estuary has been identified by MDC as a priority for monitoring because it is a moderate sized estuary with high ecological and human use values. While the immediate catchment is relatively unmodified, the estuary remains vulnerable to external pressures from excessive sedimentation and, to a much lesser extent, eutrophication. As a consequence, it is a key part of MDC's coastal monitoring programme being undertaken throughout the Marlborough region.

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

The present report addresses the inaugural broad scale mapping component of the long term programme. The recommendation for ongoing monitoring for the Kaiuma Estuary is as follows:

Broad Scale Habitat Mapping
To characterise any issues of change in habitat (e.g. soft mud extent, saltmarsh or seagrass area), it is recommended that broad scale habitat mapping be undertaken at 5-10 yearly intervals (next scheduled for consideration in 2022), unless obvious changes are observed in the interim.

Fine Scale Monitoring
To characterise ongoing sediment deposition, it is recommended that sedimentation rate be assessed annually, using sediment plates established as part of the current work.

Because the very high muddiness of the estuary will have already caused significant adverse impacts to the benthic ecology of the estuary, it is almost certain that any fine scale monitoring will simply confirm the presence of a depauperate and highly mud-tolerant benthic community. While quantification of the benthic community present in such situations is a vital component of assessing change over time, in this particular case it is considered a higher priority to first identify the source of the excessive sediment inputs apparent in the estuary, and develop management actions to reduce them. Recently completed work on sediment source tracking undertaken in Kenepuru and Beatrix Bay by NIWA showed plantation forestry contributed disproportionately high sediment loads relative to the catchment area covered by forest, with forestry a significant source of the total sediment input to Pelorus Sound (Handley et al. 2017). Sediment source tracking is underway to identify catchment sources of sediment coming into Havelock, Kaiuma and Mahakipawa estuaries from different land-uses. This will provide robust information on which to base management actions to reduce sediment inputs. Results are due in June 2018.

Once management actions are in place, it is recommended that a robust multi-year fine scale monitoring baseline be established against which future improvements in estuary condition can be assessed.

RECOMMENDED MANAGEMENT
The large spatial extent and high mud content of sediments suggest that management actions are required to minimise ongoing sedimentation in the estuary in order to limit further ecological deterioration. To defensibly address the issue of excessive muddiness and improve the condition of the estuary, it is recommended that the following management options be considered:

- Determine the relative input of sediment from dominant catchment land uses and apply relevant sediment guideline criteria for the estuary (e.g. under development ANZECC guidelines) to determine the magnitude of any changes required to maintain healthy estuary functioning. This can be readily undertaken using existing catchment models such as CLUES, and extensions incorporating refined sediment yields for specific land use activities e.g. Green et al. (2014).
- Through stakeholder involvement, identify an appropriate "target" estuary condition and determine any catchment management changes needed to achieve the target.
- Using the results of the above investigations, and other appropriate monitoring data, identify sediment input load guideline criteria that will reduce fine sediment infilling to the target state, and develop a plan to achieve such targets. For example, ensuring Best Management Practices (BMPs) are being implemented within the catchment, and contributing upstream catchments. This step may require additional detailed investigation of fine sediment sources, transport, deposition and export within the estuary, to provide underpinning information on which to base management decisions.

Overall, the step-wise approach presented above is intended to cost effectively address the source of sediment, identify management targets, and guide management to help ensure that the assimilative capacity of the estuary is not exceeded so that the estuary can flourish and provide sustainable human use and ecological values in the long term.

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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.

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 and Appendix 2), 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.

As a baseline measure of seagrass presence, a continuous index (the seagrass coefficient - SC) has been developed to rate seagrass condition based on the percentage cover of seagrass in defined categories using the following equation: ***SC=((0 x %seagrass cover <1%)+(0.5 x %cover 1-5%)+(2 x %cover 6-10%)+(3.5 x %cover 11-20%)+(6 x %cover 21-50%)+(9 x %cover 51-80%)+(12 x %cover >80%))/100.*** Because estuaries are likely to support variable natural seagrass extents, the SC rating is intended to highlight estuaries with low seagrass cover for further evaluation (i.e. estimate natural seagrass cover to determine current state), and to provide an estuary specific metric against which future change can be assessed. It is not intended that the SC be used to directly compare different estuaries. The "early warning trigger" for initiating management action is a trend of decreasing SC.

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. Two supporting metrics are also proposed: i. % 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. ii. % of available habitat supporting saltmarsh. This assumes that saltmarsh should be growing throughout the majority of the available saltmarsh habitat (tidal area above MHWN), and that where this does not occur, ecological services and habitat values are reduced. 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 or saltmarsh growing over <80% of the available habitat.

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 6. 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, 6 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 which 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). The upper and lower 90% Confidence Intervals for the SE of the EQR are presented in this report.

APPENDIX 4. DETAILS OF ANALYTICAL METHODS

Sediment Indicator	Laboratory	Method	Detection Limit
Grain Size	R.J Hill	Wet sieving, gravimetric (calculation by difference)	0.1 g/100g dry wgt

APPENDIX 5. SEDIMENT MONITORING DETAILS

Grain size results from representative sediments, Kaiuma Estuary, 2017.

Broad Scale Classification	Site #	% mud	% sand	% gravel	NZTM EAST	NZTM NORTH
Very Soft Mud	1	92.3	7.6	< 0.1	1667543	5434065
Very Soft Mud	2	91.8	8.0	0.3	1667294	5434257
Very Soft Mud (sed plate Site A)	3	75.1	24.7	0.2	1666657	5434635
Very Soft Mud	4	87.9	11.9	0.2	1667084	5434005
Very Soft Mud (sed plate Site B)	5	94.8	5.1	<0.1	1667007	5434083

See Figure 6 for site locations.

Location and depth of sedimentation rate monitoring sites, Kaiuma Estuary, 2017.

Site A Sed Plates	NZTM EAST	NZTM NORTH	26/4/2017	
Peg 1	1666662	5434638	+100	VSM - Very Soft Mud (75% mud)
Plate 1 @2m	1666660	5434635	-50	
Plate 2 @4m	1666658	5434633	-63	
Peg 2	1666657	5434635	+100	
Plate 3 @6m	1666657	5434632	-62	
Plate 4 @8m	1666656	5434630	-74	
Peg 3	1666655	5434630	+100	
Site B Sed Plates	NZTM EAST	NZTM NORTH	26/4/2017	
Peg 1	1667013	5434079	+100	VSM - Very Soft Mud (95% mud)
Plate 1 @2m	1667010	5434079	-110	
Plate 2 @4m	1667008	5434082	-82	
Peg 2	1667007	5434083	+100	
Plate 3 @6m	1667007	5434086	-94	
Plate 4 @8m	1667005	5434086	-109	
Peg 3	1667003	5434087	+100	