coastalmanagement

Waikawa Estuary (Marlborough)

Broad Scale Habitat Mapping 2016

Prepared for

Marlborough District Council

August 2016

Cover Photo: Waikawa Stream flowing into the estuary at mid tide, January 2016.

Waikawa Estuary, 2000. Photo MDC.

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by

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WAIKAWA ESTUARY - EXECUTIVE SUMMARY

Waikawa Estuary is a small (3.4ha), shallow, well-flushed, seawater-dominated, meso-tidal (tidal range ~1m), river delta type estuary that opens via a wide mouth to Waikawa Bay in Queen Charlotte Sound. The catchment has a mix of regenerating bush and urban landuse, and while the estuary has been highly modified, it still supports regionally rare seagrass dominated intertidal flats. 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 81% of the estuary, saltmarsh 0.6%, and subtidal waters 19%.
- Intertidal substrates comprised a relatively even mix of cobble (0.87ha, 31%), firm sandy mud (0.72ha, 26%), firm muddy sand (0.69ha, 25%), with smaller areas of soft and very soft mud (0.21ha, 8%), gravel (0.22ha, 8%) and man-made boulderfield (0.06ha, 2%).
- Soft mud (0.2ha) covered 8% of the unvegetated intertidal habitat and was concentrated on intertidal flats in the middle to upper estuary. Sediment mud content measured within mud habitat was high (31-53%).
- Opportunistic macroalgal growth (*Ulva intestinalis* and *Gracilaria chilensis*) was very sparse (<1% of the available intertidal habitat) and no gross eutrophic zones were present.
- Seagrass *(Zostera muelleri)* covered 30% of the estuary in extensive meadows to the east, and in small pockets among cobble to the west.
- Saltmarsh cover was very sparse (0.02ha, 0.6%).
- The 200m terrestrial margin was extensively developed (67% residential, 26% commercial, 5% roading) with no significant areas of densely vegetated margin buffer.

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)	HIGH
	200m Vegetated Terrestrial Margin	HIGH

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 extensive historical habitat modification of the estuary has degraded saltmarsh and terrestrial margin habitat, and that there is a moderate risk of adverse impacts to the estuary ecology occurring due to fine mud deposition. The estuary was not exhibiting significant nuisance macroalgal growths (i.e. expressing a low level of eutrophication) or gross eutrophic zones (combined presence of dense macroalgal growth, muds and poor sediment oxygenation). It supported extensive high value seagrass beds.

These results likely reflect the strong flushing of the estuary where the primary stressors (i.e. fine sediment, nutrients) largely pass directly through the estuary to the sea, with strong tidal flushing contributing to high water clarity required for healthy seagrass growth. These combined results place the estuary in a "MODERATE" state overall in relation to ecological health.

RECOMMENDED MONITORING AND MANAGEMENT

Waikawa Estuary is a relatively small and highly modified tidal delta estuary, with high cultural significance to Te Ātiawa o Te Waka-a-Māui, and high human use ecological values. It has therefore been identified by MDC as a priority for monitoring. 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 following monitoring recommendations are proposed by Wriggle for consideration by MDC. Repeat fine scale sampling at 5 yearly intervals in conjunction with broad scale habitat mapping (next scheduled for 2021).

A relatively simple and readily achievable way to improve the ecological value of the estuary would be to encourage replanting of saltmarsh and native vegetation around the estuary margin.

1. INTRODUCTION

Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. These objectives, along with understanding change in condition/trends, are key objectives of Marlborough District Council's State of the Environment Estuary monitoring programme. Recently, Marlborough District Council (MDC) prepared a coastal monitoring strategy which established priorities for a long-term coastal and estuarine monitoring programme (Tiernan 2012). The assessment identified Waikawa 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 Waikawa Estuary to issues has not yet been fully assessed. However, recent reports have documented selected ecologically significant marine sites in Marlborough (Davidson et al. 2011) and summarised known pressures, state, and trends of environmental health in Picton Bays (Newcombe and Johnston 2016).
2. **Broad Scale Habitat Mapping** (NEMP approach). This component (see Table 1) documents the key habitats within the estuary, and changes to these habitats over time. 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 Waikawa Estuary, was first undertaken 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 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).

Waikawa Estuary is a small (3.4ha), highly-modified, shallow, well-flushed, seawater-dominated, meso-tidal (tidal range ~1m), river delta type estuary that opens via a wide mouth to Waikawa Bay in Queen Charlotte Sound. The estuary catchment is predominantly regenerating coastal forest (previously logged) with urban and commercial/industrial development in the lower reaches, and it is not considered particularly susceptible to either sediment accumulation or eutrophication effects because of its open coastal nature and strong tidal flushing.

Historically the estuary encompassed the entire head of Waikawa Bay and covered approximately 10ha, with the Waikawa Stream discharging to the estuary via two main branches, one to the east and one to the west. Alluvial deposits built up on the seaward margins of the main freshwater inflows and comprised a range of sediment sizes from fine silts to 100mm pebbles (Stephenson 1977). Although the estuary is relatively well sheltered, Waikawa Bay is exposed to north-northeast winds and has a fetch of 5-7kms, and wind-driven waves from this direction influence the estuary makeup. Wave action sorts sediments to create an exposed berm and fan of coarse material on the upper foreshore area by removing fines and depositing them in the lower tidal reaches. The deposited fines then establish a relatively uniform pattern consisting of an intermediate strip of unvegetated intertidal sand and mud flats on the upper flats, with extensive beds of seagrass (*Zostera*) lower in the tidal range, and below this, coarser sands in lower intertidal tidal and shallow subtidal zone. Regular exposure to small waves from ferry, ship and boat wakes which travel into the head of the bay contribute to ongoing sediment sorting.

Although much modified by the development of the Waikawa marina, the same broad sequence of estuary habitat described above is still apparent. The marina displaced the entire western part of the estuary, and diverted the western branch of Waikawa Stream into the eastern branch. This combined stream is now straightened and channelised (primarily for flood management purposes), and flows through residential developments and out along the marina's eastern mole reclamation where it discharges into Waikawa Estuary (Figure 1). The flood delta of Waikawa Stream has extensive deposits of coarse material that deposit on the western edge of the estuary (true right of the Waikawa Stream channel) to create a raised bar that channels most of the flow into the bay. The main freshwater influence on the estuary flats is from a small unnamed side stream ('Centre' Stream) that flows from the south across the predominantly sandy intertidal flats of the estuary. The remainder of the upper estuary margin is highly modified and provides little direct public access to the estuary.

In terms of human values, the 2012 Deed of Settlement of Historic Claims specifically addresses the very high cultural value to Te Ātiawa o Te Waka-a-Māui of Waikawa Estuary and its surrounds. More recent values are associated with residential housing and commercial activities (e.g. boat haul out and wharf to the east, marina and associated facilities including accommodation to the west). The estuary provides obvious amenity and aesthetic value, as well as providing important ecological habitat.

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. Waikawa Estuary, showing main estuary features and fine scale monitoring site.

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 Waikawa 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%
Supporting saltmarsh indicators: **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

2. Estuary Risk Indicator Ratings (continued)

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 ~0.1m/pixel resolution colour aerial photos flown in Feb. 2015 which were laminated (scale of 1:3,000) and used by experienced scientists who walked the area in January 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 2015 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.

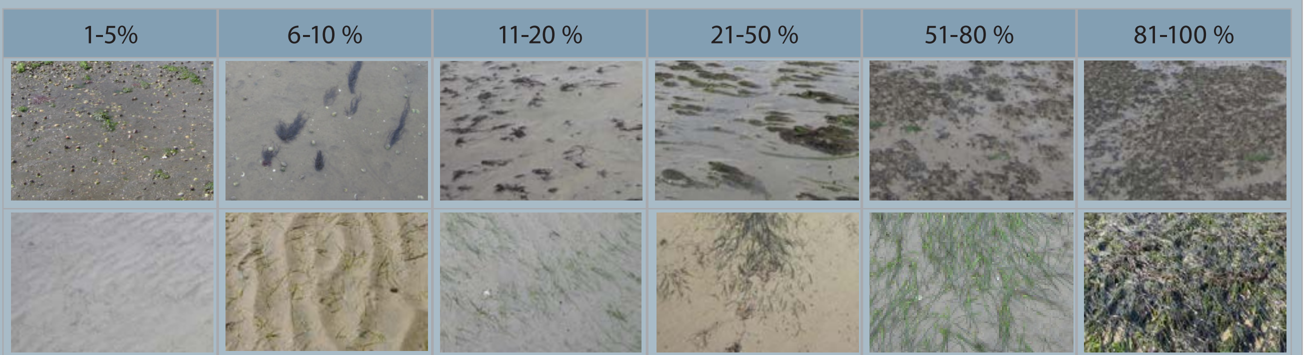
Macroalgae was further assessed by identifying patches of comparable growth, and enumerating each patch by measuring biomass and the degree of macroalgal entrainment within sediment. When macroalgae were present, the presence of soft muds and surface sediment anoxia were also noted to assess whether 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).



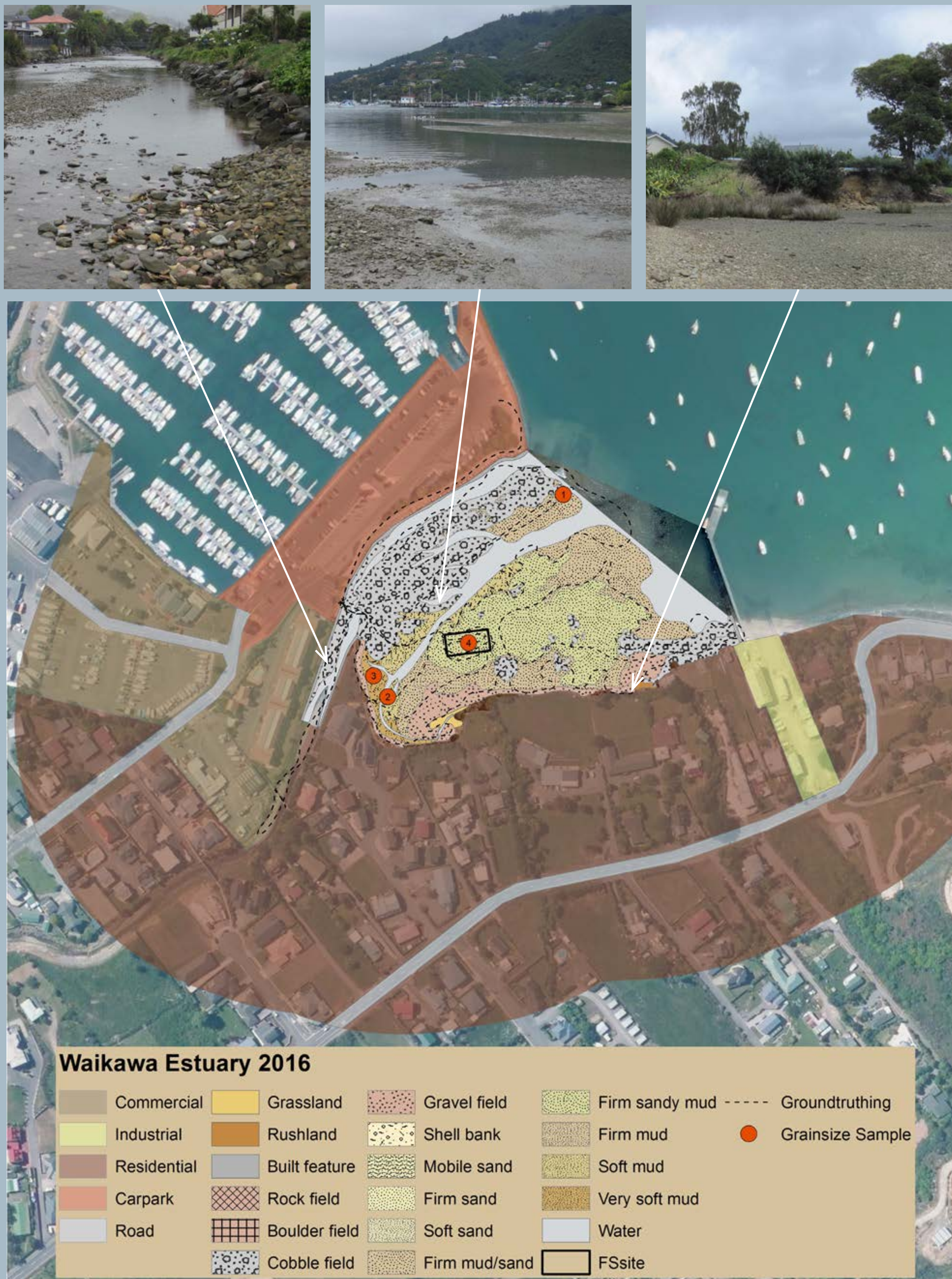
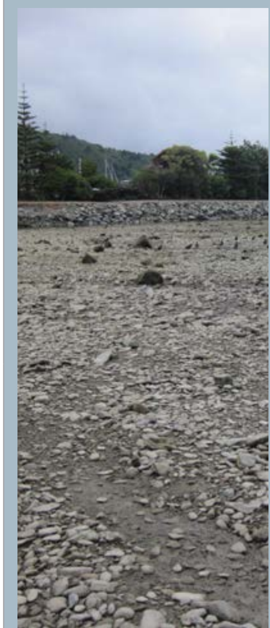
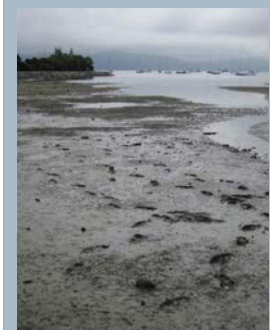


Figure 3. Waikawa Estuary - mapped estuary extent showing groundtruthing coverage, location of grain size samples used to validate substrate classifications, and examples of selected habitats.

4. RESULTS AND DISCUSSION

BROAD SCALE MAPPING

Top to bottom - gravel dominated upper tidal zones and mud flats and seagrass, Waikawa Estuary 2016.

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 intertidal delta (81%) open to Waikawa Bay and subtidal areas (19%) within the two streams channels and along the seaward edge of delta between the confining headlands used to delineate the estuary's seaward boundary. Intertidal seagrass (30%) was extensive (predominantly within muddy sands), saltmarsh (<1%) was scarce, as was dense (>50% cover) opportunistic macroalgae (<0.1ha) - present at very low biomass along the rock walls flanking the marina reclamation. The 200m wide terrestrial margin was highly modified - 67% residential, 26% commercial with no densely vegetated buffer areas.

- 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 Waikawa Estuary, 2016.

Dominant Estuary Feature		Ha	% of Estuary
1.	Intertidal flats (excluding saltmarsh)	2.8	81%
2.	Opportunistic macroalgal beds (>50% cover) [included in 1. above]	<0.1	<1%
3.	Seagrass (>50% cover) [included in 1. above]	1.01	30%
4.	Saltmarsh	0.02	0.6%
5.	Subtidal waters	0.6	19%
Total Estuary		**3.4**	**100%**
6.	Terrestrial Margin - % of 200m wide estuary buffer densely vegetated (e.g. scrub, shrub, forest)		0%

4.1. INTERTIDAL FLATS (EXCLUDING SALTMARSH)

Results (summarised in Table 4 and Figure 4) show the intertidal substrates comprised a relatively even mix of cobble (0.87ha, 31%), firm sandy mud (0.72ha, 26%), firm muddy sand (0.69, 25%), with smaller areas of soft and very soft mud (0.21ha, 8%), gravel (0.22ha, 8%) and man-made boulderfield (0.06ha, 2%).

Along the base of the Waikawa marina reclamation the raised cobble delta by Waikawa Stream created a confined freshwater dominated channel, overtopping only at high tide. Cobble beds were also prominent along the eastern seaward edge of the estuary and extended into subtidal areas. Along the south/east shoreline, regular wave action erodes fine sediments from the upper shore creating narrow gravel dominated beaches, with fines depositing on mud and sand flats in the central basin of the estuary and subtidally. There is a general transition evident across these intertidal flats from a relatively small area of poorly oxygenated (0-1cm aRPD) soft to very soft muds in the upper reaches (within ~50m-100m of the upper 'Centre' Stream inflow), through sandy muds in the mid-tide zone (where most seagrass was also located), to muddy sands near low tide. The sandier sediments generally showed moderate sediment oxygenation (1-3cm aRPD depth) reflecting high tidal flushing of the estuary, particularly near the estuary mouth.

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

Dominant Substrate	Ha	%	Comments
Artificial Substrate	0.06	2.0	Constructed boulder fields by Waikawa marina.
Cobble field	0.87	31.4	Predominantly Waikawa Stream channel and flood delta channel.
Gravel field	0.22	8.0	Upper tidal reaches south/southeastern boundary.
Firm mud/sand	0.69	24.9	Well flushed sections of the lower estuary.
Firm sandy mud	0.72	25.9	Mid tide area among seagrass in the middle estuary.
Soft mud	0.15	5.4	Margins of "Central Stream" in the upper estuary.
Very soft mud/sand	0.06	2.3	Small deposition zones in the upper estuary.
Grand Total	**2.8**	**100**	

4. Results and Discussion (continued)

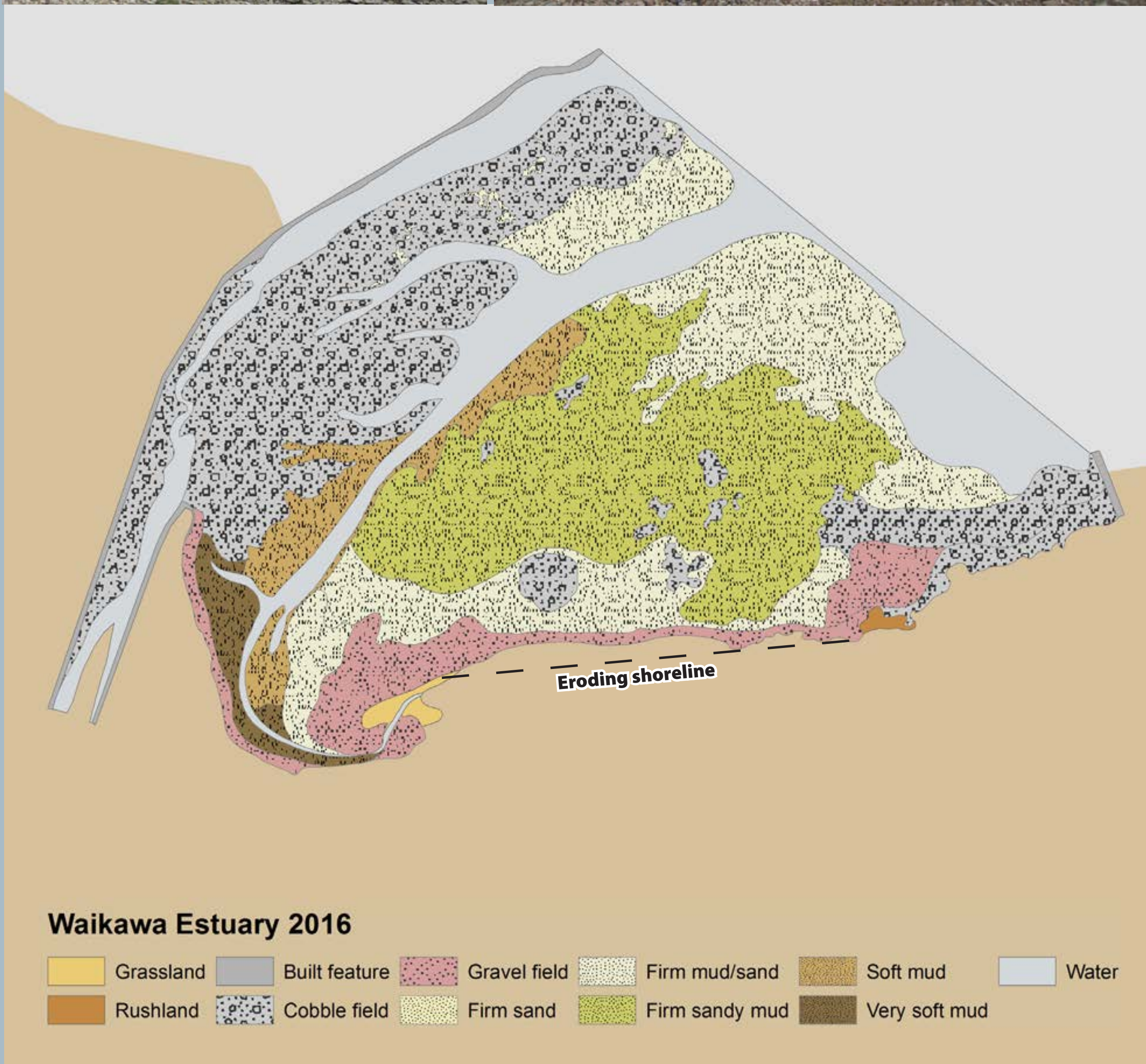
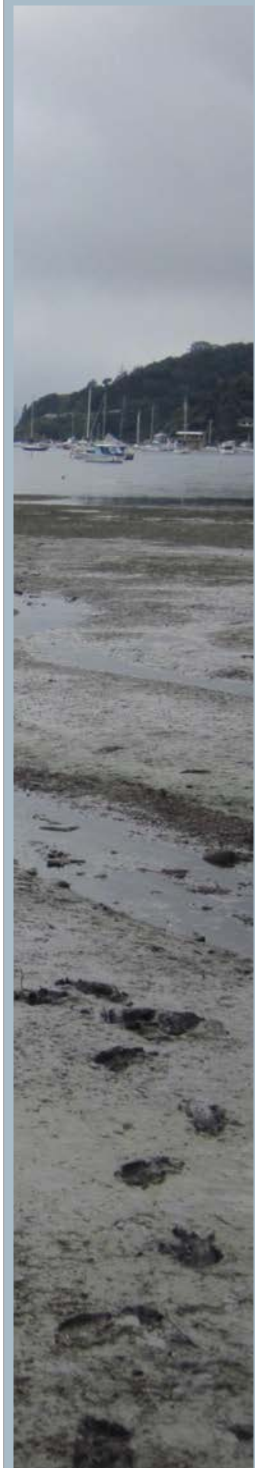


Figure 4. Map of dominant intertidal substrate types - Waikawa Estuary, 2016.



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.

Figure 4 shows that soft or very soft muds, with a relatively high mud content (31-53% - Table 5), covered 8% of the intertidal area. These results give a soft mud area risk indicator rating of MODERATE, and a supporting grain size risk indicator rating of HIGH. Soft muds were concentrated on intertidal flats in the middle to upper estuary where mud settlement is thought to predominantly reflect the combined influence of salinity driven flocculation, the influence of adjacent seagrass beds (very effective sediment traps), and where hydrodynamic boundaries change freshwater flow velocities.

Firm sandy muds (0.72ha, 26%) were present through the central part of the estuary among seagrass beds and had a grain size that ranged from 21-28% (Table 5, Robertson and Stevens 2016). While these sediments are on the cusp of being classed soft muds, they were classified as firm sandy muds on the basis that they comprised a shallow (1-2cm deep) well oxygenated surface mud layer overlying relatively clean sands, and that this fine sediment layer was seen being mobilised by wave action during high tide sampling in the estuary as a consequence of exposure to wave action from shipping vessels and wind generated waves entering Waikawa Bay. Consequently, sand is likely to remain the dominant substrate feature, particularly with more significant mobilisation expected based on evidence showing seagrass beds eroded to underlying hard sediments in several places (see following section), and a clear pattern of shoreline erosion evident in areas not directly sheltered by the marina reclamation or wharf (Figure 4).

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

Site (Fig 3)	Broad Scale Classification	% mud	% sand	% gravel	NZTM East	NZTM North
1	Firm SAND	5.2	92.9	1.9	1687178	5431065
2	Soft MUD	31.2	62.5	6.4	1687056	5430924
3	Very Soft MUD	52.7	45.4	2.9	1687046	5430938
4	Firm Sandy MUD	27.5	70.0	2.5	1687112	5430961

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, strong flushing of the estuary, and limited sources of terrestrial sediment inputs.

Above - Central estuary basin - very soft muds in the foreground and seagrass in the background.

Right - shoreline erosion on the south-east estuary edge

4. Results and Discussion (continued)

4.2. 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 6 and Figure 6 summarise the results of the intertidal seagrass extent (the mapped intertidal estuary area minus saltmarsh). The results show:

- 36% of the intertidal estuary area (1.01ha) supported seagrass growth.
- All of the seagrass beds present had growth >50% cover.
- The most extensive seagrass beds were located in muddy sand substrate in the central basin.
- Small pockets of seagrass were growing among cobble habitat on the Waikawa Stream delta in a mix of sand and mud substrates.
- Area of eroded seagrass were evident among the larger meadows.

Based on the relatively large area of intertidal seagrass present in Waikawa Estuary, environmental conditions appear highly conducive to supporting this important high diversity habitat, which is not a widely represented habitat in the Marlborough Sounds. The two factors most likely facilitating the current extent in the estuary are high water clarity combined with a relatively small extent of fine mud, both likely maintained by the strong marine tidal influence in the estuary.

Table 6. Summary of seagrass *(Z. muelleri)* cover, Waikawa Estuary, 2016.

Percentage Cover	Area (ha)	Percentage
0	1.8	60.1
50-60	0.21	7.4
70-80	0.03	1.0
80-90	0.02	0.7
90-100	0.76	27.1
	2.8	**100**

There is evidence of patch erosion within the seagrass meadows where seagrass growing within fine sands and muds has been washed out and the area eroded down to underlying hard substrates (see Figure 5). However, there is also evidence that these areas are readily recolonised from residual and adjacent patches and reflect short term patch variance rather than long term losses.

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

Figure 5. Photo showing erosion within seagrass meadows - Waikawa Estuary, 2016.

4. Results and Discussion (continued)

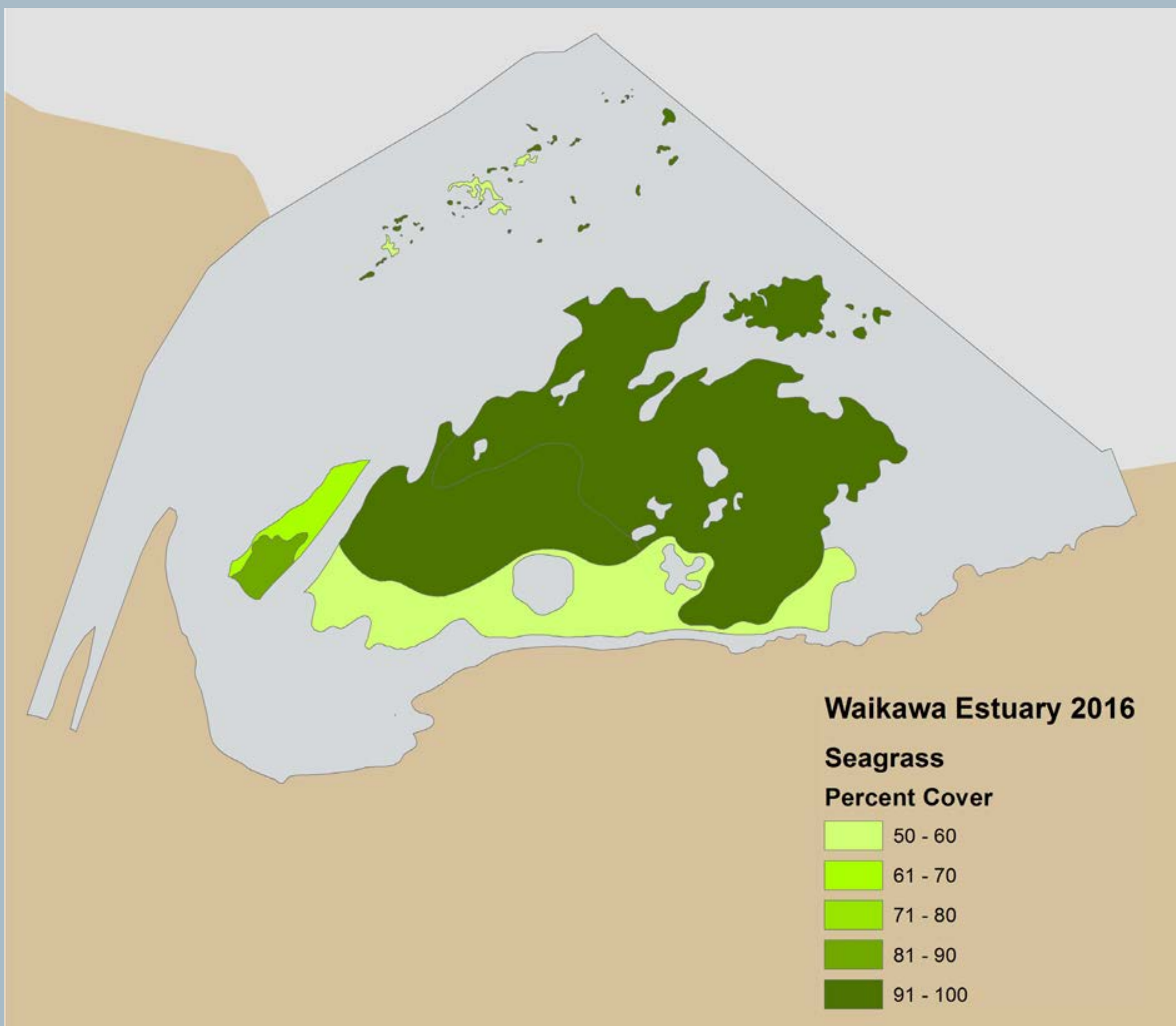


Figure 6. Map of intertidal seagrass cover - Waikawa Estuary, 2016.

4.3. SALTMARSH

Example of small area suitable for saltmarsh restoration at the edge of the estuary.

Saltmarsh (vegetation able to tolerate saline conditions where terrestrial plants are unable to survive) is important as it is highly productive, naturally filters and assimilates sediment and nutrients, acts as a buffer that protects against introduced grasses and weeds, and provides an important habitat for a variety of species including fish and birds. Saltmarsh generally has the most dense cover in the sheltered and more strongly freshwater influenced upper estuary, and relatively sparse cover in the lower (more exposed and saltwater dominated) parts of the estuary, 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 7 and Figure 7 summarise the 2016 saltmarsh mapping results and show virtually no saltmarsh is present in the estuary (0.02ha, 0.6%). Only two small patches were present, one rushland dominated area to the east, and a narrow grassland dominated sandspit near 'Centre' Stream mouth. Both appeared vulnerable to erosion and weed invasion. The saltmarsh extent has a primary risk indicator rating of HIGH. The two supporting indicators, estimated loss from natural state, and percent cover within the estimated available saltmarsh habitat were both estimated to be HIGH based on the very modified nature of the estuary margin, and the absence of saltmarsh in areas where it was expected to be growing.

There appeared to be a very good opportunity for saltmarsh cover to be increased with relatively little effort by targeted planting in areas currently dominated by mown grass strips (see lower sidebar photos). Such initiatives would provide some natural mitigation against ongoing erosion of the upper shoreline while greatly increasing and restoring key features of native biodiversity lost through past modification of the estuary.

Table 7. Summary of dominant saltmarsh cover, Waikawa Estuary, 2016.

Class	Dominant Species	Primary subdominant species	2016
Grassland			0.015
	Festuca arundinacea (Tall fescue)	*Juncus kraussii (Searush), Carpobrotus edulis (Ice plant)*	
Rushland			0.006
	Juncus kraussii (Searush)	*Carex litorosa (Sea sedge)*	
Total (Ha)			**0.02**

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

4.4. OPPORTUNISTIC MACROALGAE

Ulva intestinalis growing on rocks flanking Waikawa Stream.

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

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.

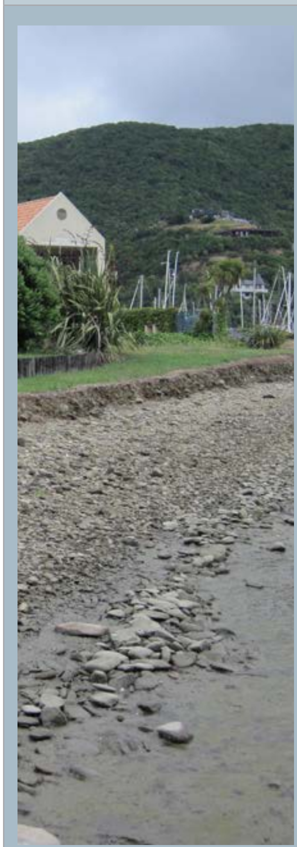
If the estuary supports <5% opportunistic macroalgal cover within the AIH, the overall quality status is reported as "high" with no further sampling required.

Within Waikawa Estuary, opportunistic macroalgal growth was very sparse (<5% cover) and confined to relatively narrow intertidal bands along rockwalls in the mid-lower estuary. No significant macroalgal growth was observed outside of these areas, a quality status of "high", and a risk indicator rating of VERY LOW indicating the estuary is not expressing significant symptoms of eutrophication.

The photos below illustrate the extent of macroalgal growth in the estuary. It comprised a narrow band of the green algae *Ulva intestinalis* present at a low biomass (<100g.m^2) but high percent cover (80-100%) on rocks along the upper tidal range of the Waikawa Stream.

The red alga *Gracilaria chilensis* was also present in the estuary, but only growing as individual plants or in very small patches within muddy pockets among cobble beds. None of the macroalgae were causing nuisance conditions, and no significant gross eutrophic zones were present in the estuary.

4.5. 200m TERRESTRIAL MARGIN



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

- The 200m wide terrestrial margin buffer comprised a mix of residential dwellings (67%), commercial developments including carparking, accommodation and restaurants (26%), roading (5%), and a small industrial (slipway) area (2%).
- There were no areas of dense buffering vegetation surrounding the estuary, although some small pockets of shrubs and trees were present in residential gardens and as amenity plantings in the marina carpark.

The absence of densely vegetated 200m terrestrial margin habitat means there is very little buffering against adverse ecological degradation (e.g. localised sediment and nutrient input mitigation), and little natural ecological connectivity between the estuary and surrounding terrestrial habitats. The risk indicator rating is therefore HIGH.

Table 8. Summary of 200m terrestrial margin land cover, Waikawa Estuary, 2016.

Class	Dominant features	Percentage
Residential	Private housing	66.8
Built Feature	Roads	5.3
Commercial	Boat storage, accommodation, restaurants, marina car park	25.8
Industrial	Slipway	2.2
Total		**100**

Small areas of native amenity plantings in the marina carpark (left) and residential properties (right) around the estuary margin.

Figure 8. Map of 200m Terrestrial Margin - Dominant Land Cover, Waikawa 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 9).

The 2016 results show that extensive historical habitat modification of the estuary has degraded saltmarsh and terrestrial margin habitat, and that there is a moderate risk of adverse impacts to the estuary ecology occurring due to fine mud deposition. The estuary was not exhibiting significant nuisance macroalgal growths (i.e. expressing a low level of eutrophication) or gross eutrophic zones (combined presence of dense macroalgal growth, muds and poor sediment oxygenation). It supported extensive high value seagrass beds.

These results likely reflect the strong flushing of the estuary where the primary stressors (i.e. fine sediment, nutrients) largely pass directly through the estuary to the sea, with strong tidal flushing contributing to high water clarity required for healthy seagrass growth. These combined results place the estuary in a "MODERATE" state overall in relation to ecological health.

Table 9. Summary of broad scale risk indicator ratings for Waikawa 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)	HIGH
	200m Vegetated Terrestrial Margin	HIGH

6. MONITORING AND MANAGEMENT

RECOMMENDED MONITORING

Waikawa Estuary is a relatively small and highly modified tidal delta estuary, with high cultural significance to Te Ātiawa o Te Waka-a-Māui, and high human use and ecological values. It has therefore been identified by MDC as a priority for monitoring. However it is not considered particularly susceptible to either sediment accumulation or eutrophication effects because of its open coastal nature and strong tidal flushing.

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 5-10 yearly intervals unless obvious changes are observed in the interim (next scheduled for consideration in 2021).

Fine Scale Monitoring

Three years of annual monitoring is commonly recommended to establish a robust baseline against which future change can be measured. The January 2016 fine scale intertidal monitoring results (Robertson and Stevens 2016) identified legacy contaminants (i.e. Hg, TBT and DDT) as the primary fine scale issue in the estuary. Because of their high affinity with fine sediments, and the relatively small extent of intertidal mud in the estuary (8%), and the low susceptibility of the estuary to sediment accumulation or eutrophication effects, it is recommended that fine scale intertidal monitoring be repeated 5 yearly.

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.

A relatively simple and readily achievable way to improve the ecological value of the estuary would be to encourage replanting of saltmarsh and native vegetation around the estuary margin.

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. Many thanks also to Ian Shapcott (Te Atiawa Trust) for sharing his time and thoughts on Waikawa Estuary.

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APPENDIX 1. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Shell bank: Area that is dominated by dead shells.

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

APPENDIX 2. 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. >1$kg.m^{-2}$ 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.

EQR calculation

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

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

The EQR calculation process is as follows:

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

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

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

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

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

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

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

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Appendix 2. Estuary Condition Risk Ratings (continued)

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

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

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

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.