Whanganui Estuary 2017
Broad Scale Habitat Mapping

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Cover Photo: Lower Whanganui Estuary, January 2017.

Intertidal flats in the lower estuary, January 2017

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WHANGANUI ESTUARY - EXECUTIVE SUMMARY

The Whanganui Estuary is a large (353ha), shallow, generally well-flushed, macrotidal (>1.8m tidal range), low susceptibility, tidal river estuary located at Whanganui. It has a simple elongate shape and the mouth is always open to the sea. The catchment is dominated by native forest (56%) and pasture (35%). It is part of Horizon Regional Council's (HRC) coastal State of the Environment monitoring programme. This report presents the results of 2017 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 27% of the estuary, subtidal waters 73%, and saltmarsh 0.1%.
- Intertidal substrates were dominated by firm muddy sand (66%), soft/very soft mud (20%), firm sand (7%), and built features e.g. artificial boulder fields, seawalls etc (7%). The soft mud risk rating was HIGH.
- Sediment mud content measured within mud habitat was high (25-67%), a risk rating of HIGH.
- Sediment oxygenation was depleted (aRPD <0.5cm deep) in most soft mud habitat (16ha), a risk rating of HIGH.
- Opportunistic macroalgal growth was sparse overall (<5% of the available intertidal habitat), an overall Ecological Quality Rating of "GOOD" (a risk rating of LOW), and no gross eutrophic zones (entrained high biomass growths and degraded sediments) were observed, a risk rating of LOW.
- No seagrass (*Zostera muelleri*) was present in intertidal areas.
- Saltmarsh cover was very sparse 0.5ha (0.1%) and reflected significant historical losses, a risk rating of HIGH.
- The 200m terrestrial margin comprised a mix of industrial developments (26%), grassland (25%), residential areas (21%), and commercial activities (6%) with 21% densely vegetated, a risk rating of 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 2017 broad scale mapping results show that extensive historical habitat modification 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. Nutrient inputs to the estuary, while relatively high, are not resulting in nuisance macroalgal growths, most likely due to strong flushing of the estuary where nutrients largely pass directly through the estuary to the open sea.

A comparison with the 2009 mapping results show a potential improvement through a decrease in soft mud (16.2ha (17%) in 2017 compared to 23.6ha (28%) in 2009), but a decline in condition with a reduction saltmarsh (0.9ha to 0.5ha) and an increase in poorly oxygenated sediments.

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

RECOMMENDED MONITORING AND MANAGEMENT

Whanganui 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-moderate susceptibility to eutrophication and a moderate susceptibility to excessive fine sediment inputs reflecting its highly flushed nature.

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 sedimentation rate plates be established and monitored annually (along with grain size) at these fine scale sites.

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. These include determining the sources and magnitude of sediment and nutrient inputs, defining thresholds to maintain healthy estuary functioning, identifying stakeholder led management targets, and establishing criteria and management plans to achieve the target state, initially for sediment, and then other relevant stressors (e.g. nutrients, toxicants, disease causing organisms) as appropriate.

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 Estuary in 2009 (Stevens and Robertson 2009), and in late 2015 HRC commissioned an Ecological Vulnerability Assessment for the majority of the estuaries within the region to assess sediment and eutrophication risks, map dominant habitat features, and provide the Council with defensible monitoring recommendations and priorities (Robertson and Stevens 2016).

In recognition of the high ecological and human use values of the Whanganui Estuary, HRC subsequently commissioned detailed broad scale habitat mapping which was undertaken in January 2017.

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. This was first undertaken in 2009 (Stevens and Robertson 2009) and the current report describes repeat mapping undertaken in Whanganui Estuary in January 2017.
3. **Fine Scale Monitoring** (NEMP approach). Monitoring of physical, chemical and biological indicators (see Table 1). This component, which provides detailed information on the condition of an estuary (initially across a three year baseline), has yet to be undertaken.

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

- Broad scale mapping of estuary sediment types and sediment oxygenation.
- Broad scale mapping of macroalgal beds (i.e. *Ulva* (sea lettuce), *Gracilaria*) and seagrass (i.e. *Zostera muelleri*).
- 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).

WHANGANUI ESTUARY

The Whanganui Estuary is a large (353ha), shallow, generally well-flushed, macrotidal (>1.8m tidal range), low susceptibility, tidal river estuary located at Whanganui. It has a large freshwater inflow (MALF 210m^3.s^{-1}), which when combined with the marine inflow, has a tidal influence that extends many kilometres inland. The estuary is highly modified and mostly confined within defined river channels and flood protection works, although the lower reaches have large intertidal flats. Saltmarsh is scarce due largely to the historical modification of the estuary margins. The estuary mouth is always open to the sea. The large estuary catchment (7169km^2) is mud and sandstone dominated (71%), extensively developed (35%) with sheep, beef and dairy farming (~14,800 cows) prominent, but also with large areas of forest (56% native, 8% exotic).

The estuary is a high use area valued for its port, aesthetic appeal, bathing, boating, fishing, whitebaiting and beach access. Ecologically it is important for freshwater fish and birds. Because the natural vegetated margin is mostly lost and much of the upper estuary channelised, habitat diversity is relatively low, with very little saltmarsh (0.5ha) and no seagrass. A large coastal dune system supports a range of native species and is relatively intact but is under threat from exotic weeds. There has been extensive planting and development of public walkways and recreation areas along the estuary margins which are very well utilised.

The estuary has a high nutrient load (estimated catchment N areal loading of 3,144mgN.m^{-2}.d^{-1} exceeds the guideline for low susceptibility tidal river estuaries of ~2000mgN.m^{-2}.d^{-1}, Robertson et al. 2016), but despite this the estuary has low susceptibility to eutrophication. This is primarily because of its highly flushed nature, given that it is strongly channelised with very few poorly flushed areas, has high freshwater inflow, is strongly affected by tidal currents and is often turbid. The presence of elevated chlorophyll a concentrations at times are likely attributable to freshwater sources upstream of the estuary.

The current suspended sediment load (CSSL) is likely to be ~7 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,
- direct physical effects e.g. gill abrasion in fish, compromised filter feeding (invertebrates including shellfish, and prey sighting (fish and birds),
- a shift towards mud-tolerant benthic organisms which often means a loss of sensitive shellfish (e.g. pipi) and other filter feeders; and
- making the water unappealing to swimmers.

Recommended Key Indicators:

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

2. Eutrophication

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

Recommended Key Indicators:

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

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

3. Disease Risk

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

Recommended Key Indicators:

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

4. Toxic Contamination

In the last 60 years, NZ has seen a huge range of synthetic chemicals introduced to the coastal environment through urban and agricultural 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. Microbeads and plastics are a recently recognised concern. When they enter estuaries these chemicals collect in sediments and bio-accumulate in fish and shellfish, causing health risks to marine life and humans. In addition, natural toxins can be released by macroalgae and phytoplankton, often causing mass closures of shellfish beds, potentially hindering the supply of food resources, as well as introducing economic implications for people depending on various shellfish stocks for their income. For example, in 1993, a nationwide closure of shellfish harvesting was instigated in NZ after 180 cases of human illness following the consumption of various 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. Whanganui 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 Whanganui Estuary broad scale monitoring programme are summarised in Table 2, with supporting notes explaining the use and justifications for each indicator on the following page. The basis underpinning most of the ratings is the observed correlation between an indicator and the presence of degraded estuary conditions from a range of tidal lagoon and tidal river estuaries throughout NZ. Work to refine and document these relationships is ongoing.

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

RISK INDICATOR RATINGS / ETI BANDS (indicate risk of adverse ecological impacts)				
BROAD AND FINE SCALE INDICATORS	Very Low - Band A	Low - Band B	Moderate - Band C	High - Band D
Soft mud (% of unvegetated intertidal substrate)*	<1%	1-5%	>5-15%	>15%
Sediment Mud Content (%mud)*	<5%	5-10%	>10-25%	>25%
Apparent Redox Potential Discontinuity (aRPD)**	Unreliable	Unreliable	0.5-2cm	<0.5cm
Redox Potential (RPmV) upper 3cm***	>+100mV	+100 to -50mV	-50 to -150mV	<-150mV
Sediment Oxygenation (aRPD <0.5cm or RP@3cm <-150mV)*	<0.5ha or <1%	0.5-5ha or 1-5%	6-20ha or >5-10%	>20ha or >10%
Macroalgal Ecological Quality Rating (OMBT)*	≥0.8 - 1.0	≥0.6 - <0.8	≥0.4 - <0.6	0.0 - <0.4
Seagrass (% change from baseline)	<5% decrease	5%-10% decrease	>10-20% decrease	>20% decrease
Gross Eutrophic Zones (ha or % of intertidal area)	<0.5ha or <1%	0.5-5ha or 1-5%	6-20ha or >5-10%	>20ha or >10%
Saltmarsh Extent (% of intertidal area)	>20%	>10-20%	>5-10%	0-5%
Supporting indicator – **Extent** (% remaining from est. natural state)	>80-100%	>60-80%	>40-60%	<40%
Vegetated 200m Terrestrial Margin	>80-100%	>50-80%	>25-50%	<25%
Percent Change from Monitored Baseline	<5%	5-10%	>10-20%	>20%
NZ ETI score*	0-0.25	0.25-0.50	0.50-0.75	0.75-1.0

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

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

Opportunistic Macroalgae. The presence of opportunistic macroalgae is a primary indicator of estuary eutrophication, and when combined with gross eutrophic conditions (see previous) can cause significant adverse ecological impacts that are very difficult to reverse. Thresholds used to assess this indicator are derived from the OMBT (WFD-UKTAG 2014), with results combined with those of other indicators to determine overall condition.

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

Saltmarsh. Saltmarshes have high biodiversity, are amongst the most productive habitats on earth, and have strong aesthetic appeal. They are sensitive to a wide range of pressures including land reclamation, margin development, flow regulation, sea level rise, grazing, wastewater contaminants, and weed invasion. Most NZ estuarine saltmarsh grows in the upper estuary margins above mean high water neap (MHWN) tide where vegetation stabilises fine sediment transported by tidal flows. Saltmarsh zonation is commonly evident, resulting from the combined influence of factors including salinity, inundation period, elevation, wave exposure, and sediment type. Highest saltmarsh diversity is generally present above mean high water spring (MHWS) tide where a variety of salt tolerant species grow including scrub, sedge, tussock, grass, reed, rush and herb fields. Between MHWS and MHWN, saltmarsh is commonly dominated by relatively low diversity rushland and herbfields. Below this, the MHWN to MSL range is commonly unvegetated or limited to either mangroves or *Spartina*, the latter being able to grow to MLWN. Further work is required to develop a comprehensive saltmarsh metric for NZ. As an interim measure, the % of the intertidal area comprising saltmarsh is used to indicate saltmarsh condition. One supporting metrics are also proposed: % loss from Estimated Natural State Cover. This assumes that a reduction in natural state saltmarsh cover corresponds to a reduction in ecological services and habitat values. The interim risk ratings proposed are Very Low=>80-100%, Low=>60-80%, Moderate=>40-60%, and High=<40%. The “early warning trigger” for initiating management action/further investigation is a trend of a decreasing saltmarsh area or saltmarsh growing over <80% of the available habitat.

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

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

3. METHODS

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

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

The georeferenced spatial habitat maps provide a robust baseline of key indicators that are used with risk ratings to assess estuary condition in response to common stressors, and assess future change.

Estuary boundaries were set seaward from an imaginary line closing the mouth to the upper extent of saline intrusion (i.e. where ocean derived salts during average annual low flow are <0.5ppt). For the current study, LINZ rectified colour aerial photos (~0.25m/pixel resolution) flown in 2015/16 were sourced from ESRI online, laminated (scale of 1:3,000), and used by experienced scientists who walked the area in January 2017 to ground-truth the spatial extent of dominant vegetation and substrate types. From representative broad scale substrate classes, 10 grain size samples were analysed to validate substrate classifications (Figure 3, Table 5). When present, macroalgae and seagrass patches were mapped to the nearest 5% using a 6 category percent cover rating scale as a guide to describe density (see Figure 2). Notes on sampling, resolution and accuracy are presented in Appendix 2. Macroalgae was further assessed by identifying patches of comparable growth, and enumerating each patch by measuring:

- % cover of opportunistic macroalgae (the spatial extent and density of algal cover providing an early warning of eutrophication issues).
- macroalgal biomass (providing a direct measure of areas of excessive growth).
- extent of algal entrainment in sediment (highlighting where nuisance 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).

Where macroalgal cover exceeded 5% of the Available Intertidal Habitat (AIH), a modified Opportunistic Macroalgal Blooming Tool (OMBT) is used to rate macroalgal condition. The OMBT, described in detail in Appendix 2, is a 5 part multimetric index that produces an overall Ecological Quality Rating (EQR) ranging from 0 (major disturbance) to 1 (minimally disturbed) and which is placed within overall quality status threshold bands (i.e. bad, poor, good, moderate, high - Appendix 2). This integrated index provides a comprehensive measure of the combined influence of macroalgal growth and distribution.

Broad scale habitat features were digitised into ArcMap 10.5 shapefiles using a Wacom Cintiq21UX drawing tablet, and combined with field notes and georeferenced photographs, to produce habitat maps showing the dominant cover of: substrate, macroalgae (e.g. *Ulva, Gracilaria*), saltmarsh vegetation, and the 200m wide terrestrial margin vegetation/landuse. These broad scale results are summarised in Section 4, with the supporting GIS files (supplied as a separate electronic output) providing a much more detailed data set designed for easy interrogation to address specific monitoring and management questions.

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

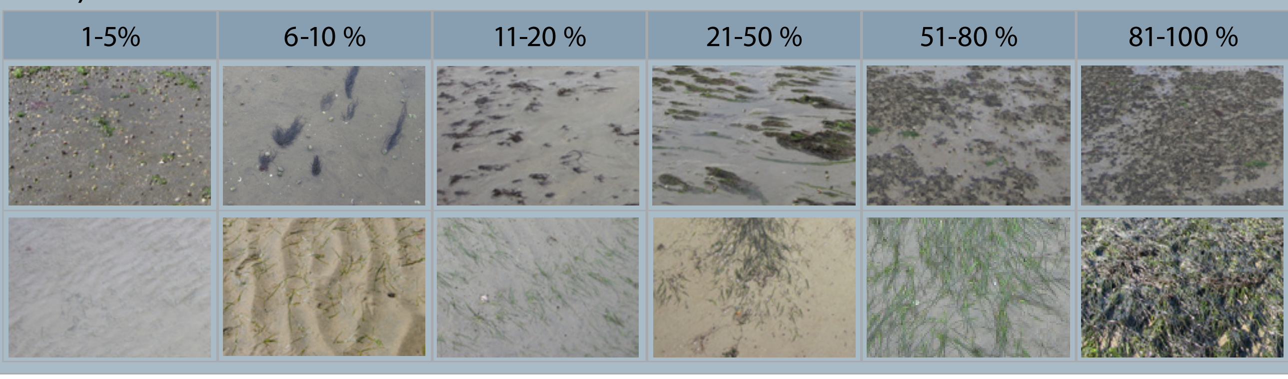


Figure 3. Whanganui Estuary - mapped estuary extent showing ground-truthing coverage, location of grain size samples used to validate substrate classes, and location of field photos.

4. RESULTS AND DISCUSSION

4.0. BROAD SCALE MAPPING SUMMARY

The 2017 broad scale habitat mapping ground-truthed and mapped all intertidal substrate and vegetation including the dominant land cover of the 200m terrestrial margin, with the six dominant estuary features summarised in Table 3.

The estuary is a large, subtidally dominated (73%) and highly modified tidal river estuary. Intertidal areas (27%) are relatively narrow in the upper estuary and expand into relatively wide intertidal flats in the lower estuary near the sea. Direct tidal seawater intrusion is limited to the lower reaches (the area mapped), but a significant tidal influence extends for several kms upstream.

Because of extensive flood protection works, the estuary supports very limited fringing saltmarsh (0.1%). Very little intertidal opportunistic macroalgae was present in January 2017, and there was no intertidal seagrass or gross eutrophic zones identified (these latter indicators not discussed further in the report). The 200m wide terrestrial margin was dominated (53%) by residential, industrial and commercial developments mostly on the true right bank, and grassland (25%). 21% of the terrestrial margin had a dense cover of vegetation (e.g. shrubs and trees).

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 compare changes from the mapping baseline established in 2009 (Stevens and Robertson 2009).

Table 3 provides a high level summary of the 2009 and 2017 mapping results. They show very little overall change in the estuary, the major difference being an increase in the intertidal area mapped in 2017 due to tidal conditions allowing better delineation of the intertidal boundary. A decrease in saltmarsh in 2017 is partly attributable to margin development, and partly to seasonally variable growth of the dominant sedge species in the estuary (three square).

In the following sections, various factors related to each of these key habitats (e.g. area of soft mud, sediment oxygenation, saltmarsh extent) are used in conjunction with risk ratings to assess key estuary issues of sedimentation, eutrophication, and habitat modification.

Table 3. Summary of dominant broad scale features in Whanganui Estuary, 2009 and 2017.

Dominant Estuary Feature		2009			2017		
		ha	% intertidal	% estuary	ha	% intertidal	% estuary
1.	Intertidal flats (excluding saltmarsh)	84.5	98.9	23.9	95.9	99.5	27.1
2.	Opportunistic macroalgal beds (>50% cover) [on intertidal flats]	-	-	-	-	-	-
3.	Seagrass (>20% cover) [on intertidal flats]	-	-	-	-	-	-
4.	Saltmarsh	0.9	1.1	0.3	0.5	0.5	0.1
5.	Subtidal waters	268.4		75.9	256.9		72.7
Total Estuary		**354**			**353**		
6.	200m wide vegetated Terrestrial Margin (e.g. scrub, forest)			16%			21%

4.1. INTERTIDAL SUBSTRATE (EXCLUDING SALTMARSH)

Results (summarised in Table 4 and Figure 4) show substrates on intertidal flats in 2017 were dominated by firm muddy sand (66%), soft/very soft mud (20%), firm sand (7%), built features e.g. artificial boulder fields, seawalls etc (7%), and small areas of rock, cobble and gravel field (<1%). Soft muds were confined largely to narrow bands along the lower tidal edges of the river channels in the upper estuary, and on the lower margins of wider tidal flats in parts of the lower estuary. Adjacent to soft mud areas, firm muddy sands were present, and were the dominant intertidal substrate. In the lower estuary, a narrow band (average width 2-10m) of firm sands was commonly present along the upper tidal reaches of the estuary. This general pattern where mud-dominated sediments in the upper estuary transition to marine sand dominated sediments in the lower estuary is a common feature within tidal river estuaries.

4. RESULTS AND DISCUSSION (CONTINUED)

The settlement of muds along upper estuary channel margins and lower tidal flats predominantly reflects salinity driven flocculation combined with a hydrodynamic boundary where fine sediment settlement is promoted by changes in freshwater flow velocities, particularly where stream and river flows reach the wider lower estuary. The relatively low incidence of muds in the lower estuary is thought to primarily reflect strong river and tidal flows which limit settlement and facilitate the export of fine sediments to the coast. However, it is also obvious within Whanganui Estuary that fine sediment inputs are spatially and temporally variable with regular floods both delivering and flushing large quantities of material from the estuary.

Table 4. Summary of dominant intertidal substrate, Whanganui Estuary, 2017.

Dominant Substrate	Ha	%	General location
Built Feature	6.6	6.9	Mostly along the upper estuary near the terrestrial margin.
Wharf	*0.7*	*0.7*	On the true right bank, near the port and Moutoa Quay.
Ramp	*0.1*	*0.1*	Several locations on both banks.
Rock field man-made	*0.01*	*0.0*	Primarily bridge supports.
Boulder field man-made	*5.5*	*5.7*	River moles and groynes, flood armour along river banks.
Seawall man-made	*0.3*	*0.3*	Groynes, flood armour along river banks.
Rock field	0.04	0.0	Outcrop adjacent to Anzac Parade/Purua Stream.
Cobble field	0.05	0.0	On the true left bank, near Corliss Island.
Gravel field	0.6	0.6	On the main river channel side of Corliss Island.
Firm sand	6.6	6.8	Upper intertidal areas on the lower true right bank.
Firm muddy sand	63.5	65.9	Mid to upper intertidal areas on both banks.
Firm sandy mud	2.8	2.9	Upper beach at west end of Gilberd Street (lower true right bank).
Soft mud	16.1	16.7	Flats by Beach Road. Lower intertidal margin on both banks.
Very soft mud	0.1	0.1	Beach at west end of Gilberd Street (lower true right bank).
Grand Total	**96.4**	**100**	

In order to validate that NEMP substrate classifications are applied correctly, it is common to undertake synoptic sampling within representative sand and mud substrate classes. While data from a range of NZ estuaries indicates that soft mud habitat is nearly always associated with mud contents >25% (Robertson et al 2016b), drying of sediments, or the presence of stabilising features e.g. gravels, can result in sediments that are firm to walk on but have a mud content >25%. To this end Table 5 presents the results of grain size analyses within dominant substrate classes. It shows that sediments classified as muddy using the NEMP protocol in this estuary had measured sediment mud contents ranging from 25-67%, and confirmed that some areas of the Whanganui Estuary can have a high mud content while remaining relatively firm to walk on.

Table 5. Grain size results from representative sediments, Whanganui Estuary, 2017.

Broad Scale Classification	Site[1]	% mud	% sand	% gravel	NZTM East	NZTM North
Firm SAND	9	2.4	96.9	0.8	1773633	5575134
Firm SAND	1	2.5	97.1	0.4	1771375	5575982
Firm muddy SAND (Mobile SAND)	4	6.6	93.3	0.1	1771640	5575777
Firm muddy SAND	7	10.8	85.2	4.0	1775248	5576538
Firm Sandy MUD	2	28.0	70.8	1.2	1771300	5575998
Soft Sandy MUD	3	25.2	74.8	< 0.1	1771365	5575870
Soft MUD	10	32.8	67.1	0.1	1775527	5578725
Soft MUD	6	67.4	32.4	0.3	1775830	5577557
Very soft MUD	5	47.4	52.5	< 0.1	1775766	5577489
Very soft MUD	8	48.6	50.8	0.5	1773819	5575141

[1]sites shown in Figure 3.

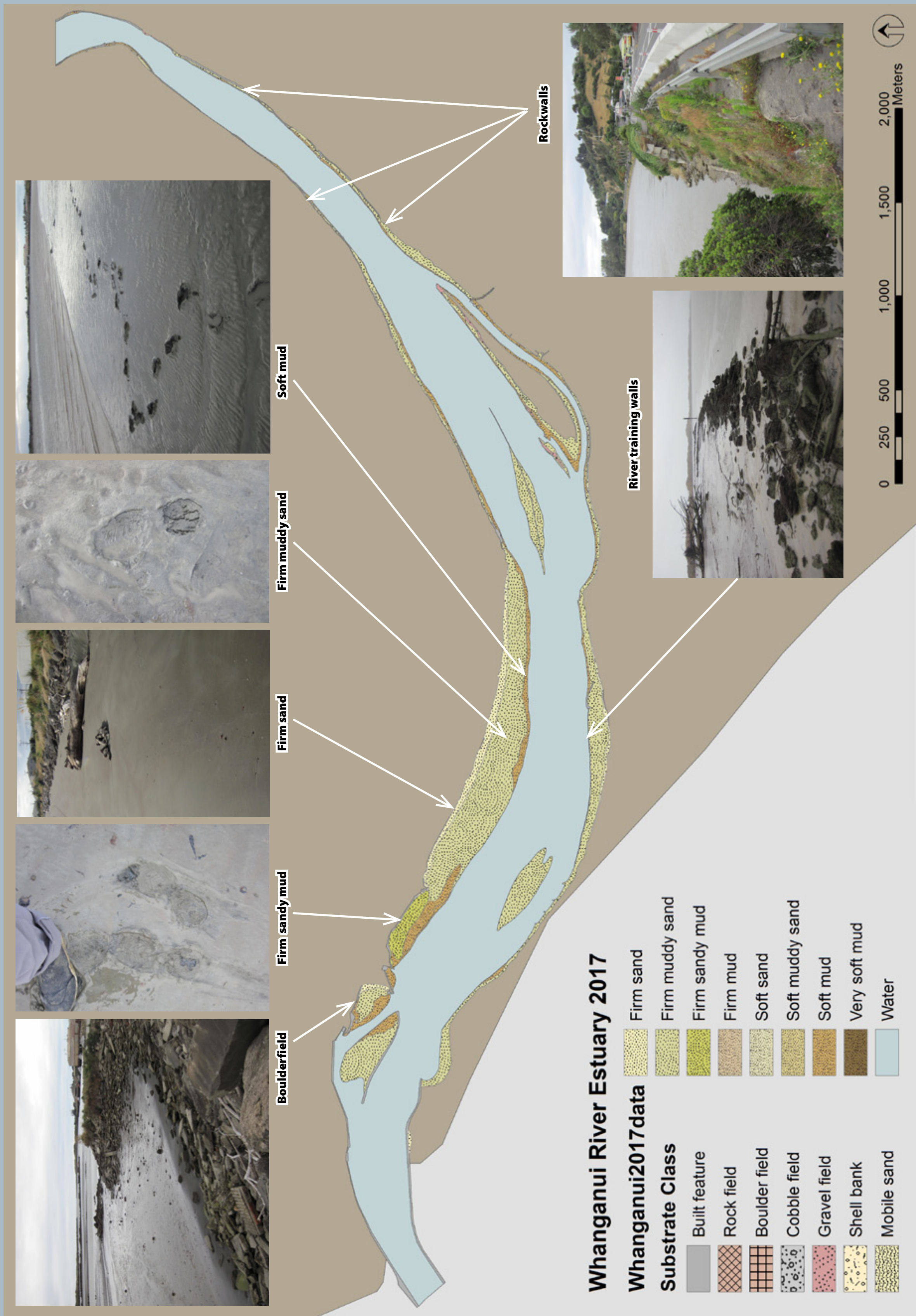


Figure 4. Map of dominant intertidal substrate types - Whanganui Estuary, 2017.

4.2. EXTENT OF SOFT MUD

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

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

i. **Horizontal extent** (area of soft mud) - broad scale indicator (see rating in Table 2).

ii. **Vertical buildup** (sedimentation rate) - fine scale assessment using sediment plates (or retrospectively through historical coring). Ratings are currently under development as part of national ANZECC guidelines.

iii. **Sediment mud content** (fine scale indicator) - recommended guideline is no increase from established baseline.

The area (horizontal extent) of intertidal soft mud is the primary sediment indicator used in the current broad scale report, with sediment mud content a supporting indicator. Figure 5 and Table 4 shows that soft or very soft muds covered 16.2ha (17%) of the intertidal area, a risk indicator rating at the lower end of the HIGH category, and had a mud content measured in representative areas of 25-67%, a supporting risk indicator rating of HIGH (Table 5). Within the dominant firm muddy sand substrate of the estuary, grain size reflected a LOW-MODERATE risk rating (7-11% mud content).

The soft mud extent recorded in 2017 (16.2ha, 17%) was less than that recorded previously by Stevens and Robertson (2009) (23.6ha, 28%). While this may be an improvement (reduction) in muddiness, it is more likely that it reflects the variable deposition and erosion of soft muds on the lower estuary flats which appear to change frequently and rapidly following flood events. Ongoing monitoring will help determine if this is an ongoing trend.

The overall risk of detrimental impacts to estuarine biota from muds was assessed as HIGH based on the relatively high area of mud-dominated substrate relative to the overall unvegetated intertidal estuary habitat (17%), the elevated mud content (>25-67%) measured in sediments in these areas, and low water clarity and a widespread presence of muds near subtidal margins indicating subtidal areas are likely to be regularly impacted by catchment derived muds.

4.3. SEDIMENT OXYGENATION

The primary indicators used to assess sediment oxygenation are aRPD depth and RP measured at 3cm. aRPD was assessed at representative sites throughout the dominant sand and mud substrate types and from these results broad boundaries have been drawn where sediment oxygen is depleted to the extent that adverse impacts to macrofauna (sediment and surface dwelling animals) are expected, i.e. aRPD <0.5cm deep (Figure 6). Because macrofauna are used as an indicator of ecological impacts to other taxa, it is expected that these zones will also be exerting adverse impacts on associated higher trophic communities including birds and fish. These results show that the majority of the estuary sediments are well to moderately well oxygenated and appeared in good (healthy) ecological condition, with the aRPD depth at 2-5cm (i.e. RP above -150mV at 3cm) in most sand and gravel dominated sediments. Intertidal soft mud areas (16ha, 17%) were identified as having depleted sediment oxygen, a NZ ETI risk rating of HIGH. Sediment oxygenation in 2009 was rated MODERATE and indicates a decline in condition from 2009 to 2017.

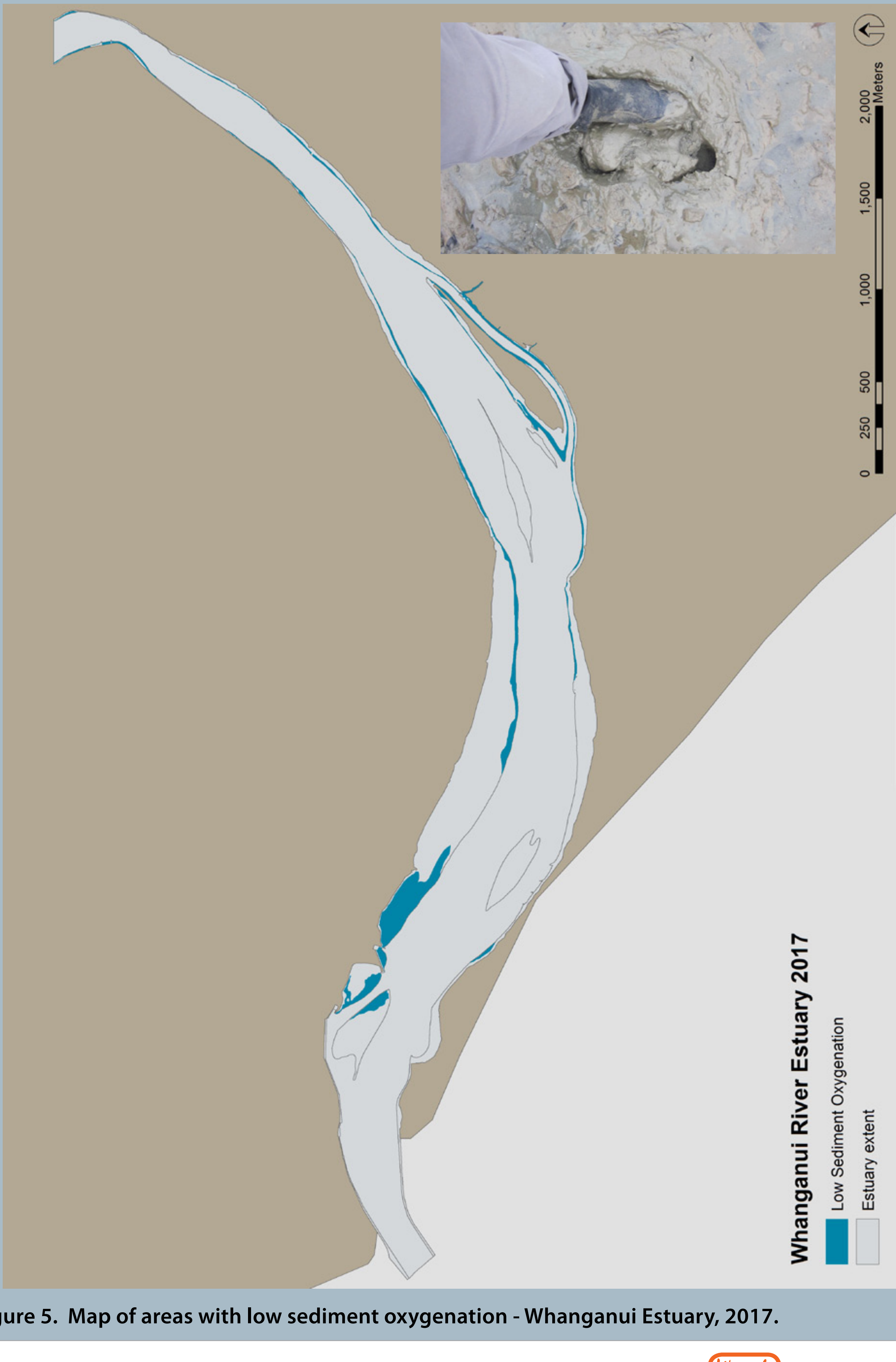


Figure 5. Map of areas with low sediment oxygenation - Whanganui Estuary, 2017.

4. RESULTS AND DISCUSSION (CONTINUED)

4.4. OPPORTUNISTIC MACROALGAE

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

If the estuary supports <5% opportunistic macroalgal cover within the Available Intertidal Habitat (AIH), overall quality status is reported as HIGH with no further sampling required. If there is >5% cover, opportunistic macroalgal growth is assessed by mapping the spatial spread and density in the AIH, and calculating an OMBT "Ecological Quality Rating" (EQR) (WFD UKTAG, 2014).

Intertidal macroalgal cover was very low in January 2017, with only small areas of the green alga *Ulva lactuca* (sea lettuce) present on rock walls near the estuary entrance. The macroalgae quality status was therefore HIGH, and the risk rating LOW. This finding is consistent with previous sampling (Stevens and Robertson 2009) which also found very little macroalgae.

These results likely reflect the strong flushing of the estuary where the primary stressors (i.e. fine sediment and nutrients, see Robertson and Stevens 2016) largely pass directly through the estuary to the open sea, low salinity water throughout much of the upper estuary, and poor clarity and regular river freshes that limit the conditions under which intertidal nuisance macroalgal growth can establish. Because 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. However it was noted that during the 2017 broad scale assessment, green subtidal waters were evident and indicated elevated nutrient and chlorophyll *a* concentrations occur in the main estuary channel at times.

4.5. SALTMARSH

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

The primary measure to assess saltmarsh condition is the percent cover of the intertidal area. Table 6 and Figure 6 summarise the 2017 results and show saltmarsh was very sparse, present across 0.5ha (0.1%) of the intertidal estuary area, a risk indicator rating of HIGH. Saltmarsh comprised a relatively even mix of sedgeland (59%) and rushland (41%) located in relatively narrow strips along the estuary margins (Figure 6). Common within rushland (searush) areas (most located near Corliss Island) was a subdominant herbfield cover of primrose, with remuremu and glasswort. Tall fescue and a range of introduced weeds and grasses were common in the upper tidal range, particularly where margins have been modified. While frequent inundation with saltwater will limit the ingress of terrestrial weeds within saltmarsh, this natural control process is likely to be less effective in the upper tidal reaches where there is a strong freshwater (river dominated) influence (i.e. upper tidal areas will be inundated largely by freshwater that floats on top of denser seawater).

The very small extent of saltmarsh is primarily because almost all of the estuary margin has been hardened and steepened as a result of flood protection measures or reclamation. As a consequence intertidal areas in the upper estuary are now commonly completely inundated at high tide making them unsuitable saltmarsh habitat. Also, as was previously observed in 2009, the estuary periodically contains large quantities of driftwood and other flotsam that is frequently deposited in areas where saltmarsh would be expected to grow in the absence of such disturbance. These factors make it very difficult for saltmarsh to thrive.

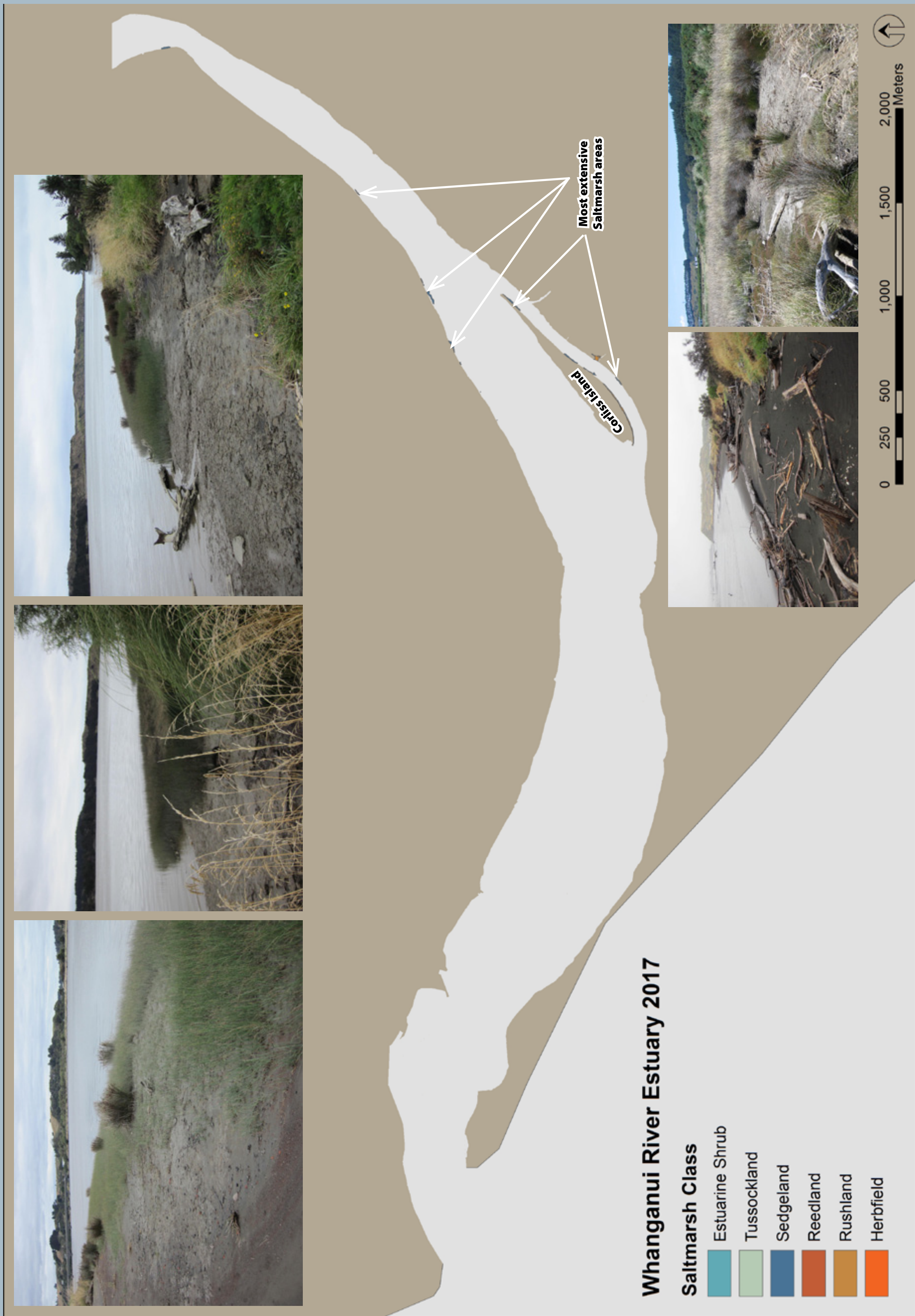


Figure 6. Map of dominant saltmarsh cover - Whanganui Estuary, 2017.

Table 6. Summary of dominant saltmarsh cover, Whanganui Estuary, 2017.

Class	Dominant Species	Primary subdominant species	2017	
Rushland			0.21	40.6
	Juncus kraussii (Searush)	*Samolus repens (Primrose)*	0.15	
		Sarcocornia quinqueflora (Glasswort)	0.06	
Sedgeland			0.30	59.4
	Schoenoplectus pungens (Three-square)	*Schoenoplectus pungens (Three-square)*	0.14	
		Juncus kraussii (Searush)	0.05	
Total (Ha)			**0.5**	**100**

Historic saltmarsh losses have been ascribed a 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 suggest that natural state saltmarsh cover has likely been reduced by >90%. In addition, since 2009 there has been a 0.4ha reduction in the mapped saltmarsh area. Because of the very small saltmarsh extent, this represents a 55% reduction in area. The losses appear to be directly related to on-going drainage and conversion of estuary margins to pasture, combined with the smothering of small patches of saltmarsh with mud and driftwood in the lower estuary. While there is limited scope for further loss of saltmarsh, its scarcity within the estuary places a high level of importance on the maintenance, protection and enhancement of remaining areas.

The combined saltmarsh ratings are ascribed an overall risk rating of HIGH, reflecting the small area of saltmarsh in the estuary, likely high historical saltmarsh losses, and a mapped reduction from the 2009 baseline extent.

A narrow strip of terrestrial plantings between the river floodbank and lower estuary intertidal flats. Extensive areas of saltmarsh would have historically been present across the (now reclaimed) estuary flood delta.

COASTAL DUNES: Although not tidally inundated and therefore not included with the previous discussion of saltmarsh, coastal dunes and dune vegetation is highly fragile and very important (e.g. Ogle et al 2004). Dunes establish when dry beach sand is blown inland and trapped by plants and other obstructions such as driftwood. As sand accumulates, the dunes become higher and wider, facilitating the development of more complex plant communities in areas protected from salt water inundation, sea spray and strong winds. Aside from ecological values, sand dunes also play an important part in protecting the coastline as they act as a buffer against wave damage during storms (they form a reservoir of sand, replenished when beach levels are high and released to nourish the foreshore during storm erosion). Given climate change will accelerate sea level rise, this function of dunes is expected to become even more important in the future. The key threats to dune condition are; sea level rise, grazing by stock, agricultural development, vehicle and pedestrian damage, weed invasion, displacement of native sand binding grasses by exotic species, and displacement by seawalls, roads and buildings.

To function effectively dunes, and dune vegetation particularly, need to be in good condition. The loss of even small patches of vegetation on the seaward slopes of dunes (the foredune, secondary dunes and backdunes), can allow strong onshore winds to initially produce small sand blowouts, which if unchecked develop into transverse mobile dunes that create an unstable dune system which migrates inland. Natural recovery from damage is slow because environmental conditions are unfavourable for plant growth. The introduced sand binder marram grass (which is prolific and has tended to out-compete the native sand-binders spinifex and/or pingao in many areas) can exacerbate dune instability from overstabilisation of the dune system. Marram grass dunes are generally taller, have a steeper front, and occupy more area than native dunes. Such dunes tend to lock up sand, limiting replenishment of sand to the beach and being susceptible to erosion of the dune front during storms. They also tend to contribute to the loss of biodiversity and natural character with blow-outs being common (Hilton 2006).

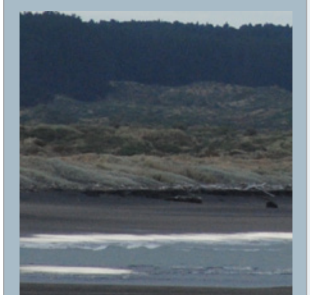
4.6. 200m TERRESTRIAL MARGIN


Grassland extending directly to the concrete rubble edge of the lower estuary.


Wooden seawall in the lower estuary.


Erosion and flood protection along the northern bank.


Public amenity area in the upper estuary.


Coastal duneland.

Like saltmarsh, a densely vegetated terrestrial margin filters and assimilates sediment and nutrients, acts as an important buffer that protects against introduced grasses and weeds, is an important habitat for a variety of species, provides shade to help moderate water temperature fluctuations (in shallow side arms), and improves estuary biodiversity. The results of the 200m terrestrial margin mapping of the estuary (Table 7 and Figure 7) showed:

- Dense buffering vegetation covered 21% of the 200m margin - comprising a mix of native and exotic scrub and forest (13%), duneland (5%) on the barrier spit, and rushland (3%).
- The remaining 200m wide terrestrial margin buffer comprised a mix of industrial developments (26%), grassland (25%), residential areas (21%), and commercial activities (6%).

The most ecologically significant areas of margin vegetation were the coastal dunes on both sides of the river mouth, supporting an almost exclusive coastal foredune cover of the native sand-binder spinifex (*Spinifex sericeus* - Silvery grass), a feature now lost from most NZ dune systems due to displacement by exotic grass species and invasive weeds. These dune systems play a vital role in coastal protection and provide important habitat for many rare native plants and animals (see text box on previous page for further details). There was no significant change in margin cover since 2009, although localised coastal erosion and accretion was evident on the barrier spit.

Figure 8 summarises land use within the large (7169km^2) estuary catchment and highlights the dominance of native forest (45%) and high producing grassland (30%), and smaller extents of mixed scrub and shrub (11%) and exotic forest (8%). Built-up areas (settlements) comprise 0.4% of the catchment.

The extent of densely vegetated 200m terrestrial margin habitat (21%) will provide some buffering against adverse ecological degradation (e.g. localised sediment and nutrient input mitigation). However, in the Whanganui Estuary, a risk indicator rating of HIGH has been applied for the following reasons:

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

Table 7. Summary of 200m terrestrial margin land cover, Whanganui Estuary, 2017.

Class	Dominant features	Percentage
Scrub/Forest	Large mainly exotic trees on the south (true left) side and Corliss Island.	2.6
Scrub	Mixed native and exotic species often amenity plantings in a relatively narrow strip on the north (true right) side of the estuary	9.7
Tussockland		0.7
Rushland	Upper reaches where tidal surge floods margins largely with freshwater	2.8
Grassland	Pasture and unmanaged grassland on the south side of the estuary	25.0
Introduced weeds	Middle estuary, south (true left) side.	0.3
Duneland	Barrier spit near the estuary entrance	4.9
Residential	Predominantly middle and upper estuary areas.	20.8
Commercial	Upper estuary, north (true right) side.	6.3
Industrial	Lower estuary, north (true right) side.	26.1
Unvegetated	Small areas of sand on the barrier spit near the entrance.	0.6
Total		**100**

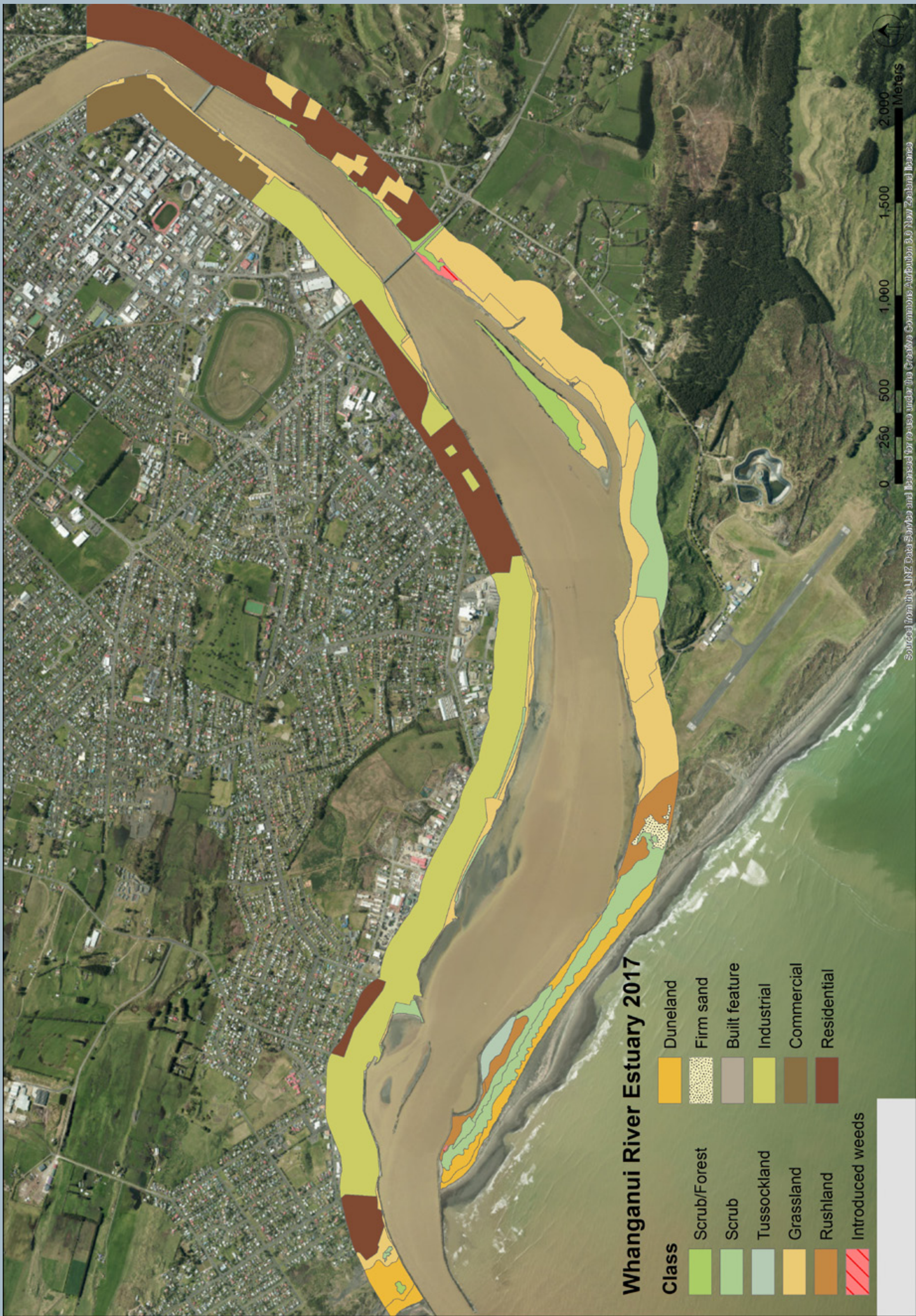
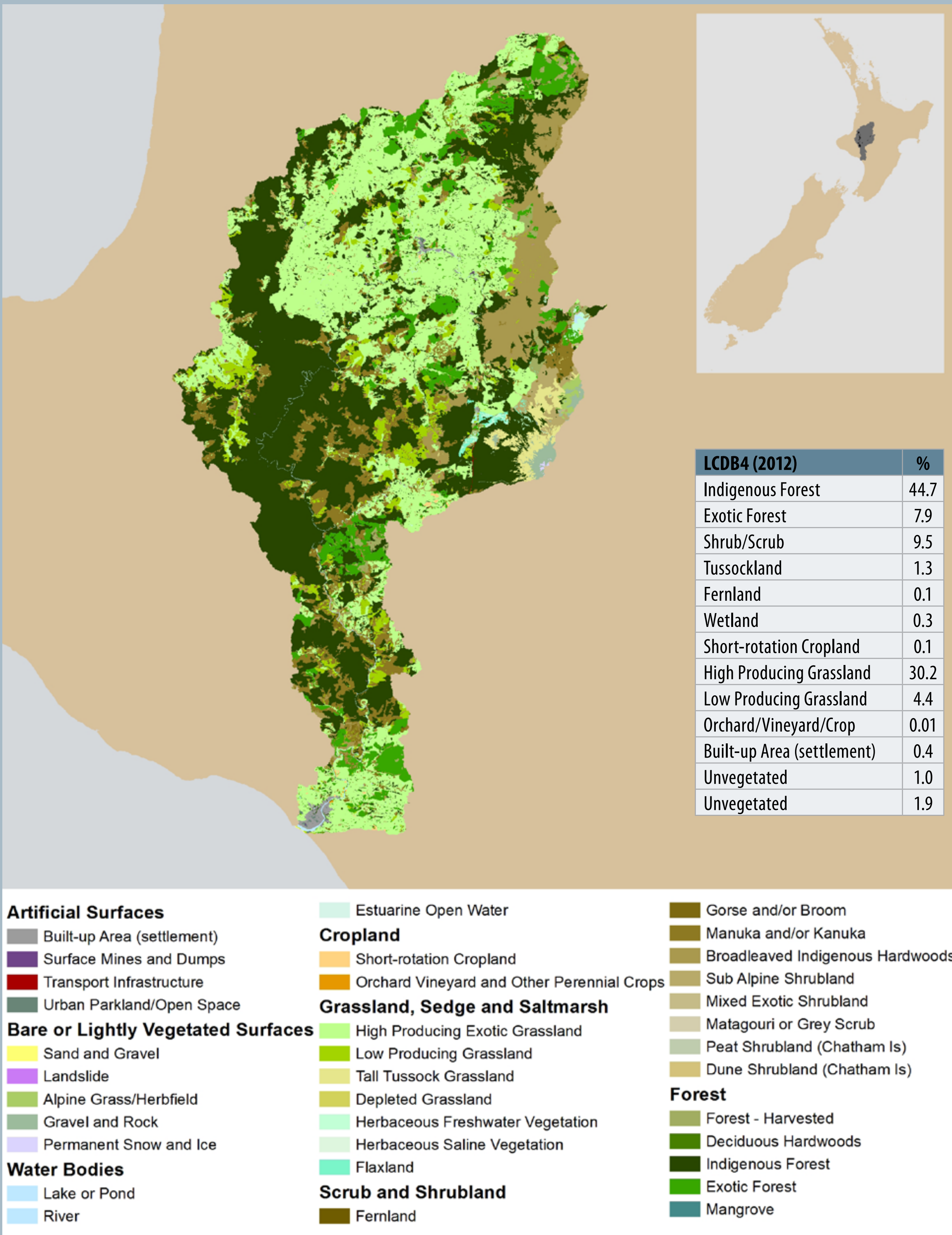


Figure 7. Map of 200m Terrestrial Margin - Dominant Land Cover, Whanganui Estuary, 2017.



LCDB4 (2012)	%
Indigenous Forest	44.7
Exotic Forest	7.9
Shrub/Scrub	9.5
Tussockland	1.3
Fernland	0.1
Wetland	0.3
Short-rotation Cropland	0.1
High Producing Grassland	30.2
Low Producing Grassland	4.4
Orchard/Vineyard/Crop	0.01
Built-up Area (settlement)	0.4
Unvegetated	1.0
Unvegetated	1.9

Figure 8. Summary of Catchment Land Cover (LCDB4 2012), Whanganui Estuary.

5. SUMMARY AND CONCLUSIONS

Broad scale habitat mapping undertaken in January 2017, combined with ecological risk indicator ratings in relation to the key estuary stressors (i.e. muddiness, eutrophication and habitat modification) have been used to assess overall estuary condition.

Muddiness

Soft or very soft muds covered 16.2ha (17%) of the intertidal area, a risk indicator rating of HIGH, and had a mud content measured in representative areas of 25-67%, a supporting risk indicator rating of HIGH. Soft mud areas also exhibited depleted sediment oxygenation to a level where adverse impacts to macrofauna (sediment and surface dwelling animals) are expected, an ETI risk indicator rating of HIGH. Soft muds were concentrated along upper estuary channel margins and lower tidal flats and reflect salinity driven flocculation combined with a hydrodynamic boundary where the settlement of fine sediments is promoted by changes in freshwater flow velocities, particularly where stream and river flows enter the wider lower estuary. Within the dominant firm sandy mud substrate of the estuary, habitat appeared to be healthy, with limited accumulation of muds and good sediment oxygenation.

Eutrophication

The NZ ETI combines a range of broad and fine scale indicators to provide an overall assessment of eutrophic expression in the estuary, including primary productivity through macroalgal growth and phytoplankton, and supporting indicators of sediment muddiness, oxygenation, organic content, nutrients, macroinvertebrates, and the presence of gross eutrophic zones (a combined presence of dense macroalgal growth, muds and poor sediment oxygenation). The overall ETI score for the estuary (based on available indicators) in January 2017 was 0.38, a risk rating of LOW for eutrophic symptoms.

Nutrient inputs to the estuary, while relatively high (N areal load 3144mg.m^2.d), are not resulting in nuisance macroalgal growths in deposition zones. This is most likely due to strong flushing of the estuary where the primary stressors (i.e. fine sediment, nutrients) largely pass directly through the estuary to the open sea, with poor clarity also restricting macroalgal growth.

Habitat modification

Almost no saltmarsh remains in the estuary 0.5ha (<1%) and remaining areas represent only a small fraction of the likely extensive historical cover. Saltmarsh comprised a relatively even mix of sedgeland (59%) and rushland (41%) located in relatively narrow strips along the estuary margins, with a range of introduced weeds and grasses common in the upper tidal range.

The 200m terrestrial margin had also been highly modified with 26% industrial developments, 25% pasture or unmaintained grassland (predominantly historically drained saltmarsh), 21% residential areas and 6% commercial activities. 21% supported a densely vegetated buffer, predominantly planted native and exotic trees with the most ecologically significant areas being the coastal dunes on both sides of the river mouth.

Changes from 2009 to 2017

A comparison with the 2009 mapping results show a potential improvement in the estuary through a decrease in the area of soft mud (16.2ha (17%) in 2017 compared to 23.6ha (28%) in 2009), but a decline in condition with a reduction saltmarsh (0.9ha to 0.5ha) and an increase in poorly oxygenated sediments. The saltmarsh losses appear to be directly related to ongoing drainage and conversion of estuary margins to pasture, displacement from ongoing flood protection works, combined with the smothering of small patches of saltmarsh with mud and driftwood in the lower estuary. There was no significant change in the 200m terrestrial margin cover since 2009, although localised coastal erosion and accretion was evident on the barrier spit. Future monitoring will determine if these results reflect ongoing trends in broad scale features of the estuary.

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

6. MONITORING RECOMMENDATIONS

Whanganui 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-moderate susceptibility to eutrophication and a moderate susceptibility to excessive fine sediment inputs reflecting current inputs and its highly flushed nature.

In order to assess ongoing long-term trends in the condition of such estuaries, it is common practice amongst NZ Regional Councils to establish a strong baseline against which future trends can be compared. This typically comprises comprehensive broad scale habitat mapping on a 5-10 yearly cycle, targeted annual monitoring where specific issues are identified (e.g. opportunistic nuisance macroalgal growth), and fine scale monitoring comprising 3-4 consecutive years of baseline monitoring, followed by 5 yearly impact monitoring.

Based on the 2017 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, focussing on the main issue of changes to sediment and saltmarsh. 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).

View of the middle estuary looking upstream past Corliss Island (right side of picture) toward Whanganui, January 2017.

7. MANAGEMENT RECOMMENDATIONS

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:

- Determine the relative input of sediment and nutrients from dominant catchment land uses and apply relevant sediment and nutrient guideline criteria for the estuary (e.g. under development ANZECC guidelines or the NZ ETI) to determine the magnitude of any changes required to maintain healthy estuary functioning. This can be readily undertaken in the first instance using existing catchment models such as CLUES, and extensions incorporating refined sediment or nutrient yields for specific land use activities e.g. Green et al. (2014).
- Through stakeholder involvement, identify an appropriate "target" estuary condition and determine any catchment management changes needed to achieve the target.
- Using the results of the above investigations, and other appropriate monitoring data, identify sediment input load guideline criteria that will reduce fine sediment infilling to the target state, and develop a plan to achieve such targets. For example, ensuring Good Management Practices (GMPs) are being implemented within the catchment. This step may require additional detailed investigation of fine sediment sources, transport, deposition and export 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

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APPENDIX 1. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Shell bank: Area that is dominated by dead shells.

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

APPENDIX 2. NOTES ON SAMPLING, RESOLUTION AND ACCURACY

Sediment sampling and analysis

Grain size samples were collected from representative mud and sand habitats (to validate substrate classifications) by sampling a composite of the top 20mm of sediment (approx. 250gms in total) using a plastic trowel. Samples were placed inside a numbered plastic bag, refrigerated within 4 hours of sample collection before being frozen and sent to R.J. Hill Laboratories for grain size analysis (% mud, sand, gravel). Details of lab methods and detection limits are presented below. Samples were tracked using standard Chain of Custody forms and results were checked and transferred electronically to avoid transcription errors.

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

Sampling resolution and accuracy

Estimates of error for different measurements have been made based on the field data collected to date. Initial broad scale mapping is intended to provide a rapid overview of estuary condition based on the mapping of features visible on aerial photographs, supported by ground-truthing to validate the visible features. The accuracy of mapping is therefore primarily determined by the resolution of the available photos, and secondarily by the extent of groundtruthing. In most instances features with readily defined edges such as saltmarsh beds, rockfields etc. can be accurately mapped to within 1-2m of their boundaries. The largest area for potential error is where boundaries are not readily visible on photographs e.g. where firm muddy sands transition to soft muds. These boundaries require field validation. Extensive mapping experience has shown that it is possible to define such boundaries to within ±10m where they have been thoroughly ground-truthed using NEMP classifications. Because broad scale mapping necessitates the grouping of variable and non-uniform patches (which introduces a certain amount of variation) overall broad scale accuracy is unlikely to exceed ±10% for boundaries not readily visible on photographs.

Where initial broad scale mapping results indicate a need for greater resolution of boundaries (e.g. to increase certainty about the extent of soft mud areas), or to define changes within NEMP categories (e.g. to define the mud content within firm muddy sand habitat), then issue-specific approaches are recommended. The former includes more widespread ground-truthing, and the latter uses transect or grid based grain size sampling.

For specific broad scale seagrass and macroalgae features that are spatially and temporally variable, the overall spatial extent, and boundaries between different percentage cover and density areas, are considered accurate to within ±10m where they have been thoroughly ground-truthed using NEMP classifications. Accuracy declines when assessed remotely e.g. from aerial photographs, and particularly so when assessing lower density (<50%) cover which is commonly not visible on aerial coverages. As previously, the most accurate measures are obtained with increasing field time (and cost).

Within mapped boundaries, broad scale estimates of percentage cover and density, due to the grouping of variable and non-uniform patches, are considered accurate to ±10%. These however can be assessed to a much higher degree of accuracy using fine scale quadrat based approaches such as the OMBT which can also be increased by applying fine scale approaches estuary-wide if a very high degree of accuracy is considered important.

For the OMBT, a methodology for calculating a measure of the confidence of class (CofC), has been developed (Davey, 2009) that defines the specific accuracy of the measures undertaken. Called CAPTAIN ('Confidence And Precision Tool Aids aNalysis') it calculates CofC at three levels: i. metric, ii. survey (single sampling event), and iii. water body over the reporting period (potentially several surveys).

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