coastalmanagement

Waikanae Estuary 2015

Broad Scale Habitat Mapping

Prepared for
Greater Wellington Regional Council
June 2015

Cover Photo: Waikanae Estuary, 2015.

Waikanae River entering the upper estuary

Waikanae Estuary 2015

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Prepared for
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by

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WAIKANAE ESTUARY - EXECUTIVE SUMMARY

Waikanae Estuary is a moderate-sized (37ha, 2km long, 40-50m wide, 1-2m deep) "tidal river mouth" type estuary which drains onto a broad flat (dissipative) beach just north of Paraparaumu. It is part of Greater Wellington Regional Council's (GWRC's) coastal State of the Environment (SOE) monitoring programme. This report summarises the results of 2015 broad scale habitat mapping of the estuary. The following sections summarise broad scale monitoring results (from the current report and previous studies), risk indicator ratings, overall estuary condition, and monitoring and management recommendations.

BROAD SCALE RESULTS

- Soft mud (1.7ha) covered 7% of the unvegetated intertidal habitat, but was concentrated mostly in the upper intertidal settling flats where it covered 54% of the intertidal area.
- Sediment (measured at the upper estuary fine scale monitoring site) has had a consistently elevated mud content (range 18% to 39%), and mean annual sediment deposition of 25.6mm/yr since 2010.
- Seagrass was not present in the estuary. This absence is likely due to poor water clarity due to excessive mud.
- Opportunistic macroalgal growth (*Ulva*) was sparse (3% of the available intertidal habitat) and no gross eutrophic zones were present.
- Saltmarsh covered 15% of the estuary (5.7ha) of which 92% was rushland, 7.5% sedgeland and 0. 3% herbfield. An estimated 90% decline in saltmarsh from natural state cover has resulted primarily from drainage and reclamation of the estuary margins.
- The densely vegetated 200m margin cover (scrub, tussock reed and duneland) of the estuary was relatively low (10%).

RISK INDICATOR RATINGS (indicate risk of adverse ecological impacts)

Major Issue	Indicator	2015 risk rating	Estimated Change from Natural State
Sediment	Soft mud (% cover)	MODERATE	Moderate increase
Eutrophication	Macroalgal Growth (EQC)	LOW	Moderate increase
	Gross Eutrophic Conditions (ha)	VERY LOW	No significant change
Habitat Modification	Seagrass Coefficient (SC)	VERY HIGH	100% loss
	Saltmarsh (% loss from estimated natural state)	VERY HIGH	~90% loss
	Saltmarsh (vegetated % of available habitat)	VERY LOW	No significant change
	200m Vegetated Terrestrial Margin	HIGH	~90% loss

ESTUARY CONDITION AND ISSUES

In relation to the key issues addressed by the broad scale monitoring (i.e. sediment, eutrophication, and habitat modification), the 2015 broad scale mapping results show that the most significant modifications to the estuary have been from historical habitat loss through the displacement and reclamation of saltmarsh, seagrass, and the densely vegetated terrestrial margin.

Fine sediment is currently the major issue present, with fine scale monitoring results showing significant deposition of sediments over the past 5 years. Overall there is a "MODERATE" risk of adverse impacts to the estuary ecology occurring, primarily in the upper estuary as a consequence of the extent, deposition rate and mud content of depositing sediments. Soft mud is likely contributing to losses of shellfish, and adverse impacts to the sediment macroinvertebrate community which will become dominated by mud tolerant species, as evident in the fine scale monitoring results (Robertson and Stevens 2012). Such conditions limit food availability for fish and birdlife, and show the ability of the estuary to assimilate sediment loads is currently exceeded.

Eutrophication is not currently a significant concern based on low opportunistic macroalgal growth, although other indicators (dense microalgal mats and apparently high chlorophyll-a) show a decline in quality since 2010.

RECOMMENDED MONITORING AND MANAGEMENT

While accelerated fine sediment inputs are likely to have been occurring since the first human development in the catchment, monitoring highlights recent deposition of mud in the upper estuary.

Consequently, it is recommended that broad scale habitat mapping be repeated every 10 years (next due in 2025), unless obvious changes are observed in the interim, focussing on the main issue of fine sediment, as well as saltmarsh and terrestrial margin changes.

Fine scale monitoring is recommended at the existing site at 5 yearly intervals (next scheduled for 2017).

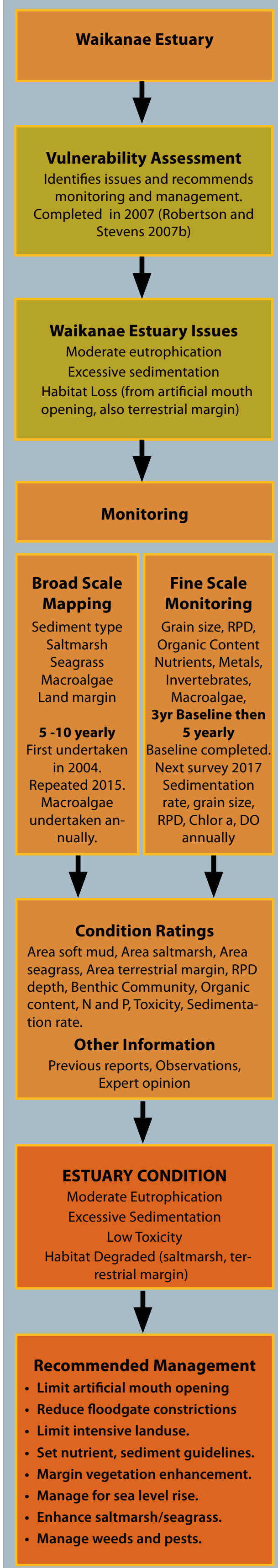
It is recommended that sedimentation rate continue to be monitored annually at fine scale Site A, with additional sites deployed in the upper and lower estuary, but only for low cost key indicators of RPD, sedimentation rate and grain size.

Macroalgal cover of the estuary should monitored 5 yearly, but be visually assessed when measuring sediment plates and initiated if obvious issues are present.

Targeted investigations are also recommended to address fine sediment knowledge gaps as follows:

- **Sediment Source Identification**. What are the main sources of fine sediments depositing in the estuary, and what is the relative influence of natural compared to human derived inputs?
- **Ecological Condition/Sediment Load Relationship**. What is the predicted ecological condition of the estuary (pristine to poor) along a full gradient of catchment sediment loads, infilling rates and within-estuary management actions (e.g. dredging, saltmarsh planting).
- **Explore catchment management and restoration options.**

1. INTRODUCTION



Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. In 2007, Greater Wellington Regional Council (GWRC) identified a number of estuaries in its region as immediate priorities for long term monitoring and initiated monitoring of key estuaries in a staged manner. The estuaries currently monitored include; Porirua Harbour, Lake Onoke, and Whareama, Hutt and Waikanae estuaries. Risk assessments have also been undertaken to establish management priorities for a number of other estuaries.

The monitoring and management process used for Waikanae Estuary is summarised in the margin flow diagram, and is described below. It consists of three components developed from the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002):

1. **Ecological Vulnerability Assessment** (EVA) of the estuary to major issues (see Table 1) and appropriate monitoring design. This component has been completed for Waikanae Estuary and is reported on in Robertson and Stevens (2007b).
2. **Broad Scale Habitat Mapping** (NEMP approach). This component (see Table 2) documents the key habitats within the estuary, and changes to these habitats over time. Preliminary broad scale intertidal mapping of Waikanae Estuary was undertaken in 2006 (Stevens and Robertson 2006). Annual mapping of macroalgal cover has been undertaken since 2010 (see Stevens and Robertson 2014). The current report focuses on detailed broad scale habitat mapping undertaken in the summer of 2014/15 to assess the current state of the estuary, and any changes since 2006.
3. **Fine Scale Monitoring** (NEMP approach). Monitoring of physical, chemical and biological indicators (see Table 2). This component, comprising an initial 3 year baseline of detailed information on the condition of Waikanae Estuary, commenced in 2010 and is reported on in Robertson and Stevens 2010, 2011, 2012. Sedimentation rates in the estuary have been monitored annually since 2010 (see Stevens and Robertson 2015, Figure 1).

To help evaluate overall estuary condition and decide on appropriate monitoring and management actions, a series of risk indicator ratings have also been developed and are described in Section 3.

The current report describes the following work undertaken in January 2015:

- Broad scale mapping of intertidal estuary sediment types.
- Broad scale mapping of intertidal macroalgal beds (i.e. *Ulva* (sea lettuce), *Gracilaria*).
- Broad scale mapping of intertidal seagrass (*Zostera muelleri*) beds.
- Broad scale mapping of saltmarsh vegetation.
- Broad scale mapping of the 200m terrestrial margin surrounding the estuary.

Waikanae Estuary is a moderate-sized (2km long, 40-50m wide, 1-2m deep) "tidal river mouth" type estuary which drains onto a broad flat (dissipative) beach just north of Paraparaumu. As is typical in such situations, the majority of the estuary area consists of a long, shallow lagoon type estuary running along the back of the beach parallel to the sea. This results from the continual action of ocean currents from the north that generate a sandspit that pushes the mouth progressively southwards. However, in the case of the Waikanae Estuary, this lower part of the estuary is periodically lost when the channel naturally realigns, or opens more directly to the sea at the north before progressively migrating south. In addition, floodgates restrict tidal action and flushing to a large historical estuarine arm. Such instability greatly diminishes ecological values in the lower estuary by limiting the potential for long-term estuarine communities to establish. The middle and upper estuary in the main arm are, however, much more stable (including some saltmarsh and tidal flats) and, consequently, have been targeted for the fine scale monitoring programme. There are also various freshwater lakelets around the margins.

Like other moderate-sized tidal river estuaries, the Waikanae is usually freshwater dominated at low tide and at high tide consists of a freshwater layer on top of saline bottom water. Plant and animal life is therefore restricted to those that tolerate such regular salinity extremes.

Human and ecological use of the estuary is high. It is one of very few sizable estuary/wetland areas in the southwestern North Island, and is a nationally significant wetland habitat for waders, seabirds and waterfowl, both local and migratory. More wild birds reportedly visit Waikanae Estuary Scientific Reserve than any other area in the Wellington province. In terms of human use, the estuary is a local focal point for conservation, walking, picnicking, boating, fishing, paddling, bird watching, bathing, and white-baiting. The estuary receives moderate inputs of nutrients and sediment from the large catchment and tertiary treated wastewater from the Paraparaumu Treatment Plant (via Mazengarb Drain) (Robertson and Stevens 2007b).

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

1. Sediment Changes

Because estuaries are a sink for sediments, their natural cycle is to slowly infill with fine muds and clays (Black et al. 2013). Prior to European settlement they were dominated by sandy sediments and had low sedimentation rates (<1 mm/year). In the last 150 years, with catchment clearance, wetland drainage, and land development for agriculture and settlements, New Zealand's estuaries have begun to infill rapidly with fine sediments. Today, average sedimentation rates in our estuaries are typically 10 times or more higher than before humans arrived (e.g. see Abrahim 2005, Gibb and Cox 2009, Robertson and Stevens 2007, 2010, and Swales and Hume 1995). Soil erosion and sedimentation can also contribute to turbid conditions and poor water quality, particularly in shallow, wind-exposed estuaries where re-suspension of fine sediments is common. These changes to water and sediment result in negative impacts to estuarine ecology that are difficult to reverse. They include;

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

Recommended Key Indicators:

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

2. Eutrophication

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

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Eutrophication	Macroalgal Cover	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 Potenial Depth - aRPD) and/or redox probe. Note: Total Sulphur is also currently under trial.
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

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

3. Disease Risk

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

Recommended Key Indicators:

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

4. Toxic Contamination

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

Recommended Key Indicators:

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

5. Habitat Loss

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

Recommended Key Indicators:

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

1. INTRODUCTION (CONTINUED)

Figure 1. Waikanae Estuary, including location of fine scale monitoring site.

OVERVIEW OF ESTUARY CONDITION

Estuaries are coastal transitional waters that are formed when freshwater from rivers flows into, and mixes with, saltwater from the ocean. Many are highly valued by humans and contain a wide variety of plant and animal life. In good condition, they provide more life per square metre than the richest New Zealand farmland. Their high value lies in two main characteristics; i. the wide diversity of habitats they offer, and ii. their natural ability to collect and assimilate sediment and nutrients from the surrounding catchment and inflowing tidal waters. If either of these features are degraded, then the estuary condition deteriorates and the value to humans and estuary plants and animals is lessened. The condition of an estuary is commonly reflected by the extent and intensity of development in the surrounding catchment. They are typically in one of three contrasting states: PRISTINE, MODERATE, OR DEGRADED.

PRISTINE: In a pristine state, estuaries have high water clarity, low nutrient and sediment inputs, high sediment quality (very little mud), and high biodiversity. They retain an intact saltmarsh and terrestrial margin that buffers against weed and pest invasions, assimilates sediment and nutrients, and provides key habitat for birds and fish. Disease risk and toxicity are low, and there are no extensive growths of nuisance macroalgae (e.g. *Ulva* (sea lettuce) and *Gracilaria*), microalgae or phytoplankton.

MODERATE: Following initial catchment development, sediment, nutrient, and faecal bacteria inputs typically increase, and modification of the estuary margin (primarily by drainage and reclamation) is common. Increased nutrients cause a shift to increased eutrophication, evident in low-moderate nuisance macroalgal growth, and increased phytoplankton production. This, along with increased fine sediment deposition, starts to reduce sediment oxygenation and water clarity. The increasing inputs of fine sediment may also lead to a reduction in seagrass populations and a shift in the macroinvertebrate community to one more tolerant of fine muds.

DEGRADED: With more intensive catchment development, soft muds commonly accumulate in the upper estuary and on sheltered tidal flats, and water clarity decreases further. The combined effects of sediment smothering and reduced light levels may contribute to the loss of seagrass and shellfish beds. Aggressive macrophyte growth is encouraged by high sediment and nutrient inputs. Farm runoff, human wastewater, and inputs from urban and agricultural stormwater increase disease risk and toxicity, and as a result can constrain bathing and shellfish gathering, particularly after rainfall events. Further habitat loss, particularly of remaining upper intertidal saltmarsh and terrestrial buffer vegetation, increasingly degrades bird habitat and whitebait spawning areas, facilitates the encroachment of weeds and pests into saltmarsh areas, reduces natural assimilation and filtering of sediment and nutrients, and reduces the important role saltmarsh plays in flood attenuation e.g. bank stabilisation, decreased flow velocity, temporal spreading of flow peaks. Protection of developed margins from erosion and inundation becomes an increasing issue.

An overall assessment of vulnerability to key stressors indicates Waikanae Estuary is currently in a MODERATE state due to excessive muddiness, habitat loss and, to a lesser extent, disease risk and eutrophication.

2. 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 aerial photography, detailed ground-truthing, and GIS-based digital mapping used to record the primary habitat features present. Appendix 1 lists the definitions used to classify substrate and saltmarsh vegetation. Very simply, the method involves three key steps:

- Obtaining laminated aerial photos for recording dominant habitat features.
- Carrying out field identification and mapping (i.e. ground-truthing).
- Digitising the field data into GIS layers (e.g. ArcMap).

The results are then used with risk indicators to assess estuary condition in response to common stressors.

For the current study, rectified ~0.3m/pixel resolution colour aerial photos flown by LINZ in 2012/13 were laminated (scale of 1:2,500) and used by experienced scientists who walked the area in January 2015 to ground-truth the spatial extent of dominant vegetation and substrate types (Figure 3). The "iGIS HD" Ipad app. was used to show live position tracking on aerial photos (via an inbuilt GPS accurate to ~5m), and to log field notes. When present, macroalgae and seagrass were mapped to the nearest 5% using a 6 category percent cover rating scale as a guide to describe density (see Figure 2 below).

Broad scale habitat features were digitised into ArcMap 10.2 shapefiles using a Wacom Cintiq21UX drawing tablet, and combined with field notes and georeferenced photographs to produce habitat maps showing the dominant cover of: substrate, macroalgae (e.g. *Ulva, Gracilaria*), seagrass, saltmarsh vegetation, and the 200m wide terrestrial margin vegetation/landuse. These broad scale results are summarised in Section 4, with the supporting GIS files (supplied on a separate CD) providing a much more detailed data set designed for easy interrogation to address specific monitoring and management questions. An example of the detail available on the GIS files is presented in Figure 3.

Macroalgae was further assessed by identifying patches of comparable growth, and enumerating each patch by measuring biomass and the degree of macroalgal entrainment within sediment. When macroalgae was present, the presence of soft muds and surface sediment anoxia were also noted to assess whether gross nuisance conditions had established. Results were interpreted using a multi-index approach that included:

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

The key component of the interpretative assessment of macroalgae is the use of a modified Opportunistic Macroalgal Blooming Tool (OMBT). 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) to rate macroalgal condition (Table 2). This integrated index provides a comprehensive measure of the combined influence of macroalgal growth and distribution in the estuary.

The georeferenced spatial habitat maps provide a robust baseline of key indicators. Wherever possible, 2015 results have been compared to the previous 2006 broad scale survey, noting in some instances improvements have been made since then in the classification and mapping of key parameters like seagrass and macroalgae.

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

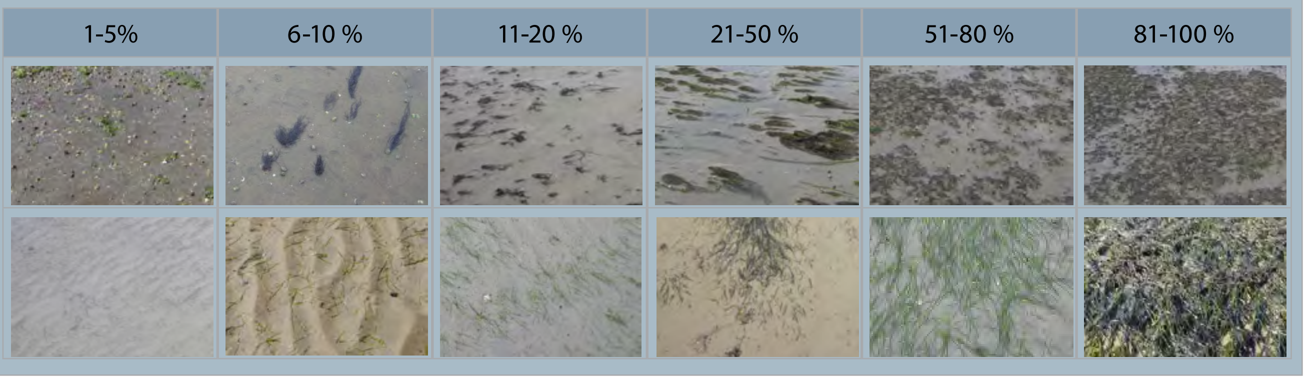


Figure 3. Estuary extent indicating 2015 ground-truthing (top), and example of the more detailed GIS mapping and photos that underpin this summary report (bottom).

3. 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, very 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.
- That rating and ranking systems can easily mask or oversimplify results. For instance, large changes can occur within the same risk category, but small changes near the edge of one risk category may shift the rating to the next risk level.
- Most issues will have a mix of primary and secondary ratings, primary ratings being given more weight in assessing the significance of indicator results. It is noted that many secondary estuary indicators will be monitored under other programmes and can be used if primary indicators reflect a significant risk exists, or if risk profiles have changed over time.
- Ratings have been established in many cases using statistical measures based on NZ estuary data. 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 Waikanae Estuary broad scale monitoring programme are summarised in Tables 2 and 3, along with supporting notes explaining the use and justifications for each indicator. 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 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.

INDICATOR	RISK RATING				
	Very Low	Low	Moderate	High	Very High
Soft mud (% cover)	<2%	2-5%	>5-15%	>15-25%	>25%
Gross Eutrophic Conditions (ha)	<0.5ha	0.5-5ha	6-20ha	20-30ha	>30ha
Macroalgal Ecological Quality Rating	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2
Seagrass Coefficient (SC)	>7.0	>4.5-7.0	>1.5-4.5	>0.2 - 1.5	0.0 - 0.2
Saltmarsh (% remaining from estimated natural state)	>80-100%	>60-80%	>40-60%	>20-40%	<20%
Saltmarsh Extent (vegetated % of available saltmarsh habitat)	>80-100%	>60-80%	>40-60%	>20-40%	<20%
Vegetated 200m Terrestrial Margin	>80-100%	>50-80%	>25-50%	>5-25%	<5%

See NOTES on following page, and Appendix 2 for further information.

Table 3. Summary of indicators used to rate opportunistic macroalgal quality.

MACROALGAL INDICATORS (OBMT approach - WFD_UKTAG 2014 - see Appendix 2 for details)					
QUALITY RATING	High	Good	Moderate	Poor	Bad
EQR (Ecological Quality Rating)	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2
% cover on Available Intertidal Habitat (AIH)	0 - ≤5	>5 - ≤15	>15 -≤25	>25 - ≤75	>75 - 100
Affected Area (AA) [>5% macroalgae] (ha)*	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass ($g.m^2$) of AIH	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
Average biomass ($g.m^2$) of AA	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
% algae entrained >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

*Only the lower EQR of the 2 metrics, AA or AA/AIH is used in the final EQR calculation - see Appendix 2 for further detail.

NOTES to Table 2:

Soft Mud Percent Cover. Estuaries are a sink for sediments. Where large areas of soft mud are present, they are likely to lead to major and detrimental ecological changes that could be very difficult to reverse. In particular, excessive mud decreases water clarity, lowers biodiversity and affects aesthetics and access. Its presence indicates where changes in land management may be needed.

Sedimentation Rate. Elevated sedimentation rates are likely to lead to major and detrimental ecological changes within estuary areas that could be very difficult to reverse, and indicate where changes in land use management may be needed. Note the very low risk category is based on a typical NZ pre-European average rate of <1mm/year, which may underestimate sedimentation rates in soft rock catchments.

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.

Redox Potential Discontinuity (RPD): RPD 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 RPD close to the surface is important for two main reasons:

1. As the RPD 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 RPD 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.

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

Opportunistic Macroalgae. Opportunistic macroalgae is a primary indicator of estuary eutrophication, and when combined with gross eutrophic conditions (see previous) can cause significant adverse ecological impacts that are very difficult to reverse. Thresholds used to assess this indicator are derived from the OMBT (see Section 2 and Appendix 2), with results combined with those of other indicators to determine overall condition.

Seagrass. Seagrass (*Zostera muelleri*) grows in soft sediments in NZ estuaries where its presence enhances estuary biodiversity. 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.

A continuous index (the seagrass coefficient - SC) has been developed to rate seagrass condition based on the percentage cover of seagrass in defined categories using the following equation: ***SC=((0 x %seagrass cover <1%)+(0.5 x %cover 1-5%)+(2 x %cover 6-10%)+(3.5 x %cover 11-20%)+(6 x %cover 21-50%)+(9 x %cover 51-80%)+(12 x %cover >80%))/100.*** The “early warning trigger” for initiating management action is a trend of a decreasing Seagrass Coefficient.

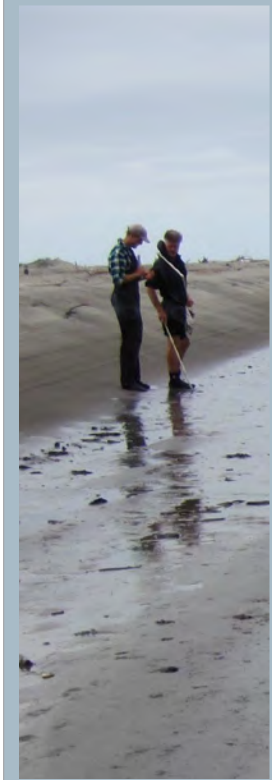
Saltmarsh. Saltmarshes have high biodiversity, are amongst the most productive habitats on earth, and have strong aesthetic appeal. They are sensitive to a wide range of pressures including land reclamation, margin development, flow regulation, sea level rise, grazing, wastewater contaminants, and weed 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. The proposed interim risk rating of % loss from Estimated Natural State Cover assumes that a reduction in saltmarsh cover corresponds to a reduction in ecological services and habitat values. It it further assumed that saltmarsh should be growing throughout the majority of the available saltmarsh habitat (tidal area above MHWN), and that where this does not occur, ecological services and habitat values are reduced. The “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.

See Appendix 2 for further information supporting these ratings.

4. RESULTS AND DISCUSSION

BROAD SCALE MAPPING



Lower Waikanae Estuary with the raised sand spit developing in the previously intertidal zone, 2015.

The 2015 broad scale habitat mapping ground-truthed and mapped all intertidal substrate and vegetation including the dominant land cover of the terrestrial margin, with the six dominant estuary features summarised in Table 4. As expected for an estuary with a strong tidal river influence and discharging to the coast via a shore parallel lagoon, the estuary was dominated by extensive intertidal flats (64% of estuary - mostly in the lower sections) and subtidal water confined to a defined river channel (21%). Saltmarsh (15%) was relatively extensive but confined to the upper estuary. Dense opportunistic macroalgal growth (0.1%) was very low, and no seagrass was present. Just 10% of the 200m wide terrestrial margin was dominated by a densely vegetated buffer, the vast majority surrounded by grassland (50%) or residential areas (35%).

- In the following sections, various factors related to each of these habitats (e.g. area of soft mud) are used to apply risk ratings to assess key estuary issues of sedimentation, eutrophication, and habitat modification. Trends in broad scale features have been assessed based on estimates of natural state cover or previous broad scale mapping results, where relevant.
- In addition, the supporting GIS files underlying this written report provide a detailed spatial record of the key features present throughout the estuary. These are intended as the primary supporting tool to help the Council address a wide suite of estuary issues and management needs, and to act as a baseline to assess future change.

Table 4. Summary of dominant broad scale features in Waikanae Estuary, 2015.

	Dominant Estuary Feature	Ha	% of Estuary
1.	Intertidal flats (excluding saltmarsh)	24.5	66%
2.	Opportunistic macroalgal beds (>50% cover) [included in 1. above]	0.3	0.1%
3.	Seagrass (>50% cover) [included in 1. above]	0	0%
4.	Saltmarsh	5.7	15%
5.	Subtidal waters	6.8	28%
	Total Estuary	**37**	**100%**
6.	Terrestrial Margin - % of 200m wide estuary buffer densely vegetated (e.g. scrub, shrub, forest)		10%

4.1. INTERTIDAL FLATS (EXCLUDING SALTMARSH)

Results (summarised in Table 5 and Figure 4) show firm sand (74%) and firm muddy sand (18%) were by far the most dominant unvegetated intertidal substrates in Waikanae Estuary. These substrates were generally well oxygenated (aRPD >1cm) and reflect the strong coastal marine influence over the lower estuary which is regularly flushed with waves, and where dune systems periodically develop and erode through natural accretion and erosion processes. A consequence of the strong marine influence is that the lower estuary has a relatively variable intertidal extent that can change rapidly, particularly if the mouth (which naturally migrates to the south) breaks through the dune system at the north of the estuary. Figure 1 shows the estuary open to the sea, while Figure 4 highlights how a narrow shore parallel lagoon develops at other times.

These processes facilitate the capacity of the lower estuary to assimilate and/or export soft muds, and consequently the majority of catchment derived mud is concentrated in the relatively small intertidal flats of the upper estuary (Figure 4) where salinity driven flocculation is most pronounced.

Table 5. Summary of dominant intertidal substrate, Waikanae Estuary, 2015.

Dominant Substrate	Area Ha	Percentage	Comments
Boulder field man-made	0.0	0.1	Erosion protection in the middle estuary and by the constructed floodgate.
Cobble field	0.3	1.2	Along the well flushed tidal margins of the Waikanae River in the upper estuary.
Firm sand	18.0	73.7	In the open coast sections of the lower estuary.
Firm mud/sand	4.5	18.2	In relatively well flushed areas that border deposition zones in both the upper and lower estuary.
Soft mud	1.7	6.9	Settling basin/flocculation zones in both the upper and lower estuary.
TOTAL	**24.5**	**100%**	

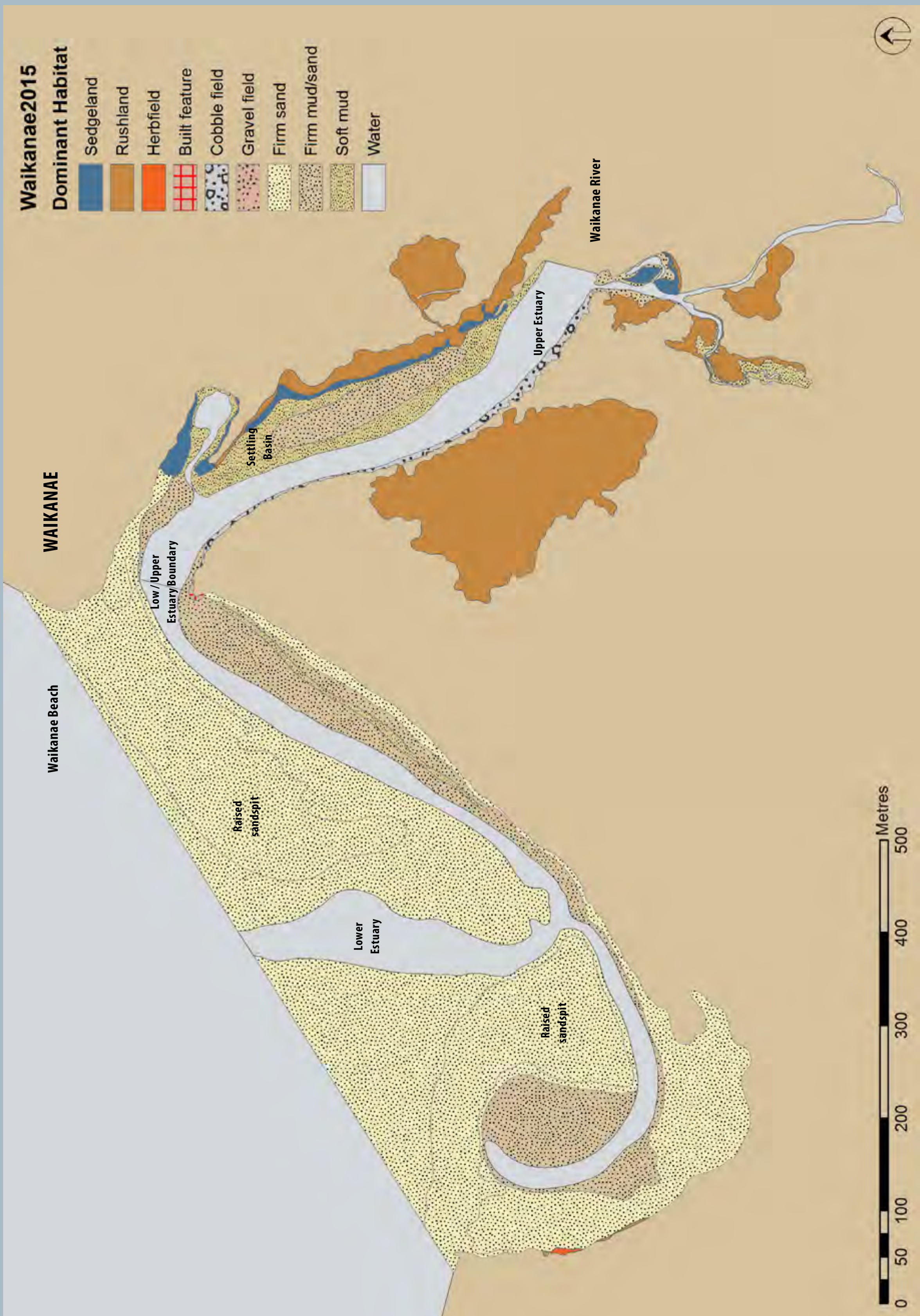


Figure 4. Map of dominant habitat types - Waikanae Estuary, 2015.

4. RESULTS AND DISCUSSION (CONTINUED)

Soft Mud Habitat.

The extent of intertidal soft mud habitat outside of saltmarsh is a primary indicator of fine sediment (or increased muddiness) impacts. This reflects that where soil erosion from catchment development exceeds the assimilative capacity of an estuary, impacts such as increased muddiness and turbidity, shallowing, increased nutrients, changes in saltmarsh and seagrass habitats, reduced sediment oxygenation, increased organic matter degradation by anoxic processes (e.g. sulphide production), alterations to fish and invertebrate communities, and the establishment of invasive species can result. Also, because contaminants are most commonly associated with finer sediment particles, extensive areas of fine soft muds provide a sink which concentrate catchment contaminants.

Figure 4 shows that soft mud habitat in Waikanae Estuary was concentrated in the upper intertidal flats (the primary estuary settling zone), and in a narrow intertidal strip in the lower estuary. The area of soft mud covered 6.9% of the overall intertidal area, a risk indicator rating of "MODERATE".

Because the lower estuary is dominated by marine influences, it comprises clean sands (99%) with very little soft mud present (1%) and thus experiences few mud related impacts. In contrast, the unvegetated upper estuary intertidal area is dominated by mud (53%), and a mix of sand (37%) and cobble (10%). Fine scale measurements show an overall mean annual sedimentation rate in the upper estuary of +25.6mm/yr, and a high-very high sediment mud content (range 18%-39%) at the fine scale monitoring site for the 2010-2015 period (Stevens and Robertson 2015). The extent of mud dominated sediments does not appear to have altered significantly since preliminary mapping undertaken in 2004. This is thought to predominantly reflect a hydrodynamic boundary, with both salinity driven flocculation, and changes in flow velocities in the upper estuary basins, promoting settling of fine sediments in these areas.

Multiple studies have shown estuarine macroinvertebrate communities to be adversely affected by the accumulation of muddy sediments, 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; Jones et al. 2011; Wehkamp and Fischer 2012; Robertson 2013). Generally, increased muddiness results in a community dominated by species tolerant of muddy conditions, with species like cockles and pipi being displaced. The current absence of seagrass is likely to directly reflect the influence of excessive soft mud and reduced water clarity displacing and limiting where seagrass can grow.

Ecological changes such as the above are expected to have a direct and cascading effect on a range of organisms including fish, birdlife, other primary producers, and human uses as a result of changes to physico-chemical conditions (e.g. increased mud content, reduced sediment oxygenation, and lower water clarity) and highlight the likely adverse impact of fine sediment deposition on the upper estuary flats.

Because floods in the river contribute to both periodic deposition of fresh sediment, as well as flushing of fine sediments from the estuary to the sea, flow/flood data for the river should be used in conjunction with ongoing measurement of the sedimentation rate in the estuary to characterise trends and enable predictions of likely future sedimentation rates.

Figure 5. Examples of soft muds in the upper Waikanae Estuary settling basin, 2015.

Figure 6. Examples of firm sands in the lower Waikanae Estuary, 2015.

4.2. 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. Decaying macroalgae can also accumulate subtidally and on shorelines causing oxygen depletion and nuisance odours and conditions. The greater the density, persistence, and extent of macroalgal entrainment within sediments, the greater the subsequent impacts.

Opportunistic macroalgal growth was assessed by mapping the spatial spread and density of macroalgae in the Available Intertidal Habitat (AIH) (Figure 7), and calculating an "Ecological Quality Rating" (EQR) using the Opportunistic Macroalgal Blooming Tool (OMBT) described in Appendix 2.

The EQR score can range from zero (major disturbance) to one (reference/minimally disturbed) and relates to a quality status threshold band (i.e. bad, poor, good, moderate, high - Section 3, Table 2). The individual metrics that are used to calculate the EQR (spatial extent, density, biomass, and degree of sediment entrainment of macroalgae within the affected intertidal area), are also scored and have quality status threshold bands to guide key drivers of change.

The vast bulk of the estuary exhibited no appreciable opportunistic macroalgal growth apart from small areas of dense (biomass 1000-4000g.m^2) green alga *Ulva intestinalis* growth near the sheltered embayment by the floodgate (Figure 7). This algae was not entrained within the underlying sediments and was not causing nuisance conditions. There were no gross eutrophic zones present in the estuary.

The opportunistic macroalgal EQR for Waikanae Estuary in March 2015 was 0.72 (Table 6), a quality status of "GOOD" and indicate that the estuary overall is not expressing significant symptoms of eutrophication, a risk indicator rating of "LOW".

However, other indicators of increasing eutrophication have been evident in the estuary since 2010. These, first reported on in Robertson and Stevens (2012), were:

- A reduction in sediment oxygenation (shallow RPD depth).
- Increased sediment nutrient concentrations (total nitrogen and phosphorus).
- Increased organic content (measured as total organic carbon).
- Dense microalgal mats growing on estuary sediments.
- A distinctive green tinge (chlorophyll a) in the estuary water, particularly in temperature/salinity stratified bottom waters.

Symptoms again observed in 2015 were a shallow RPD depth and dense microalgal mats growing on upper estuary sediments. Visual assessment of flood deposition of organic material on the upper intertidal flats indicates sediment organic content was also likely to have remained elevated, while estuary waters had a moderate green tinge (indicating the presence of chlorophyll a).

Table 6. Summary of intertidal opportunistic macroalgal cover, Waikanae Estuary, January 2015.

Metric	Face Value	Final Equidistant Score (FEDS)	Quality Status
AIH - Available Intertidal Habitat (ha)	6.6		
Percentage cover of AIH (%) = (Total % Cover / AIH} x 100 *where Total % cover = Sum of {(patch size) / 100} x average % cover for patch*	2.7	0.89	High
Biomass of AIH (g.m^{-2}) = Total biomass / AIH *where Total biomass = Sum of (patch size x average patch biomass)*	107	0.72	Good
Biomass of Affected Area (g.m^{-2}) = Total biomass / AA *where Total biomass = Sum of (>5% cover patch size x average patch biomass)*	1562	0.26	Poor
Presence of Entrained Algae = (No. quadrats or area (ha) with entrained algae / total no. of quadrats or area (ha)) x 100	0.0	1.00	High
Affected Area (use the lowest of the following two metrics)		0.76	Good
Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%)	0.5	0.99	High
Size of AA in relation to AIH (%) = (AA / AIH) x 100	6.8	0.76	Good
OVERALL MACROALGAL ECOLOGICAL QUALITY RATING - EQR (AVERAGE OF FEDS)		**0.72**	**GOOD**

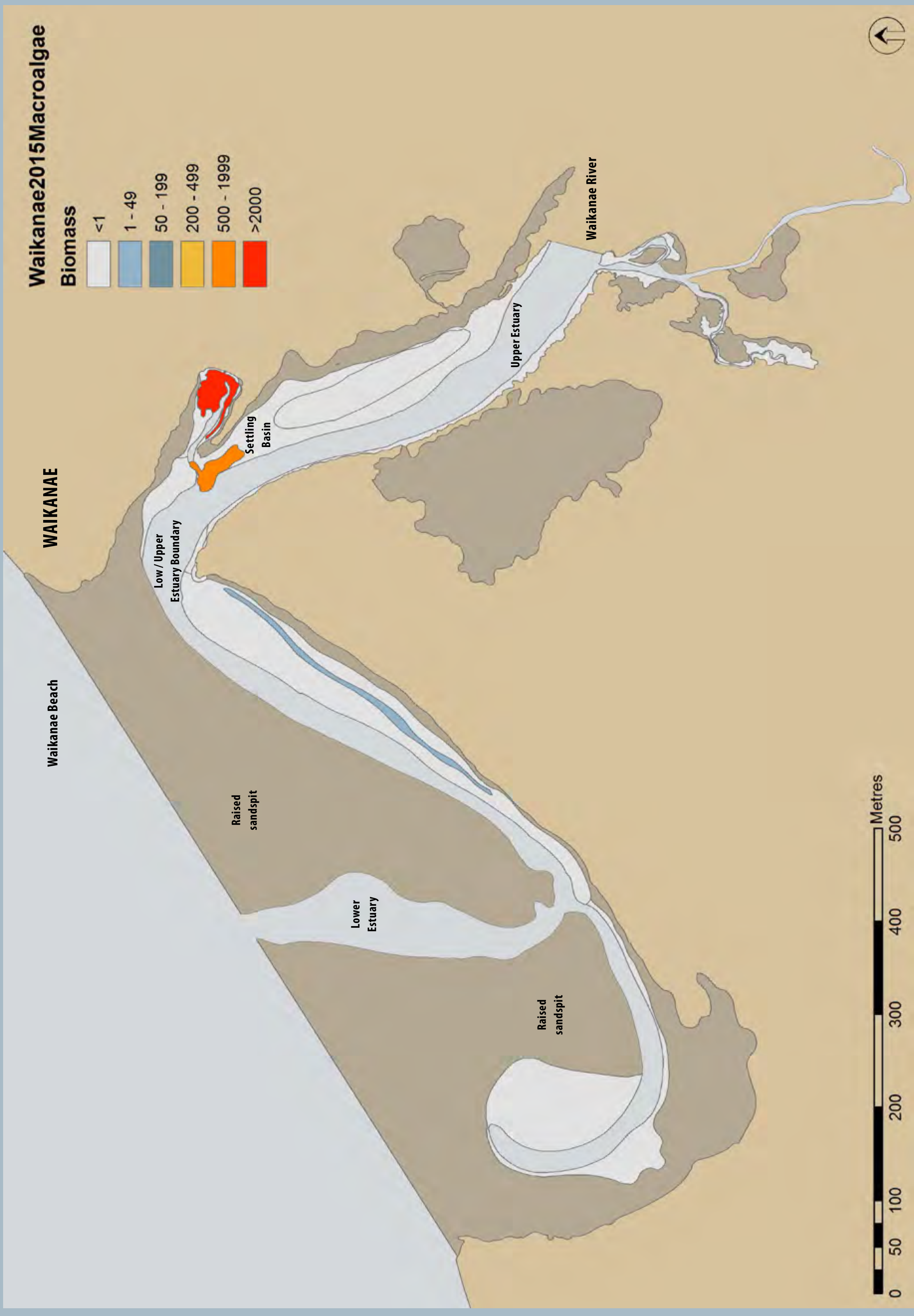
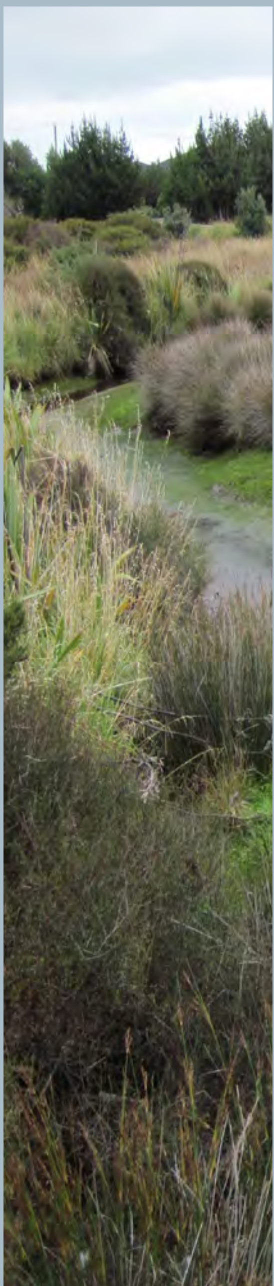


Figure 7. Map of intertidal opportunistic macroalgal biomass (g.m^{-2}) - Waikanae Estuary, 2015.

4.3 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, mitigates flood peaks, 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 limit of saltmarsh growth limited for most species to above the height of mean high water neap (MHWN).

Two measures were used to assess saltmarsh condition, i. loss compared to estimated natural state cover, and ii. percent cover within the available saltmarsh habitat - defined as the area between MHWN and the upper tidal extent.

Table 7 and Figure 8 summarise the results of the 2015 saltmarsh mapping and show 5.7ha of saltmarsh was present. This represents approximately 10% of an estimated natural state saltmarsh cover of ~55ha based on an appraisal of aerial photos and historical maps. Greatest historical losses have occurred in the northern arm of the estuary which is no longer tidally flushed, and through the loss of fringing saltmarsh and wetland vegetation bordering urban development. Such losses reflect a risk indicator rating of "VERY HIGH".

Of the 6.6ha of estimated available saltmarsh habitat (which excludes mobile sands above MHWN on the seaward side of the lower estuary), 86% is vegetated, a risk indicator rating of "VERY LOW".

Key characteristics of the remaining saltmarsh were:

- The most extensive saltmarsh areas were located in the upper river sections of the estuary.
- The overwhelmingly dominant saltmarsh cover was rushland (92%), which comprised a mix of jointed wire rush and searush.
- Sedgeland (7.5%) was the next most dominant, present as fringing vegetation (predominantly three square) along the upper estuary channels, with small herbfield dominated areas (0.3%) located in the lower estuary.
- Introduced weeds were a conspicuous subdominant cover near the terrestrial margin, and included common species such as gorse, broom, blackberry, willows, introduced grasses.

Table 7. Dominant saltmarsh cover, Waikanae Estuary, 2015.

Class	Dominant Vegetation	Area (ha)	Percentage
Sedgeland		0.4	7.5
	Schoenoplectus pungens (Three square)	0.3	6.0
	Isolepis cernua (Slender clubrush)	0.1	1.5
Rushland		5.3	92.2
	Apodasima similis (Jointed wirerush)	3.5	60.7
	Juncus kraussii (Searush)	1.8	31.5
Herbfield		0.02	0.3
	Selliera radicans (Remuremu)	0.02	0.3
TOTAL		**5.7ha**	**100%**

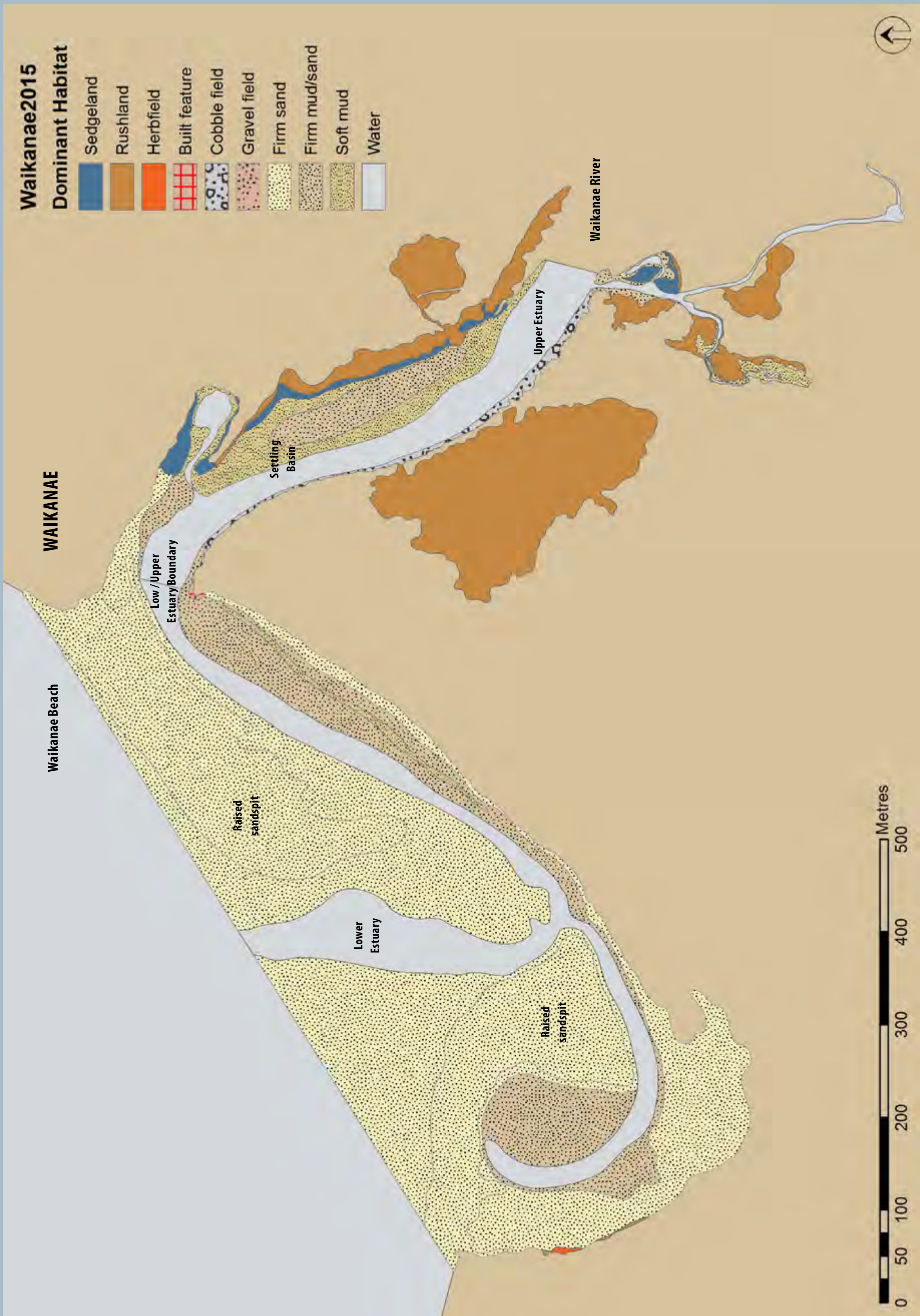


Figure 8. Map of dominant saltmarsh cover - Waikanae Estuary, 2015.

The saltmarsh in Waikanae was dominated by wide and extensive beds of rushland located in the upper reaches of the estuary. These large beds are predominantly free of introduced weeds and grasses in the lower tidal areas, but the terrestrial margins often contained a mix of saltmarsh ribbonwood, gorse, and a wide variety of introduced grass and weeds. Upstream, along the upper river margins leading into the main body of the estuary, saltmarsh was generally confined to narrow strips with saltmarsh habitat limited by elevated banks and surrounding grassland, parkland, or urban development.

In the middle part of the estuary, historical drainage, channelling or reclamation activities have restricted saltmarsh to remnant pockets or narrow bands along the upper tide range. Such areas are highly susceptible to sea level rise (SLR) related impacts and, where inland migration is not possible, saltmarsh will be eroded or inundated and displaced over time.

In the lower estuary, strong tidal flows, wave action, channel migration, mobile sands, and high and variable salinity all limit the establishment of stable saltmarsh. The saltmarsh present is generally restricted to localised patches that undergo regular cycles of establishment and displacement. Dune areas flanking the estuary are dominated by introduced species (primarily marram grass, tree lupins and terrestrial grasses and weeds).

4.4 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 stream temperature fluctuations, and improves estuary biodiversity. The results of the 200m terrestrial margin of the estuary (Table 8 and Figure 9) showed:

- The mapped 200m wide terrestrial margin buffer was dominated by grassland (50%) and residential development (35%).
- Dense buffering vegetation covered 10% of the 200m margin and comprised scrub (6%), duneland (2%), tussock and reedland (2%).
- A network of walkways, complimented by revegetation initiatives, were evident in the margin areas which appear to be highly valued and well used for recreational purposes.

The relatively limited extent of a densely vegetated buffer (10%) fits the risk indicator rating of "HIGH". Aerial photos (Google Earth) indicate no significant change in the terrestrial margin cover over the past 10 years.

The extensive residential development, and associated drainage, flood, and erosion protection measures, have resulted in a steepened and hardened estuary margin, often with a vertical face along the edge of past reclamations, around which very little buffering vegetation remains. This, combined with associated drainage of wetland areas and channelisation of streams, and the cutting off of tidal flows to the northern arm of the estuary, significantly adversely impacts on native fish spawning and bird habitat, and greatly compromises the natural capacity of the estuary to respond to climate change related sea level rise and to assimilate and buffer against inputs of sediment and nutrients.

While there have been significant amenity planting initiatives along parts of the developed estuary margin, most of the low lying estuary fringes, where there was once a gentle natural transition from the estuarine to terrestrial habitat, have now been significantly modified by human development.

Initiatives being undertaken to improve the quality of the estuary margin, particularly the planting of native trees and creation of bird roosting islands, and protection of saltmarsh on private land should be encouraged wherever possible.






Margin areas around Waikanae Estuary highlighting the grassland, introduced weed and residential nature of much of the area.

Table 8. Summary of 200m terrestrial margin land cover, Waikanae Estuary, 2015.

Class	Dominant Cover	Percentage
Scrub		5.9
	Native scrub	2.0
	Ulex europaeus (Gorse)	3.8
Reedland		0.2
	Typha orientalis (Raupo)	0.2
Tussockland		1.4
	Phormium tenax (New Zealand flax)	1.4
Grassland		50.2
	Festuca arundinacea (Tall fescue)	30.9
	Grassland (undeveloped pasture and parkland)	19.3
Duneland		2.1
	Ammophila arenaria (Marram grass)	2.1
Residential		35.1
Water		5.1
Total		**100%**

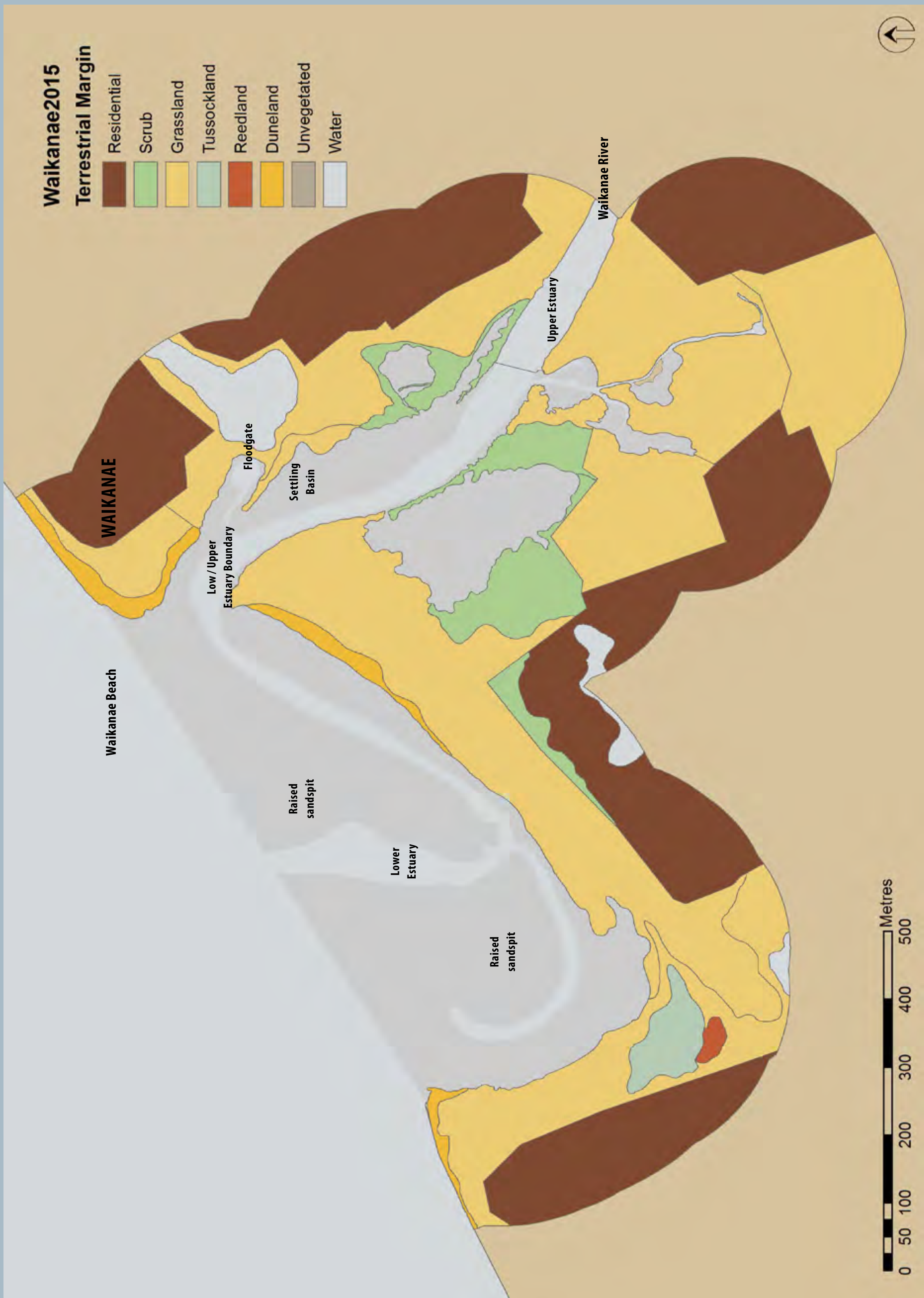


Figure 9. Map of 200m Terrestrial Margin - Dominant Land Cover, Waikanae Estuary, 2015.

5. SUMMARY AND CONCLUSIONS

Broad scale habitat mapping undertaken in January 2015 used risk indicator ratings in relation to the key estuary stressors (i.e. sediment, eutrophication and habitat modification), and changes from estimated natural state conditions, to assess overall condition (Table 9). The overall estuary condition in 2015 was found to be "MODERATE".

Table 9. Summary of broad scale risk indicator ratings for Waikanae Estuary, 2015, and changes from estimated natural state conditions.

Major Issue	Indicator	2015 risk rating	Estimated Change from Natural State
Sediment	Soft mud (% cover)	MODERATE	Moderate increase
Eutrophication	Macroalgal Growth (EQC)	LOW	Moderate increase
	Gross Eutrophic Conditions (ha)	VERY LOW	No significant change
Habitat Modification	Seagrass Coefficient (SC)	VERY HIGH	100% loss
	Saltmarsh (% loss from estimated natural state)	VERY HIGH	~90% loss
	Saltmarsh (vegetated % of available habitat)	VERY LOW	No significant change
	200m Vegetated Terrestrial Margin	HIGH	~90% loss

The results highlight that historical habitat loss through the displacement and reclamation of saltmarsh, seagrass, and a densely vegetated terrestrial margin have been the most significant modifications to the estuary, with a consequent reduction in the ecological value of these important habitat features, including their ability to assimilate sediment and nutrient inputs and provide supporting habitat to birds and fish, particularly whitebait.

Remaining saltmarsh, able to grow wherever suitable habitat was present (covering >85% of the intertidal area above MHWN), provides important remnant habitat areas for a wide range of estuary plant and animal species. However, this saltmarsh, now confined largely to the upper estuary, was under obvious pressure from the ingress of terrestrial weeds and land drainage/channelisation.

Eutrophication, expressed through indicators of macroalgal growth and the presence of gross eutrophic conditions, was not a significant concern in the estuary, although localised accumulations of high biomass were present near the floodgate embayment where it was smothering the sediment surface. Despite low macroalgal cover, other indicators of eutrophication (e.g. reduced sediment oxygenation, increased organic content, dense growths of microalgal mats) indicate a decline in estuary quality since 2010.

Sediment was considered the main issue currently affecting the estuary. Despite the overall estuary cover of soft mud being moderate (7%), the unvegetated intertidal upper estuary was mud dominated (54% cover), with the mean sediment mud content (measured at the fine scale monitoring site) consistently elevated (range 18% to 39%), and with a mean sediment deposition rate of 25.6mm/yr since 2010.

Based on the current rate of sediment deposition, the upper estuary is consequently expected to infill rapidly, and become muddier and less biodiverse. The lower estuary showed no significant soft mud issues, predominantly due to the strong coastal marine influence - it is regularly flushed with waves, and dune systems periodically develop and erode through natural accretion and erosion processes.

To date, no targeted modelling has been undertaken to assess the source or extent of sediment inputs although, as part of floodplain management work, Opus (2012) assessed sediment loads in the Waikanae River. While primarily focussed on gravel migration, they highlighted exotic forest harvesting as a significant source of suspended sediment, but noted more work was required to identify and manage sources.

To clarify the primary sources of fine sediment to the estuary, the most cost effective approach would be to use an existing catchment based landuse/sediment yield model to predict sediment sources (e.g. CLUES Model) under different landuse patterns. This would enable development of a conceptual outline of what the estuary would look like under various sediment load scenarios (e.g. low, medium, high, and existing), allowing defined changes in estuary condition to be related to natural or human influenced processes that influence the estuary. This will provide a basis, through stakeholder involvement, to agree on the type and potential extent of management actions needed to meet or maintain a defined "target" estuary condition or state.

The outcome would help address, early in the process, such important questions as;

- Where are the current sediment loads coming from and are they excessive for this type of estuary?
- If input loads are reduced, will existing mud gradually dissipate, or will it always be muddy?
- Can existing mud in the estuary be removed through dredging or some other artificial means?
- Can existing mud be stabilised, and ecology improved, by expanding saltmarsh?

5. SUMMARY AND CONCLUSIONS (CONTINUED)

Understanding the assimilative capacity of an estuary and how it responds to changing inputs is fundamental to defining sediment input load guideline criteria to either maintain existing state, or transition the estuary toward an agreed target condition.

While it is readily achievable to establish sediment input load guideline criteria, it would require additional investigations into fine sediment source, transport, deposition, and export within the estuary. Ideally this would incorporate a model that predicts the estuary response to input loads (i.e. a hydrodynamic model of how the estuary retains and distributes sediment, with the model linked to catchment based landuse/sediment yield model predictions (under different land use scenarios). This would enable different management options to be evaluated, in particular the likely way the estuary would respond to mitigation measures or changes in catchment land use.

6. MONITORING

Waikanae Estuary has been identified by GWRC as a priority for monitoring, and is a key part of GWRC's coastal monitoring programme being undertaken in a staged manner throughout Wellington region. Based on the 2015 monitoring results and risk indicator ratings, particularly those related to fine sediment, the following monitoring recommendations are proposed by Wriggle for consideration by GWRC:

Broad Scale Habitat Mapping, Including Macroalgae.
Continue broad scale habitat mapping at 10 yearly intervals, unless obvious changes are observed in the interim, focussing on the main issue of fine sediment. Next monitoring recommended for January 2025. Undertake macroalgal mapping 5 yearly (next monitoring recommended for January 2020).

Fine Scale Monitoring.
Continue fine scale monitoring at five yearly intervals (next monitoring scheduled for 2017) or as deemed necessary based on the condition ratings.

Eutrophication and Sedimentation Monitoring.
To better assess current symptoms of sedimentation, it is recommended that annual monitoring be continued, with additional sites deployed in the upper and lower estuary, but only for low cost key indicators of RPD, sedimentation rate and grain size. At the same time, quickly assess macroalgal cover of the whole estuary. If issues are present, undertake macroalgal mapping and synoptic sampling to characterise chlorophyll a concentrations in surface water and bottom water (downstream pool).

Catchment Landuse.
Track and map key broad scale changes in catchment landuse (5 yearly).

7. MANAGEMENT

The combined results from the broad scale and fine scale monitoring (Robertson and Stevens 2012) identify fine sediment as the major current stressor in Waikanae Estuary. Although elevated fine sediment inputs have likely been occurring since the first human development of the catchment, the current monitoring highlights recent inputs are contributing to significant muddiness in the upper estuary. To address this issue, it is recommended that the following be considered:

- Develop a conceptual outline of what the estuary would look like under various sediment load scenarios (e.g. low, medium, high and existing) and, through stakeholder involvement, identify an appropriate "target" estuary condition.
- Following this initial step, undertake a detailed investigation of fine sediment sources through the application of a catchment based landuse/sediment yield model to predict sediment sources under different landuse patterns.
- Apply an estuary model that predicts how the estuary retains and distributes sediment under various input load scenarios.
- Using the results of the above investigations, and other appropriate monitoring data, identify sediment input load guideline criteria to required for fine sediment infilling to meet a target state.
- Explore catchment management and estuary restoration options, and develop a plan, to achieve targets.

8. ACKNOWLEDGEMENTS

This survey and report has been undertaken with help from the staff of Greater Wellington Regional Council, in particular, the support and feedback of Megan Oliver (GWRC) was much appreciated. Thanks to Ben Robertson (Wriggle) for help with the fieldwork.

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APPENDIX 1. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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.

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: The substrate is clearly recognised by the granular beach sand appearance and the often rippled surface layer. Mobile sand is continually being moved by strong tidal or wind-generated currents and often forms bars and beaches. When walking on the substrate you'll sink <1 cm.

Firm sand: Firm sand flats may be mud-like in appearance but are granular when rubbed between the fingers, and solid enough to support an adult's weight without sinking more than 1-2 cm. Firm sand may have a thin layer of silt on the surface making identification from a distance difficult.

Soft sand: Substrate containing greater than 99% sand. When walking on the substrate you'll sink >2 cm.

Firm mud/sand: A mixture of mud and sand, the surface appears brown, and may have a black anaerobic layer below. When walking you'll sink 0-2 cm.

Soft mud/sand: A mixture of mud and sand, the surface appears brown, and may have a black anaerobic layer below. When walking you'll sink 2-5 cm.

Very soft mud/sand: A mixture of mud and sand, the surface appears brown, and may have a black anaerobic layer below. When walking you'll sink >5 cm.

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.

ESTUARY CONDITION RISK RATINGS FOR KEY INDICATORS

Developed by Wriggle Coastal Management

June 2014

GUIDELINES FOR USE

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), 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 process, "risk indicator ratings" have been proposed that assign a relative level of risk of adversely affecting estuarine conditions (e.g. very low, low, moderate, high, very high) to each indicator. 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.
- That rating and ranking systems can easily mask or oversimplify results. For instance, large changes can occur within a risk category, but small changes near the edge of one risk category may shift the rating to the next risk level.
- Most issues will have a mix of primary and secondary ratings, primary ratings being given more weight in assessing the significance of indicator results. It is noted that many secondary estuary indicators will be monitored under other programmes and can be used if primary indicators reflect a significant risk exists, or if risk profiles have changed over time.
- Ratings have been established in many cases using statistical measures based on NZ estuary data. 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 risk ratings used in the Waimea Inlet broad scale monitoring programme, and their justifications, are summarised in the following sections.

APPENDIX 2. ESTUARY CONDITION RISK RATINGS (CONTINUED)

1. SEDIMENT: PERCENT SOFT MUD COVER

Estuaries are a sink for sediments. However, where large areas of "soft mud" are present in estuaries that are not naturally prone to such impacts, they are likely to lead to major and detrimental ecological changes that could be very difficult to reverse, and indicate where changes in land management may be needed. "Total Soft Mud" is defined as the combination of the "soft mud" and "very soft mud" which are two indicators used to assess broad scale estuary condition in the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002). These are defined as follows:

- Soft Mud: A mixture of mud and sand, the surface appears grey-brown (may have a black anaerobic layer below) and when a human walks on it they sink 2-5cm.
- Very Soft Mud. A mixture of mud and sand, the surface appears grey-brown and may have a black anaerobic layer below and when a human walks on it they sink >5cm.

Subsequent to the development of NEMP, the characteristics of "total soft mud" has been further defined and related to; percentage mud content (i.e. grain size), the macroinvertebrate community, and seagrass cover (see supporting evidence below). As a consequence, the characteristics of "total soft mud" are generally as follows:

"Total Soft Mud" Characteristics

- Sediments are relatively incohesive at mud contents below 20-30% (i.e. are not sticky and are relatively firm to walk on), but become cohesive and "sticky" at higher mud contents (i.e. you begin to sink into the muds).
- There is a marked shift in the macroinvertebrate assemblage when mud content exceeds 25-30% to one dominated by mud tolerant and/or species of intermediate tolerance. This shift is most apparent when elevated mud content is contiguous with high total organic carbon (TOC) concentrations.
- Seagrass (*Zostera muelleri*) cover is often absent or less than 1% for estuaries with greater than 20-30% soft mud.

These characteristics indicate that the presence of extensive areas of soft mud sediments (i.e. greater than 20-30% of the estuary as soft mud) in typical NZ tidal lagoon and tidal river estuaries means that seagrass cover is likely to be absent, the macroinvertebrate community degraded and the soft mud areas overlain with the dense nuisance beds of the red macroalga Gracilaria sp. in enclosed embayments or sheltered areas. Following on from these findings, a preliminary rating to reflect the likely risk of adverse impacts to the estuarine ecology was therefore developed (see following section).

SUPPORTING EVIDENCE

1. Total Soft Mud - Relationship to Mud Content

Based on the results from a selection of typical NZ tidal lagoon and tidal river estuaries (Table 1), the percent mud content of "Total Soft Mud" generally equates to estuarine sediments with a % mud content in the 25-100% range (i.e. the range where sediments become "cohesive" or sticky - Houwing 2000).

Table 1. Relationship between "muddiness category" and % mud content of intertidal habitat of various typical NZ estuaries.

Estuary	Muddiness Category	Human Footprint Depth (cm)	% Mud Content	Source
Porirua Harbour	Firm Muddy Sand	0-2cm	1.7-11.1%	Stevens and Robertson (2013)
	Soft Mud	2-5cm	37-49%	
	Very Soft Mud	>5cm		
Waikanae Estuary	Soft Mud	2-5cm	27-47%	Robertson and Stevens (2012a)
	Very Soft Mud	>5cm		
Hutt Estuary	Firm Muddy Sand	0-2cm	21%	Stevens and Robertson (2014a)
	Soft Mud	2-5cm	28-51%	Robertson and Stevens (2012b)
	Very Soft Mud	>5cm		
Whareama Estuary	Firm Muddy Sand	0-2cm	21%	Stevens and Robertson (2013)
	Soft Mud	2-5cm	39-86%	
	Very Soft Mud	>5cm		
Waimea Estuary	Firm Muddy Sand	0-2cm		Stevens and Robertson (2014b)
	Soft Mud	2-5cm	>25%	
	Very Soft Mud	>5cm		
Havelock Estuary	Firm Muddy Sand	0-2cm	17%	Stevens and Robertson (current report)
	Soft Mud	2-5cm	>25%	
	Very Soft Mud	>5cm		

APPENDIX 2. ESTUARY CONDITION RISK RATINGS (CONTINUED)

1. SEDIMENT: PERCENT SOFT MUD COVER (CONTINUED)

2. Mud Content - Relationship to Macroinvertebrate Community

A review of monitoring data from 25 typical NZ estuaries (shallow, short residence time estuaries) (Wriggle database 2009-2014) confirmed a "high" risk of reduced macrobenthic species richness for NZ estuaries when mud values were >25-30% mud and a "very high" risk at >55% (this last value is more tentative given the low number of data-points beyond this mud content) (Figure 1). This is supported statistically (canonical analysis of the principal coordinates (CAP) for the effect of mud content) by the increasing dissimilarity in the macrobenthic community as mud contents increase above 25-30% mud (Figure 2).

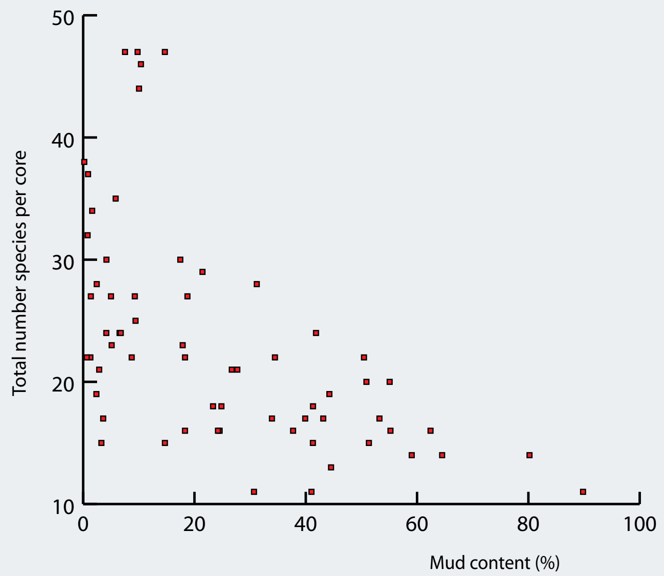

Figure 1. Sediment mud content and number of macrobenthic species per core from 12 estuaries scattered throughout NZ, and representing most NZ shallow, short residence time estuary types. (Wriggle Coastal Management database 2009-14).

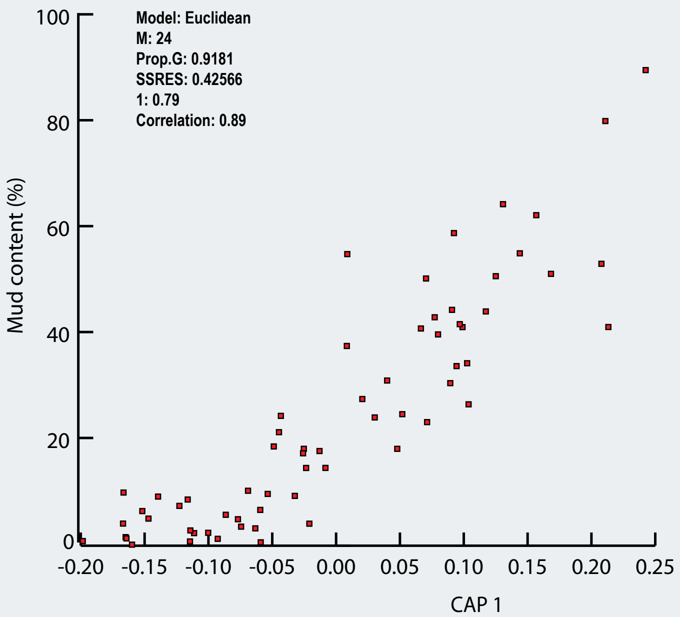

Figure. 2. Canonical analysis of the principal coordinates (CAP) for the effect of sediment mud content (exclusively) on the macroinvertebrate assemblages from 25 typical NZ estuaries (i.e. CAP1) among sites. Note: M = the number of PCO axes used for the analysis, Prop.G = the proportion of the total variation in the dissimilarity matrix explained by the first m PCO axes, SSRES = the leave-one-out residual sum of squares, 1 = the squared canonical correlation for the canonical axis, Correlation = the correlation between the canonical axis and the sediment mud content or pollution gradient.

1. SEDIMENT: PERCENT SOFT MUD COVER (CONTINUED)

3. Total Soft Mud - Relationship to Seagrass Cover

- Tidal Lagoon and Tidal River Estuaries: Seagrass (Zostera *muelleri*) typically requires sandy sediments with a low mud content for healthy growth. Extensive broad scale mapping of seagrass cover for 45 typical NZ tidal lagoon and tidal river estuaries (shallow, residence time <3 days) indicate that seagrass cover is absent or less than 1% cover for estuaries with greater than 20-30% of the estuary area as soft mud (Figure 3). It is expected that this is primarily caused by reduced water clarity, and hence light availability, as a result of resuspension and elevated suspended sediment input loads.
- ICOLLS: Submerged aquatic vegetation (SAV) in intermittently open and closed lagoons/lakes (i.e. brackish waterbodies) in NZ can survive in some ICOLLs that are dominated by muddy sediments (Figure 4). This occurs primarily as a result of the ability of SAV (unlike Zostera) to grow up to the surface and hence obtain sufficient light for growth. ICOLLs with low SAV are generally SAV limited by reasons other than soft muds, unless the SAV is Zostera (such as in Papanui Inlet). For example, in Lake Onoke, SAV is limited by the short period opening/closing regime: in Waimatuku, SAV is limited by the very long opening period and short closed period, in Waituna SAV is limited by a combination of macroalgal/epiphyte cover and muddiness and the opening/closing regime.

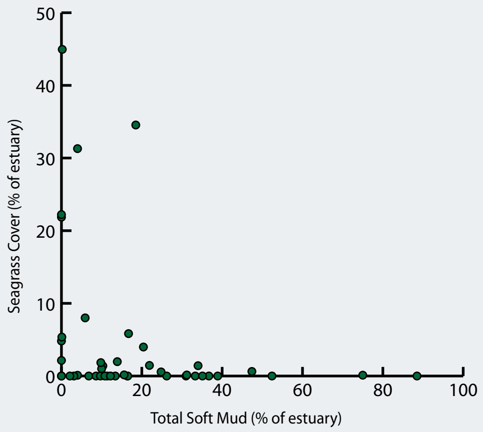

Figure 3. Percentage soft mud and seagrass cover of 45 typical NZ tidal lagoon and tidal river) estuaries (shallow, residence time <3 days) (data sourced from Wriggle Coastal Management monitoring reports 2006-2013 and Robertson et al. 2002).

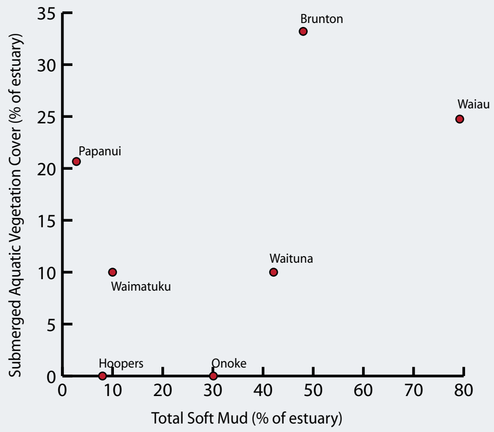

Figure 4. Percentage soft mud and seagrass cover of 7 typical NZ ICOLL estuaries (shallow, residence time variable) (data sourced from Wriggle Coastal Management monitoring reports 2006-2013).

RECOMMENDED SEDIMENT SOFT MUD PERCENT COVER RISK RATING (INTERIM)

The following rating specifies the magnitude of likely risk that the measured % soft mud will cause adverse impacts to estuarine ecology and is based on data for a wide range of NZ estuary types. These results showed that most estuaries in a dataset of 50 typical NZ estuaries fit the <10% soft mud category (Wriggle data 2001-2013).

Estuary Condition Risk Rating (Interim): Sediment Soft Mud Percent Cover					
Risk Rating	Very Low	Low	Moderate	High	Very High
Soft Mud Percent Cover	<2%	2-5%	>5-15%	>15-25%	>25%

RECOMMENDED RESEARCH

Undertake extensive grain size validation monitoring of the following habitat types: firm muddy sand, soft mud, and very soft mud to confirm and refine the measured range of % mud found in each these broad scale monitoring categories from estuaries throughout NZ.
Undertake further studies in typical NZ estuaries on % cover of mud and the incidence of gross eutrophic conditions, and adverse impacts to macroinvertebrates, seagrass, saltmarsh, fish, and/or birds.

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2. OPPORTUNISTIC MACROALGAL BLOOMING TOOL

The UK-WFD (Water Framework Directive) Opportunistic Macroalgal Blooming Tool (OMBT) (WFD-UKTAG 2014) is a comprehensive 5 part multimetric index approach suitable for characterising the different types of estuaries and related macroalgal issues found in NZ. The tool allows simple adjustment of underpinning threshold values to calibrate it to the observed relationships between macroalgal condition and the ecological response of different estuary types. It incorporates sediment entrained macroalgae, a key indicator of estuary degradation, and addresses limitations associated with percentage cover estimates that do not incorporate biomass e.g. where high cover but low biomass are not resulting in significantly degraded sediment conditions. It is supported by extensive studies of the macroalgal condition in relation to ecological responses in a wide range of estuaries.

The 5 part multimetric OMBT, modified for NZ estuary types, is fully described below. It is based on macroalgal growth within the Available Intertidal Habitat (AIH) - the estuary area between high and low water spring tide able to support opportunistic macroalgal growth. Suitable areas are considered to consist of ***mud, muddy sand, sandy mud, sand, stony mud and mussel beds***. Areas which are judged unsuitable for algal blooms e.g. channels and channel edges subject to constant scouring, need to be excluded from the AIH. The following measures are then taken:.

1. Percentage cover of the available intertidal habitat (AIH).

The percent cover of opportunistic macroalgal within the AIH is assessed. While a range of methods are described, visual rating by experienced ecologists, with independent validation of results is a reliable and rapid method. All areas within the AIH where macroalgal cover >5% are mapped spatially.

2. Total extent of area covered by algal mats (affected area (AA)) or affected area as a percentage of the AIH (AA/AIH, %).

In large water bodies with proportionately small patches of macroalgal coverage, the rating for total area covered by macroalgae (Affected Area - AA) might indicate high or good status, while the total area covered could actually be quite substantial and could still affect the surrounding and underlying communities. In order to account for this, an additional metric established is the affected area as a percentage of the AIH (i.e. (AA/AIH)*100). This helps to scale the area of impact to the size of the water body. In the final assessment the lower of the two metrics (the AA or percentage AA/AIH) is used, i.e. whichever reflects the worse case scenario.

3. Biomass of AIH ($g.m^{-2}$).

Assessment of the spatial extent of the algal bed alone will not indicate the level of risk to a water body. For example, a very thin (low biomass) layer covering over 75% of a shore might have little impact on underlying sediments and fauna. The influence of biomass is therefore incorporated. Biomass is calculated as a mean for (i) the whole of the AIH and (ii) for the Affected Areas. The potential use of maximum biomass was rejected, as it could falsely classify a water body by giving undue weighting to a small, localised blooming problem. Algae growing on the surface of the sediment are collected for biomass assessment, thoroughly rinsed to remove sediment and invertebrate fauna, hand squeezed until water stops running, and the wet weight of algae recorded.

For quality assurance of the percentage cover estimates, two independent readings should be within +/- 5%. A photograph should be taken of every quadrat for inter-calibration and cross-checking of percent cover determination. Measures of biomass should be calculated to 1 decimal place of wet weight of sample. For both procedures the accuracy should be demonstrated with the use of quality assurance checks and procedures.

4. Biomass of AA ($g.m^{-2}$).

Mean biomass of the Affected Area (AA), with the AA defined as the total area with macroalgal cover >5%.

5. Presence of Entrained Algae (percentage of quadrats).

Algae are considered as entrained in muddy sediment when they are found growing >3cm deep within muddy sediments. The persistence of algae within sediments provides both a means for over-wintering of algal spores and a source of nutrients within the sediments. Build-up of weed within sediments therefore implies that blooms can become self-regenerating given the right conditions (Raffaelli et al. 1989). Absence of weed within the sediments lessens the likelihood of bloom persistence, while its presence gives greater opportunity for nutrient exchange with sediments. Consequently, the presence of opportunistic macroalgae growing within the surface sediment was included in the tool.

All the metrics are equally weighted and combined within the multimetric, in order to best describe the changes in the nature and degree of opportunist macroalgae growth on sedimentary shores due to nutrient pressure.

Timing: The OMBT has been developed to classify data over the maximum growing season so sampling should target the peak bloom in summer (Dec-March), although peak timing may vary among water bodies, so local knowledge is required to identify the maximum growth period. Sampling is not recommended outside the summer period due to seasonal variations that could affect the outcome of the tool and possibly lead to misclassification; e.g. blooms may become disrupted by stormy autumn weather and often die back in winter. Sampling should be carried out during spring low tides in order to access the maximum area of the AIH.

Suitable Locations: The OMBT is suitable for use in estuaries and coastal waters which have intertidal areas of soft sedimentary substratum (i.e. areas of AIH for opportunistic macroalgal growth). The tool is not currently used for assessing ICOLLs due to the particular challenges in setting suitable reference conditions for these water bodies.

Derivation of Threshold Values.

Published and unpublished literature, along with expert opinion, was used to derive critical threshold values suitable for defining quality status classes (Table A2).

- **Reference Thresholds.** A UK Department of the Environment, Transport and the Regions (DETR) expert workshop suggested reference levels of <5% cover of AIH of climax and opportunistic species for high quality sites (DETR, 2001). In line with this approach, the WFD adopted <5% cover of opportunistic macroalgae in the AIH as equivalent to High status. From the WFD North East Atlantic intercalibration phase 1 results, German research into large sized water bodies revealed that areas over 50ha may often show signs of adverse effects, however if the overall area was less than 1/5th of this adverse effects were not seen, so the High/Good boundary was set at 10ha. In all cases a reference of 0% cover for truly un-impacted areas was assumed. Note: opportunistic algae may occur even in pristine water bodies as part of the natural community functioning.
  The proposal of reference conditions for levels of biomass took a similar approach, considering existing guidelines and suggestions from DETR (2001), with a tentative reference level of <100g m^{-2} wet weight. This reference level was used for both the average biomass over the affected area and the average biomass over the AIH. As with area measurements a reference of zero was assumed.
  An ideal of no entrainment (i.e. no quadrats revealing entrained macroalgae) was assumed to be reference for un-impacted waters. After some empirical testing in a number of UK water bodies a High / Good boundary of 1% of quadrats was set.
- **Class Thresholds for Percent Cover:**
  High/Good boundary set at 5%. Based on the finding that a symptom of the potential start of eutrophication is when: (i) 25% of the available intertidal habitat has opportunistic macroalgae and (ii) at least 25% of the sediment (i.e. 25% in a quadrat) is covered (Comprehensive Studies Task Team (DETR, 2001)). This implies that an overall cover of the AIH of 6.25% (25*25%) represents the start of a potential problem.
  Good / Moderate boundary set at 15%. True problem areas often have a >60% cover within the affected area of 25% of the water body (Wither 2003). This equates to 15% overall cover of the AIH (i.e. 25% of the water body covered with algal mats at a density of 60%).
  Poor/Bad boundary is set at >75%. The Environment Agency has considered >75% cover as seriously affecting an area (Foden et al. 2010).
- **Class Thresholds for Biomass.** Class boundaries for biomass values were derived from DETR (2001) recommendations that <500 $g.m^{-2}$ wet weight was an acceptable level above the reference level of <100 $g.m^{-2}$ wet weight. In Good status only slight deviation from High status is permitted so 500 $g.m^{-2}$ represents the Good/Moderate boundary. Moderate quality status requires moderate signs of distortion and significantly greater deviation from High status to be observed. The presence of >500 $g.m^{-2}$ but less than 1,000 $g.m^{-2}$ would lead to a classification of Moderate quality status at best, but would depend on the percentage of the AIH covered. >1kg.m^{-2} wet weight causes significant harmful effects on biota (DETR 2001, Lowthion et al. 1985, Hull 1987, Wither 2003).
- **Thresholds for Entrained Algae.** Empirical studies testing a number of scales were undertaken on a number of impacted waters. Seriously impacted waters have a very high percentage (>75%) of the beds showing entrainment (Poor / Bad boundary). Entrainment was felt to be an early warning sign of potential eutrophication problems so a tight High /Good standard of 1% was selected (this allows for the odd change in a quadrat or error to be taken into account). Consequently the Good / Moderate boundary was set at 5% where (assuming sufficient quadrats were taken) it would be clear that entrainment and potential over wintering of macroalgae had started.

Each metric in the OMBT has equal weighting and is combined to produce the ecological quality ratio score (EQR).

Table A2. The final face value thresholds and metrics for levels of the ecological quality status

Quality Status	High	Good	Moderate	Poor	Bad
EQR (Ecological Quality Rating)	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2
% cover on Available Intertidal Habitat (AIH)	0 - ≤5	>5 - ≤15	>15 -≤25	>25 - ≤75	>75 - 100
Affected Area (AA) of >5% macroalgae (ha)*	≥0 - 10	≥10 - 50	≥50 - 100	≥100 - 250	≥250
AA/AIH (%)*	≥0 - 5	≥5 - 15	≥15 - 50	≥50 - 75	≥75 - 100
Average biomass ($g.m^2$) of AIH	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
Average biomass ($g.m^2$) of AA	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
% algae >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

*N.B. Only the lower EQR of the 2 metrics, AA or AA/AIH is used in the final EQR calculation.

EQR calculation

Each metric in the OMBT has equal weighting and is combined to produce the **Ecological Quality Ratio** score (EQR).
The face value metrics work on a sliding scale to enable an accurate metric EQR value to be calculated; an average of these values is then used to establish the final water body level EQR and classification status. The EQR determining the final water body classification ranges between a value of zero to one and is converted to a Quality Status by using the following categories:

Quality Status	High	Good	Moderate	Poor	Bad
EQR (Ecological Quality Rating)	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	≥0.2 - <0.4	0.0 - <0.2

The EQR calculation process is as follows:

1. Calculation of the face value (e.g. percentage cover of AIH) for each metric. To calculate the individual metric face values:

- Percentage cover of AIH (%) = (Total % Cover / AIH} x 100 - *where Total % cover = Sum of {(patch size) / 100} x average % cover for patch*
- Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%).
- Biomass of AIH (g.m^{-2}) = Total biomass / AIH - *where Total biomass = Sum of (patch size x average biomass for the patch)*
- Biomass of Affected Area (g.m^{-2}) = Total biomass / AA - *where Total biomass = Sum of (patch size x average biomass for the patch)*
- Presence of Entrained Algae = (No. quadrats with entrained algae / total no. of quadrats) x 100
- Size of AA in relation to AIH (%) = (AA/AIH) x 100

2. Normalisation and rescaling to convert the face value to an equidistant index score (0-1 value) for each index (Table A3).

The face values are converted to an equidistant EQR scale to allow combination of the metrics. These steps have been mathematically combined in the following equation:

Final Equidistant Index score = Upper Equidistant range value – ({Face Value - Upper Face value range} * (Equidistant class range / Face Value Class Range)).

Table A3 gives the critical values at each class range required for the above equation. The first three numeric columns contain the face values (FV) for the range of the index in question, the last three numeric columns contain the values of the equidistant 0-1 scale and are the same for each index. The face value class range is derived by subtracting the upper face value of the range from the lower face value of the range.
Note: the table is "simplified" with rounded numbers for display purposes. The face values in each class band may have greater than (>) or less than (<) symbols associated with them, for calculation a value of <5 is given a value of 4.999'.
The final EQR score is calculated as the average of equidistant metric scores.

A spreadsheet calculator is available to download from the UK WFD website to undertake the calculation of EQR scores.

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APPENDIX 2. ESTUARY CONDITION RISK RATINGS (CONTINUED)

Table A3. Values for the normalisation and re-scaling of face values to EQR metric.

METRIC	QUALITY STATUS	FACE VALUE RANGES			EQUIDISTANT CLASS RANGE VALUES		
		Lower face value range (measurements towards the "Bad" end of this class range)	Upper face value range (measurements towards the "High" end of this class range)	Face Value Class Range	Lower 0-1 Equidistant range value	Upper 0-1 Equidistant range value	Equidistant Class Range
% Cover of Available Intertidal Habitat (AIH)	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤25	>15	9.999	≥0.4	<0.6	0.2
	Poor	≤75	>25	49.999	≥0.2	<0.4	0.2
	Bad	100	>75	24.999	0	<0.2	0.2
Average Biomass of AIH (g m-2)	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.999	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.999	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.999	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.999	0	<0.2	0.2
Average Biomass of Affected Area (AA) (g m-2)	High	≤100	0	100	≥0.8	1	0.2
	Good	≤500	>100	399.999	≥0.6	<0.8	0.2
	Moderate	≤1000	>500	499.999	≥0.4	<0.6	0.2
	Poor	≤3000	>1000	1999.999	≥0.2	<0.4	0.2
	Bad	≤6000	>3000	2999.999	0	<0.2	0.2
Affected Area (Ha)*	High	≤10	0	100	≥0.8	1	0.2
	Good	≤50	>10	39.999	≥0.6	<0.8	0.2
	Moderate	≤100	>50	49.999	≥0.4	<0.6	0.2
	Poor	≤250	>100	149.999	≥0.2	<0.4	0.2
	Bad	≤6000	>250	5749.999	0	<0.2	0.2
AA/AIH (%)*	High	≤5	0	5	≥0.8	1	0.2
	Good	≤15	>5	9.999	≥0.6	<0.8	0.2
	Moderate	≤50	>15	34.999	≥0.4	<0.6	0.2
	Poor	≤75	>50	24.999	≥0.2	<0.4	0.2
	Bad	100	>75	27.999	0	<0.2	0.2
% Entrained Algae	High	≤1	0	1	≥0.0	1	0.2
	Good	≤5	>1	3.999	≥0.2	<0.0	0.2
	Moderate	≤20	>5	14.999	≥0.4	<0.2	0.2
	Poor	≤50	>20	29.999	≥0.6	<0.4	0.2
	Bad	100	>50	49.999	1	<0.6	0.2

*N.B. Only the lower EQR of the 2 metrics, AA or AA/AIH should be used in the final EQR calculation.

APPENDIX 3. WAIKANAE ESTUARY MACROALGAL DATA

Patch ID	Rep	Dominant species	Patch area (ha)	Percent cover of macroalgae	Presence (1) or absence (0) of entrained algae	Mean Biomass ($g.m^{-2}$ wet weight)	Mean Patch Biomass (kg wet weight)	aRPD depth (cm)	Presence (1) or absence (0) of soft mud
1	1	*Ulva intestinalis*	0.1473	80	0	4000		>1	0
1	2	*Ulva intestinalis*	0.1473	80	0	3700	5892	>1	0
1	3	*Ulva intestinalis*	0.1473	80	0	4350		>1	0
2	1	*Ulva intestinalis*	0.1067	40	0	1000		>1	0
2	2	*Ulva intestinalis*	0.1067	40	0	960	1067	>1	0
2	3	*Ulva intestinalis*	0.1067	40	0	1150		>1	0
3	1	*Ulva intestinalis*	0.1981	10	0	20		>1	0
3	2	*Ulva intestinalis*	0.1981	10	0	25	40	>1	0
3	3	*Ulva intestinalis*	0.1981	10	0	15		>1	0
		Total	0.5ha				6999kg		

APPENDIX 3. WAIKANAE ESTUARY MACROALGAL DATA

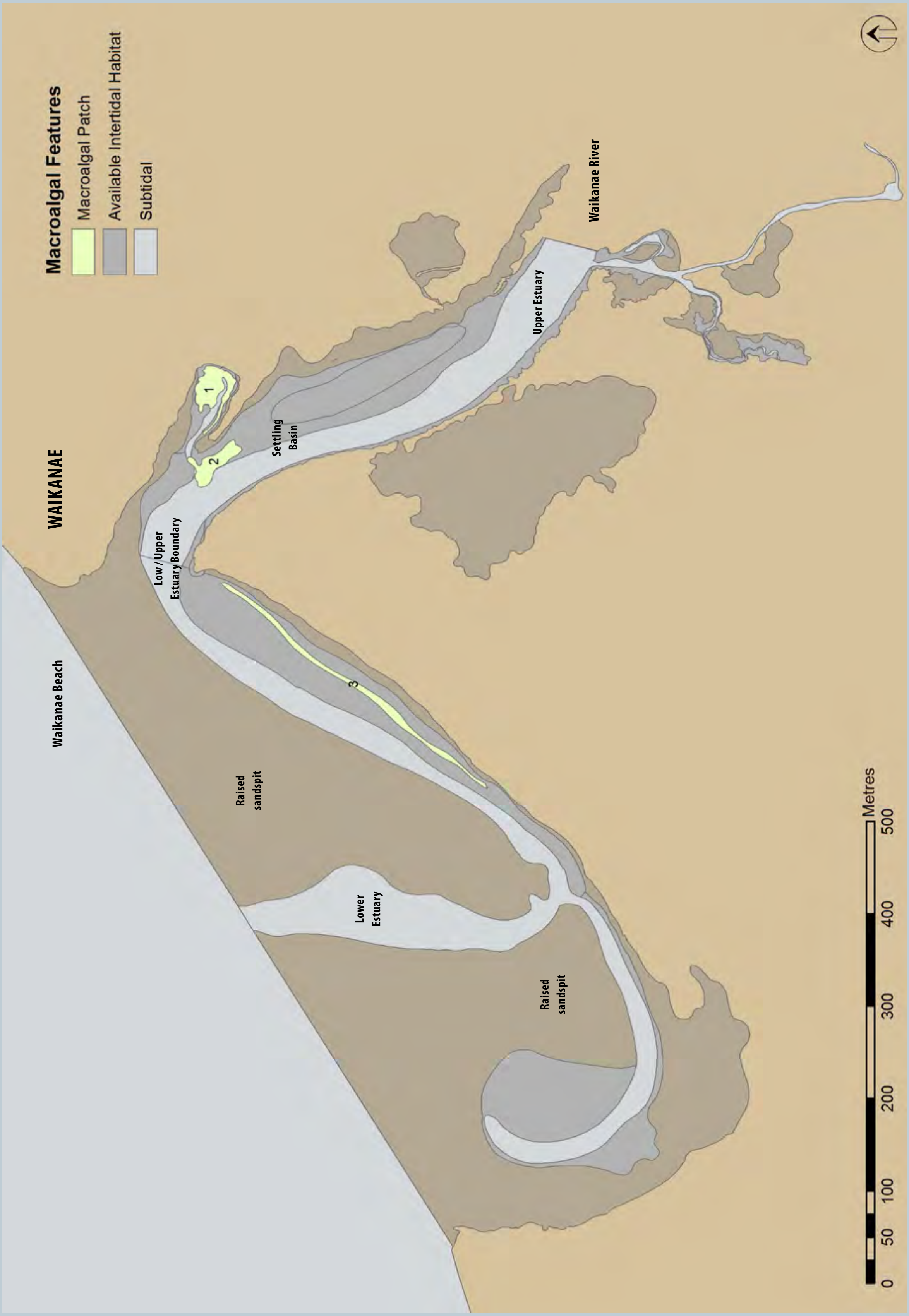

Figure A1. Location of macroalgal patches >5% cover used in assessing Waikanae Estuary, January 2015.