Manawatu Estuary 2016
Broad Scale Habitat Mapping

August 2016

Horizons Report 2016/EXT/1506

Prepared for:

Abby Matthews
Science & Innovation Manager
Horizons Regional Council

August 2016
Report No. 2016/EXT/1506
ISBN 978-1-927259-73-3

Prepared by:

Leigh Stevens and Ben Robertson
Wriggle Limited
P O Box 1622
Nelson 7040
Telephone 021 417 936 / 0275 417 935
www.wriggle.co.nz

CONTACT	**24 hr Freephone 0508 800 800**		**help@horizons.govt.nz**	**www.horizons.govt.nz**
SERVICE CENTRES	**Kairanga** Cnr Rongotea and Kairanga-Bunnythorpe Roads Palmerston North **Marton** Hammond Street **Taumarunui** 34 Maata Street	**REGIONAL HOUSES**	**Palmerston** North 11-15 Victoria Avenue **Wanganui** 181 Guyton Street	**DEPOTS**	**Levin** 11 Bruce Road **Taihape** Torere Road Ohotu **Woodville** 116 Vogel Street
POSTAL ADDRESS	Horizons Regional Council, Private Bag 11025, Manawatu Mail Centre, Palmerston North 4442			F 06 9522 929

coastalmanagement

Manawatu Estuary 2016

Broad Scale Habitat Mapping

Prepared for

Horizons Regional Council

August 2016

Cover Photo: Sunrise over the lower Manawatu Estuary, January 2016.

Muddy intertidal flats in the lower estuary, January 2016

Manawatu Estuary 2016

Broad Scale Habitat Mapping

Prepared for
Horizons Regional Council

by

Leigh Stevens and Ben Robertson

Wriggle Limited, PO Box 1622, Nelson 7040, Ph 021 417 936, 0275 417 935, www.wriggle.co.nz

RECOMMENDED CITATION:
Stevens, L.M. and Robertson, B.P. 2016. Manawatu Estuary 2016 Broad Scale Habitat Mapping. Prepared for Horizons Regional Council by Wriggle Coastal Management. 28p.

Contents

List of Figures

List of Tables

All photos by Wriggle except where noted otherwise.

MANAWATU ESTUARY - EXECUTIVE SUMMARY

The Manawatu Estuary is a large (533ha), shallow, generally well-flushed, tidal river estuary located near Foxton. It is part of Horizons Regional Council's (HRC) coastal State of the Environment (SOE) 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 22% of the estuary, saltmarsh 30%, and subtidal waters 48%, with a tidal influence extending ~11km inland.
- Mud (55.6ha) covered 47% of the unvegetated intertidal habitat and was concentrated along the Manawatu River banks, and on intertidal flats and saltmarsh in the middle and lower estuary. Sediment mud content measured within mud habitat was high (46-92%).
- Other dominant substrate features were clean marine sands (43%), muddy sands (9%), and small areas of gravel and rockwall (1%).
- Opportunistic macroalgal growth (*Ulva intestinalis* and *Gracilaria chilensis*) was very sparse (<1% of the available intertidal habitat) and no gross eutrophic zones were present. No seagrass *(Zostera* or *Ruppia)* was present in the estuary.
- Saltmarsh cover was high at 161ha (30% of the estuary) - 61% rushland, 17% sedgeland, 7% herbfield and 6% estuarine shrub.
- 45% of the 200m terrestrial margin was densely vegetated (forest, scrub, dune, wetland), 46% grassland, and 9% residential.

RISK INDICATOR RATINGS (indicate risk of adverse ecological impacts)

Major Issue	Indicator	2016 risk rating
Sediment	Soft mud (% cover, grain size)	HIGH
Eutrophication	Macroalgal Growth (EQR)	VERY LOW
	Gross Eutrophic Conditions (ha)	VERY LOW
Habitat Modification	Seagrass (not present)	VERY LOW
	Saltmarsh (% cover, vegetated % of available habitat, estimated historical loss)	LOW
	200m Vegetated Terrestrial Margin	MODERATE-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 high risk of adverse impacts to the estuary ecology occurring due to excessive muddiness. Perhaps surprisingly given predicted high sediment and nutrient inputs from the Manawatu River catchment, 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). 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 open sea, with poor water clarity also limiting macroalgal growth. This, combined with the remaining presence of extensive high value saltmarsh habitat, means the estuary is currently rated in a "MODERATE" state overall in relation to ecological health.

RECOMMENDED MONITORING AND MANAGEMENT

Manawatu Estuary has been identified by HRC as a priority for monitoring because of its high ecological and human use values. It has been assessed as having a low susceptibility to eutrophication and a moderate susceptibility to excessive fine sediment inputs reflecting its highly flushed nature (Robertson and Stevens 2016).

Recommendations are that broad scale habitat mapping be repeated every 5 years (focussing on the main issue of fine sediment and including an estimate of the historical extent of the estuary), and that a 3 year baseline of estuary condition is established at two fine scale sites (with subsequent monitoring every 5 years). It is recommended that at these fine scale sites, sedimentation rate plates be established and monitored annually (along with grain size).

In addition, various factors suggest that management actions are appropriate to minimise fine sediment impacts in the estuary in order to prevent future deterioration in the estuary's ecological condition.

To defensibly address this, it is recommended that the following management be considered:

- Determine the fine sediment (and nutrient) inputs to the estuary including relative inputs from dominant catchment land uses.
- Determine relevant sediment and nutrient guideline criteria for the estuary (e.g. under development ANZECC guidelines or NZ ETI) to maintain healthy estuary functioning.
- Determine any load reductions required to maintain health estuary functioning by comparing current catchment loads with what could be achieved under best landuse soil conservation practices and, through stakeholder involvement, identify an appropriate "target" estuary condition, sediment loads to achieve that condition and any catchment management changes needed to meet the target.

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

1. INTRODUCTION

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

In addition, and in recognition of the high ecological value of the Manawatu Estuary, HRC commissioned detailed broad scale habitat mapping which was undertaken in January 2016.

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

1. **Ecological Vulnerability Assessment** (EVA) of the estuary to major issues (see Table 1) and appropriate monitoring design. This component has been partially undertaken (includes assessment of vulnerabilities to sediment and eutrophication only but excludes other coastal resources and pressures), and is reported on in Robertson and Stevens (2016).
2. **Broad Scale Habitat Mapping** (NEMP approach). This component (see Table 1) documents the key habitats within the estuary, and changes to these habitats over time. The current report describes inaugural broad scale habitat mapping undertaken in Manawatu Estuary in January 2016 in tandem with the EVA.
3. **Fine Scale Monitoring** (NEMP approach). Monitoring of physical, chemical and biological indicators (see Table 1). This component, which provides detailed information on the condition of an estuary (across a three year baseline), has yet to be undertaken.

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

The Manawatu Estuary is a large (533ha), shallow, generally well-flushed, tidal river estuary located near Foxton. It has a large freshwater inflow, which when combined with the marine inflow, has a tidal influence that extends ~11km inland. The upper estuary is largely confined within defined river channels and is characterised by low salinity waters, flanked by narrow bands of predominantly brackish aquatic plants then pasture. In contrast, the middle and lower reaches have large intertidal flats and saltmarsh. The estuary mouth is always open to the sea. The estuary catchment is extensively developed with land use predominantly sheep, beef and dairy farming, but also some urban.

The estuary is a high use area valued for its aesthetic appeal, bathing, boating, fishing, whitebaiting and beach access. Ecologically it is important for freshwater fish and internationally significant for birds. Although the natural vegetated margin is mostly lost and much of the upper estuary channelised, habitat diversity is moderate-high, with relatively extensive areas of saltmarsh remaining (161ha, 30%). It was designated a wetland of international importance under the Ramsar Convention in July 2005.

The estuary has a high nutrient load (estimated catchment N areal loading of 3,245 $mgN.m^{-2}.d^{-1}$ exceeds the guideline for low susceptibility tidal river estuaries of ~2000 $mgN.m^{-2}.d^{-1}$, Robertson et al. 2016), but despite this the estuary has low susceptibility to eutrophication. This is primarily because of its highly flushed nature, given that it is strongly channelised with very few poorly flushed areas, has high freshwater inflow, is strongly affected by tidal currents and is often turbid (mean 35 NTU). However, on occasions during low flows when the estuary is stratified, nuisance algal/macrophyte growth may occur. The presence of elevated chlorophyll a concentrations at times are likely attributable to freshwater sources upstream of the estuary.

The current suspended sediment load (CSSL) is likely to be >10 times the estimated natural state SS load (NSSL), however the estuary is rated as only moderately vulnerable to muddiness issues as it is well-flushed.

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.

1. Introduction (Continued)

Figure 1. Manawatu Estuary, showing main estuary zones.

2. ESTUARY RISK INDICATOR RATINGS

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

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

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

The indicators and interim risk ratings used for the Manawatu 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

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.

For the current study HRC supplied rectified ~0.4m/pixel resolution colour aerial photos flown in 2010 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 2010 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.

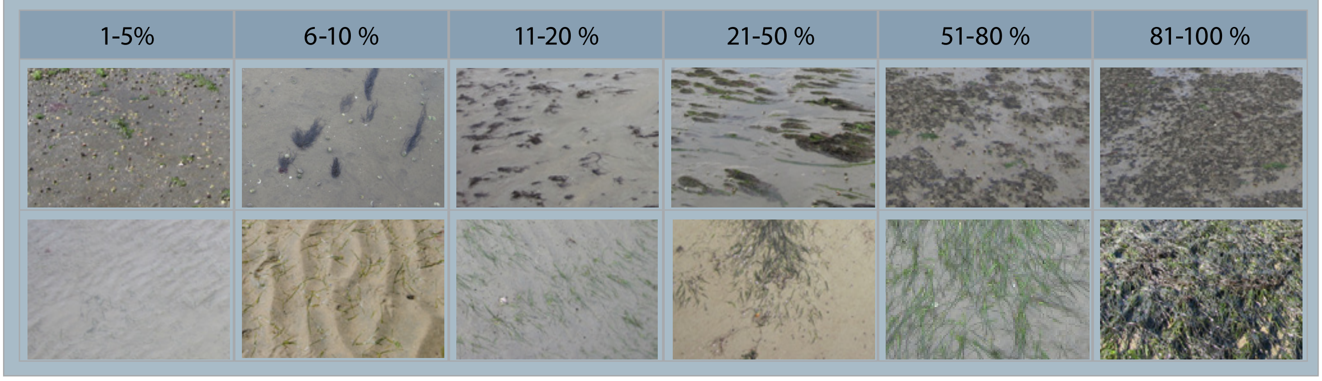
Macroalgae was further assessed by identifying patches of comparable growth, and enumerating each patch by measuring biomass and the degree of macroalgal entrainment within sediment. When macroalgae were present, the presence of soft muds and surface sediment anoxia were also noted to assess whether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



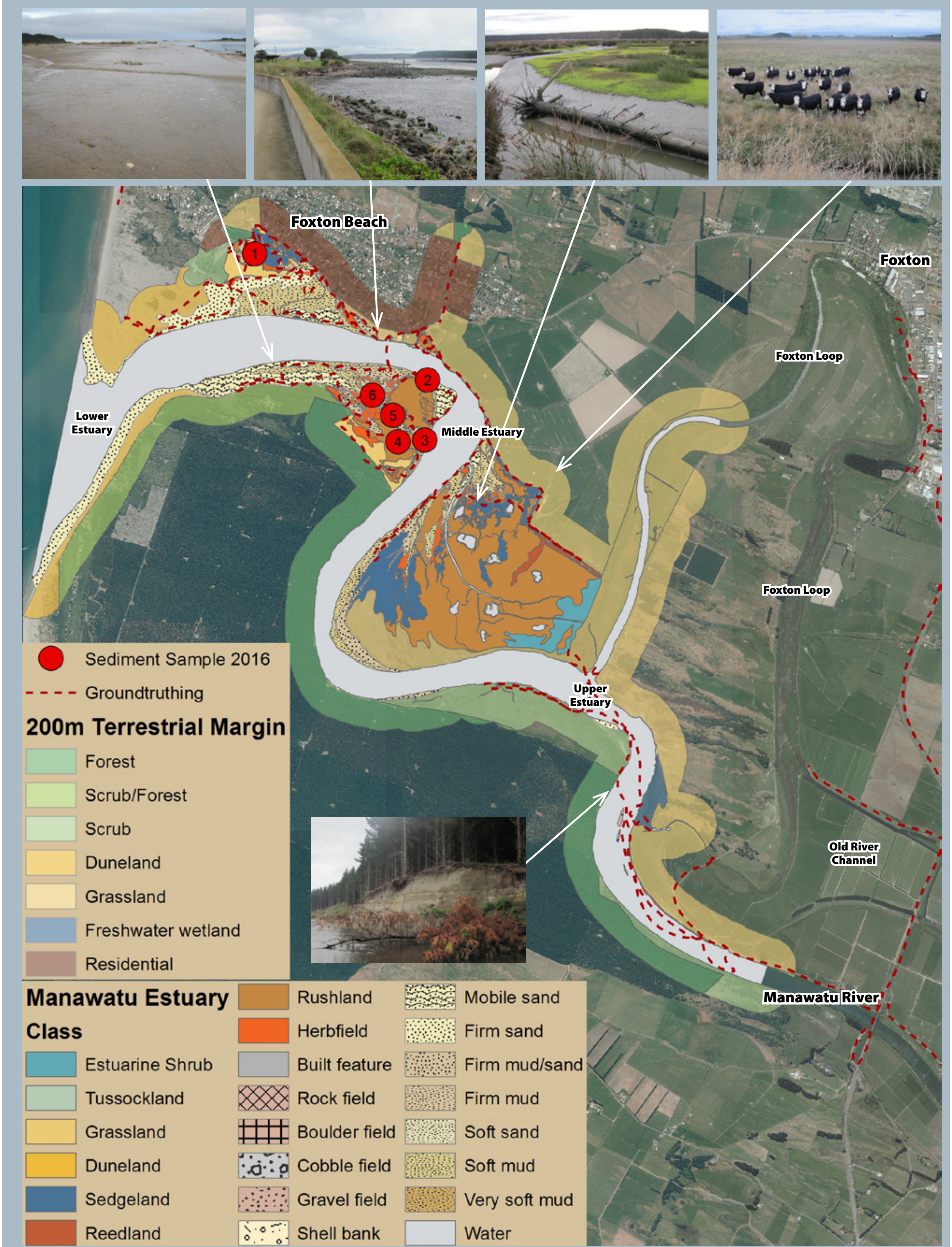
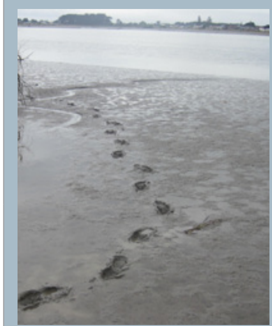
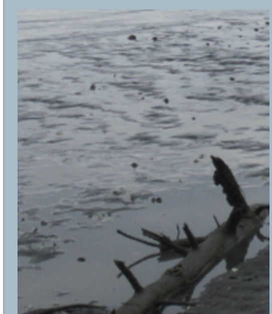


Figure 3. Manawatu Estuary - mapped estuary extent showing groundtruthing coverage, location of grain size samples used to validate substrate classifications, and examples of selected habitats.

4. RESULTS AND DISCUSSION

BROAD SCALE MAPPING





Top to bottom - mud dominated river banks and saltmarsh, firm mud flats, and clean mobile sand in Manawatu 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 was characterised by an extensive subtidal area within the main river channel and several small side channels (48% of the estuary), extensive saltmarsh (30%), and intertidal flats (22%). Seagrass was not found (so is not discussed further) and dense (>50% cover) opportunistic macroalgae was very sparse (<1ha cover). The 200m wide terrestrial margin was 45% densely vegetated (forest, scrub, or dune vegetation), with remaining areas dominated by pasture (46%) and residential developments (9%).

- 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 Manawatu Estuary, 2016.

	Dominant Estuary Feature	Ha	% of Estuary
1.	Intertidal flats (excluding saltmarsh)	118	22%
2.	Opportunistic macroalgal beds (>50% cover) [included in 1. above]	0.7	<1%
3.	Seagrass (>50% cover) [included in 1. above]	0.0	0%
4.	Saltmarsh	161	30%
5.	Subtidal waters	254	48%
	Total Estuary	**533**	**100%**
6.	Terrestrial Margin - % of 200m wide estuary buffer densely vegetated (e.g. scrub, shrub, forest)		45%

4.1. INTERTIDAL FLATS (EXCLUDING SALTMARSH)

Results (summarised in Table 4 and Figure 4) show the dominant intertidal substrate was mud (55.6ha, 47.5%), comprising firm mud (9.5ha, 8.1%) soft mud (45.6ha, 38.9%) and very soft mud (0.5ha, 0.5%). This was located predominantly in the middle and upper estuary and generally showed moderate sediment oxygenation (1-3cm aRPD depth). In the lower estuary, well oxygenated sand dominated (49.9ha, 42.6%) reflecting high tidal flushing of the estuary, particularly near the estuary entrance and lower river margins where clean mobile sand substrates were common. Firm muddy sands (10.1ha, 8.6%) were generally present across the transition between sand and mud dominated habitat. Because the estuary and river cut through extensive coastal sand dune systems, there were relatively few areas of natural cobble, gravel, or rock present. The largest hard substrate areas were flood protection/seawalls on the lower true right bank adjacent to the settlement at Foxton Beach.

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

Dominant Substrate	Ha	%	Comments
Artificial Substrate	1.0	0.9	Wharf, ramp and constructed boulder fields by Foxton Beach settlement.
Rock field	0.1	0.1	Along mid-lower river margins by Foxton Beach settlement.
Gravel field	0.4	0.4	Islands within the upper estuary channel.
Mobile sand	18.0	15.4	High flow channel areas in the middle to lower estuary.
Firm sand	31.8	27.2	Well flushed sections of the lower estuary near the entrance.
Firm mud/sand	10.1	8.6	Among saltmarsh in the upper tidal margins of the middle estuary.
Firm mud	9.5	8.1	Upper tidal margins of the middle estuary.
Soft mud	45.6	38.9	In estuary saltmarsh and throughout middle estuary intertidal flats.
Very soft mud/sand	0.5	0.5	Low velocity channel edges among saltmarsh.
Grand Total	**117.1**	**100**	

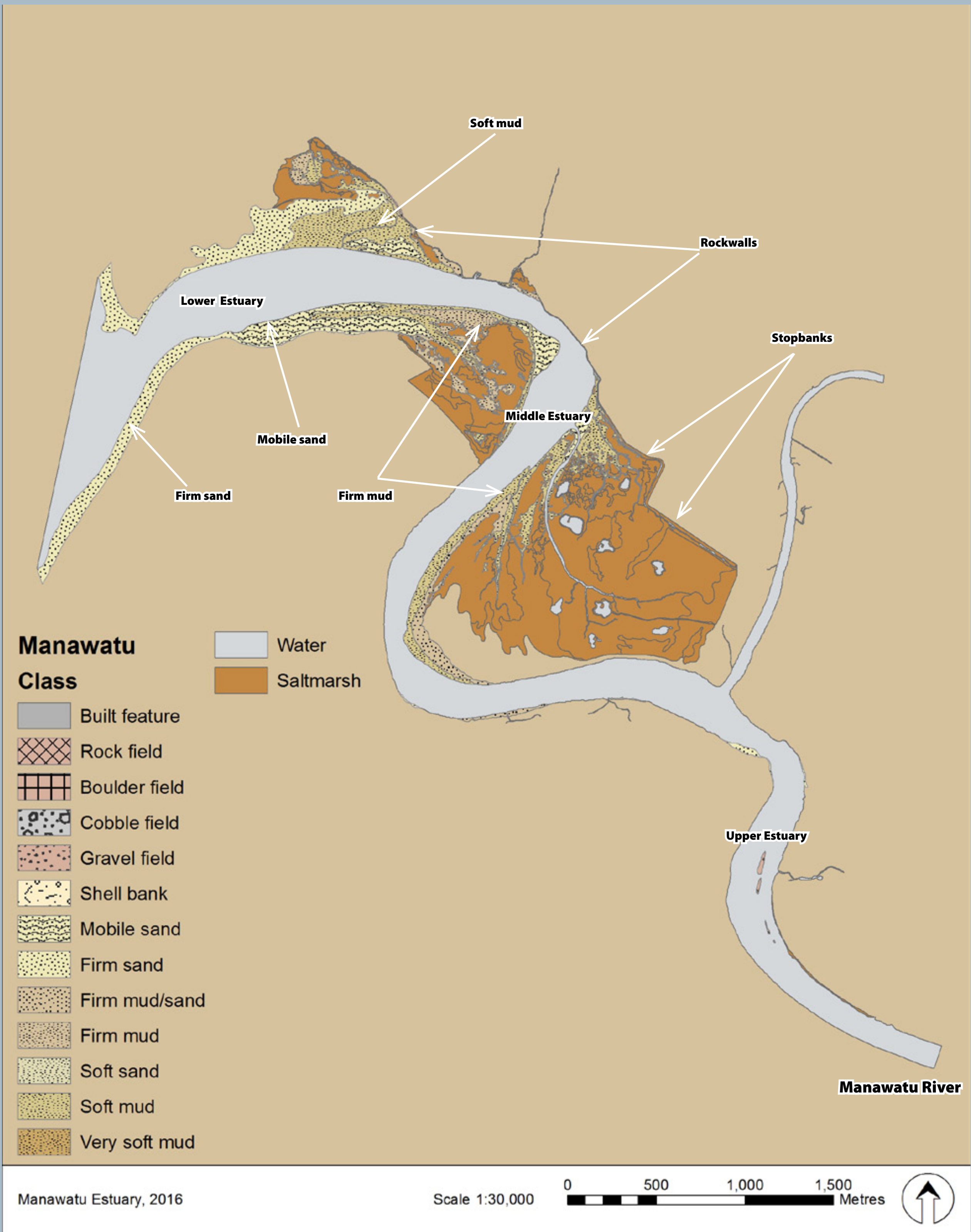


Figure 4. Map of dominant intertidal substrate types - Manawatu Estuary, 2016.

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. Figure 4 shows that mud habitat was concentrated along the banks of the Manawatu River, and on the intertidal flats located within saltmarsh in the middle and lower estuary.

The settlement of muds in these areas is thought to predominantly reflect a hydrodynamic boundary where stream and river flows enter the wider estuary, with the settlement of fine sediments promoted by changes in freshwater flow velocities, combined with salinity driven flocculation. The relatively low incidence of muds in the lower estuary is thought to primarily reflect strong river and tidal flows which limit settlement and facilitate the export of fine sediments to the coast. The upper estuary had very little unvegetated intertidal habitat with terrestrial and freshwater wetland vegetation growing right to the river edge in most places. Elsewhere, river bank erosion in the middle estuary was exposing clean marine derived sands from extensive old dune systems planted in exotic pine forest.

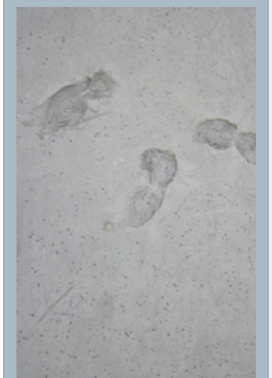
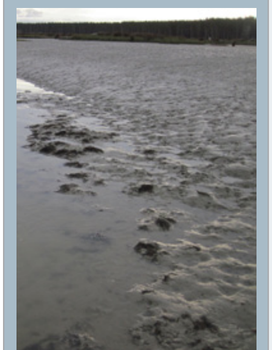
Data from a range of NZ estuaries indicates that mud contents >25% are nearly always associated with soft mud habitat (Robertson et al 2016b). However, drying of sediments, or the presence of stabilising features e.g. gravels, can result in sediments that are firm to walk on but have a mud content >25%. Where such features appear, it is recommended that sediment mud content be measured from representative areas to ensure the NEMP classifications are applied correctly. To this end Table 5 presents the results of synoptic sampling to confirm substrate classes. It shows that sediments classified as muddy using the NEMP protocol in this estuary had measured sediment mud contents ranging from 46-92%, and confirmed that areas of the Manawatu Estuary that dry out can have a high mud content while remaining relatively firm to walk on.

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

Site (Fig 3)	Broad Scale Classification	% mud	% sand	% gravel	NZTM East	NZTM North
1	Soft MUD	56.8	43.1	0.1	1788690	5518009
2	Firm SAND	2.0	98.0	0.0	1788887	5517131
3	Very soft MUD	91.6	8.4	0.0	1789868	5516712
4	Firm Sandy MUD	46.2	53.8	0.0	1789681	5516700
5	Soft MUD	86.4	13.2	0.4	1789648	5516884
6	Very soft MUD	76.6	22.7	0.7	1789505	5517025

The overall risk of detrimental impacts to estuarine biota from muds was assessed as "VERY HIGH" based on the large area of mud dominated substrate relative to the overall unvegetated intertidal estuary habitat (56.5ha, 48%), the widespread cover of muds in middle estuary areas where the most extensive intertidal flats were present, and the elevated mud content (>40%) measured in sediments in these areas.




Unvegetated sand and mud flats in the middle estuary.

4.2. OPPORTUNISTIC MACROALGAE

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

Opportunistic macroalgal growth was assessed by mapping the spatial spread and density of macroalgae in the Available Intertidal Habitat (AIH) (Figure 5), and calculating an "Ecological Quality Rating" (EQR) using the Opportunistic Macroalgal Blooming Tool (OMBT) described in Appendix 2.

The EQR score can range from zero (major disturbance) to one (reference/minimally disturbed) and relates to a quality status threshold band (i.e. bad, poor, good, moderate, high - Appendix 2). The individual metrics that are used to calculate the EQR (spatial extent, density, biomass, and degree of sediment entrainment of macroalgae within the affected intertidal area), are also scored and have quality status threshold bands to guide key drivers of change (Table 6).

Opportunistic macroalgal growth was sparse and confined to relatively narrow intertidal bands along rockwalls in the mid-lower estuary, and one patch in muddy sediments in the lower estuary adjacent to the Foxton Beach settlement. No significant macroalgal growth was observed outside of these areas (Figure 5). When present, macroalgae was relatively sparse (average biomass 295g/m^2 wet weight) and comprised a dominant cover of the green algae *Ulva intestinalis* (generally low biomass high percent cover on rocks) and the red alga *Gracilaria chilensis* (generally a higher biomass and lower percent cover growing on muddy sediments) - data in Appendix 3. Although some *Gracilaria* was entrained within the underlying sediments, it was not causing nuisance conditions, and no significant gross eutrophic zones were present in the estuary.

Overall the risk of detrimental effects being caused by excessive macroalgal growth were assessed as "VERY LOW" based on an overall opportunistic macroalgal EQR of 0.85, a quality status of "HIGH" (Table 6), indicating the estuary is not expressing significant symptoms of eutrophication. This is very much likely to reflect mitigation of high catchment nutrient loads (Robertson and Stevens 2016) by extensive flushing of the estuary. Because the nutrient inputs to the estuary are effectively flushed directly to sea, any consequences of excessive nutrient inputs are likely to manifest in the nearshore coastal environment.

Table 6. Summary of intertidal opportunistic macroalgal cover, Manawatu Estuary, January 2016.

Metric	Face Value	Final Equidistant Score (FEDS)	Quality Status
AIH - Available Intertidal Habitat (ha)	78		
Percentage cover of AIH (%) = (Total % Cover / AIH} x 100 *where Total % cover = Sum of {(patch size) / 100} x average % cover for patch*	0.6	0.98	High
Biomass of AIH (g.m^{-2}) = Total biomass / AIH *where Total biomass = Sum of (patch size x average patch biomass)*	2.8	0.99	High
Biomass of Affected Area (g.m^{-2}) = Total biomass / AA *where Total biomass = Sum of (>5% cover patch size x average patch biomass)*	295	0.54	Moderate
Presence of Entrained Algae = (No. quadrats or area (ha) with entrained algae / total no. of quadrats or area (ha)) x 100	1.4	0.78	Good
Affected Area (use the lowest of the following two metrics)		0.96	High
Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%)	0.72	0.99	High
Size of AA in relation to AIH (%) = (AA / AIH) x 100	0.95	0.96	High
OVERALL MACROALGAL ECOLOGICAL QUALITY RATING - EQR (AVERAGE OF FEDS)		**0.85**	**HIGH**

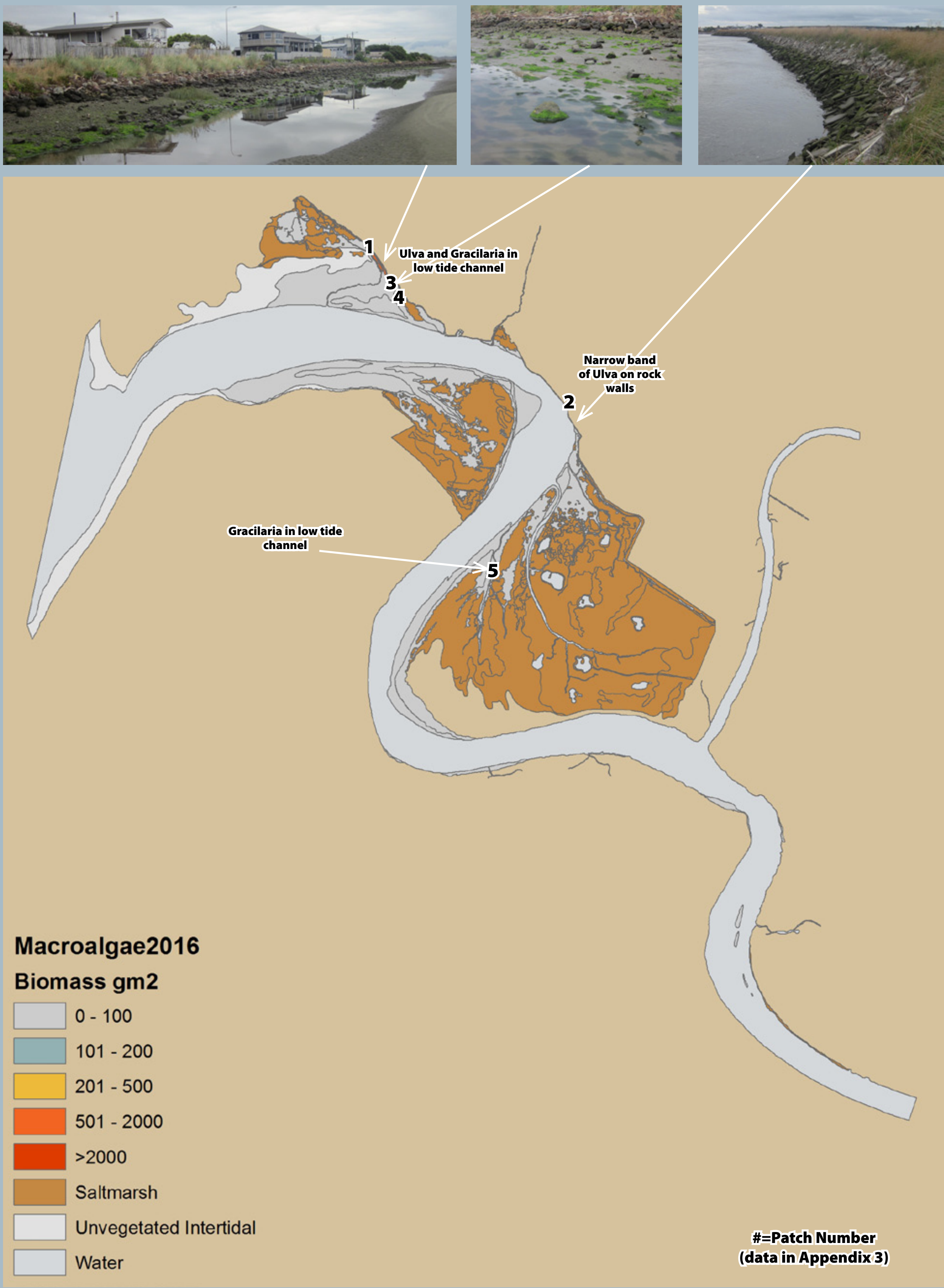


Figure 5. Map of intertidal opportunistic macroalgal biomass (g.m^{-2}) - Manawatu Estuary, 2016.

4.3. SALTMARSH

Saltmarsh (vegetation able to tolerate saline conditions where terrestrial plants are unable to survive) is important as it is highly productive, naturally filters and assimilates sediment and nutrients, acts as a buffer that protects against introduced grasses and weeds, 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 6 summarise the 2016 saltmarsh mapping results and show 161ha of saltmarsh present (30% of the estuary area) and growing throughout the available habitat (the area between MHWN and the upper tidal extent), risk indicator ratings of "VERY LOW".

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

Class	Dominant Species	Primary subdominant species	2016	
Estuarine Shrub			10.0	6.2
	Plagianthus divaricatus (Saltmarsh ribbonwood)	*Juncus kraussii (Searush)*	10.0	6.2
		Festuca arundinacea (Tall fescue)	0.03	0.02
Sedgeland			26.6	16.5
	Schoenoplectus pungens (Three-square)	*Schoenoplectus pungens (Three-square)*	1.0	0.6
		Juncus kraussii (Searush)	25.6	15.9
		Samolus repens (Primrose)	0.03	0.02
Grassland			10.8	6.7
	Festuca arundinacea (Tall fescue)	*Festuca arundinacea (Tall fescue)*	0.8	0.5
		Plagianthus divaricatus (Saltmarsh ribbonwood)	5.7	3.6
		Juncus kraussii (Searush)	3.7	2.3
	Unmaintained introduced grass		0.6	0.3
Duneland			0.2	0.1
	Ammophila arenaria (Marram grass)	*Lupinus arboreus (Tree lupin)*	0.2	0.1
Rushland			98.5	61.1
	Apodasmia similis (Jointed wirerush)	*Juncus kraussii (Searush)*	0.04	0.03
	Juncus kraussii (Searush)	*Juncus kraussii (Searush)*	1.5	1.0
		Apodasmia similis (Jointed wirerush)	35.3	21.9
		Festuca arundinacea (Tall fescue)	0.4	0.3
		Plagianthus divaricatus (Saltmarsh ribbonwood)	0.02	0.01
		Samolus repens (Primrose)	11.0	6.8
		Sarcocornia quinqueflora (Glasswort)	2.1	1.3
		Schoenoplectus pungens (Three-square)	46.4	28.8
		Selliera radicans (Remuremu)	1.7	1.1
Reedland			3.6	2.2
	Spartina anglica (Cord grass)	*Spartina anglica (Cord grass)*	0.6	0.4
	Typha orientalis (Raupo)	*Phormium tenax (New Zealand flax)*	3.0	1.9
Herbfield			11.6	7.2
	Samolus repens (Primrose)	*Samolus repens (Primrose)*	0.0	0.0
		Selliera radicans (Remuremu)	1.2	0.7
	Sarcocornia quinqueflora (Glasswort)	*Juncus kraussii (Searush)*	0.6	0.4
		Carpobrotus edulis (Ice Plant)	0.3	0.2
		Selliera radicans (Remuremu)	0.2	0.1
		Ficinia (Isolepis) nodosa (Knobby clubrush)	0.1	0.1
		Samolus repens (Primrose)	0.04	0.03
	Selliera radicans (Remuremu)	*Samolus repens (Primrose)*	8.6	5.3
		Juncus kraussii (Searush)	0.5	0.3
Total (Ha)			**161.3**	**100**

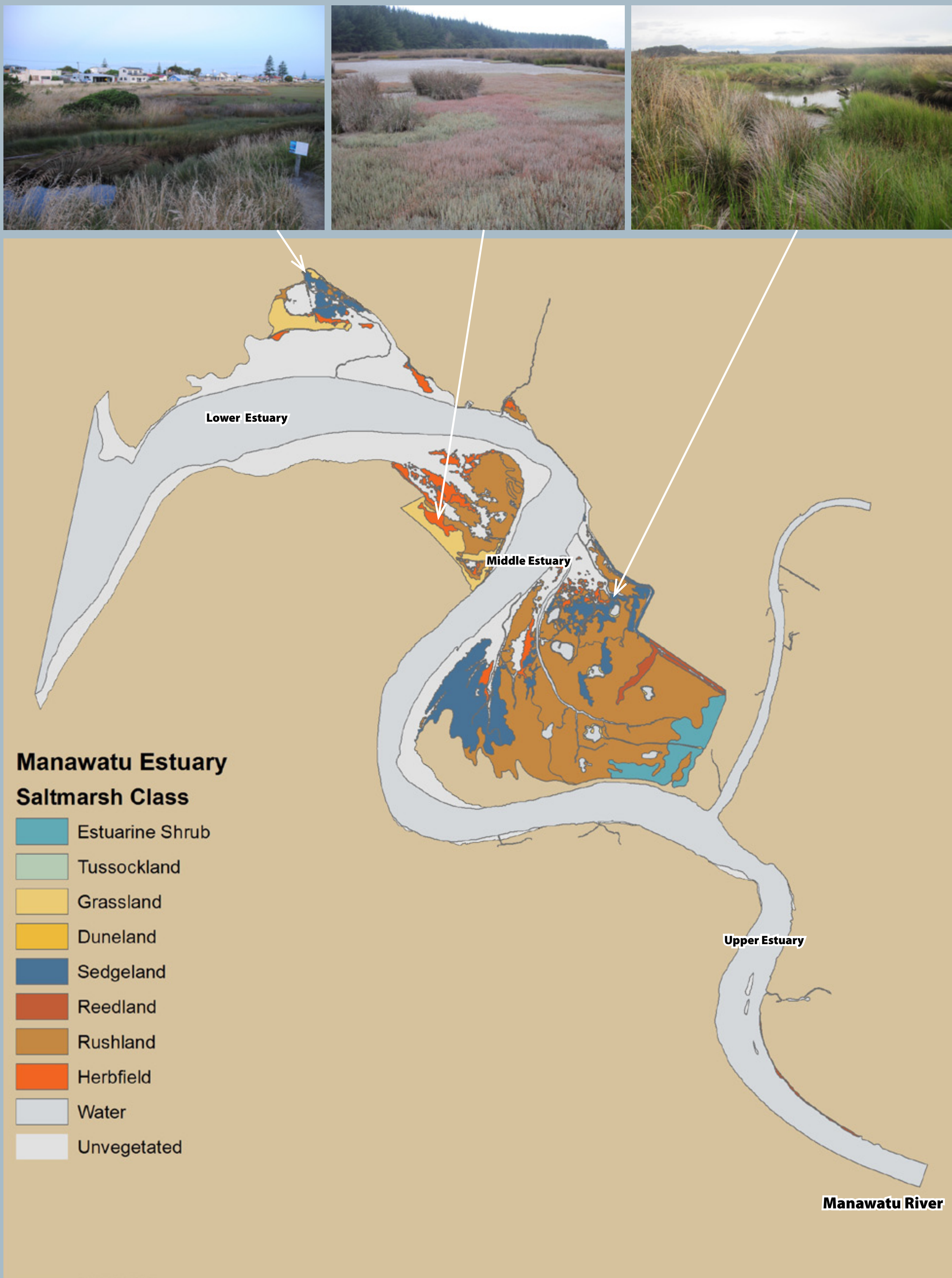


Figure 6. Map of dominant saltmarsh cover - Manawatu Estuary, 2016.

4. Results and Discussion (continued)

However, within this saltmarsh it was noted that there were many areas where terrestrial grasses and weeds were well established in the upper tidal range. While frequent inundation with saltwater will limit the ingress of terrestrial weeds further into the saltmarsh, this natural control process is likely to be less effective in the upper tidal reaches of the Manawatu Estuary because of the strong freshwater (river dominated) influence (i.e. upper tidal areas will be tidally inundated largely by freshwater that floats on top of denser seawater). Should these areas continue to trap sediment and infill, there is likely to be a transition over time to a more terrestrially dominated community than is currently present.

Historic saltmarsh losses have been ascribed a “MODERATE” to “HIGH” risk rating. While beyond the scope of the current work to map the historical estuary extent, drainage and re-contouring of extensive areas of low lying land for flood control, pastoral farming or urban development, particularly below the Foxton Loop, suggests that natural state saltmarsh cover has likely been reduced by at least 40%-60%. There appears to be no obvious risk of any further loss of saltmarsh from such activities.

The combined saltmarsh ratings are ascribed an overall risk rating of “LOW” reflecting the relatively large total area of saltmarsh remaining in the estuary (161ha), its presence throughout the available habitat (but with the presence of terrestrial weeds), and likely relatively high historical saltmarsh losses.

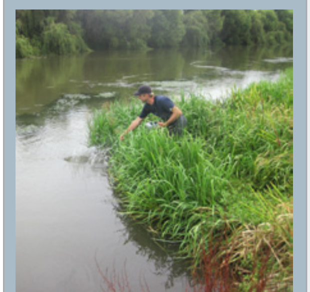
Terrestrial grasses and weeds flanking rushland in the middle and upper estuary (left), and along the estuary margins in the lower estuary (right).

4.4. 200m TERRESTRIAL MARGIN

Pasture margin extending directly to the edge of the upper estuary.

Large eroding river banks cutting through old dune-land as a consequence of past channel modification.

Erosion and flood protection adjacent to Foxton Beach settlement.



Tidally influenced but fresh-water dominated habitat in the Foxton Loop.

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 7) showed:

- Dense buffering vegetation covered 45% of the 200m margin - plantation pine forest (19%) a mix of native and exotic scrub and forest (18%) [both predominantly located on the southern side (true left bank) of the estuary], duneland (7%) [along the barrier spit near the estuary entrance], and freshwater wetland (1%) [among freshwater dominated upper tidal flats].
- The remaining 200m wide terrestrial margin buffer comprised a mix of pasture (24%), unmanaged (often weedy) grassland (20%), and maintained parks and amenity areas (1%).

The extent of densely vegetated 200m terrestrial margin habitat (45%) will provide some buffering against adverse ecological degradation (e.g. localised sediment and nutrient input mitigation). However, in the Manawatu Estuary, a risk indicator rating of "MODERATE-HIGH" has been applied for the following reasons:

- The influence of the 200m terrestrial buffer around the estuary is likely to be relatively small because of the overall catchment size and channelised nature of the estuary with most sediment and nutrient inputs to the estuary likely to be delivered from upstream river sources as opposed to localised overland sources directly adjacent to the estuary.
- Much of the lower estuary has been extensively modified in the past and is confined within floodbanks, disrupting natural ecological gradients. In particular, there is very little buffer adjacent to areas developed for pasture, a strong presence of terrestrial weeds (as discussed in the previous section), and significant river bank erosion in several places.
- Almost all of the buffering vegetation is located on the southern side of the estuary where plantation forests dominate land cover and will be harvested in the future.

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

Class	Dominant features	Percentage
Forest	Predominantly plantation pine forest on the south side of the estuary	19.3
Scrub/Forest	Mixed native and exotic species often in a relatively narrow strip in front of pine plantations on the south side of the estuary	7.8
Scrub		10.2
Grassland	Pasture and unmanaged grassland on the north side of the estuary	45.8
Duneland	Barrier spit near the estuary entrance	7.1
Freshwater wetland	Upper reaches where tidal surge floods margins largely with freshwater	0.9
Residential	Lower estuary, north side. Often with exotic plantings and stopbanks	8.8
Total		**100**

Terrestrial exotic plantings and residential development directly abutting the lower estuary.

Figure 7. Map of 200m Terrestrial Margin - Dominant Land Cover, Manawatu 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 high risk of adverse impacts to the estuary ecology occurring due to excessive muddiness. Perhaps surprisingly, given predicted high sediment and nutrient inputs from the Manawatu River catchment, 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). 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 open sea, with poor clarity also limiting macroalgal growth. This, combined with the remaining presence of extensive high value saltmarsh habitat, means the estuary is currently rated in a "MODERATE" state overall in relation to ecological health.

Table 9. Summary of broad scale risk indicator ratings for Manawatu Estuary, 2016.

Major Issue	Indicator	2016 risk rating
Sediment	Soft mud (% cover, grain size)	HIGH
Eutrophication	Macroalgal Growth (EQR)	VERY LOW
	Gross Eutrophic Conditions (ha)	VERY LOW
Habitat Modification	Seagrass (not present)	VERY LOW
	Saltmarsh (% cover, vegetated % of available habitat, estimated historical loss)	LOW
	200m Vegetated Terrestrial Margin	MODERATE-HIGH

Broad scale habitat mapping is commonly the first step undertaken when evaluating estuary condition, followed by targeted fine scale monitoring within representative intertidal habitat of ecological and contaminant indicators (including sedimentation rate). Combined with other measures of estuary quality (e.g. water quality data, catchment sediment and nutrient loads, land use changes, etc.), the approach gathers defensible information on estuary condition (and trends over time with repeat monitoring) that targets key stressors and facilitates effective management of the estuary. Recommended monitoring and management is presented in the following sections.

6. MONITORING

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

Based on the 2016 monitoring results and risk indicator ratings, particularly those related to fine sediment, the following monitoring recommendations are proposed for consideration by HRC:

Broad Scale Habitat Mapping.
Undertake broad scale habitat mapping at 5 yearly intervals, focusing on the main issue of sediment. It is recommended that an estimate also be made of the historical extent of the estuary using combined information derived from historical maps, photos, descriptions, as well as any available survey or LIDAR data.

Fine Scale Monitoring.
Undertake fine scale intertidal monitoring at two sites over three consecutive years to establish a robust baseline of estuary condition. Once the baseline has been established, subsequent fine scale monitoring is recommended to be undertaken every 5 years.

Sedimentation Rate Monitoring.
Because fine sediment is the priority issue in the estuary it is recommended that sediment plates be established at fine scale sites and deposition measured annually, with sediment also analysed for grain size at these sites (if not done as part of fine scale monitoring), to determine if sediments are getting muddier.

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

7. MANAGEMENT

Overall, a step-wise management approach is recommended to cost effectively address the source of stressors, identify management targets, and guide management to help ensure that the assimilative capacity of the estuary is not exceeded so that the estuary can flourish and provide sustainable human use and ecological values in the long term. The data available to date suggest that management actions are required to minimise ongoing fine sediment impacts in the estuary in order to prevent deterioration in the estuary's ecological condition. While currently not a significant issue in the estuary itself, high nutrient concentrations flushing through the estuary may be contributing to impacts in coastal areas outside of the estuary.

As an initial step, it is recommended that the following management actions be considered by HRC:

To defensibly address this, it is recommended that the following management be considered:

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

8. ACKNOWLEDGEMENTS

Many thanks to Amy Shears and Logan Brown (HRC) for their support and feedback on the draft report.

9. 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.

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.

Green, M., Stevens, L. and Oliver, M. 2014. Te Awarua-o-Porirua Harbour and catchment sediment modelling. Development and application of the CLUES and Source-to-Sink models, Greater Wellington Regional Council Publication Number GW/ESCI-T-14/132.

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.

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. and 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.

9. References (Continued)

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. and 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. and 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. and Stevens, L. 2016. Manawatu-Wanganui Estuaries. Habitat Mapping, Vulnerability Assessment and Monitoring Recommendations Related to Issues of Eutrophication and Sedimentation. Prepared for Envirolink Medium Advice Grant: 1624-HZLC127 Assessment of the susceptibility of Horizons' estuaries to nutrient enrichment and sedimentation. MBIE/NIWA Contract No:CO1X1513. 102pp + appendices.

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.M. and Stevens, L. 2015. Kokorua Inlet 2015 Fine Scale Monitoring. Prepared for Nelson City Council. 34p.

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. and 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.M. and Robertson, B.M. 2009. Whanganui Estuary. Broad Scale Habitat Mapping 2008/09. Report prepared by Wriggle Coastal Management for Department of Conservation. 17p.

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.

Wehkamp, S. and 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. and 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.

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. MANAWATU ESTUARY MACROALGAL DATA, JAN. 2016

Patch ID	Patch area (ha)	Percent cover	Mean Biomass (g.m^{-2} wet weight)	Presence (1) or absence (0) of entrained algae)	aRPD (cm)	Presence (1) or absence (0) of soft mud	Patch Biomass (kg)	Dominant species
1	0.31	50	20	0	0	0	155	*Ulva intestinalis*
2	0.16	80	30	0	0	0	126	*Ulva intestinalis*
3	0.10	80	700	0	0	0	78	*Ulva intestinalis*
4	0.15	50	800	0	2	0	75	*Gracilaria chilensis, Ulva intestinalis*
5	0.01	20	1500	1	2	0	2	*Gracilaria chilensis*

horizons
regional council

11-15 Victoria Avenue
Private Bag 11 025
Manawatu Mail Centre
Palmerston North 4442

T 0508 800 800
F 06 952 2929
help@horizons.govt.nz
www.horizons.govt.nz