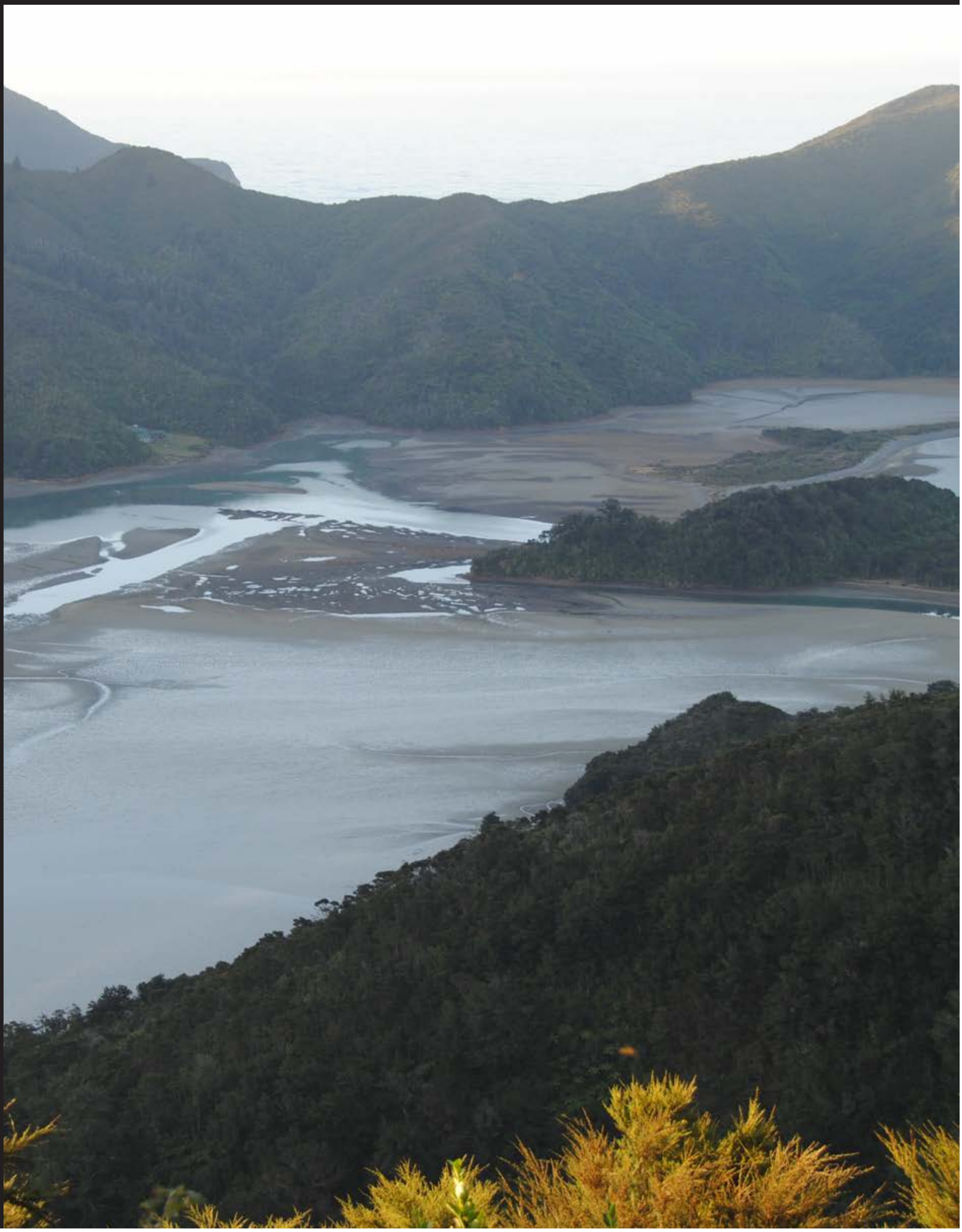
coastalmanagement

Whangarae Estuary

Broad Scale Habitat Mapping 2016



Prepared for

Marlborough District Council

August 2016

Cover Photo: Whangarae Estuary, view over the main basin to the north arm, January 2016.

Whangarae Estuary at high tide.

Whangarae Estuary

Broad Scale Habitat Mapping 2016

Prepared for
Marlborough District Council

by

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RECOMMENDED CITATION:
Stevens, L.M. and Robertson, B.M. 2016. Whangarae Estuary: Broad Scale Habitat Mapping 2016. Report prepared by Wriggle Coastal Management for Marlborough District Council. 29p.

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WHANGARAE ESTUARY - EXECUTIVE SUMMARY

Whangarae Estuary is a relatively unmodified, moderate-sized (124ha), macrotidal (3.1m spring tidal range), shallow (mean depth ~1-2m at high water), well-flushed (residence time <1 day), seawater-dominated, tidal lagoon type estuary located within Croiselles Harbour on the east side of Tasman Bay. It has a single narrow tidal opening, a central basin and three small arms. The catchment is >95% native scrub/forest, and the estuary is perceived to be near pristine. It is one of the key estuaries in Marlborough District Council's (MDC's) long-term coastal monitoring programme. This report presents the results of 2016 broad scale estuary habitat mapping with broad scale monitoring results, risk indicator ratings, overall estuary condition, and monitoring and management recommendations summarised below.

BROAD SCALE RESULTS

- Intertidal flats comprised 86% of the estuary, saltmarsh 8%, and subtidal waters 7%.
- Intertidal substrates dominated by firm muddy sands (69ha, 65%), with smaller areas of gravelfields (21ha, 19%), muds (12.6ha, 12%), cobble (3.3ha, 3.1%) and rock (0.6ha, 0.6%)
- Soft mud (10.1ha) covered 9.5% of the unvegetated intertidal habitat and was concentrated on intertidal flats in the upper estuary. Sediment mud content measured within mud habitat was high (45-72%).
- Opportunistic macroalgal growth (*Ulva intestinalis* and *Gracilaria chilensis*) was very sparse (~5% of the available intertidal habitat), had an Ecological Quality Rating of "HIGH", and no gross eutrophic zones were present.
- Seagrass *(Zostera muelleri)* covered 2ha (1.8%) of the estuary near the main entrance in the central basin that has strong tidal flushing.
- Saltmarsh cover was relatively extensive (9.4ha, 8.8%) and dominated by rushland (79%) and herbfields (21%).
- The 200m terrestrial margin was dominated by regenerating native forest and scrub (97%), with some pasture (3%).

RISK INDICATOR RATINGS (indicate risk of adverse ecological impacts)

Major Issue	Indicator	2016 risk rating
Sediment	Soft mud (% cover, grain size)	MODERATE
Eutrophication	Macroalgal Growth (EQR)	VERY LOW
	Gross Eutrophic Conditions (ha)	VERY LOW
Habitat Modification	Seagrass	Baseline established
	Saltmarsh (% cover, vegetated % of available habitat, estimated historical loss)	LOW
	200m Vegetated Terrestrial Margin	VERY LOW

ESTUARY CONDITION AND ISSUES

In relation to the key issues addressed by the broad scale monitoring (i.e. sediment, eutrophication, and habitat modification), the 2016 broad scale mapping results show that the estuary was not exhibiting significant nuisance macroalgal growths (i.e. expressing a very low level of eutrophication) or gross eutrophic zones (combined presence of dense macroalgal growth, muds and poor sediment oxygenation). It supported small areas of high value seagrass beds and extensive areas of saltmarsh that transition directly into a regenerating native scrub and forest catchment.

The only stressor identified with an elevated risk rating was sediment, with fine mud having a moderate risk of causing adverse impacts to the estuary ecology, a finding further supported by the fine scale monitoring of estuary sediments (Robertson and Stevens 2016). This fine mud is considered most likely to be from past land disturbance.

These combined results place the estuary in a "GOOD" state overall in relation to ecological health.

RECOMMENDED MONITORING AND MANAGEMENT

Because Whangarae Inlet is a moderate-sized tidal lagoon estuary with high ecological and human use values, situated in a largely undeveloped catchment, this estuary has been identified by MDC as a priority for monitoring. Fine scale monitoring, in conjunction with sedimentation rate monitoring and broad scale habitat mapping, provides valuable information on current estuary condition and trends over time, particularly in relation to the sedimentation issue identified in the estuary. The following monitoring recommendations are proposed by Wriggle for consideration by MDC.

Repeat broad scale habitat mapping every 10 years, focussing on the main issue of fine sediment (next scheduled for 2026). Complete a three year annual baseline of fine scale monitoring. It is recommended that the second year of baseline monitoring of intertidal sites (including sedimentation rate measures) be undertaken in the period Jan-March 2017. Once the baseline has been established, a recommendation will be made on the frequency of any subsequent fine scale monitoring, likely to be repeat sampling at 5-10 yearly intervals.

Using the results of the above investigations, it is recommended that the Council identify, through stakeholder involvement, an appropriate "target" estuary condition and determine management strategies to maintain or achieve the target condition.

1. INTRODUCTION

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

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

1. **Ecological Vulnerability Assessment** (EVA) of estuaries in the region to major issues (see Table 1) and appropriate monitoring design. To date, neither estuary specific nor region-wide EVAs have been undertaken for the Marlborough region and therefore the vulnerability of Whangarae Estuary to issues has not yet been fully assessed. However, a recent report has documented selected ecologically significant marine sites in Marlborough (Davidson et al. 2011).
2. **Broad Scale Habitat Mapping** (NEMP approach). This component (see Table 1) documents the key habitats within the estuary, and changes to these habitats over time. The current report focuses on detailed broad scale habitat mapping undertaken in January 2016 to assess the current state of the estuary.
3. **Fine Scale Monitoring** (NEMP approach). Monitoring of physical, chemical and biological indicators (see Table 1). This component, which provides detailed information on the condition of Whangarae Estuary, was first undertaken in 2016 and is reported on in Robertson and Stevens (2016).

Report Structure: The current report presents an overview of key estuary issues in NZ and recommended monitoring indicators (Section 1). This is followed by risk indicator ratings (Section 2) and the sampling methods (Section 3) used in this broad scale assessment. Summarised results of the 21 March 2016 field sampling are then presented and discussed (Section 4) for the following:

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

To help the reader interpret the findings, results are related to relevant risk indicator ratings to facilitate the assessment of overall estuary condition (summarised in Section 5), and to guide monitoring and management recommendations (Sections 6 and 7 respectively).

Whangarae Estuary is a moderate-sized (124ha), relatively unmodified, shallow, well-flushed, seawater-dominated, tidal lagoon type estuary that is open to the sea via a narrow entrance mouth. The estuary is located approximately 5km south-east of Cape Soucis in Tasman Bay and forms the south-western arm of Croiselles Harbour. It is fed by one main stream, Castor Stream, and several smaller streams. Much of the estuary catchment is regenerating coastal forest that has all been logged in the past. Around the estuary fringes are some small areas of pasture as well as stands of the regionally rare swamp maire tree, representing one of the few known sites of its kind in the South Island. Apart from the south-eastern hillside and estuary edge, most of the bush catchment is privately owned. *Spinifex*, a regionally rare sand dune plant grows on the south-east sand-spit, along with other native coastal and sand-inhabiting plants. Currently, Whangarae Estuary provides habitat for several regionally rare bird species, including the banded rail and fern bird (Davidson at al. 2011).

The area is also of high cultural value to Maori. The Ngāti Kōata Deed of Settlement for historical Treaty of Waitangi claims formally recognises the traditional, historical, cultural and spiritual association of Ngāti Kōata with Whangarae Estuary (and surrounds) and provides for formal cultural, financial and commercial redress resulting from acts or omissions by the Crown prior to 21 September 1992.

Whangarae Estuary is currently being monitored every 5-10 years and the results will help determine the extent to which the estuary is affected by major estuary issues (Table 1), both in the short and long term.

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

1. Sediment Changes

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

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

Recommended Key Indicators:

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

2. Eutrophication

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

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Eutrophication	Macroalgal Cover/Biomass	Broad scale mapping - macroalgal cover/biomass over time.
	Phytoplankton (water column)	Chlorophyll a concentration (water column).
	Sediment Organic and Nutrient Enrichment	Chemical analysis of sediment total nitrogen, total phosphorus, and total organic carbon concentrations.
	Water Column Nutrients	Chemical analysis of various forms of N and P (water column).
	Redox Profile	Redox potential discontinuity profile (RPD) using visual method (i.e. apparent Redox Potential Depth - aRPD) and/or redox probe. Note: Total Sulphur is also currently under trial.
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in 0.0133m^2 replicate cores), and on the sediment surface (epifauna in 0.25m^2 replicate quadrats).

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

3. Disease Risk

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

Recommended Key Indicators:

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

4. Toxic Contamination

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

Recommended Key Indicators:

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

5. Habitat Loss

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

Recommended Key Indicators:

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

Figure 1. Whangarae Estuary, showing main estuary features and fine scale monitoring sites.

2. ESTUARY RISK INDICATOR RATINGS

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

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

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

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

Table 2. Summary of estuary condition risk indicator ratings used in the present report.

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

* NZ ETI (Robertson et al. 2016b), ** Hargrave et al. (2008), ***Robertson (in prep.), Keeley et al. (2012),

See NOTES on following page for further information

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

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

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

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

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

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

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

Opportunistic Macroalgae. The presence of opportunistic macroalgae is a primary indicator of estuary eutrophication, and when combined with gross eutrophic conditions (see previous) can cause significant adverse ecological impacts that are very difficult to reverse. Thresholds used to assess this indicator are derived from the OMBT (see Section 3 and Appendix 2), with results combined with those of other indicators to determine overall condition.

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

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

Saltmarsh. Saltmarshes have high biodiversity, are amongst the most productive habitats on earth, and have strong aesthetic appeal. They are sensitive to a wide range of pressures including land reclamation, margin development, flow regulation, sea level rise, grazing, wastewater contaminants, and weed invasion. Most NZ estuarine saltmarsh grows in the upper estuary margins above mean high water neap (MHWN) tide where vegetation stabilises fine sediment transported by tidal flows. Saltmarsh zonation is commonly evident, resulting from the combined influence of factors including salinity, inundation period, elevation, wave exposure, and sediment type. Highest saltmarsh diversity is generally present above mean high water spring (MHWS) tide where a variety of salt tolerant species grow including scrub, sedge, tussock, grass, reed, rush and herb fields. Between MHWS and MHWN, saltmarsh is commonly dominated by relatively low diversity rushland and herbfields. Below this, the MHWN to MSL range is commonly unvegetated or limited to either mangroves or *Spartina*, the latter being able to grow to MLWN. Further work is required to develop a comprehensive saltmarsh metric for NZ. As an interim measure, the % of the intertidal area comprising saltmarsh is used to indicate saltmarsh condition. Two supporting metrics are also proposed: i. % loss from Estimated Natural State Cover. This assumes that a reduction in natural state saltmarsh cover corresponds to a reduction in ecological services and habitat values. ii. % of available habitat supporting saltmarsh. This assumes that saltmarsh should be growing throughout the majority of the available saltmarsh habitat (tidal area above MHWN), and that where this does not occur, ecological services and habitat values are reduced. The interim risk ratings proposed for these ratings are Very Low=>80-100%, Low=>60-80%, Moderate=>40-60%, and High=<40%. The “early warning trigger” for initiating management action/further investigation is a trend of a decreasing saltmarsh area or saltmarsh growing over <80% of the available habitat.

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

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

3. METHODS

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

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

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

Estuary boundaries were set seaward from an imaginary line closing the mouth to the upper extent of saline intrusion (i.e. where ocean derived salts during average annual low flow are <0.5ppt). For the current study MDC supplied rectified ~0.4m/pixel resolution colour aerial photos flown in 2011/12 which were laminated (scale of 1:3,000) and used by experienced scientists who walked the area in March 2016 to ground-truth the spatial extent of dominant vegetation and substrate types (Figure 3). It is noted that the boundaries of substrates and macroalgal cover represent the features observed on the ground in 2016 and are occasionally different to the features evident on the underlying 2011/12 photos. The "iGIS HD" ipad app. was used to show live position tracking (via an inbuilt GPS accurate to ~5m), and to log field notes. When present, macroalgae and seagrass patches were mapped to the nearest 5% using a 6 category percent cover rating scale as a guide to describe density (see Figure 2 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*), saltmarsh vegetation, and the 200m wide terrestrial margin vegetation/landuse. These broad scale results are summarised in Section 4, with the supporting GIS files (supplied as a separate electronic output) providing a much more detailed data set designed for easy interrogation to address specific monitoring and management questions. An example of the detail available on the GIS files is presented in Figure 3.

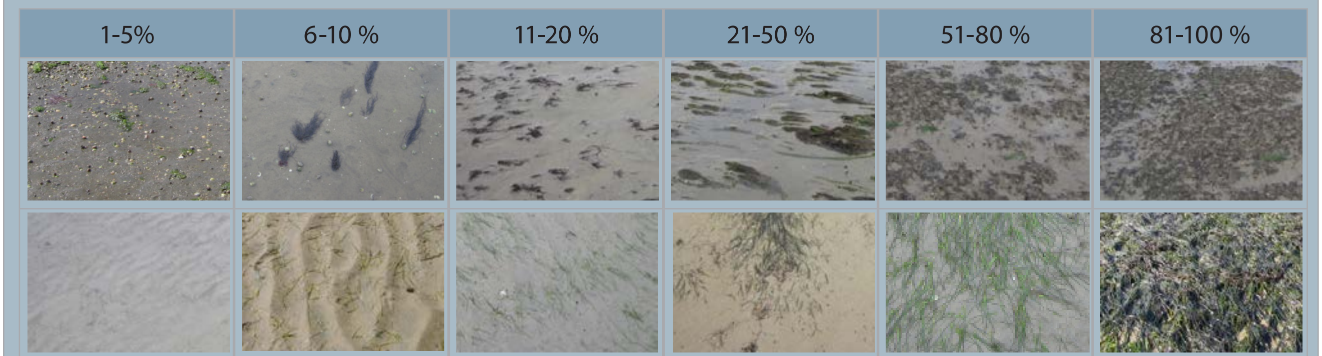
Macroalgae was further assessed by identifying patches of comparable growth, and enumerating each patch by measuring biomass and the degree of macroalgal entrainment within sediment. When macroalgae were present, the presence of soft muds and surface sediment anoxia were also noted to assess whether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

- % 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 against which future change can be assessed.

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



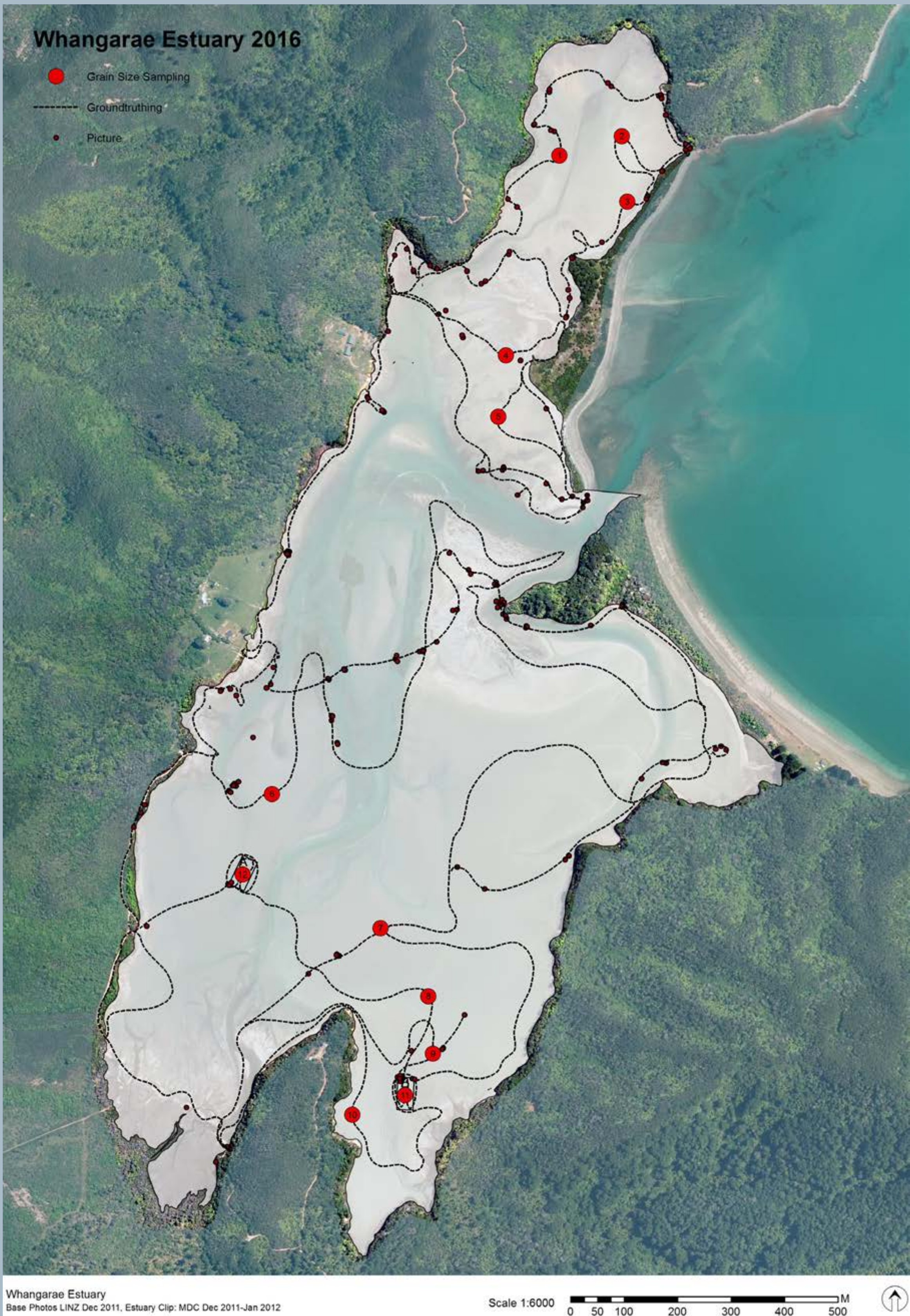


Figure 3. Whangarae Estuary - mapped estuary extent showing groundtruthing coverage, field photos and location of grain size samples used to validate substrate classifications.

4. RESULTS AND DISCUSSION

BROAD SCALE MAPPING

The 2016 broad scale habitat mapping ground-truthed and mapped all intertidal substrate and vegetation including the dominant land cover of the 200m terrestrial margin, with the six dominant estuary features summarised in Table 3. The estuary comprises an enclosed tidal lagoon with 3 tidal arms, dominated by intertidal flats (86%), saltmarsh (7.6%) and a small subtidal component (6.5%). Intertidal seagrass (2%) was sparse, and there was no dense (>50% cover) opportunistic macroalgae present. 97% of the 200m wide terrestrial margin was densely vegetated, and 3% in grassland.

- In the following sections, various factors related to each of these habitats (e.g. area of soft mud) are used in conjunction with risk ratings to assess key estuary issues of sedimentation, eutrophication, and habitat modification. Estimates of natural state cover have been used to indicate likely changes in broad scale features over time.
- 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 3. Summary of dominant broad scale features in Whangarae Estuary, 2016.

	Dominant Estuary Feature	Ha	% of Estuary
1.	Intertidal flats (excluding saltmarsh)	106.8	85.9%
2.	Opportunistic macroalgal beds (>50% cover) [included in 1. above]	<0	0%
3.	Seagrass (>20% cover) [included in 1. above]	2.0	1.6%
4.	Saltmarsh	9.4	7.6%
5.	Subtidal waters	8.1	6.5%
Total Estuary		**124**	**100%**
6.	Terrestrial Margin - % of 200m wide estuary buffer densely vegetated (e.g. scrub, shrub, forest)		97%

4.1. INTERTIDAL FLATS (EXCLUDING SALTMARSH)

Results (summarised in Table 4 and Figure 4) show intertidal flats were dominated by firm muddy sands (69ha, 65%), with smaller areas of gravelfields (21ha, 19%), muds (12.6ha, 12%), cobble (3.3ha, 3.1%) and rock (0.6ha, 0.6%). Bedrock around the estuary entrance creates a relatively narrow opening with strong tidal flushing action that facilitates the removal of fine material and helps to maintain the large gravel and cobble beds evident in this area, while wave action serves to flush fine sediments from the upper shore leaving narrow bands of well sorted cobbles and gravels, most evident along the western shore of the main basin and the eastern shore of the northern arm.

In the main basin and central northern arm, where current flows are much less pronounced, muddy sands dominate with occasional shell banks and smaller patches of cobble and gravel. The largest areas of soft mud were located in the southwest and south of the estuary.

The sand dominated sediments showed moderate sediment oxygenation (2-5cm aRPD depth), while soft mud sediments in the estuary were the least well oxygenated (1-2cm aRPD depth).

Table 4. Summary of dominant intertidal substrate, Whangarae Estuary, 2016.

Dominant Substrate	Ha	%	Comments
Rock field	0.6	0.6	Estuary entrance and the lower northern arm (western side)
Cobble field	3.3	3.1	Predominantly near the entrance and along northern barrier spit
Gravel field	20.5	19.2	Predominantly near the entrance, western shoreline, and Castor Stream
Shell bank	0.4	0.4	Small pockets in the main basin and near the entrance
Firm sand	0.4	0.3	Well flushed upper tidal beaches
Firm muddy sand	69.0	64.6	Dominant habitat throughout the main basin
Firm sandy mud	2.5	2.3	Predominantly in the northern arm
Soft mud	5.4	5.1	Along the southwestern shoreline and lower southeastern embayment
Very soft mud	4.7	4.4	Southeastern embayment
Grand Total	**106.8**	**100.0**	

Figure 4. Map of dominant intertidal substrate types - Whangarae Estuary, 2016.

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

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

i. **Horizontal extent** (area of soft mud) - broad scale indicator (see rating in Table 2)
ii. **Vertical buildup** (sedimentation rate) - fine scale assessment using sediment plates (or retrospectively through historical coring). Ratings are currently under development as part of national ANZECC guidelines.
iii. **Sediment mud content** - fine scale indicator - recommended guideline is no increase from established baseline.

The area (horizontal extent) of intertidal soft mud is the primary sediment indicator used in the current broad scale report, with sediment mud content a supporting indicator. Sediment plates have been established to enable future monitoring of vertical buildup (see Robertson and Stevens 2016 for details).

Localised landslide depositing fine sediment at the upper edge of the estuary in the northern arm.

Figure 4 and Table 4 shows that soft or very soft muds covered 10.1ha (9.5%) of the intertidal area, a risk indicator rating of MODERATE, and had a relatively high mud content (45-72% - Figure 4), a supporting risk indicator rating of HIGH. Soft muds were concentrated in the upper tidal reaches of the estuary (mostly in the south) where mud settlement is thought to predominantly reflect the presence of sheltered deposition zones and, to a lesser extent, salinity driven flocculation. In the northern arm an additional 2.5ha (2.3%) comprised firm muds with a relatively high mud content of (32-34%). This substrate reflected localised landslides depositing fine muds directly into the estuary (sidebar photo) where it had spread in a relatively thin layer over firmer underlying sediments (i.e. sand and gravels).

Within the dominant firm sandy mud substrate in the main basin and among seagrass beds, grain size ranged from 7-17% (Figure 4) reflecting a LOW to MODERATE risk rating.

Table 5. Grain size results from representative sediments, Whangarae Estuary, 2016.

Site (Fig 3)	Broad Scale Classification	% mud	% sand	% gravel	NZTM East	NZTM North
1	Firm Muddy SAND	13.1	81.4	5.5	1652466	5451502
2	Firm Sandy MUD	33.5	64.3	4.0	1652583	5451538
3	Firm Sandy MUD	32.2	63.0	5.9	1652592	5451415
4	Firm Muddy SAND	13.5	65.9	20.6	1652365	5451128
5	Firm Muddy SAND	15.9	70.8	13.3	1652351	5451013
6	Firm Muddy SAND	15.9	83.8	0.4	1651928	5450308
7	Firm Muddy SAND	7.2	91.8	1.0	1652131	5450057
8	Firm Muddy SAND	16.5	82.4	1.1	1652220	5449930
9	Soft MUD	45.3	53.7	1.0	1652229	5449822
10	Very Soft MUD	64.8	34.8	0.3	1652078	5449708
11	Very Soft MUD	71.9	27.5	0.5	1652176	5449745
12	Firm Muddy SAND	13.6	85.0	1.3	1651873	5450158

The overall risk of detrimental impacts to estuarine biota from muds was assessed as MODERATE reflecting the relatively limited area in the estuary where poorly oxygenated soft muds have accumulated, the generally strong flushing of the estuary, and the very limited extent of current catchment modification (predominantly regenerating native bush). These factors strongly suggest that the majority of the fine sediment currently present within the estuary is derived from historical inputs, most likely as a consequence of historical forest burning and land clearance undertaken in the catchment in the late 1960s - early 1970s.

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. Macroalgae that becomes detached can also accumulate and decay in subtidal areas and on shorelines causing oxygen depletion and nuisance odours and conditions. The greater the density, persistence, and extent of macroalgal entrainment within sediments, the greater the subsequent impacts.

Macroalgae is assessed using the WFD-UKTAG (2014) Opportunistic Macroalgal Blooming Tool (OMBT) described in Appendix 2. Where there is >5% opportunistic macroalgal cover within the Available Intertidal Habitat (AIH) of an estuary, macroalgae is mapped and described to enable calculation of an overall "Ecological Quality Rating" (EQR). The EQR score (zero=major disturbance, 1=reference/minimally disturbed) relates to quality status threshold bands (i.e. bad, poor, good, moderate, high) based on the series of individual metrics applied (spatial extent, density, biomass, and degree of sediment entrainment of macroalgae within the affected intertidal area). While these metrics are combined to produce the overall EQR they are also scored individually within defined quality status threshold bands to indicate potential drivers of change within the estuary.

If the estuary supports <5% opportunistic macroalgal cover within the AIH, the overall quality status is reported as "high" with no further sampling required.

Whangarae Estuary supported just over 5% opportunistic macroalgal cover, and the vast bulk of the estuary exhibited no appreciable macroalgal growth and there were no significant gross eutrophic zones present in the estuary. The few relatively small areas with opportunistic macroalgae present had <50% cover with low-moderate biomass (150-500g.m^2) and comprised the green alga *Ulva lactuca* and the red alga *Gracilaria chilensis*. These were located primarily near the low tide channels in the main basin (Figure 5) and were either not entrained, or only partially entrained, within the underlying sediments and were not causing nuisance conditions. The establishment of small areas with partially entrained growths of *Gracilaria* is a very early indicator of the areas where potential problems could develop if nuisance growths increased. These areas should ideally be quickly checked if other monitoring is being undertaken in the estuary to assess if areas are expanding or sediment conditions are degrading and whether a more formal assessment is warranted.

The overall opportunistic macroalgal EQR for Whangarae Estuary in March 2016 was 0.816 (Table 6), a quality status of 'High' and indicates that the estuary overall is not expressing significant symptoms of eutrophication, a risk indicator rating of VERY LOW. The absence of any significant gross eutrophic zones also reflected a risk indicator rating of VERY LOW. It is also noted that no conspicuous introduced marine pest organisms were observed in the estuary.

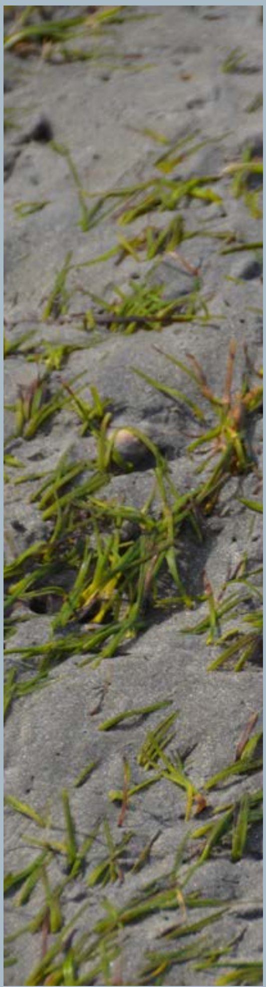
Table 6. Summary of intertidal opportunistic macroalgal cover, Whangarae Estuary, March 2016.

Metric	Face Value	Final Equidistant Score (FEDS)	Quality Status
AIH - Available Intertidal Habitat (ha)	108		
Percentage cover of AIH (%) = (Total % Cover / AIH} x 100 *where Total % cover = Sum of {(patch size) / 100} x average % cover for patch*	1.0	0.959	High
Biomass of AIH (g.m^{-2}) = Total biomass / AIH *where Total biomass = Sum of (patch size x average patch biomass)*	9.4	0.962	High
Biomass of Affected Area (g.m^{-2}) = Total biomass / AA *where Total biomass = Sum of (>5% cover patch size x average patch biomass)*	181.5	0.625	Good
Presence of Entrained Algae = (No. quadrats or area (ha) with entrained algae / total no. of quadrats or area (ha)) x 100	2.2	0.738	Good
Affected Area (use the lowest of the following two metrics)		0.796	Good
Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%)	5.6	0.889	High
Size of AA in relation to AIH (%) = (AA / AIH) x 100	5.2	0.796	Good
OVERALL MACROALGAL ECOLOGICAL QUALITY RATING - EQR (AVERAGE OF FEDS)		**0.816**	**HIGH**

Figure 5. Map of intertidal opportunistic macroalgal biomass ($g.m^{-2}$) - Whangarae Estuary, 2016.

4. RESULTS AND DISCUSSION (CONTINUED)

4.3. SEAGRASS



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

Table 7 and Figure 6 summarise the results of the intertidal seagrass extent (the mapped intertidal estuary area minus saltmarsh). The results show:

- 1.8% of the intertidal estuary area (2.0ha) supported seagrass growth.
- All seagrass beds were located in muddy sand substrate in the central basin near low tide channels.
- Seagrass was present in two density categories, very dense beds (100% cover), and moderately dense beds (40% cover.)

The natural extent of intertidal seagrass in Whangarae Estuary is relatively small and confined to areas near the main entrance in the central basin that have strong tidal flushing and are subsequently not prone to excessive fine mud deposition. It is considered most likely that the absence of seagrass within the main basin areas of the estuary is driven by tidal elevations and exposure periods being unsuitable for seagrass growth e.g. extended exposure periods resulting in plant stress from dessication.

In the absence of any comprehensive rating of seagrass extent within NZ estuaries, which can be highly variable in the extent of seagrass that they support, changes from a documented baseline currently represent the most reliable method for monitoring seagrass extent and assessing . The current study has provided a high resolution GIS map of seagrass extent for this purpose.

Table 7. Summary of seagrass *(Z. muelleri)* cover, Whangarae Estuary, 2016.

Percentage Cover	Area (ha)	Percentage
0	104.8	98.1
40%	1.1	1.0
100%	0.9	0.8
	106.8	**100**

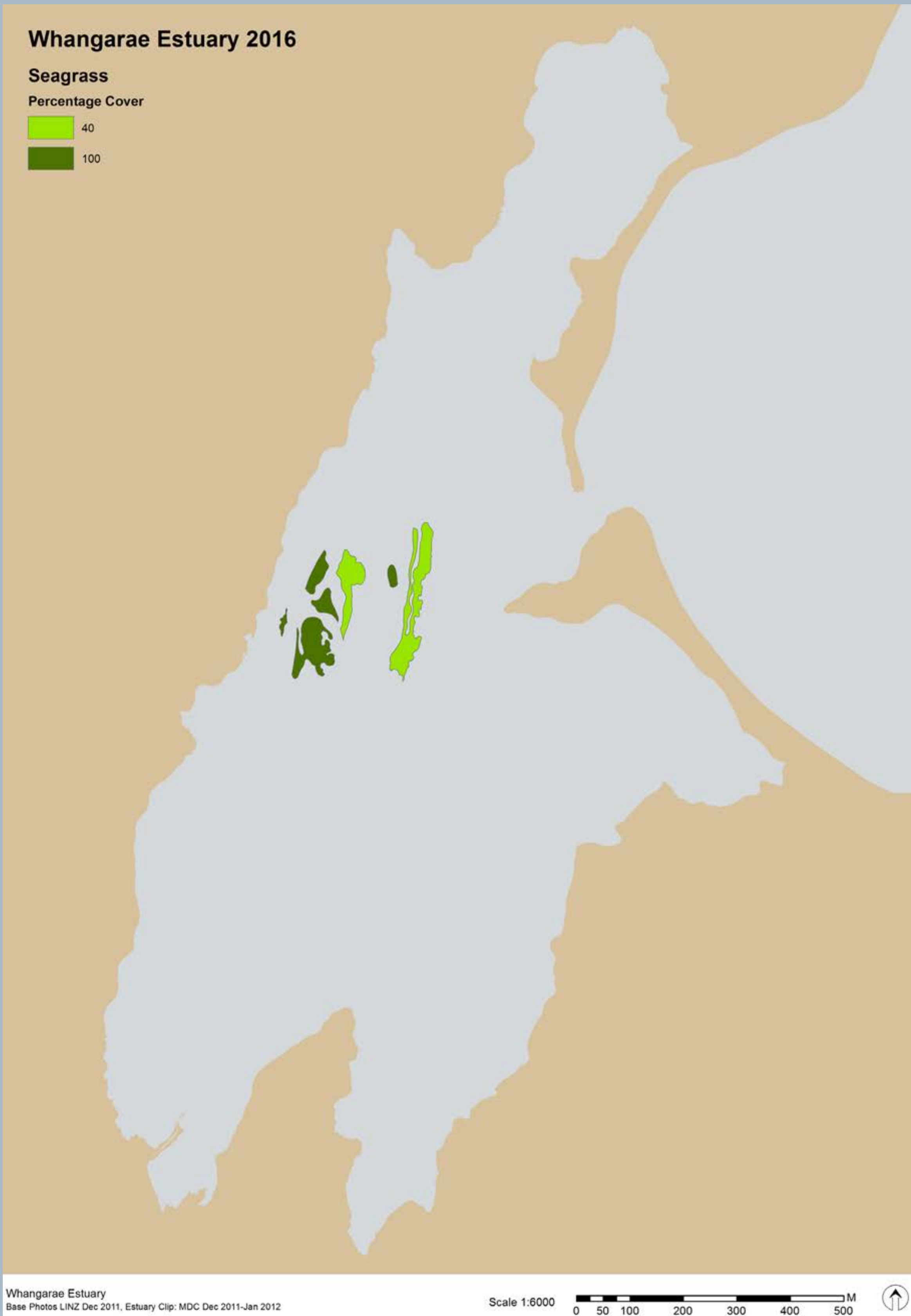


Figure 6. Map of intertidal seagrass cover - Whangarae Estuary, 2016.

4.4. SALTMARSH

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

The primary measure to assess saltmarsh condition is the percent cover of the intertidal area. Two supporting measures are used: i. loss compared to estimated natural state cover, and ii. percent cover within the estimated available saltmarsh habitat - defined as the area between MHWN and the upper tidal extent in the upper estuary, and getting progressively narrower as marine salinities limit growth in the lower estuary.

Table 8 and Figure 7 summarise the 2016 saltmarsh mapping results and show saltmarsh is present throughout the estuary (9.4ha, 8.8% of the intertidal area), with the most expansive beds located in the northern and southern ends of the estuary (Figure 7). Elsewhere the relatively steep landforms that surround the estuary limit the growth of saltmarsh to a relatively narrow strip along the upper tidal reaches (see sidebar photos). Rushland (79%) dominated in the upper tidal reaches with herbfield (21%) dominant among the cobble and gravel beds near the entrance and in the northern arm.

The saltmarsh extent has a primary risk indicator rating of LOW-MODERATE. The two supporting indicators, estimated loss from natural state, and percent cover within the estimated available saltmarsh habitat were both estimated to be VERY LOW based on the relatively unmodified nature of the estuary margin, and the presence of saltmarsh throughout areas where it was expected to be growing. The combined overall risk rating was assessed as LOW.

Of high ecological value is the relatively intact sequence of terrestrial forest, wetland and estuarine saltmarsh present, particularly surrounding the small streams that enter the estuary. These provide very good habitat for freshwater fish, invertebrates, and birds and are relatively free from introduced weeds.

Table 8. Summary of dominant saltmarsh cover, Whangarae Estuary, 2016.

Class	Dominant Species	Primary subdominant species	Area (ha)	Percentage
Rushland			7.4	79%
	Juncus kraussii (Searush)	*Juncus kraussii (Searush)*	0.1	
		Apodasmia similis (Jointed wirerush)	6.7	
		Sarcocornia quinqueflora (Glasswort)	0.5	
	Apodasmia similis (Jointed wirerush)	*Juncus kraussii (Searush)*	0.1	
		Plagianthus divaricatus (Saltmarsh ribbonwood)	0.01	
Herbfield			2.0	21%
	Sarcocornia quinqueflora (Glasswort)	*Sarcocornia quinqueflora (Glasswort)*	0.4	
		Samolus repens (Primrose)	0.1	
		Suaeda novae–zelandiae (Sea blite)	1.2	
	Suaeda novae–zelandiae (Sea blite)	*Sarcocornia quinqueflora (Glasswort)*	0.3	
Total (Ha)			**9.4**	

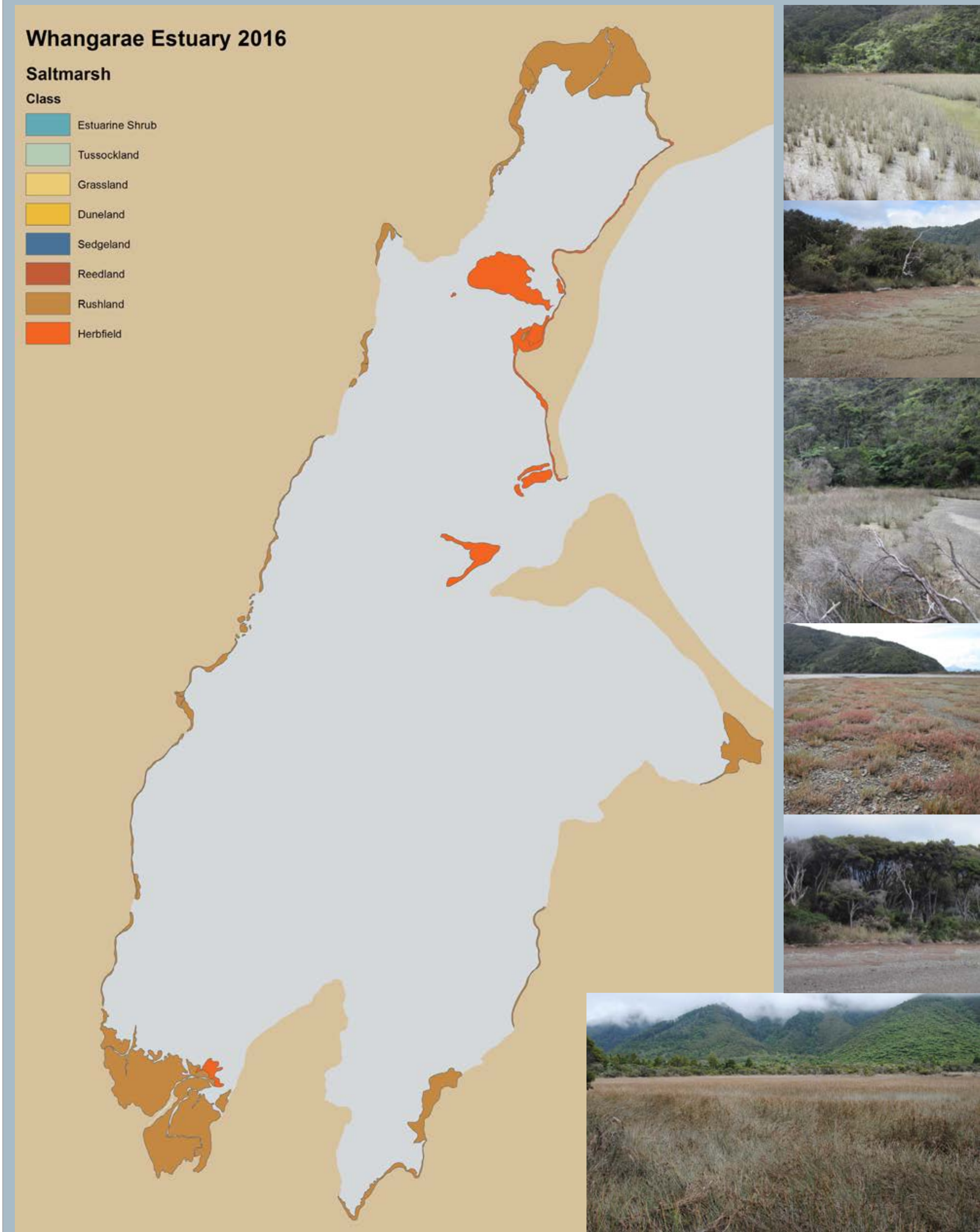
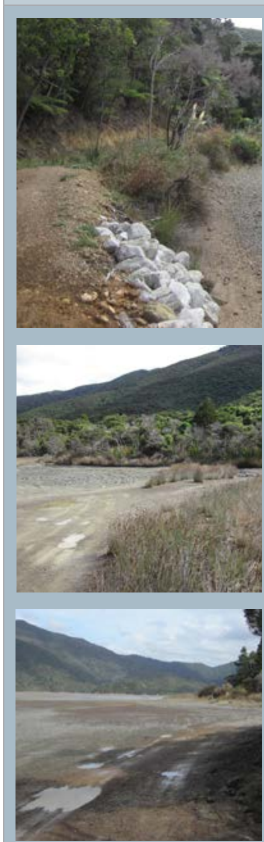


Figure 7. Map of dominant saltmarsh cover - Whangarae Estuary, 2016.

4. RESULTS AND DISCUSSION (CONTINUED)

4.5. 200m TERRESTRIAL MARGIN



Vehicle access tracks along the western margin of the estuary.

Like saltmarsh, a densely vegetated terrestrial margin filters and assimilates sediment and nutrients, acts as an important buffer that protects against introduced grasses and weeds, is an important habitat for a variety of species, provides shade to help moderate stream temperature fluctuations, and improves estuary biodiversity. The results of the 200m terrestrial margin of the estuary (Table 9 and Figure 8) showed:

- The 200m wide terrestrial margin was dominated by regenerating native forest and scrub (97%), with some small areas of pasture around residential dwellings (3%).
- Introduced weeds (eg. gorse, tall fescue and marram grass) were well established on the barrier spits separating the estuary from Whangarae Bay and common growing among manuka and saltmarsh ribbonwood. Gorse was also common throughout the catchment.

Historically there has been minor disturbance within the 200m terrestrial margin from road construction (e.g. sidebar photo) which provides private access to residential dwellings by the estuary as well as to the outer coastline. Parts of the western shoreline (on bedrock and gravels) are also utilised for access, although vehicle movements are infrequent, and impacts are both minor and localised.

The presence of a densely vegetated 200m terrestrial margin habitat continuous with catchment-wide native scrub and forest cover means there is very good buffering against adverse ecological degradation (e.g. localised sediment and nutrient inputs), and there is strong natural ecological connectivity between the estuary and surrounding terrestrial habitats. The 200m terrestrial margin risk indicator rating is therefore VERY LOW.

Table 9. Summary of 200m terrestrial margin land cover, Whangarae Estuary, 2016.

Class	Dominant features	Percentage
Forest/Scrub	Mix of regenerating native dominated forest and scrub	93.6
Scrub	Small areas on the coastal spits either side of the entrance	3.4
Grassland	Cleared residential areas and low intensity grazing	3.0
Total		**100**

Localised presence of introduced weeds on the northern barrier spit (top), and scrub and forest margins surrounding the estuary (bottom) .

Figure 8. Map of 200m Terrestrial Margin - Dominant Land Cover, Whangarae Estuary, 2016.

5. SUMMARY AND CONCLUSIONS

Broad scale habitat mapping undertaken in January 2016, combined with ecological risk indicator ratings in relation to the key estuary stressors (i.e. sediment, eutrophication and habitat modification), and changes from baseline conditions, have been used to assess overall estuary condition (Table 10).

The 2016 results show that the estuary was not exhibiting significant nuisance macroalgal growths (i.e. expressing a very low level of eutrophication) or gross eutrophic zones (combined presence of dense macroalgal growth, muds and poor sediment oxygenation). It supported small areas of high value seagrass beds and extensive areas of saltmarsh that transition directly into a regenerating native scrub and forest dominated catchment.

The only stressor identified with an elevated risk rating was sediment, with fine mud having a moderate risk of causing adverse impacts to the estuary ecology, a finding further supported by the fine scale monitoring of estuary sediments (Robertson and Stevens 2016). This fine mud is considered most likely to be from past land disturbance following burning and clearing of the catchment in the late 1960s-early 1970s.

These combined results place the estuary in a "GOOD" state overall in relation to ecological health.

Because the estuary is in a good ecological state, human pressures are low, and significant changes to catchment land cover are not expected, Whangarae Estuary represents a good reference estuary against which the existing state and changes in other more-impacted, Marlborough estuaries can be compared.

Table 10. Summary of broad scale risk indicator ratings for Whangarae Estuary, 2016.

Major Issue	Indicator	2016 risk rating
Sediment	Soft mud (% cover, grain size)	MODERATE
Eutrophication	Macroalgal Growth (EQR)	VERY LOW
	Gross Eutrophic Conditions (ha)	VERY LOW
Habitat Modification	Seagrass	Baseline established
	Saltmarsh (% cover, vegetated % of available habitat, estimated historical loss)	LOW
	200m Vegetated Terrestrial Margin	VERY LOW

6. MONITORING AND MANAGEMENT

RECOMMENDED MONITORING

Whangarae Estuary has been identified by MDC as a priority for monitoring because of its relatively unmodified condition, high ecological and human use values, and because its estuary type means it is very vulnerable to excessive sedimentation and eutrophication. As a consequence, it is a key part of MDC's coastal monitoring programme being undertaken in a staged manner throughout the region.

To support management decisions, a combined approach of broad and fine scale monitoring is applied to provide robust information on current estuary condition and trends over time. The present report addresses the broad scale intertidal component of the long term programme, with the following monitoring recommendations proposed by Wriggle for consideration by MDC:

Broad Scale Habitat Mapping

It is recommended that broad scale habitat mapping be undertaken at 10 yearly intervals unless obvious changes are observed in the interim (next scheduled for consideration in 2026).

Fine Scale Monitoring

Fine scale intertidal sampling of Sites A and B has now been undertaken for one baseline year (March 2016). It is recommended that fine scale intertidal monitoring of the two established sites (including sedimentation rate measures) be undertaken for the next two years to establish a robust baseline of estuary condition. As the SVOCs and pesticide toxicant indicators showed a low risk, it is recommended that these be excluded from subsequent baseline monitoring.

Once the baseline has been established, a recommendation will be made on the frequency of any subsequent fine scale monitoring.

RECOMMENDED MANAGEMENT

Using the results of the above investigations, it is recommended that the Council identify, through stakeholder involvement, an appropriate "target" estuary condition and determine management strategies to maintain or achieve the target condition.

7. ACKNOWLEDGEMENTS

This survey and report has been undertaken with the support and assistance of Steve Urlich (Coastal Scientist, MDC). His review of this report was much appreciated. We are also very grateful to Roy and Twinkle Te Kotua for their warm welcome to Whangarae, and for sharing their vast knowledge of the estuary with us, and to Megan Southwick and Sally O'Neill for help with the field sampling.

8. REFERENCES

Atkinson, I.A.E. 1985. Derivation of vegetation mapping units for an ecological survey of Tongariro National Park Nth Island, NZ. NZ Journal of Botany, 23; 361-378.

Birchenough, S., Parker N., McManus E. and Barry, J. 2012. Combining bioturbation and redox metrics: potential tools for assessing seabed function. Ecological Indicators 12: 8-16.

Davidson R. J., Duffy C.A.J., Gaze P., Baxter, A., du Fresne S., Courtney S., Hamill P. 2011. Ecologically significant marine sites in Marlborough, New Zealand. Co-ordinated by Davidson Environmental Limited for Marlborough District Council and Department of Conservation.

Ellis, J., Cummings, V., Hewitt, J., Thrush, S., Norkko, A. 2002. Determining effects of suspended sediment on condition of a suspension feeding bivalve (Atrina zelandica): results of a survey, a laboratory experiment and a field transplant experiment. Journal of Experimental Marine Biology and Ecology, 267, 147–174.

Fenchel, T. and Riedl, R. 1970. The sulphide system: a new biotic community underneath the oxidized layer of marine sand bottoms. Mar Biol 7: 255-268.

Hargrave, B.T., Holmer, M. and Newcombe, C.P. 2008. Towards a classification of organic enrichment in marine sediments based on biogeochemical indicators. Marine Pollution Bulletin, 56(5), pp.810–824.

Hunting, E.R. and Kampfraath, A.A. 2012. Contribution of bacteria to redox potential (E h) measurements in sediments. International Journal of Environmental Science and Technology, 10(1): 55-62.

Jørgensen, N. and Revsbech, N.P. 1985. Diffusive boundary layers and the oxygen uptake of sediments and detritus. Limnology and Oceanography 30:111-122.

Keeley, N.B. et al. 2012. Exploiting salmon farm benthic enrichment gradients to evaluate the regional performance of biotic indices and environmental indicators. Ecological Indicators, 23, pp.453–466.

Lohrer, A., Thrush, S., Hewitt, J., Berkenbusch, K., Ahrens, M., Cummings, V. 2004. Terrestrially derived sediment: response of marine macrobenthic communities to thin terrigenous deposits. Marine Ecology Progress Series, 273, 121–138.

Mannino, A. and Montagna, P. 1997. Small-Scale Spatial Variation of Macrobenthic Community. Estuaries, 20, 159–173.

Nelson, Walter G. (ed.) 2009. Seagrasses and Protective Criteria: A Review and Assessment of Research Status. Office of Research and Development, National Health and Environmental Effects Research Laboratory, EPA/600/R-09/050.

Norkko, A., Talman, S., Ellis, J., Nicholls, P. and Thrush, S. 2002. Macrofaunal Sensitivity to Fine Sediments in the Whitford Embayment. Auckland Regional Council, Technical Publication, 158, 1–30.

Peeters, E., Gardeniers, J., Koelmans, A. 2000. Contribution of trace metals in structuring in situ macroinvertebrate community composition along a salinity gradient. Environmental Toxicology and Chemistry, 19, 1002–1010.

Rakocinski, C., Brown, S., Gaston, G., Heard, R., Walker, W. and Summers, J. 1997. Macrobenthic Responses to Natural and Contaminant-Related Gradients in Northern Gulf of Mexico Estuaries. Ecological Applications, 7, 1278–1298.

Revsbech, N.P., Sørensen, J., Blackburn, T.H. and Lomholt, J.P. 1980. Distribution of oxygen in marine sediments measured with microelectrodes. Limnology and Oceanography 25: 403-411.

Robertson, B.M., Gillespie, P.A., Asher, R.A., Frisk, S., Keeley, N.B., Hopkins, G.A., Thompson, S.J., Tuckey, B.J. 2002. Estuarine Environmental Assessment and Monitoring: A National Protocol. Part A. Development, Part B. Appendices, and Part C. Application. Prepared for supporting Councils and the Ministry for the Environment, Sustainable Management Fund Contract No. 5096. Part A. 93p. Part B. 159p. Part C. 40p plus field sheets.

Robertson, B.M. and Stevens, L.M. 2016. Whangarae Estuary: Fine Scale Monitoring 2016. Report prepared by Wriggle Coastal Management for Marlborough District Council. 28p.

Robertson, B.M., Stevens, L., Robertson, B.P., Zeldis, J., Green, M., Madarasz-Smith, A., Plew, D., Storey, R., Hume, T. and Oliver, M. 2016a. NZ Estuary Trophic Index. Screening Tool 1. Determining eutrophication susceptibility using physical and nutrient load data. Prepared for Envirolink Tools Project: Estuarine Trophic Index MBIE/NIWA Contract No: C01X1420. 47p.

Robertson, B.M., Stevens, L., Robertson, B.P., Zeldis, J., Green, M., Madarasz-Smith, A., Plew, D., Storey, R., Hume, T. and Oliver, M. 2016b. NZ Estuary Trophic Index. Screening Tool 2. Screening Tool 2. Determining Monitoring Indicators and Assessing Estuary Trophic State. Prepared for Envirolink Tools Project: Estuarine Trophic Index MBIE/NIWA Contract No: C01X1420. 68p.

Robertson, B.P., Gardner, J.P.A., Savage, C., Roberston, B.M. and Stevens, L.M. 2016. Optimising a widely-used coastal health index through quantitative ecological group classifications and associated thresholds. Ecological Indicators. 69. 595-605.

Robertson, B.P., Gardner, J.P.A. and Savage, C. 2015. Macrobenthic - mud relations strengthen the foundation for benthic index development : A case study from shallow, temperate New Zealand estuaries. Ecological Indicators, 58, pp.161–174. Available at: http://dx.doi.org/10.1016/j.ecolind.2015.05.039.

Robertson, B.P. 2013. Determining the sensitivity of macroinvertebrates to fine sediments in representative New Zealand estuaries. Honours dissertation, Victoria University of Wellington.

Rosenberg, R., Nilsson, H.C. and Diaz, R.J. 2001. Response of benthic fauna and changing sediment redox profiles over a hypoxic gradient. Estuarine Coast Shelf Science 53: 343-350.

Sakamaki ,T., Nishimura, O. 2009. Is sediment mud content a significant predictor of macrobenthos abundance in low-mud-content tidal flats? Marine and Freshwater Research, 60, 160.

Stevens, L. and Robertson, B.M. 2015. Havelock Estuary 2014 Broad Scale Habitat Mapping. Prepared for Marlborough District Council. 43p.

Thrush, S.F., Hewitt, J., Norkko, A., Nicholls, P., Funnell, G. and Ellis, J. 2003. Habitat change in estuaries: predicting broad-scale responses of intertidal macrofauna to sediment mud content. Marine Ecology Progress Series 263, 101–112.

Tiernan, F. 2012. Coastal Monitoring Strategy, Marlborough. MDC Report No 12-101.

Wehkamp, S., Fischer, P. 2012. Impact of hard-bottom substrata on the small-scale distribution of fish and decapods in shallow subtidal temperate waters. Helgoland Marine Research, 67, 59–72.

WFD-UKTAG (Water Framework Directive – United Kingdom Technical Advisory Group). (2014). UKTAG Transitional and Coastal Water Assessment Method Macroalgae Opportunistic Macroalgal Blooming Tool. Retrieved from http://www.wfduk.org/sites/default/files/Media/Characterisation of the water environment/Biological Method Statements/TraC Macroalgae OMBT UKTAG Method Statement.PDF.

References for Table 1

Abrahim, G. 2005. Holocene sediments of Tamaki Estuary: characterisation and impact of recent human activity on an urban estuary in Auckland, NZ. PhD Thesis, University of Auckland, Auckland, NZ, p 361.

Anderson, D., Gilbert, P. and Burkholder, J. 2002. Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences. Estuaries 25, 704–726.

Ferreira, J., Andersen, J. and Borja, A. 2011. Overview of eutrophication indicators to assess environmental status within the European Marine Strategy Framework Directive. Estuarine, Coastal and Shelf Science 93, 117–131.

Gibb, J.G. and Cox, G.J. 2009. Patterns & Rates of Sedimentation within Porirua Harbour. Consultancy Report (CR 2009/1) prepared for Porirua City Council. 38p plus appendices.

IPCC. 2007. Intergovernmental Panel on Climate Change web site. https://www.ipcc.ch/publications_and_data/ar4/wg1/ (accessed December 2009).

IPCC. 2013. Intergovernmental Panel on Climate Change web site. https://www.ipcc.ch/report/ar5/wg1/ (accessed March 2014).

Kennish, M.J. 2002. Environmental threats and environmental future of estuaries. Environmental Conservation 29, 78–107.

National Research Council. 2000. Clean coastal waters: understanding and reducing the effects of nutrient pollution. Ocean Studies Board and Water Science and Technology Board, Commission on Geosciences, Environment, and Resources. Washington, DC: National Academy Press. 405p.

Painting, S.J., Devlin, M.J., Malcolm, S.J., Parker, E.R., Mills, D.K., Mills, C., and Winpenny, K. 2007. Assessing the impact of nutrient enrichment in estuaries: susceptibility to eutrophication. Marine pollution bulletin 55(1-6), 74–90.

Robertson, B.M. and Stevens, L.M. 2007. Waikawa Estuary 2007 Fine Scale Monitoring and Historical Sediment Coring. Prepared for Environment Southland. 29p.

Robertson, B.M. and Stevens, L.M. 2010. New River Estuary: Fine Scale Monitoring 2009/10. Report prepared by Wriggle Coastal Management for Environment Southland. 35p.

de Salas, M.F., Rhodes, L.L., Mackenzie, L.A., Adamson, J.E. 2005. Gymnodinoid genera Karenia and Takayama (Dinophyceae) in New Zealand coastal waters. New Zealand Journal of Marine and Freshwater Research 39,135–139.

Stewart, J.R., Gast, R.J., Fujioka, R.S., Solo-Gabriele, H.M., Meschke, J.S., Amaral-Zettler, L.A., Castillo, E. Del., Polz, M.F., Collier, T.K., Strom, M.S., Sinigalliano, C.D., Moeller, P.D.R. and Holland, A.F. 2008. The coastal environment and human health: microbial indicators, pathogens, sentinels and reservoirs. Environmental Health 7 Suppl 2, S3.

Swales, A., and Hume, T. 1995. Sedimentation history and potential future impacts of production forestry on the Wharekawa Estuary, Coromandel Peninsula. Prepared for Carter Holt Harvey Forests Ltd. NIWA report no. CHH004.

Valiela, I., McClelland, J., Hauxwell, J., Behr, P., Hersh, D., and Foreman, K. 1997. Macroalgal blooms in shallow estuaries: Controls and ecophysiological and ecosystem consequences. Limnology and Oceanography 42, 1105–1118.

Wade, T.J., Pai, N., Eisenberg, J.N.S., and Colford, J.M., 2003. Do U.S. Environmental Protection Agency Water Quality Guidelines for Recreational Waters Prevent Gastrointestinal Illness? A Systematic Review and Meta-analysis. Environmental Health Perspective 111, 1102–1109.

APPENDIX 1. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Shell bank: Area that is dominated by dead shells.

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

APPENDIX 2. ESTUARY CONDITION RISK RATINGS

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 with 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: Because the OMBT has been developed to classify data over the maximum growing season, sampling should target the peak bloom in summer (Dec-March), although peak timing may vary among water bodies, therefore 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 ecological quality status in the UK-WFD 2014.

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.

APPENDIX 2. ESTUARY CONDITION RISK RATINGS (CONTINUED)

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.

References

DETR, 2001. Development of ecological quality objectives with regard to eutrophication. Final report, unpublished.

Foden, J., Wells, E., Scanlan, C. and Best M.A. 2010. Water Framework Directive development of classification tools for ecological assessment: Opportunistic Macroalgae Blooming. UK TAG Report for Marine Plants Task Team, January 2010, Publ. UK TAG.

Hull, S.C. 1987. Macroalgal mats and species abundance: a field experiment. Estuar. Coast. Shelf Sci. 25, 519-532.

Lowthion, D., Soulsby, P.G. and Houston, M.C.M. 1985. Investigation of a eutrophic tidal basin: 1. Factors affecting the distribution and biomass of macroalgae. Marine Environmental Research 15: 263–284.

Raffaelli, D., Hull, S. and Milne, H. 1989. Long-term changes in nutrients, weedmats and shore birds in an estuarine system. Cah. Biol. Mar. 30, 259–270.

WFD-UKTAG (Water Framework Directive – United Kingdom Technical Advisory Group) 2014. UKTAG Transitional and Coastal Water Assessment Method Macroalgae Opportunistic Macroalgal Blooming Tool. Retrieved from http://www.wfduk.org/sites/default/files/Media/Characterisation of the water environment/Biological Method Statements/TraC Macroalgae OMBT UKTAG Method Statement.PDF.

Wither, A. 2003. Guidance for sites potentially impacted by algal mats (green seaweed). EC Habitats Directive Technical Advisory Group report WQTAG07c.

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.

Table A4. The final face value thresholds and metrics for levels of ecological quality status used to rate opportunistic macroalgae in the current in the study (modified from UK-WFD 2014).

MACROALGAL INDICATORS (OBMT approach - WFD_UKTAG 2014)					
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 ($g.m^2$ wet wgt) of AIH	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 2000	≥2000
Average biomass ($g.m^2$ wet wgt) of AA	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 2000	≥2000
% 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.

APPENDIX 3. WHANGARAE ESTUARY MACROALGAL DATA

Figure A1. Location of macroalgal patches (>5% cover) used in assessing Whangarae Estuary, March 2016.

APPENDIX 3. WHANGARAE ESTUARY MACROALGAL DATA (CONT.)

Macroalgal cover >15% used in calculating the OMBT EQR (see Figure A1 for locations).

Patch ID	Dominant species	Patch area (ha)	Percent cover of macroalgae	Presence (1) or absence (0) of entrained algae	Mean Biomass (g.m^{-2} wet weight)	aRPD depth (cm)	Presence (1) or absence (0) of soft mud
1	*Gracilaria chilensis*	0.05	40	0.5	400	2	1
2	*Gracilaria chilensis*	0.10	40	0.5	410	5	1
3	*Gracilaria chilensis*	0.10	40	0.5	380	5	0
4	*Gracilaria chilensis*	0.26	45	0	405	5	0
5	*Gracilaria chilensis*	0.20	45	0	380	4	0
6	*Gracilaria chilensis Ulva lactuca*	0.26	35	0	200	5	0
7	*Gracilaria chilensis*	3.40	15	0	150	5	0
8	*Gracilaria chilensis Ulva lactuca*	1.19	15	0	140	5	0