Rangitīkei Estuary 2018
Broad Scale Habitat Mapping

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Rangitikei Estuary 2018

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Cover Photo: Lower Rangitikei Estuary, January 2018.

Intertidal flats in the lower estuary, January 2018

Rangitikei Estuary 2018

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by

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RANGITIKEI ESTUARY - EXECUTIVE SUMMARY

The Rangitikei Estuary is a relatively large (118ha), shallow, generally well-flushed, macrotidal (>1.8m tidal range), low susceptibility, shallow short residence time tidal river estuary (SSRTRE) located near Tangimoana ~40km south of Whanganui. The lower estuary supports 79ha of intertidal habitat with the mouth always open to the sea. Based on LCDB4 (2012/13) data the upper catchment is dominated by native forest, scrub and tussock (35%) and the lower catchment by sheep and beef farming (54%), with dairy farming (4%, ~42,400 cows) also significant.
The estuary is part of Horizon Regional Council's (HRC) coastal State of the Environment monitoring programme. This report presents the 2018 broad scale estuary habitat mapping results, risk indicator ratings, overall estuary condition, and monitoring and management recommendations as summarised below.

BROAD SCALE RESULTS

- Intertidal flats comprised 43% of the estuary, subtidal waters 33%, and saltmarsh 24%.
- Intertidal substrates were dominated by firm muddy sand (56%), soft/very soft mud (26%), firm sand (17%), and built features e.g. artificial boulder fields, seawalls etc. (<1%). The soft mud risk rating was HIGH.
- Sediment mud content measured within mud habitat was 25-78%, a risk rating of HIGH.
- Sediment oxygenation was depleted (aRPD <1cm deep) in most soft mud habitat (13ha), a risk rating of HIGH.
- Opportunistic macroalgal growth was sparse (<5% of the available intertidal habitat), an overall Ecological Quality Rating of "GOOD", phytoplankton (chl-*a*) was low (90th percentile <5ug/L, 33/40 monthly measures below detection), and no gross eutrophic zones (entrained high biomass growths and degraded sediments) were observed, all risk ratings of LOW.
- No seagrass (*Zostera muelleri*) was present in intertidal areas.
- Saltmarsh was present across 29ha (36%) of the intertidal area, a risk rating of LOW, with rushland (70%) and sedgeland (21%) dominant. Estimated historical losses of >50% have a risk rating of MODERATE. The combined risk rating is MODERATE.
- The 200m terrestrial margin was 15.5% densely vegetated, a risk rating of HIGH. Grassland and pasture were the dominant cover (49%), with coastal duneland also significant (25%).

ESTUARY CONDITION AND ISSUES

In relation to the key issues addressed by the broad scale monitoring (i.e. sediment, eutrophication, and habitat modification), the 2018 results show that extensive historical habitat modification has degraded saltmarsh and terrestrial margin habitat, and that due to elevated muddiness there is a moderately high risk of adverse impacts to estuary ecology occurring. Nutrient inputs to the estuary are high but are not resulting in nuisance macroalgal growths, most likely due to strong flushing of nutrients directly to the open sea. The ETI score for the estuary (0.4) placed it in Band B GOOD category.

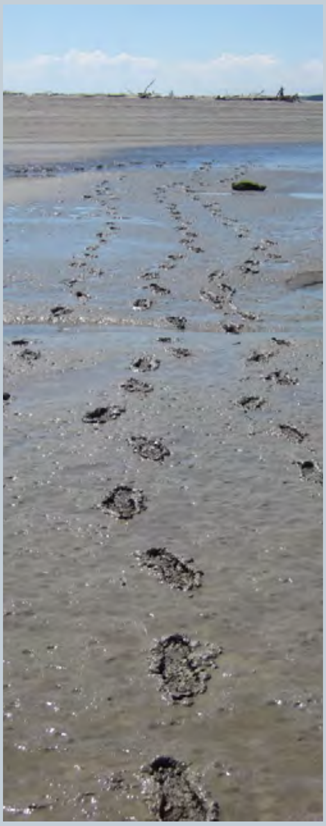
The combined results place the estuary in a MODERATE state overall in relation to ecological health with fine sediment issues evident in the estuary, and significant historical modification and loss of estuary saltmarsh around the margins.

RECOMMENDED MONITORING AND MANAGEMENT

Rangitikei Estuary has been identified by HRC as a priority for monitoring because of its high ecological and human use values. It has been assessed as having a low susceptibility to eutrophication and a moderate susceptibility to excessive fine sediment inputs reflecting its highly flushed nature. Recommendations are to:

- Repeat broad scale habitat mapping every 10 years, focussing on the main issue of fine sediment.
- Track and map key broad scale changes in catchment landuse (~5 yearly).
- Evaluate the potential for pest plants like the giant reed *Phragmites karka* to spread and consider removal or containment strategies as appropriate.
- Undertake a desktop assessment of the vulnerability of inshore coastal habitats from river plume discharges as the vast majority of water borne catchment derived stressors (nutrients, sediment, and disease causing organisms) are flushed directly to the coast. If issues are present, identify the potential sources of stressors and management options.

1. INTRODUCTION



Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. A long-term objective of the Horizons Regional Council (HRC) is to incorporate all significant estuaries within their State of Environment monitoring framework through implementation of the NZ National Estuary Monitoring Protocol (NEMP, Robertson et al. 2002). While the region's estuaries have received relatively little attention, the Department of Conservation funded broad scale habitat mapping of the Whanganui Estuary in 2009 (Stevens and Robertson 2009), and in late 2015 HRC commissioned an Ecological Vulnerability Assessment for the majority of the estuaries within the region to assess sediment and eutrophication risks, map dominant habitat features, and provide the Council with defensible monitoring recommendations and priorities (Robertson and Stevens 2016).

In recognition of the high ecological and human use values of the Rangitikei Estuary, HRC subsequently commissioned detailed broad scale habitat mapping which was undertaken in January 2018.

The estuary monitoring process consists of three components developed from the NEMP (see Robertson et al. 2002 for original programme design, and subsequent extensions for fine scale monitoring (see Robertson and Stevens 2015) and broad scale habitat mapping (see Stevens and Robertson (2015) as follows:

1. **Ecological Vulnerability Assessment** (EVA) of the estuary to major issues (see Table 1) and appropriate monitoring design. This component has been partially undertaken (includes assessment of vulnerabilities to sediment and eutrophication only but excludes other coastal resources and pressures), and is reported on in Robertson and Stevens (2016).
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. Preliminary mapping was undertaken in 2016 (Robertson and Stevens (2016) and the current report describes more detailed mapping undertaken in Rangitikei Estuary in January 2018.
3. **Fine Scale Monitoring** (NEMP approach). Monitoring of physical, chemical and biological indicators (see Table 1). This component, which provides detailed information on the condition of an estuary (initially across a three year baseline), 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 broad scale mapping of the following components:

- substrate types
- sediment oxygenation
- macroalgal beds (i.e. *Ulva* (sea lettuce), *Gracilaria*)
- seagrass (i.e. *Zostera muelleri*)
- gross eutrophic zones (GEZs)
- saltmarsh vegetation
- 200m terrestrial margin land cover

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).

RANGITIKEI ESTUARY OVERVIEW

The Rangitikei Estuary is a relatively large (118ha), shallow, generally well-flushed, macrotidal (>1.8m tidal range), low susceptibility, shallow short residence time tidal river estuary (SSRTRE) located near Tangimoana ~40km south of Whanganui. The Rangitikei, the 6th largest river in the North Island, has a large freshwater inflow ($76m3.s^{-1}$) which, when combined with the marine inflow, has a tidal influence that likely extends 3-4 kilometres inland. Both the river and estuary have been significantly modified with defined river channels and flood protection works, although the lower reaches of the estuary have large intertidal flats.

Despite the historical modification of the estuary margins (primarily channelisation and drainage) saltmarsh is still relatively plentiful. The estuary mouth is always open to the sea. The large estuary catchment ($3933km^2$) rises in the interior of the central North Island bounded by the Kaimanawa ranges in the north and west, and the Kaweka ranges in the northeast and east. The geology of the upper catchment is predominantly older hard greywacke with increasingly younger and more erodible sediment in the lower catchment evident in the river canyons and mudstone bluffs that characterise the river.

Catchment land cover in the upper catchment is predominantly tall tussockland and sub alpine shrubs (16%), native forest (13%) and smaller extents of mixed scrub and shrub (6%). The lower catchment is dominated by sheep and beef farming (54%), with dairy farming (4%, 42,389 cows) and exotic forest (3%).

The estuary is a high use area valued for its aesthetic appeal, bathing, boating, fishing, whitebaiting and beach access. Ecologically it is important for freshwater fish and birds. Because the natural vegetated margin is mostly lost and much of the upper estuary channelised or drained, habitat diversity is relatively low. A large coastal dune system supports a range of native species and is relatively intact but is under threat from exotic weeds.

The estuary has a high nutrient load (estimated catchment N areal loading of $4,900mgN.m^{-2}.d^{-1}$ exceeds the guideline for low susceptibility tidal river estuaries of $\sim2000mgN.m^{-2}.d^{-1}$, Robertson et al. 2016), but despite this the estuary has low susceptibility to eutrophication. This is primarily because of its highly flushed nature, given that it is strongly channelised with very few poorly flushed areas, has high freshwater inflow, is strongly affected by tidal currents and is often turbid. The presence of elevated chlorophyll a concentrations at times are likely attributable to freshwater sources upstream of the estuary.

The current suspended sediment load (CSSL) is likely to be ~10 times the estimated natural state SS load (NSSL), however the estuary is rated as only moderately vulnerable to muddiness issues as it is well-flushed, although some areas are susceptible to localised sediment accumulation.

Saltmarsh (three square) in the southern arm in front of terrestrial grassland dominated by tall fescue, January 2018

Figure 1. Rangitikei Estuary, showing main estuary zones.

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,
- direct physical effects e.g. gill abrasion in fish, compromised filter feeding (invertebrates including shellfish, and prey sighting (fish and birds),
- 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, polychlorinated biphenyls (PCBs), endocrine disrupting compounds, and pesticides. Microbeads and plastics are a recently recognised concern. 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 shell-fish 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.

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 analyses.
- 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 Rangitikei 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 (RPmV) 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*	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 (in prep.), Keeley et al. (2012), See NOTES in Appendix 4 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 ~2010 were sourced from ESRI online, laminated (scale of 1:3,000), and used by experienced scientists who walked the area in January 2018 to ground-truth the spatial extent of dominant vegetation and substrate types. From representative broad scale substrate classes, 8 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 2. Macroalgae was 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 conditions 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 exceeded 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 Appendix 2, 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 - 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*), 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).

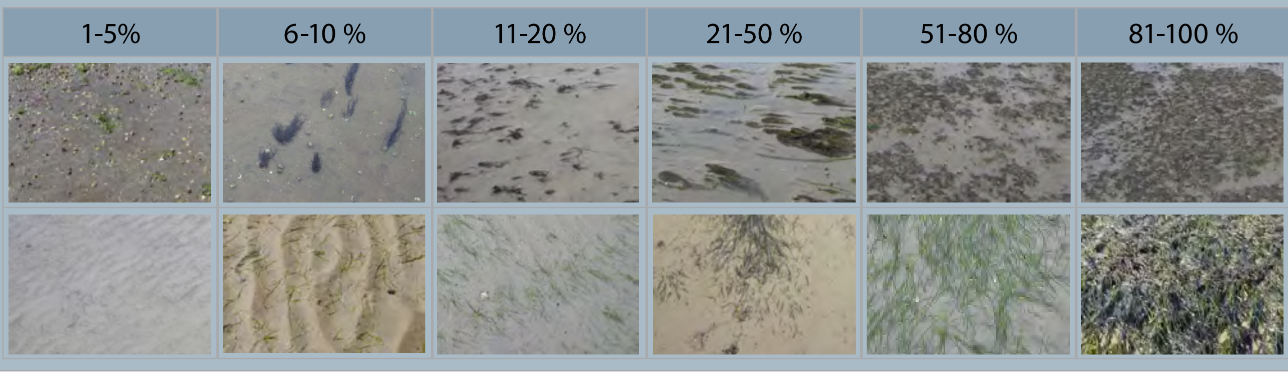


Figure 3. Rangitikei Estuary - mapped estuary extent showing ground-truthing coverage, location of grain size samples used to validate substrate classes, and location of field photos.

4. RESULTS AND DISCUSSION

4.0. 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 six dominant estuary features summarised in Table 3.

The estuary is a moderately large, intertidally dominated (67%) highly modified tidal river estuary. Intertidal areas are relatively narrow in the upper estuary and expand into wide intertidal flats in the lower estuary near the sea, including perched tidal flats running parallel to the shore behind coastal dune systems (Figure 3). Tidal seawater intrusion is confined to the lower reaches of the estuary (the area mapped), but the seawater influence is expected to extend for several kms upstream as freshwater flows back up at high tide. The perched northern arm behind the coastal dune receives seawater flows only on spring tides, while the low-lying terrestrial flats in the central estuary appear to be only infrequently inundated during flood events or when freshwater floating on top of denser seawater reaches those areas on spring tides. The estuary mouth regularly shifts its position depending on prevailing coastal conditions and particularly river flows with flood discharges often carving a channel directly to sea.

Despite extensive historical drainage and reclamation, the estuary still supports a large proportion of fringing saltmarsh (36% of the intertidal area). Very little intertidal opportunistic macroalgae was present in January 2018, and there was no intertidal seagrass or gross eutrophic zones identified (these latter two indicators not discussed further in the report). Fifteen percent of the 200m wide terrestrial margin had a dense cover of buffering vegetation (e.g. shrubs and trees). The dominant terrestrial margin cover was undeveloped grassland (31%) and pasture (18%).

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, in future, to compare changes from the mapping baseline established.

Table 3 provides a high level summary of the 2018 mapping results. In the following sections, various factors related to each of these key habitats (e.g. area of soft mud, sediment oxygenation, saltmarsh extent) 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 Rangitikei Estuary, 2018.

Dominant Estuary Feature		2018		
		ha	% intertidal	% estuary
1.	Intertidal flats (excluding saltmarsh)	50.8	64%	43%
2.	Opportunistic macroalgal beds (>50% cover) [on intertidal flats]	-	-	-
3.	Seagrass (>20% cover) [on intertidal flats]	-	-	-
4.	Saltmarsh	28.7	36%	24%
5.	Subtidal waters	38.5	-	33%
Total Estuary		**118**		**100%**
6.	200m wide vegetated Terrestrial Margin (e.g. scrub, forest)			15.5%

4.1. INTERTIDAL SUBSTRATE (EXCLUDING SALTMARSH)

Results (summarised in Table 4 and Figure 4) show substrates on intertidal flats in 2018 were dominated by firm muddy sand (56%), soft/very soft mud (26%), firm sand (17%), and small areas of artificial boulder fields/seawalls etc (<1%) and gravel field (<1%). The majority of the firm muddy sands were located in the main river channel and indicated that river borne sediment is deposited in this area, but does not persist, likely due to regular river flushing. Soft muds were confined largely to narrow bands along the lower tidal edges of the river channels in the upper estuary, and on the lower margins of wider tidal flats in parts of the lower estuary, particularly where river flows entered blind channels with limited flushing.

The settlement of muds along upper estuary channel margins and lower tidal flats predominantly reflects salinity driven flocculation combined with a hydrodynamic boundary where fine sediment settlement is promoted by reductions in freshwater flow velocities, particularly where river flows enter the wider lower estuary. The relatively low incidence of muds in the lower estuary is thought to primarily reflect strong river and tidal flows which limit settlement and facilitate the export of fine sediments to the coast. However, it is also obvious within Rangitikei Estuary that fine sediment inputs are spatially and temporally variable with regular floods both delivering and flushing large quantities of material from the estuary. Sediments within saltmarsh was dominated by firm muddy sands. Mud content appeared relatively high, but sediments were firm largely due to the sediments being relatively well drained and able to dry out.

Near the coast there was a strong marine influence with clean sands being dominant. This general pattern, where mud-dominated sediments in the upper estuary transition to marine sand dominated sediments in the lower estuary, is a common feature within tidal river estuaries.

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

Dominant Substrate	Intertidal Flats		Within Saltmarsh		Total Estuary	
	Ha	%	Ha	%	Ha	%
Boulder field man-made	0.01	0.03			0.01	0.02
Gravel field	0.3	0.6			0.3	0.4
Firm muddy sand	28.4	56.0	23.1	80.5	51.6	64.8
Firm sand	8.8	17.2	0.04	0.1	8.8	11.1
Firm mud	0.1	0.3	3.2	11.1	3.3	4.2
Soft mud	10.8	21.2	2.4	8.3	13.1	16.5
Very soft mud	2.4	4.8		0.0	2.4	3.0
Grand Total	**50.8**	**100.0**	**28.7**	**100.0**	**79.6**	**100.0**

In order to validate that NEMP substrate classifications are applied correctly, it is common to undertake synoptic sampling within representative sand and mud substrate classes. While data from a range of NZ estuaries indicates that soft mud habitat is nearly always associated with mud contents >25% (Robertson et al 2016b), drying of sediments, or the presence of stabilising features e.g. gravels, can result in sediments that are firm to walk on but have a mud content >25%. To this end Table 5 presents the results of grain size analyses within dominant substrate classes. It shows that sediments classified as muddy using the NEMP protocol in this estuary had measured sediment mud contents ranging from 25-78%, and confirmed that some areas of the Rangitikei Estuary can have a high mud content while remaining relatively firm to walk on. Not surprisingly there was also a common trend for sediment oxygenation to decrease as mud content increased.

Table 5. Grain size results from representative sediments, Rangitikei Estuary, 2018.

Broad Scale Classification	Site[1]	% mud	% sand	% gravel	NZTM East	NZTM North	aRPD depth (cm)
Firm MUDDY sand	4	24.7	73.2	2.1	1789677	5537657	1
Firm MUDDY sand	8	26.2	73.6	0.1	1789592	5536787	2
Very Soft MUD	1	38.5	60.0	1.5	1789333	5536805	0.5
Very Soft MUD	5	39.1	58.7	2.2	1789273	5536652	0.5
Firm MUD	7	46.3	52.5	1.2	1789883	5536580	1
Very Soft MUD	3	48.9	49.8	1.3	1789109	5537583	1
Firm MUD	2	75.0	24.1	0.8	1789476	5536760	0.5
Very Soft MUD	6	78.2	21.3	0.4	1789296	5537598	0.5

[1]sites shown in Figure 3.

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

4. RESULTS AND DISCUSSION (CONTINUED)

4.2. SOFT MUD EXTENT

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. Figure 4 and Table 4 shows that soft or very soft muds covered 13.2ha (26%) of the intertidal area, a risk indicator rating of HIGH, and had a mud content measured in representative areas of 25-78%, a supporting risk indicator rating of HIGH (Table 5). Within the dominant firm muddy sand substrate of the estuary, grain size is likely to reflect a LOW-MODERATE risk rating (<25% mud content).

Based on the relatively high area of mud-dominated substrate relative to the overall unvegetated intertidal estuary habitat and the elevated mud content measured in sediments in these areas, the overall risk of detrimental impacts to estuarine biota from muds was assessed as HIGH. It was also noted that water clarity appears regularly to be low, indicating sediment related impacts are also present in subtidal areas and that sediment has the capacity to rapidly accumulate where flushing is restricted such as in the blind channel of the old estuary entrance.

Re-suspended muds in the shallow subtidal main channel

Soft muds in the blind channel of the old entrance

4.3. SEDIMENT OXYGENATION

The primary indicators used to assess sediment oxygenation are aRPD depth and RP measured at 3cm. At representative sites throughout the dominant sand and mud substrate of the estuary, aRPD was assessed and from these results broad boundaries have been drawn where sediment oxygen is depleted to the extent that adverse impacts to macrofauna (sediment and surface dwelling animals) are expected, i.e. aRPD <0.5cm deep (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 most estuary sediments are well to moderately well oxygenated and appeared in good (healthy) ecological condition, with the aRPD depth at 2-5cm (i.e. RP above -150mV at 3cm) in most sand and gravel dominated sediments. Intertidal soft mud areas (13ha, 26%) were identified as having depleted sediment oxygen, an overall estuary risk rating of HIGH.

Figure 5. Map of areas with low sediment oxygenation - Rangitikei Estuary, 2018.

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 become 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 ‹5% in January 2018 with <0.2ha of the green alga *Ulva lactuca* (sea lettuce) present in a blind channel near the coast growing at a density of ~500g/m^2 (see Figure 6, photos below). The macroalgae EQR was therefore HIGH, and the risk rating LOW. Shallow subtidal growth of *Ulva* adjacent to this area covered ~0.3ha at a density of ~1500g/m^2.

Synoptic measures of phytoplankton growth taken during the 2018 broad scale assessment recorded chlorophyll *a* concentrations ranging from 0.2-1.1 ug/L in subtidal waters, with no indication of stratification on the day of sampling. These results are consistent with monthly sampling undertaken by HRC from Jan. 2015-April 2018 of which 33 of 40 samples were below detection (i.e. <2ug/L) with a 90th percentile value of <5ug/L, an ETI risk rating of VERY LOW (Band A).

These results indicate that despite high catchment nutrient loadings, nutrient inputs appear to be efficiently flushed directly to sea, such that any consequences of excessive nutrient inputs are likely to manifest in the nearshore coastal environment rather than within the estuary. The lack of algal growth observed is likely driven by strong flushing of the estuary, low salinity conditions dominating throughout most of the upper estuary, and poor clarity and regular river freshes that limit the conditions under which intertidal nuisance macroalgal growth can establish.


Ulva **growing in the blind channel of the old entrance, southern arm, January 2018**

4.5. 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.

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 29ha (36%) of the intertidal estuary area, a risk indicator rating of VERY LOW.

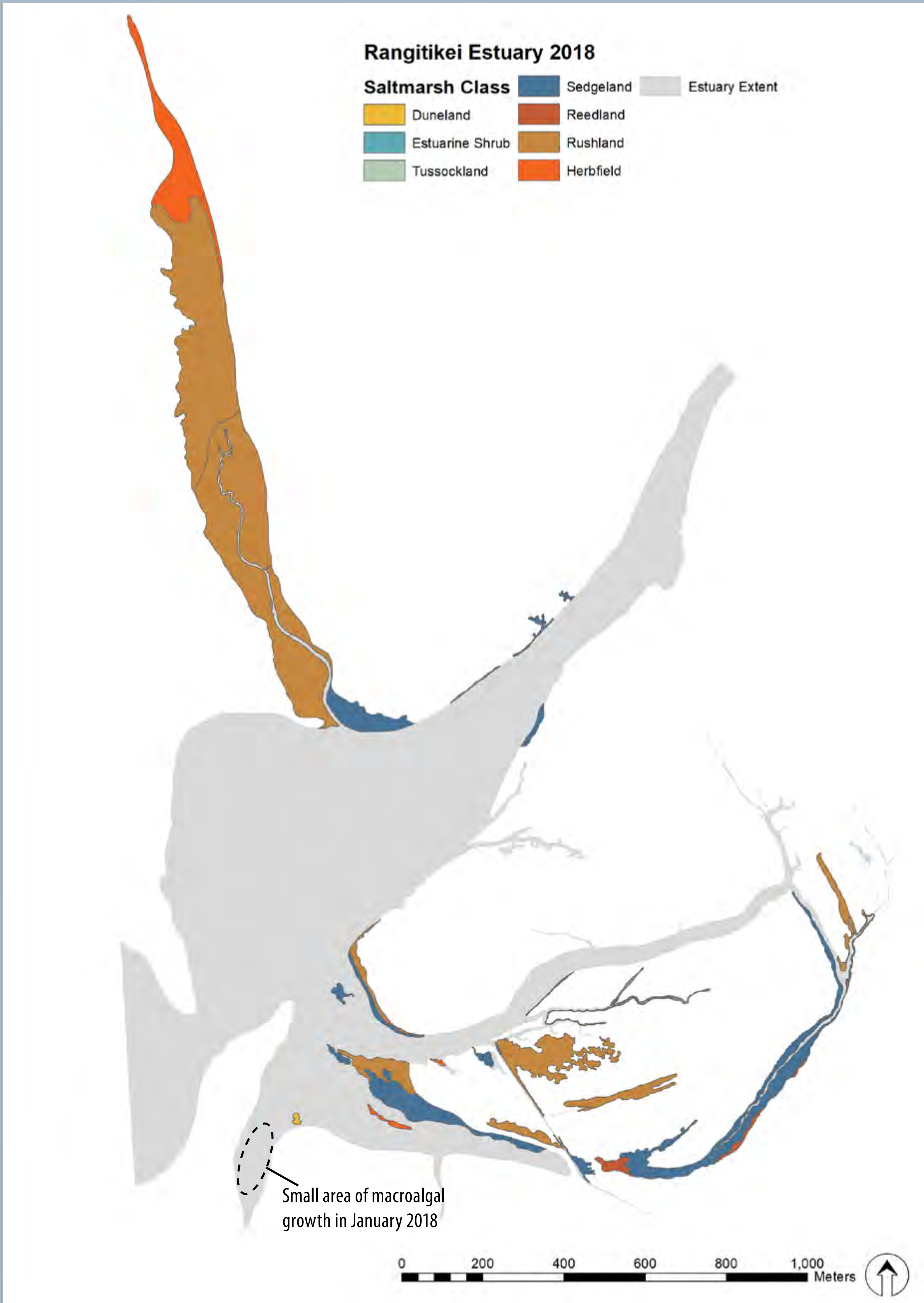


Figure 6. Map of dominant saltmarsh cover - Rangitikei Estuary, 2018.

Saltmarsh was dominated by rushland (70%) and sedgeland (21%) located predominantly in the northern and southern arms. Sedgeland dominated along the river margins and comprised species that favour freshwater e.g. *Schoenoplectus* spp. (three square, lake clubrush) while the parts of the estuary slightly higher in the tidal elevation were dominated by rushland (*Juncus kraussii* - sea rush) often with a sub dominant cover of herbfield species. The most extensive area of rushland dominated habitat was in the northern arm where the perched arm of the estuary extends for over 1km at 90^{o} to the main river channel. This area is generally only inundated on spring tides and has a contiguous connection with the coastal dune system making it a regionally rare and important feature. It is also an area subjected to disturbance from vehicle use for access to the outer coast, and because of the relatively infrequent inundation, weed ingress at the terrestrial margins. In the southern arm, the saltmarsh is relatively patchy due to extensive historical drainage of the upper estuary. There is a broad transition to wetland plants in the upper tidal reaches where freshwater dominates over saline water. Most vegetation is confined to channel edges, and much of the remaining saltmarsh is impacted by terrestrial weeds and grasses. A prominent weed is the giant reed *Pragmites karka* which has established in several patches throughout the upper estuary and within terrestrial grassland. Large quantities of driftwood are periodically deposited in saltmarsh.

While beyond the scope of the current work to map the historical estuary extent, drainage and re-contouring of extensive areas of low lying land for flood control and pastoral farming suggest that natural state saltmarsh cover has likely been reduced by >50%. Historic saltmarsh losses have been ascribed a MODERATE risk rating. The combined saltmarsh ratings are ascribed an overall risk rating of MODERATE, reflecting the relatively large area of saltmarsh in the estuary, but likely high historical saltmarsh losses.

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

Saltmarsh Class, Dominant and subdominant species	Ha	%
Duneland	0.04	0.1
Spinifex sericeus (Silvery grass)		
Calystegia sepium (Pink bindweed)	0.04	
Reedland	0.38	1.3
Phragmites karka	0.17	
Typha orientalis (Raupo)	0.21	
Sedgeland	5.90	20.5
Cyperus eragrostis (Umbrella sedge)		
Apodasmia similis (Jointed wirerush)	0.15	
Schoenoplectus pungens (Three-square)	0.46	
Juncus kraussii (Searush)	2.36	
Apodasmia similis (Jointed wirerush)	0.09	
Ficinia (Isolepis) nodosa (Knobby clubrush)	0.95	
Samolus repens (Primrose)	1.41	
Schoenoplectus tabernaemontani (Lake clubrush)	0.17	
Schoenoplectus tabernaemontani (Lake clubrush)	0.31	
Rushland	20.01	69.6
Juncus kraussii (Searush)	0.29	
Apodasmia similis (Jointed wirerush)		
Festuca arundinacea (Tall fescue)	1.72	
Festuca arundinacea (Tall fescue)	0.78	
Schoenoplectus pungens (Three-square)	0.41	
Schoenoplectus pungens (Three-square)		
Apodasmia similis (Jointed wirerush)	1.03	
Selliera radicans (Remuremu)		
Samolus repens (Primrose)	15.78	
Herbfield	2.42	8.4
Sarcocornia quinqueflora (Glasswort)		
Juncus kraussii (Searush)	0.02	
Selliera radicans (Remuremu)		
Samolus repens (Primrose)		
Juncus kraussii (Searush)	2.39	
Grand Total	28.74	100


Driftwood overlying saltmarsh in the southern arm


Searush and knobby clubrush growing along the stopbank edge in the southern arm. Tall fescue grassland in the background


Searush and herbfield in the northern arm. Coastal duneland in the background


Searush and jointed wire rush in the northern arm

Three square growing along the stopbank edge in the southern arm. Tall fescue dominated grassland in the background

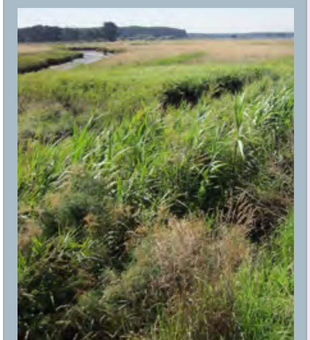
Phragmites karka (1-2m high) growing along the stopbank edge in the southern arm.

Phragmites karka (foreground) and three square growing along the channel edge in the southern arm.

P. karka growing among three square in the northern arm.

4.6. 200m TERRESTRIAL MARGIN




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 water temperature fluctuations (in shallow side arms), and improves estuary biodiversity. The results of the 200m terrestrial margin mapping of the estuary (Table 7 and Figure 7) showed:

- Dense buffering vegetation covered 15.5% of the 200m margin - comprising a mix of native and exotic scrub and forest.
- Duneland (25%) was also extensive but provided limited terrestrial buffering of the estuary as it is located almost exclusively on the outer coast.
- The remaining 200m wide terrestrial margin buffer comprised a mix of grassland (31%), pasture (18%) residential areas (3%), or unvegetated sands (7%).

The most ecologically significant areas of margin vegetation were the coastal dunes on both sides of the river mouth, supporting the native sand-binders spinifex (*Spinifex sericeus* - Silvery grass) and pingao (*Desmoschoenus spiralis*), a feature now lost from most NZ dune systems due to displacement by exotic grass species and invasive weeds. These dune systems play a vital role in coastal protection and provide important habitat for many rare native plants and animals. Figure 8 summarises land use within the large (3933km^2) estuary catchment based on LCDB4 (2012/13) land cover and highlights the dominance of high producing grassland (54%) and some exotic forest (3%) predominantly in the lower catchment, with tall tussockland and sub alpine shrubs (16%), native forest (13%) and smaller extents of mixed scrub and shrub (6%) predominantly in the upper catchment. Built-up areas (settlements) comprise 0.5% of the catchment.

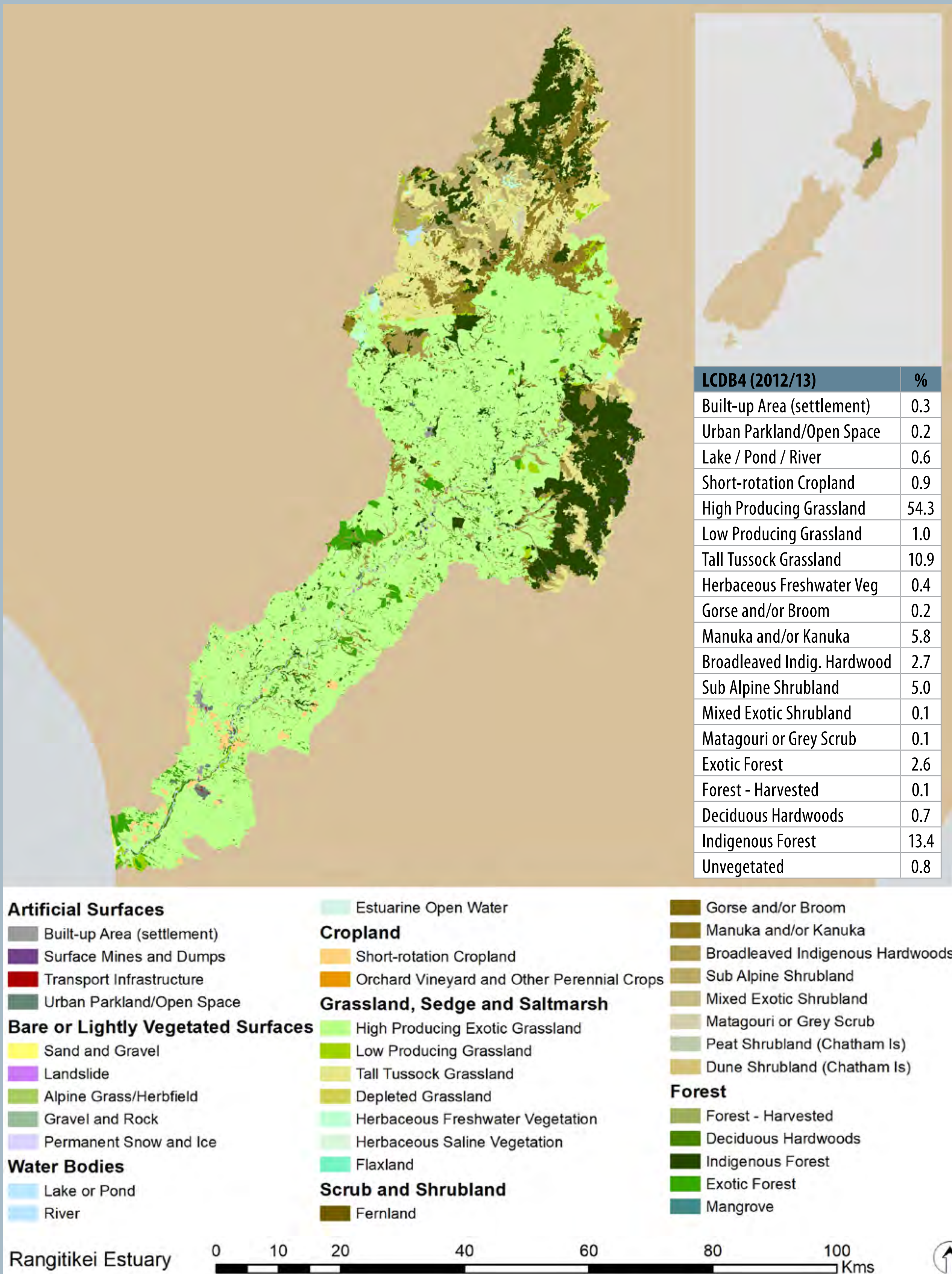
The extent of densely vegetated 200m terrestrial margin habitat (15.5%) will provide some buffering against adverse ecological degradation (e.g. localised sediment and nutrient input mitigation). However, in the Rangitikei Estuary, a risk indicator rating of HIGH has been applied for the following reasons:

- The influence of the 200m terrestrial buffer around the estuary is likely to be small because the large catchment size means most sediment and nutrient inputs to the estuary will originate from upstream river sources as opposed to localised sources directly adjacent to the estuary.
- Much of the lower estuary has been extensively modified and is confined within floodbanks with virtually no intact native vegetation remaining. Consequently, natural ecological gradients have been significantly disrupted, biodiversity is relatively low, and exotic species are common.

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

Class	Dominant features	Percentage
Forest	Exotic pine plantations	0.9
Scrub/Forest	Mixed cover predominantly flanking duneland in the northern arm	9.4
Scrub	Native and exotic scrub flanking duneland to the south of the estuary	5.2
Grassland	Largely un-managed grassland where saltmarsh drained historically	31.1
Pasture	High quality pasture on both sides of the upper estuary	18.1
Residential	Small areas at Scotts Ferry and Tangimoana	3.4
Duneland	Along the coastal fringe	25.2
Unvegetated	Mobile sands on the coastal dunes near the entrance.	6.8
Total		**100**

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



LCDB4 (2012/13)	%
Built-up Area (settlement)	0.3
Urban Parkland/Open Space	0.2
Lake / Pond / River	0.6
Short-rotation Cropland	0.9
High Producing Grassland	54.3
Low Producing Grassland	1.0
Tall Tussock Grassland	10.9
Herbaceous Freshwater Veg	0.4
Gorse and/or Broom	0.2
Manuka and/or Kanuka	5.8
Broadleaved Indig. Hardwood	2.7
Sub Alpine Shrubland	5.0
Mixed Exotic Shrubland	0.1
Matagouri or Grey Scrub	0.1
Exotic Forest	2.6
Forest - Harvested	0.1
Deciduous Hardwoods	0.7
Indigenous Forest	13.4
Unvegetated	0.8

Figure 8. Summary of Catchment Land Cover (LCDB4 2012/13), Rangitikei Estuary.

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.

The indicators used to derive an ETI score for the estuary are presented below using the broad scale monitoring results (this report) with input values used in the online calculator presented in appendix 5. ETI Tool 1 rates the ETI susceptibility of Rangitikei Estuary as Band A "LOW". This is driven primarily by high flushing of the estuary.

The ETI Tool 2 online calculator scores the estuary 0.29, Band B, for eutrophic symptoms, a rating of "GOOD". This is driven primarily by the absence of opportunistic algal growth. Additional parameters that incorporate the influence of muddiness, added by spreadsheet, increase the score to 0.4 but it remains within Band B.

Table 8. ETI scoring summary for Rangitikei Estuary, January 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
Required	Macroalgal GEZ %	% Gross Eutrophic Zone (GEZ)/Estuary Area	shallow inter-tidal	0	0
Required	Macroalgal GEZ Ha	Ha Gross Eutrophic Zone (GEZ)	shallow inter-tidal	0	0
Optional	Phytoplankton biomass	Chl- a (summer 90 pctl, mg/m^3)	water column	2*	2*
Optional	Cyanobacteria (if issue identified) NOTE ETI rating not yet developed		water column	-	-
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	25	25
Required Indicators	Sediment Oxygenation	% of estuary with Redox Potential <-150mV at 3cm or aRPD <1cm	shallow inter-tidal		13
Required Indicators	Sediment Oxygenation	Ha of estuary with Redox Potential <-150mV at 3cm or aRPD <1cm	shallow inter-tidal		22
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		
Optional Indicators	Muddy sediment	Proportion of estuary area with >25% mud content	shallow inter-tidal	0.26	0.26
Optional Indicators	Sedimentation Rate	Ratio of mean annual Current State Sediment Load (CSSL) relative to mean annual Natural State (NSSL)	shallow inter-tidal		~10
Optional Indicators	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	6.8	6.8
NZ ETI Score				**0.29**	**0.40**

* Phytoplankton was not used in calculating the ETI scores presented (available data from a single day of synoptic sampling only).
Measurements from >1m depth in the upper estuary collected on 30/1/18 were <2mg/m^3.
Surface water concentrations throughout the estuary were<1mg/m^3.

5. SUMMARY AND CONCLUSIONS

Broad scale habitat mapping undertaken in January 2018, 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 13.2ha (26%) of the intertidal area, a risk indicator rating of HIGH, and mud content measured in representative areas was 25-78%, a supporting risk indicator rating of HIGH. Soft mud areas also exhibited depleted sediment oxygenation 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 along upper estuary channel margins and lower tidal flats and reflect salinity driven flocculation combined with a hydrodynamic boundary where the settlement of fine sediments is promoted by changes in freshwater flow velocities, particularly where stream and river flows enter the wider lower estuary. Within the dominant firm muddy sand substrate of the estuary, habitat appeared to be healthy, with limited accumulation of muds and good sediment oxygenation.

Eutrophication

The NZ ETI combines a range of broad and fine scale indicators to provide an overall assessment of eutrophic expression in the estuary, including primary productivity through macroalgal growth and phytoplankton, and supporting indicators of sediment muddiness and oxygenation, the presence of gross eutrophic zones (a combined presence of dense macroalgal growth, muds and poor sediment oxygenation), and where available sediment organic content, nutrients, and macroinvertebrate community. The overall ETI score for the estuary (based on available indicators) in January 2018 was 0.40, a risk rating of LOW for eutrophic symptoms.

Nutrient inputs to the estuary are high (N areal load 4900mg.m^{2}.d^{-1}) and exceed the recommended guideline for low susceptibility tidal river estuaries (~2000mgN.m^{-2}.d^{-1}). However, there were no significant nuisance macroalgal growths in deposition zones, most likely due to strong flushing of the estuary where the primary stressors (i.e. fine sediment, nutrients) largely pass directly through the estuary to the open sea, with poor clarity also restricting macroalgal growth.

Habitat modification

Saltmarsh was present across 29ha (36%) of the estuary and was dominated by rushland (70%) and sedgeland (21%) located predominantly in the northern and southern arms. The northern arm has a contiguous connection with the coastal dune system making it a regionally rare and important feature, but is subject to localised vehicle impacts. There is a broad transition to wetland plants in the upper tidal reaches where freshwater dominates over saline water. Most vegetation is confined to channel edges, and much of the remaining saltmarsh is impacted by terrestrial weeds and grasses, including the giant reed *Pragmites karka*. The 200m terrestrial margin had also been highly modified with 15.5% remaining in a densely vegetated buffer, predominantly planted native and exotic trees with the most ecologically significant areas being the coastal dunes on both sides of the river mouth. Grassland and pasture was the dominant cover (49%), a risk indicator rating of HIGH.

The combined results place the estuary in a “MODERATE” state overall in relation to ecological health with fine sediment issues evident in the estuary, and significant historical modification and loss of estuary saltmarsh around the margins.

6. RECOMMENDATIONS

Rangitikei Estuary has been identified by HRC as a priority for monitoring because of its high ecological and human use values. It has been assessed as having a low susceptibility to eutrophication and a moderate susceptibility to excessive fine sediment inputs reflecting current inputs and its highly flushed nature.

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.

6. RECOMMENDATIONS (CONTINUED)

This typically comprises comprehensive broad scale habitat mapping on a 5-10 yearly cycle, targeted annual monitoring where specific issues are identified (e.g. opportunistic nuisance macroalgal growth), and fine scale monitoring comprising 3-4 consecutive years of baseline monitoring, followed by 5 yearly impact monitoring.

Based on the 2018 monitoring results and risk indicator ratings, particularly those related to fine sediment, the following monitoring recommendations are proposed for consideration by HRC:

- Undertake broad scale habitat mapping at 10 yearly intervals, focussing on the main issue of changes to sediment and saltmarsh and a reassessment of the likely risk rating of the estuary.
- Track and map key broad scale changes in catchment landuse (~5 yearly). This is partially achieved by existing land cover assessments e.g. Landcare Research Land Cover Database, but intensification of activities within land use classes may require specific assessment.
- Evaluate the potential for pest plants like the giant reed *Phragmites karka* to spread and consider removal or containment strategies as appropriate.
- As the vast majority of water borne catchment derived stressors (nutrients, sediment, and disease causing organisms) are flushed directly to the coast, undertake a desktop assessment of the vulnerability of inshore coastal habitats from river plume discharges. If issues are present, identify the potential sources of stressors and management options:

As initial guidance, the following management actions could be considered by HRC:

- Determine the relative input of sediment and nutrients from dominant catchment land uses and apply relevant sediment and nutrient guideline criteria for the estuary (e.g. under development ANZECC guidelines or the NZ ETI) to determine the magnitude of any changes required to maintain healthy estuary and coastal functioning. This can be readily undertaken in the first instance using existing catchment models such as CLUES, and extensions incorporating refined sediment or nutrient yields for specific land use activities e.g. Green et al. (2014).
- Through stakeholder involvement, identify an appropriate "target" estuary or coastal 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 Good Management Practices (GMPs) are being implemented within the catchment. This step may require additional detailed investigation of fine sediment sources, transport, deposition and export, to provide underpinning information upon which to base management decisions.
- If the Council determined it a priority to know the previous state of the estuary (was it always muddy or has it become muddier more recently), or wished to relate changes to specific time periods e.g. following Maori or European settlement in the region, or known land clearance events, a range of forensic techniques are available (e.g. radioactive isotopes, lead, carbon, pollen analyses) to assess historical sediment rates.
- Undertake similar assessments for other relevant stressors e.g. toxicants, disease causing organisms, as appropriate.

7. ACKNOWLEDGEMENTS

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APPENDICES

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 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 below. Samples were tracked using standard Chain of Custody forms and results were checked and transferred electronically to avoid transcription errors.

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

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).

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Certificate of Analysis

SPv1

Client:	Salt Ecology Limited	**Lab No:**	1918468
Contact:	Leigh Stevens	**Date Received:**	02-Feb-2018
	C/- Salt Ecology Limited	**Date Reported:**	26-Mar-2018
	21 Mount Vernon Place	**Quote No:**	90051
	Washington Valley	**Order No:**	
	Nelson 7010	**Client Reference:**	Horrons Manawatu
		Submitted By:	Leigh Stevens

Sample Name:		Rangitikei 1 30-Jan-2018	Rangitikei 2 30-Jan-2018	Rangitikei 3 30-Jan-2018	Rangitikei 4 30-Jan-2018
Lab Number:		1918468.7	1918468.8	1918468.9	1918468.10
Individual Tests					
Dry Matter of Sieved Sample	g/100g as rcvd	76	52	76	74
Fraction >/= 2 mm*	g/100g dry wt	1.5	0.8	1.3	2.1
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	60.0	24.1	49.8	73.2
Fraction < 63 µm*	g/100g dry wt	38.5	75.0	48.9	24.7

Sample Name:		Rangitikei 5 30-Jan-2018	Rangitikei 6 30-Jan-2018	Rangitikei 7 30-Jan-2018	Rangitikei 8 30-Jan-2018
Lab Number:		1918468.11	1918468.12	1918468.13	1918468.14
Individual Tests					
Dry Matter of Sieved Sample	g/100g as rcvd	78	54	77	70
3 Grain Sizes Profile					
Fraction >/= 2 mm*	g/100g dry wt	2.2	0.4	1.2	0.1
Fraction < 2 mm, >/= 63 µm*	g/100g dry wt	58.7	21.3	52.5	73.6
Fraction < 63 µm*	g/100g dry wt	39.1	78.2	46.3	26.2

For clarity, this laboratory summary has been edited to present only results from the Rangitikei Estuary.

IANZ ACCREDITED LABORATORY

APPENDIX 3. ANALYTICAL RESULTS

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			
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation. May contain a residual moisture content of 2-5%.	-	1-6
Dry Matter for Grainsize samples	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-17
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-	1-6
Total Recoverable Phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt	1-6
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-6
Total Organic Carbon*	Acid pretreatment to remove carbonates present followed by Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-6
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg	Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level.	0.010 - 0.4 mg/kg dry wt	1-6
3 Grain Sizes Profile*		0.1 g/100g dry wt	1-17
3 Grain Sizes Profile			
Fraction >/= 2 mm*	Wet sieving with dispersant, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-17
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	1-17
Fraction < 63 µm*	Wet sieving with dispersant, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-17

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.

Ara Heron BSc (Tech)
Client Services Manager - Environmental

APPENDIX 4. ESTUARY RISK INDICATOR RATING NOTES

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 RPD 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 (WFD-UKTAG 2014), 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. One supporting metrics are also proposed: % 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 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 5. ETI ONLINE CALCULATOR INPUT DATA

NZ ETI Tool 1 Input details	Calculator Heading	Unit	**Input Value**
Estuary Number	Est_no		183
Estuary Name	Est_name		Rangitikei River
Regional Council	Reg_Council		MWRC
Island	Island		North Island
NZCHS geomorphic code	NZCHS_code		6B
NZCHS geomorphic class	NZCHS_class		Tidal river mouth (spit enclosed)
ETI Class	ETI_class		SSRTRE
Latitude	LAT	decimal degrees	-40.30287783
Longitude	LON	decimal degrees	175.2123366
Freshwater inflow	Qf	m3/s	76.38115
Annual river total nitrogen loading	TNriver	T/yr	1929.17
Annual river total phosphorus loading	TPriver	T/yr	307.85
Volume	V	m3	1690595.114
Tidal Prism	P	m3	931086.7755
Return flow fraction	b	unitless	NA
ACExR fitted exponent	A	unitless	-0.508592245
ACExR fitted constant	B	unitless	166.3383512
Ratio NO3	R_NO3	unitless	0.814137742
Ratio DRP	R_DRP	unitless	0.729054412
Ocean salinity	OceanSalinity_mean	ppt	34.97059433
Ocean nitrate concentration	NOcean	mg/m3	16.83200388
Ocean DRP concentration	POcean	mg/m3	6.964952398
Intertidal area	Intertidal	%	3.59
Typical closure length	Tl	days	NA
ICOE class	isICOE	one of: TRUE, FALSE	FALSE
Closure length	closure_length	one of: days, months	months
Estuary Area	est_area_m2	m2	393895
Mean depth	mean_depth	m	4.29199435
Tidal height	tidal_height	m	2.407
Estuary Area at low tide	LOWTIDEest_area_m2	m2	
Mean depth at low tide	LOWTIDEmean_depth	m	
Estuary volume at low tide	LOWTIDEvolume	m3	

NZ ETI Tool 2 Input details			
Name of estuary	estuary_name		Rangitikei River Estuary
Phytoplankton Biomass	CHLA	mg/m3	2
Macroalgal GNA	macroalgae_GNA_ha	ha	0
Macroalgal GNA/Estuary Area	macroalgae_GNA_percent	%	0
Opportunistic Macroalgae	macroalgae_EQR	OMBT EQR	0.9
Dissolved Oxygen (DO)	DO	mg/m3	6.8
Sediment Redox Potential (RP)	REDOX	mV	25
Total Organic Carbon (TOC)	TOC	%	NA
Total Nitrogen (TN)	TN	mg/kg	NA
Macroinvertebrates	AMBI	NZ AMBI	NA
Area of soft mud	soft_mud	Proportion	0.26
Estuary type	estuary_type		SSRTRE
ICOE status	isICOE	TRUE/FALSE	FALSE

HRC monitoring data
Rangitikei Estuary Boat Ramp

Date	Chl-a (ug/L)
15/01/15	2.7
12/02/15	<1.9
5/03/15	<2.0
9/04/15	<1.9
7/05/15	<1.9
4/06/15	<3.8
9/07/15	<3.1
6/08/15	<1.9
3/09/15	2.4
8/10/15	2.9
5/11/15	<1.9
3/12/15	<1.9
14/01/16	<1.9
11/02/16	<1.9
3/03/16	<1.9
7/04/16	<9.5
5/05/16	<1.9
9/06/16	<1.9
7/07/16	<1.9
11/08/16	<1.9
8/09/16	<1.9
6/10/16	<1.9
10/11/16	5.3
8/12/16	16
12/01/17	<1.9
9/02/17	<1.9
9/03/17	<1.9
6/04/17	<5.2
4/05/17	<1.9
8/06/17	2.2
6/07/17	<1.9
10/08/17	<1.9
7/09/17	4.3
5/10/17	<1.9
9/11/17	<1.9
7/12/17	<1.9
11/01/18	<1.9
9/02/18	<1.9
8/03/18	<1.9
5/04/18	<1.9

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