Wriggle coastalmanagement

Whanganui Inlet 2016

Broad Scale Habitat Mapping

Prepared for

Tasman District Council

June 2017

Cover Photo: Whanganui inlet - central basin and entrance, 2016.

Southern arm looking towards central basin.

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Prepared for
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by

Leigh Stevens and Barry Robertson

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

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WHANGANUI INLET - EXECUTIVE SUMMARY

Whanganui Inlet is a relatively unmodified, large-sized (2741ha), macrotidal (3.1m spring tidal range), shallow (mean depth ~1-2m at high water), well-flushed (residence time <1 day), seawater-dominated, tidal lagoon type estuary. It has a single wide tidal opening (1.5km), a large well flushed central basin, several islands, and two main arms (5km and 7km long, 1-2km wide), each with many small arms where streams enter the estuary, and which are often flow constricted by road causeways. The catchment is 91% native forest, and the estuary is perceived to be near pristine.

The estuary is part of Tasman District Council's (TDC's) coastal State of the Environment (SOE) monitoring programme. Fine scale monitoring of the dominant habitat in the estuary was undertaken in December 2015 and 2016. The current report summarises the results of 2016 broad scale habitat mapping of the estuary using 2012/13 aerial photos, and additional seagrass mapping using aerial photos flown in early 2016. The following sections summarise broad scale monitoring results, risk indicator ratings, overall estuary condition, and monitoring and management recommendations.

BROAD SCALE RESULTS

- Intertidal flats (71% of the estuary area) were dominated by mud (54%, 1061ha), sand (43%, 853ha) and cobble/gravel/rock (3%, 41ha).
- Sediment oxygenation was generally good in sands (aRPD >1cm), poor in muds (aRPD <1cm), and highly variable within seagrass beds.
- Soft mud covered 33% of the estuary with very soft mud covering 19%. Mud was concentrated mostly in the upper intertidal flats of each arm, and was common among seagrass beds.
- In 1990 seagrass covered 863ha (44% of the intertidal area), in 2012/13, 779ha (40% of the intertidal area) and in 2016, 376ha (19% of the intertidal area). The very rapid and extensive loss of 403ha of seagrass from 2012/13 to 2015/16 (a 52% decrease) is highly significant. Soft mud appears the major cause of seagrass decline, but there is no obvious recent source of increased mud inputs from the estuary catchment and there is a possibility the decline is natural.
- Opportunistic macroalgal growth (primarily *Ulva lactuca* and *Gracilaria chilensis*) was sparse (~4% of the available intertidal habitat) and no significant gross eutrophic zones were present.
- Saltmarsh covered 4% of the estuary (113ha) of which 72% was dominated by rushland, 26% by estuarine shrubs and 1% by herbfield. The extent of saltmarsh was naturally limited by steep landforms surrounding much of the estuary. Saltmarsh extent prior to 1990 has not been mapped but was estimated to fall within the condition rating band of 40-60% of natural extent, losses occurring primarily as a result of drainage and reclamation of estuary margins developed for pasture.
- Within the 200m margin, the densely vegetated cover (i.e. forest, scrub, tussock, and duneland) of the estuary was high (85%).

RISK INDICATOR RATINGS (indicate risk of adverse ecological impacts)

Major Issue	Indicator	2016 risk rating	Change since 1990 baseline
Sediment	Soft mud (% cover)	HIGH	Large increase
Eutrophication	Macroalgal Growth (EQR)	LOW	No significant change
	Gross Eutrophic Conditions (ha)	VERY LOW	No significant change
Habitat Modification	Seagrass (% change from 1990 baseline)	HIGH	Large decrease
	Saltmarsh (% of intertidal area)	LOW	Small decrease
	200m Vegetated Terrestrial Margin	VERY LOW	No significant change

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 overall there is currently a "HIGH" risk of adverse impacts to the estuary ecology occurring because of the large extent of soft mud (54% of the estuary), combined with the recent rapid and extensive decline in seagrass cover. Eutrophication, expressed through indicators of macroalgal growth and the presence of gross eutrophic conditions, and habitat modification, primarily localised historical saltmarsh drainage and reclamation and construction of road causeways, were not considered to be significant ongoing estuary stressors.

Within Whanganui Inlet, the key consequence of increased muddiness (most commonly caused by land disturbance) is predicted to be seagrass loss due to both smothering and reduced water clarity and habitat modification through sandy sediments becoming muddier. Such changes will reduce the ecological value of these important habitats, degrading macroinvertebrate communities and reducing supporting habitat to birds, fish (whitebait) and shellfish.

RECOMMENDED MONITORING AND MANAGEMENT

The following monitoring recommendations are proposed by Wriggle for consideration by TDC:

Repeat broad scale habitat mapping 5-10 yearly (next due in 2021), unless obvious changes are observed in the interim, focusing on the main issue of fine sediment. Map saltmarsh and seagrass cover based on 1948 aerial photos and estimate likely natural state saltmarsh extent based on landforms and historical records of the estuary.

Complete a three year annual baseline of fine scale monitoring, followed by repeat sampling at five yearly intervals.

Measure sediment plates established at the three fine scale monitoring sites annually for sediment deposition rate and grain size to track changes in fine sediment.

Intensive investigations recommended to defensibly address issues of increasing muddiness and seagrass loss are:

- Identify the potential source, magnitude and timing of fine sediment (mud) inputs impacting seagrass beds and intertidal flats, i.e. recent or historical inputs, and origin of the dominant source mud inputs in terms of landuse (e.g. sheep/beef, native forest landuse) and catchments.
- If recent increases in muddiness are not explained by predicted catchment inputs, assess whether fine sediment inputs from outside the local catchment (i.e. coastal inputs from west coast sources, erosion of estuary margins) require assessment.
- Determine the magnitude of any changes required to maintain health estuary functioning by comparing current catchment loads with what could be achieved under best landuse soil conservation practices.

1. INTRODUCTION

Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. These objectives, along with understanding change in condition/trends, are key objectives of Tasman District Council's State of the Environment Estuary monitoring programme. Recently, Tasman District Council (TDC) undertook a vulnerability assessment of the region's coastlines to establish priorities for a long-term monitoring programme (Robertson and Stevens 2012). The assessment identified the Waimea, Moutere, Motueka Delta, Motupipi, Ruataniwha and Whanganui estuaries as priorities for monitoring.

For Whanganui Estuary, the monitoring and management process consists of three components developed from the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002) as follows:

1. **Ecological Vulnerability Assessment** (EVA) of the estuary to major issues (see Table 1) and appropriate monitoring design. A region-wide EVA has been undertaken (Robertson and Stevens 2012) providing specific recommendations for Whanganui Inlet.
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. A comprehensive assessment of Whanganui Inlet was undertaken by the Department of Conservation (Davidson 1990) which includes many outputs consistent with the NEMP approach. Broad scale assessments undertaken in early 2016 are the focus of the current report.
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 Whanganui Inlet, was undertaken in parallel with the broad scale mapping in December 2015 and is reported on in Robertson and Stevens (2016).

In 2015, TDC commissioned Wriggle Coastal Management to undertake broad and fine scale monitoring of Whanganui Inlet. The current report describes the following broad scale assessments:

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

Whanganui Inlet is a large (2741ha), relatively unmodified, shallow, well-flushed, seawater-dominated, tidal lagoon type estuary that is open to the sea via a narrow entrance mouth. The inlet is the third largest estuary of its type in the South Island and is located 19km southwest of Farewell Spit on the top of west coast of NZ's South Island (Figure 1). It is fed by 4 main streams on the south and east sides, (Mangarakau Drain (mean flow $0.66m^3.s^{-1}$), Mangarakau Stream ($0.48m^3.s^{-1}$), Wairoa River ($0.16m^3.s^{-1}$), and Muddy Creek ($0.59m^3.s^{-1}$) - flow data from NIWA Coastal Explorer) and a large number of smaller streams. A number of other water bodies (e.g. the Kaihoka Lakes and Lake Otuhie) in the immediate vicinity increase the value of the estuary/freshwater complex for wildlife. Much of the estuary catchment is forest (primarily native 91%), with intensive pastoral use at 6%. The road along the southern and eastern estuary margins has resulted in numerous causeways restricting tidal flushing to many of the upper estuary arms.

Previous broad scale mapping (Davidson 1990) identified the dominant intertidal estuary habitat as seagrass (859ha) growing predominantly in soft muds, sandflats (826ha), mudflats (146ha), saltmarsh (96ha), and cobble, gravel and rock fields (27ha). The subtidal zone comprised 769ha (28%) of the estuary area. There has been some historical loss of high value saltmarsh habitat due to reclamation and drainage around margin areas (~60ha), with resulting shoreline modification (e.g. seawalls, bunds, roads) now restricting the capacity of saltmarsh to migrate inland in response to predicted sea level rise.

The estuary is valued for its aesthetic appeal, rich biodiversity, duck shooting, whitebaiting, fishing, boating, walking, and scientific appeal. It is a dual protected area with a marine reserve in the southern third and a wildlife reserve over the remaining two-thirds, and a RAMSAR application is pending on Westhaven Inlet Mangarakau Swamp and Lake Otuihe. Ecologically, habitat diversity and condition is high. It has almost all of its intertidal vegetation intact, including saltmarsh (113ha) and large areas of seagrass (778ha in 2013), as well as dunes, cliffs, islands, rock platforms, underwater reefs, and a well-vegetated terrestrial margin dominated by coastal forest (including kahikatea, pukatea, rata, beech, rimu and nikau palm). Approximately 30 species of marine fish use the inlet at some stage of their life history. It is an important breeding and nursery area for snapper, flatfish, kahawai and whitebait. It is also important for birdlife (particularly waders), and is connected to large areas of relatively unmodified wetland, freshwater streams and terrestrial vegetation.

Whanganui Inlet has largely avoided major human impacts and consequently has few threats. The potential stressors identified are:

- Potential for excessive muddiness if runoff from intensive landuse or forest clearance is poorly managed. Climate change (increased storms) is expected to exacerbate these issues.
- Loss of high value saltmarsh habitat caused by impending sea level rise if inland migration of beds is not facilitated.
- Changes in biological communities as a result of climate changes to sea pH and temperature (e.g. loss of larger shelled invertebrates).
- Other lesser stressors include; a partially modified terrestrial margin, presence of causeways, increased population pressure and margin encroachment (wildlife disturbance, predator introductions, habitat loss), and invasive species (e.g. Pacific oyster, iceplant).

It is recommended that Whanganui Inlet be monitored every 5-10 years and the results used to help determine the extent to which the estuary is affected by major estuary issues (Table 1), both in the short and long term.

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

1. Sediment Changes

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

- habitat loss such as the infilling of saltmarsh and tidal flats,
- prevention of sunlight from reaching aquatic vegetation such as seagrass meadows,
- increased toxicity and eutrophication by binding toxic contaminants (e.g. heavy metals and hydrocarbons) and nutrients,
- 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 storm-water 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 shell-fish 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 pollut-ants, and the ability of shorelines to resist storm-related erosion. Within New Zealand, habitat degradation or loss is common-place with the major causes being sea level rise, population pressures on margins, dredging, drainage, reclamation, pest and weed invasion, reduced flows (damming and irrigation), over-fishing, polluted runoff, and wastewater discharges (IPCC 2007 and 2013, Kennish 2002).

Recommended Key Indicators:

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

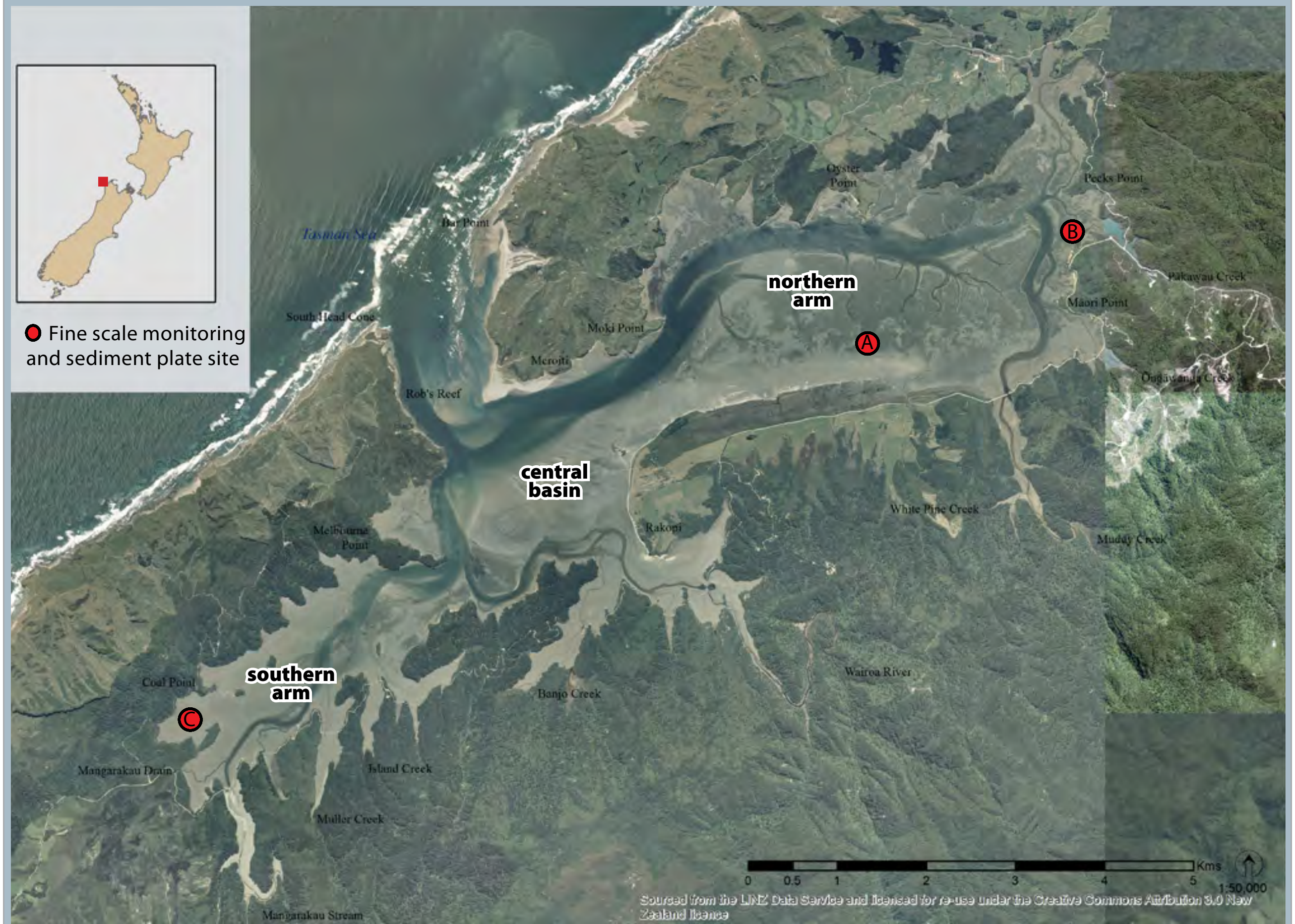


Figure 1. Whanganui Inlet, northwest Nelson.

OVERVIEW OF TYPICAL STATES OF ESTUARY CONDITION

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

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

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

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

An overall vulnerability assessment to key stressors placed Whanganui Inlet at low risk with the estuary currently in a MODERATE condition, driven by elevated muddiness, localised historical habitat loss, but low risks from eutrophication, pathogens, and toxicants.

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 Inlet broad scale monitoring programme are summarised in Table 2, along with supporting notes explaining the use and justifications for each indicator. Detailed background notes for several indicators are presented in the NZ ETI (Robertson et al. 2016b).

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)				
a. BROAD 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%
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%
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 - 1990 in this report)	<5% decrease	5%-10% decrease	>10-20% decrease	>20% decrease
Saltmarsh Extent (% of intertidal area)	>20%	>10-20%	>5-10%	0-5%
Supporting indicator — **Extent** (% remaining from estimated natural state)	>80-100%	>60-80%	>40-60%	<40%
Densely Vegetated 200m Terrestrial Margin	>80-100%	>50-80%	>25-50%	0-25%
Percent Change from Monitored Baseline	<5%	5-10%	>10-20%	>20%

* NZ ETI (Robertson et al. 2016b)

See NOTES on following page for further information

2. Estuary Risk Indicator Ratings (continued)

NOTES to Table 2: See Appendix 2, and 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 Rate. Elevated sedimentation rates are likely to lead to major and detrimental ecological changes within estuary areas that could be very difficult to reverse, and indicate where changes in land use management may be needed. Note the very low risk category is based on a typical NZ pre-European average rate of <1mm/year, which may underestimate sedimentation rates in soft rock catchments.

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

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

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

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

Gross Eutrophic Conditions. Gross eutrophic conditions occur when sediments exhibit combined symptoms of: a high mud content, a shallow Redox Potential Discontinuity (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 (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.

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 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:

- Obtain aerial photos of the estuary for recording dominant habitat features.
- Carry out field identification and mapping (i.e. ground-truthing) using laminated aerial photos.
- Digitise ground-truthed features evident on aerial photographs into GIS layers (e.g. ArcMap) (photos: 1988, 2012/13, 2015/16)

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

For the current study, rectified ~1.0m/pixel resolution colour aerial photos flown by LINZ in 2012/13 were laminated (scale of 1:3,000) and used by experienced scientists who walked the area in early 2016 (2 x 5 days) to ground-truth the spatial extent of dominant vegetation and substrate types (Figure 3). Grain size samples were collected and analysed from 21 representative sand and mud habitats to validate substrate classifications. The boundaries of substrate, saltmarsh, seagrass and terrestrial margin cover were digitised on the extents visible in the 2013 photos. Substrate types and macroalgal cover represent the features present on the ground in 2016. Seagrass maps produced by Davidson et al. (1990) were digitised and compared with 2013 cover. In late 2016, TDC provided aerial photos from 2015/16 to enable 2016 seagrass cover to be mapped.

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*), seagrass, saltmarsh vegetation, and the 200m wide terrestrial margin vegetation/landuse. These broad scale results are summarised in Section 4, with the supporting GIS files (supplied as a separate electronic output) providing a much more detailed data set designed for easy interrogation to address specific monitoring and management questions.

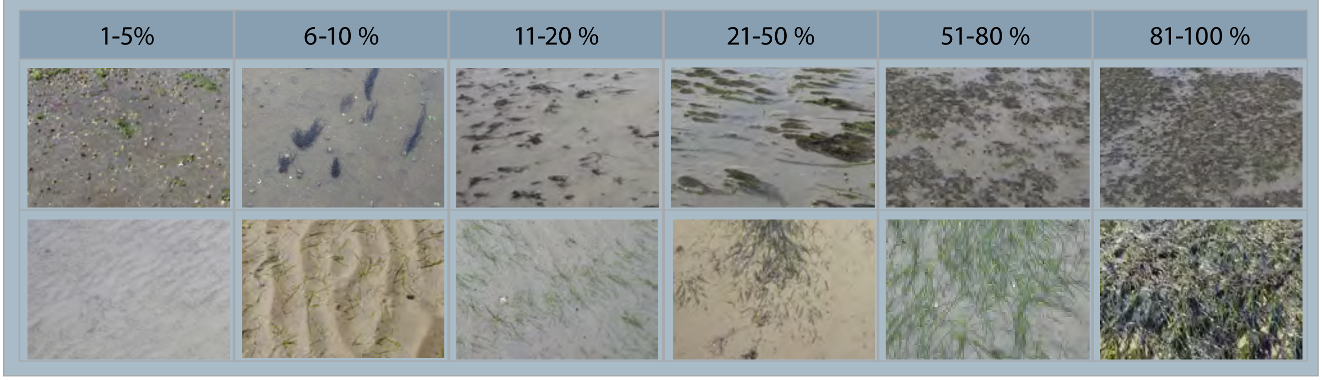
Macroalgae were further assessed by identifying and enumerating patches of comparable growth as follows:

- % 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 (Appendix 2). This integrated index provides a comprehensive measure of the combined influence of macroalgal growth and distribution in the estuary.

The georeferenced spatial habitat maps provide a robust baseline of key indicators. Wherever possible, 2016 results have been compared to the previous 1990 broad scale survey, noting in some instances since then, improvements have been made in the classification and mapping of key parameters like seagrass and macroalgae.

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



3. Methods (continued)

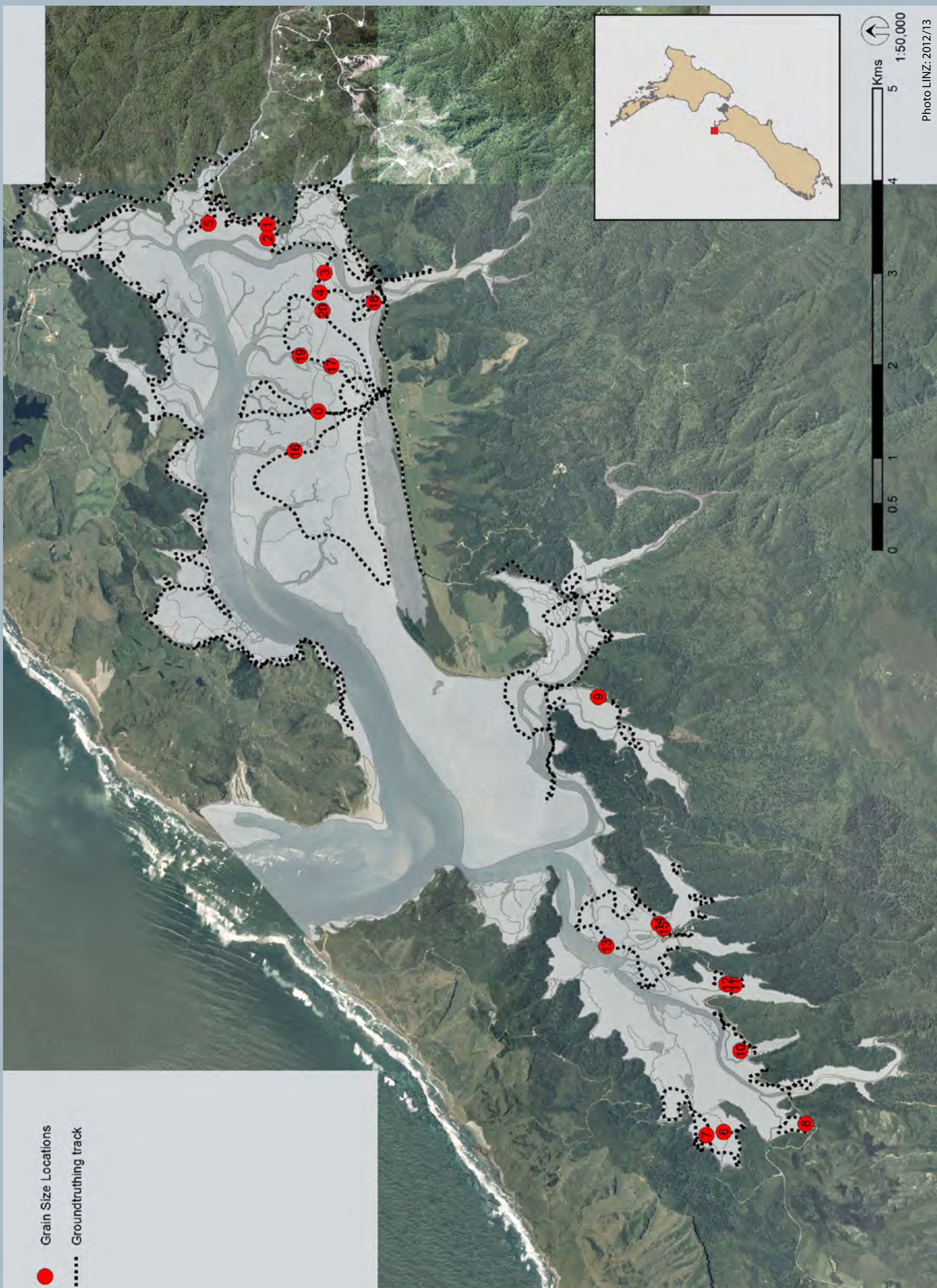
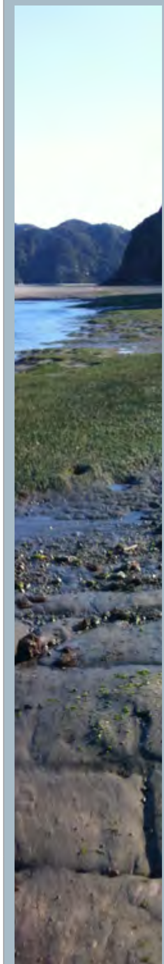


Figure 3. Mapped estuary extent and location of grain size samples used to validate substrate types.

4. RESULTS AND DISCUSSION

BROAD SCALE MAPPING



The 2016 broad scale habitat mapping ground-truthed and mapped all intertidal substrate and vegetation including the dominant land cover of the terrestrial margin, with the six dominant estuary features summarised in Table 3. As expected for a large tidally-dominated drowned river valley, the estuary was dominated by extensive intertidal flats (71% of estuary) and subtidal water within low tide channels (25%). Saltmarsh (4%) was relatively limited because of the presence of steep hillsides around the upper margins of much of the estuary, while extensive seagrass beds were present in the estuary (376ha, 14%), particularly in the northern arm. Dense (>50%) opportunistic macroalgae cover was relatively sparse (23ha, 1%). The extent of the 200m wide terrestrial margin dominated by a densely vegetated buffer (primarily native forest and scrub) was high (85%) with pasture (15%) the other dominant feature.

- In the following sections, various factors related to each of these habitats (e.g. area of soft mud) are used to apply risk ratings to assess key estuary issues of sedimentation, eutrophication, and habitat modification. Trends in broad scale features have been assessed based on the most relevant of either estimates of natural state cover or previous broad scale mapping results.
- 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 Whanganui Inlet, 2016.

Dominant Estuary Feature		Ha	% of Estuary
1.	Intertidal flats (excluding saltmarsh)	1954	71%
2.	Opportunistic macroalgal beds (>50% cover) [included in 1. above]	23	1%
3.	Seagrass (>20% cover) [included in 1. above]	376	14%
4.	Saltmarsh	113	4%
5.	Subtidal waters	674	25%
Total Estuary		**2741**	**100%**
6.	Terrestrial Margin - % of 200m wide estuary buffer densely vegetated (e.g. scrub, shrub, forest)		85%

4.1 INTERTIDAL FLATS (INCLUDING SALTMARSH)

Results (summarised in Table 4 and Figure 4) show the dominant intertidal substrates were muds (54%) and sands (43%). The majority of the mud dominated substrates were located in the upper estuary (Figure 4) where salinity driven flocculation is most pronounced and tidal and wave energy is lowest. Sediment oxygenation in mud was generally <1cm. Sands were most widespread near the well flushed central basin and entrance, and generally well oxygenated (aRPD >1cm).

Table 4. Summary of dominant intertidal substrate, Whanganui Inlet, 2016.

Dominant Substrate	Area Ha	Percentage	Comments
Boulder field man-made	1.8	0.1	Rockwalls flanking causeways, and adjacent to the wharf.
Rock field	13.0	0.7	Relatively flat platforms where landforms have been previously eroded by the sea.
Boulder field	3.9	0.2	Commonly near cliff faces and associated with cobble fields
Cobble field	10.0	0.5	Commonly near cliff faces and associated with boulder fields
Gravel field	12.7	0.7	Many small areas, particularly around causeway mouths where flushing is concentrated.
Shell bank	4.4	0.2	Near channel margins in the well flushed central basin.
Cocklebed	0.7	0.0	Near channel margins in the well flushed central basin.
Mobile sand	449.8	23.0	Primarily near the entrance and central estuary basin.
Mobile mud/sand	65.1	3.3	Primarily near the transition between the central basin and the upper southern arm
Firm sand	68.1	3.5	Near the estuary entrance and on wave flushed beaches near high tide.
Firm muddy sand	264.5	13.5	Primarily in the lower part of the northern arm.
Firm mud	45.3	2.3	Primarily in perched upper tidal zone areas in the upper southern arm that dry out.
Soft mud	643.2	32.9	Extensive reaches of settling basin areas in the upper northern and southern arms.
Very soft mud	371.9	19.0	Extensive areas throughout much of the northern arm and in causeway restricted upper arms.
TOTAL	**1954.4**	**100%**	

4. Results and Discussion (continued)

Figure 4. Map of dominant habitat types - Whanganui Inlet, 2016.

Soft Mud Habitat

The extent of intertidal soft mud habitat (outside of saltmarsh areas) is a primary indicator of fine sediment (or increased muddiness) impacts. This reflects that, where soil erosion from catchment development exceeds the assimilative capacity of an estuary, detrimental impacts can result (e.g. increased muddiness and turbidity, shallowing, increased nutrients, changes in saltmarsh and seagrass habitats, reduced sediment oxygenation, increased organic matter degradation by anoxic processes, alterations to fish and invertebrate communities, and the establishment of invasive species). 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 (Mannino and Montagna 1997; Rakocinski et al. 1997; Peeters et al. 2000; Norkko et al. 2002; Ellis et al. 2002; Thrush et al. 2003; Lohrer et al. 2004; Sakamaki and Nishimura 2009; Jones et al. 2011; Wehkamp and Fischer 2012; Robertson 2013). Generally, increased muddiness results in a community dominated by species that are tolerant of muddy conditions, with valued species like cockles and pipi being displaced. Such ecological changes are expected to have a direct and cascading effect on a range of organisms including fish, birdlife and other primary producers and on human use, as a result of changes to physicochemical conditions (e.g. increased mud content, reduced sediment oxygenation, and lower water clarity). Excessive muddiness is also recognised as an important stressor of seagrass beds (Brown et al. 2009).

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

i. **Horizontal extent** (area of soft mud) - broad scale indicator (see rating in Table 2).
ii. **Sediment mud content** - fine scale indicator - recommended guideline is no increase from established baseline.
iii. **Vertical buildup** (sedimentation rate) - fine scale assessment using sediment plates (or retrospectively through historical coring). Sites established in 2016, reported on in Robertson and Stevens (2016). Ratings are currently under development as part of National ANZECC guidelines.

The horizontal extent of soft mud was very large (1061ha) and covered 54% of the intertidal area, a risk indicator rating of "HIGH". Figure 4 shows large beds of soft mud located on upper intertidal flats in the main northern and southern arms, as well as in many sheltered upper arms, particularly where causeways limit tidal exchange. Settlement in these upper estuary zones is thought to predominantly reflect a hydrodynamic boundary, combined with salinity driven flocculation in the upper estuary basins, promoting settling of fine sediments. Extensive seagrass beds in the northern arm are likely to facilitate the trapping and accumulation of fine sediments in these areas, while the relatively low incidence of muds in the central basin of the estuary is likely to reflect strong tidal flows combined with ocean swells (more pronounced than in other Tasman estuaries) and wind generated waves limiting settlement and facilitating export of fine sediments from this part of the estuary.

Grain size sampling (sites in Figure 3, data in Appendix 4) showed sediments classified as mud (firm mud, soft mud, very soft mud) had a mud fraction of 47%-93% (mean 70%), while those classified as sand dominated contained <25% mud. High mud contents like those recorded indicate macroinvertebrate communities will be adversely affected (e.g. Robertson et al. 2016).

Although a detailed spatial analysis comparing the 1990 mud coverage with current mud cover is outside the scope of the current work and has yet to be undertaken, a preliminary assessment indicates that many unvegetated areas mapped as sand by Davidson (1990) are now mud-dominated indicating a large increase in mud-dominated habitat since 1990. Increases to the already large horizontal extent of mud, and the high mud fraction within these areas, represents a "HIGH" risk of adverse ecological consequences in the estuary, a result seemingly at odds with most of the estuary largely surrounded by protected native forest. Consequently, the potential source of such muds (natural or human induced, local catchment or offshore coastal inputs) should be investigated to determine whether any management action is necessary.

Figure 5. Examples of soft muds in the upper Whanganui Inlet settling basin, 2016.

Figure 6. Examples of firm mobile sands in the cental basin of the lower Whanganui Inlet, 2016.

4. Results and Discussion (continued)

4.2. OPPORTUNISTIC MACROALGAE

Opportunistic macroalgae are a primary symptom of estuary eutrophication. They are highly effective at utilising excess nitrogen, enabling them to out-compete other seaweed species and, at nuisance levels, can form mats on the estuary surface which adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and saltmarsh. Macroalgae that become 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.

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

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

The vast bulk of the estuary exhibited no appreciable opportunistic macroalgal growth and there were no significant gross eutrophic zones present in the estuary. This is consistent with the very low estimated nitrogen areal load to the estuary (<5mg/m^2/day - NIWA CLUES model (Version 10.3, released May 2016 default setting using REC2 and LCBB3 (2008/2009) land cover)).

The few relatively small areas with macroalgae present generally had low-moderate biomass (10-150g.m^2) and comprised the green alga *Ulva lactuca* and the red alga *Gracilaria chilensis*. These were located primarily near the low tide channels and were not entrained within the underlying sediments or causing nuisance conditions. A narrow strip of *Ulva* was also apparent on many of the near vertical estuary edges that intersected the upper tidal reaches of the estuary, but had a very low biomass (<5g.m^2). The only area with a relatively high biomass of *Gracilaria* was located in the sheltered bay immediately south of the main entrance channel. While estuary currents may naturally facilitate the collection of debris and sediment in this bay, this area has supported entrained growths of *Gracilaria* since at least 1990 (see Davidson 1990 for details), and the establishment of entrained nuisance algae is an early warning indicator of potential problems.

The overall opportunistic macroalgal EQR for Whanganui Inlet in March 2016 was 0.67 (Table 5), a quality status of "GOOD" and indicates that the estuary overall is not expressing significant symptoms of eutrophication, a risk indicator rating of "LOW".

Table 5. Summary of intertidal opportunistic macroalgal cover, Whanganui Inlet, March 2016.

Metric	Face Value	Final Equidistant Score (FEDS)	Quality Status
AIH - Available Intertidal Habitat (ha)	1954		
Percentage cover of AIH (%) = (Total % Cover / AIH) x 100 *where Total % cover = Sum of {(patch size) / 100} x average % cover for patch*	0.92	0.96	Very Good
Biomass of AIH (g.m^{-2}) = Total biomass / AIH *where Total biomass = Sum of (patch size x average patch biomass)*	18.57	0.96	Very Good
Biomass of Affected Area (g.m^{-2}) = Total biomass / AA *where Total biomass = Sum of (>5% cover patch size x average patch biomass)*	470.29	0.61	Good
Presence of Entrained Algae = (No. quadrats or area (ha) with entrained algae / total no. of quadrats or area (ha)) x 100	35.82	0.29	Bad
Affected Area (use the lowest of the following two metrics)		0.49	Moderate
Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%)	77.17	0.49	Moderate
Size of AA in relation to AIH (%) = (AA / AIH) x 100	3.95	0.84	Very Good
OVERALL MACROALGAL ECOLOGICAL QUALITY RATING - EQR (AVERAGE OF FEDS)		**0.67**	**GOOD**

4. Results and Discussion (continued)

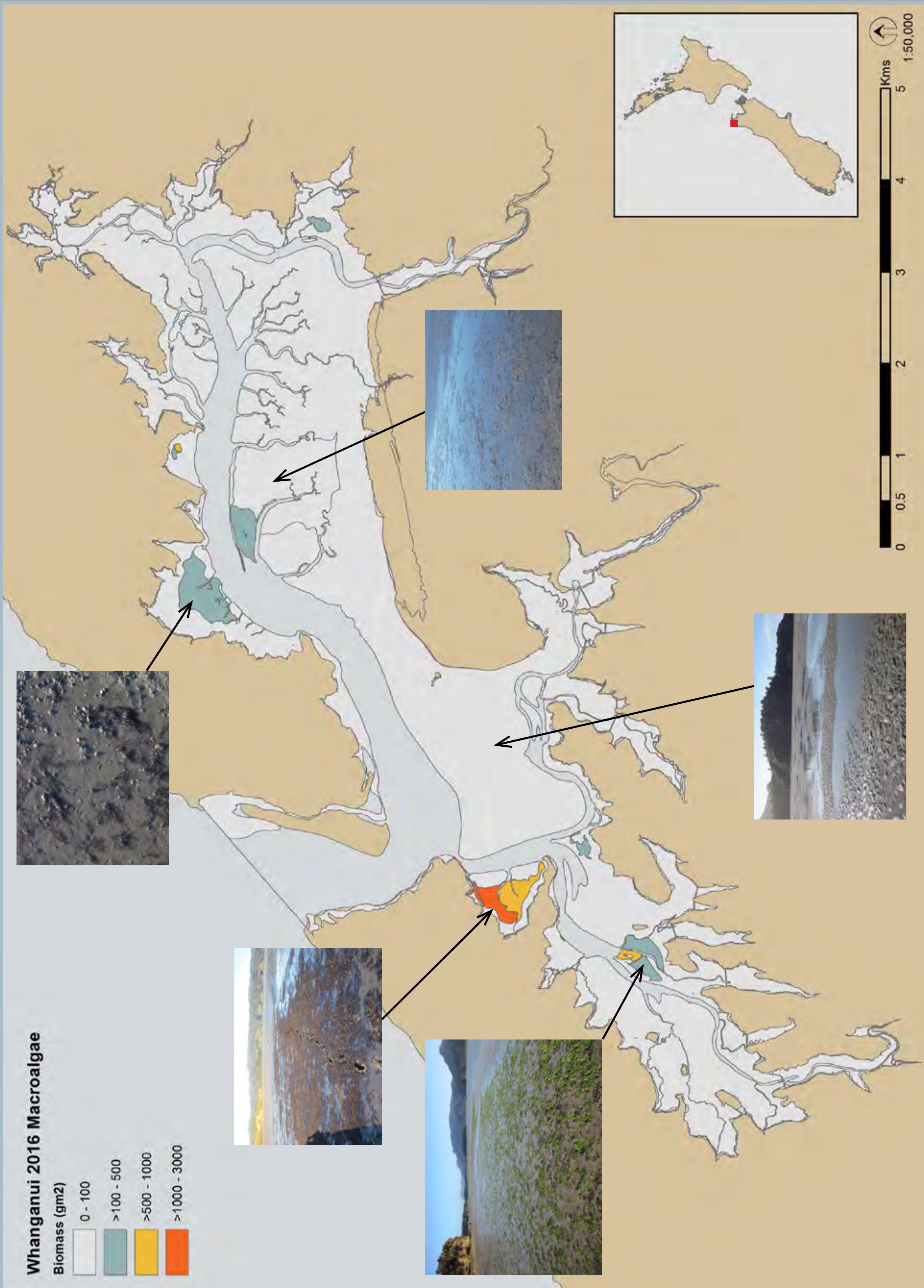
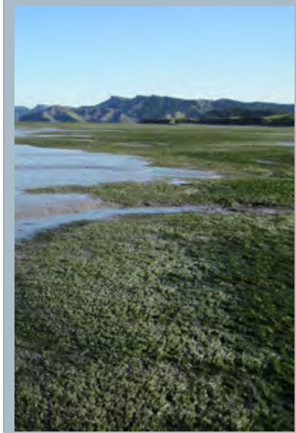
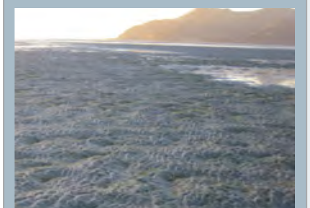


Figure 7. Map of intertidal opportunistic macroalgal biomass (g.m^{-2}) - Whanganui Inlet, 2016.

4. Results and Discussion (continued)

4.3. SEAGRASS





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

Table 6 and Figures 8, 9, and 10 summarise the results of the intertidal seagrass extent (the mapped intertidal estuary area minus saltmarsh) based on Davidson et al. (1990) and groundtruthed mapping using aerial photos flown in 2012/13 and 2015/2016. The results show that in 1990 the seagrass extent mapped by Davidson et al. (1990) covered 863ha, 44% of the intertidal area (Figure 8). The northern arm was relatively muddy but supported very dense and extensive beds of seagrass, while the southern arm and central basin supported generally smaller and less contiguous beds growing in a mix of substrates including firm sands, mobile sands and soft muds.

Re-mapping onto 2012/13 photos showed little overall change in the general extent or location of seagrass beds since 1990, but an estimated 84ha (10%) loss in seagrass cover to 779ha, 40% of the intertidal area (Figure 9). Allowing for likely differences in mapping accuracy between the two assessments, this is considered to represent a risk indicator rating of "LOW" and shows estuary seagrass was relatively stable from 1990 to 2012/13.

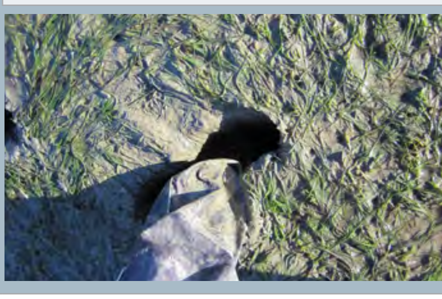
However in the 3 years from 2012/13 to 2015/2016 there was a very dramatic (403ha 52%) reduction in seagrass cover to 376ha, 19% of the intertidal area (Figures 10 and 11). The most significant changes occurred in the northern arm of the estuary where extensive areas of soft mud are now present where seagrass previously flourished, and remaining seagrass beds are being significantly impacted by fine mud deposition. This is evident in the smothering of seagrass beds in mud, fragmentation of previously contiguous beds, and localised erosion along the edges of fragmented beds.

Although such a dramatic and rapid decline in seagrass is not linked to any obvious local land use changes within the catchment, it has a risk indicator rating of "HIGH" and is likely to be one of the single largest recent losses of seagrass recorded in NZ.

While there is a possibility that the seagrass is dying back as part of a natural cycle, it is recommended that the potential source of the muds currently displacing seagrass beds be investigated, and that mapping of seagrass continue at 5 yearly intervals to monitor ongoing change.

Table 6. Summary of seagrass cover, Whanganui Inlet, 1990, 2012/13 and 2016.

Percentage Cover	1990		2012/13		2016	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
No seagrass	1091	55.9	1175	60.1	1578	80.8
<50% cover	46.5	2.4	65.0	3.3	46.7	2.4
50-80% cover	46.9	2.4	68.6	3.5	18.4	0.9
>80% cover	769.2	39.4	645.3	33.0	310.5	15.9
	1954	**100**	**1954**	**100**	**1954**	**100**



4. Results and Discussion (continued)

Figure 8. Map of intertidal seagrass cover - Whanganui Inlet, 1990. (Redrawn from Davidson et al. 1990)

4. Results and Discussion (continued)

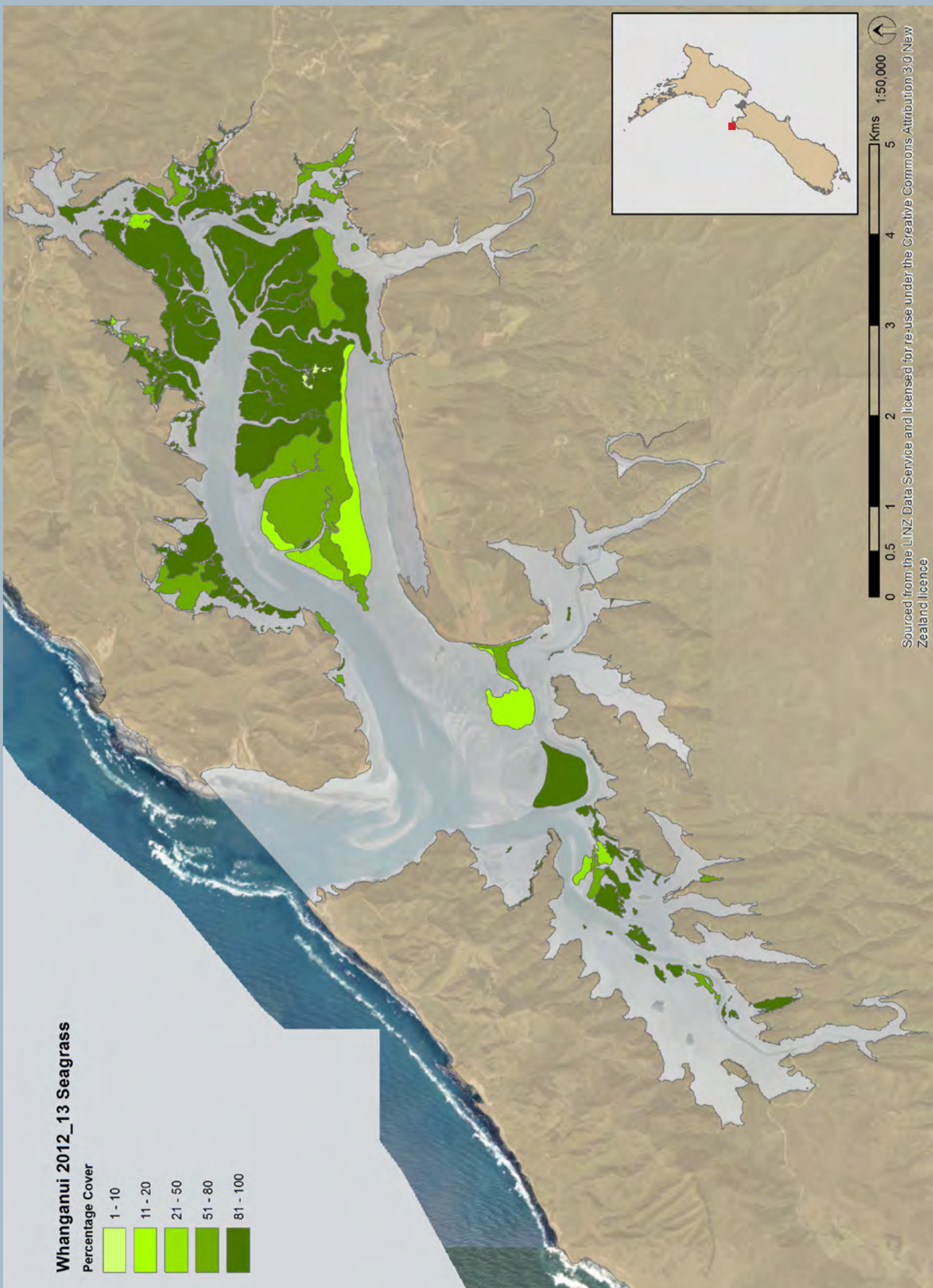


Figure 9. Map of intertidal seagrass cover - Whanganui Inlet, 2012/13.

4. Results and Discussion (continued)

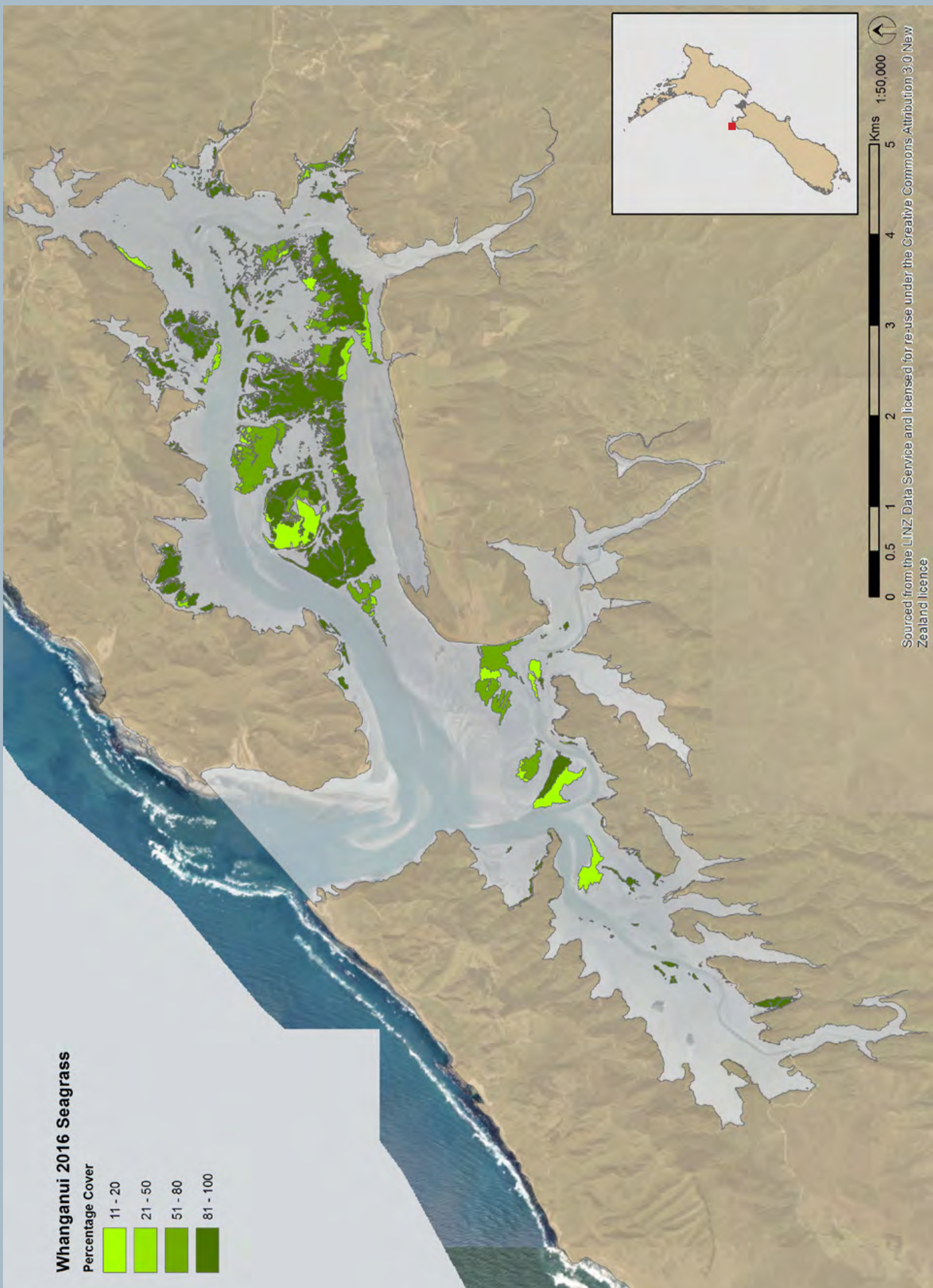


Figure 10. Map of intertidal seagrass cover - Whanganui Inlet, 2016.

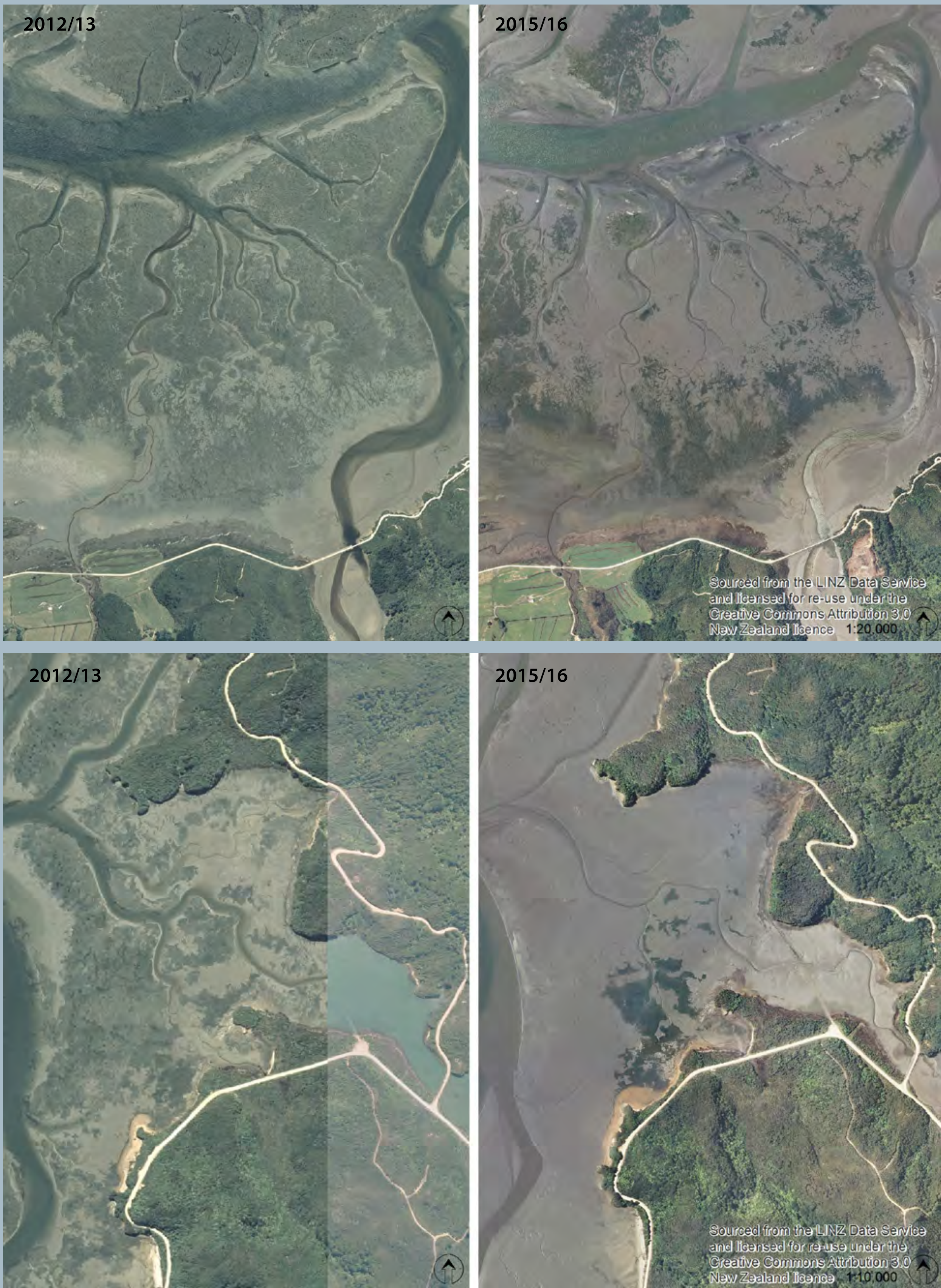


Figure 11. Aerial photos illustrating changes in seagrass cover - Whanganui Inlet, 2012/13 (L) and 2016 (R).

4.4. SALTMARSH

Saltmarsh (vegetation able to tolerate saline conditions where terrestrial plants are unable to survive) is important as it has high ecological productivity, 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. A recommended supporting indicator is loss compared to estimated natural state cover, acknowledging that estimates of natural state cover can be difficult to accurately quantify.

Table 7 and Figure 12 summarise the results of the 2016 saltmarsh mapping and show saltmarsh was present in 112ha, 4% of the intertidal area. The vast majority of this saltmarsh is located on the relatively flat shore of the northern arm (Rakopi), an important area for bittern, and which is also where the greatest loss of historical saltmarsh appears to have occurred (as a consequence of drainage and reclamation for farming). Elsewhere the relatively steep natural landforms that border much of the estuary restrict saltmarsh to narrow strips near the upper tidal range, with occasionally wider margins along stream banks in smaller arms. Many of these smaller arms now have constricted tidal flows as a consequence of embayments created by road causeways. Where they no longer drain as freely as they naturally did, there is likely to be some limitation of saltmarsh growth.

Key characteristics of the saltmarsh present were:

- The dominant saltmarsh cover was rushland (72%), which comprised a mix of searush and jointed wire rush.
- Estuarine shrub (26%) was a dominant cover to rushland around the upper estuary tidal margins and channels.
- Small herbfields (1%) fringed the lower tidal margins of rushland in many areas, often in cobble/gravel fields.
- Patches of sedge (three square) (0.5%) were also a notable feature in many areas around the upper shore.
- Introduced weeds were not a conspicuous subdominant component within saltmarsh in most areas, although adjacent to farmland common weed species such as gorse, broom, blackberry, and introduced grasses were all present.

Although the relatively low overall saltmarsh area fits a risk indicator rating category of "HIGH", a "LOW" risk rating has been applied primarily because natural landforms limit the extent of saltmarsh across much of the estuary, while there is estimated to be 40-60% of the naturally occurring saltmarsh remaining in the estuary.

Saltmarsh mapped from 2012/13 photos (113ha) was slightly less than in 1990 (121ha - Davidson, 1990). Allowing for likely differences in mapping accuracy and coverage between the two assessments, this represents a risk indicator rating of "LOW".

Table 7. Dominant saltmarsh cover, Whanganui Inlet, 2016.

Class	Dominant Vegetation	Area (ha)	Percentage
Estuarine Shrub		29.2	25.9%
	Plagianthus divaricatus (Saltmarsh ribbonwood)	29.2	
Tussockland		0.04	0.03%
	Phormium tenax (New Zealand flax)	0.04	
Duneland		0.1	0.1%
	Ammophila arenaria (Marram grass)	0.1	
Sedgeland		0.6	0.5%
	Schoenoplectus pungens (Three-square)	0.6	
Reedland		0.5	0.4%
	Typha orientalis (Raupo)	0.5	
Rushland		81.6	72.3%
	Apodasmia similis (Jointed wirerush)	16.3	
	Juncus kraussii (Searush)	65.4	
Herbfield		0.9	0.8%
	Samolus repens (Primrose)	0.3	
	Selliera radicans (Remuremu)	0.3	
	Sarcocornia quinqueflora (Glasswort)	0.3	
Grand Total		113ha	100%

4. Results and Discussion (continued)

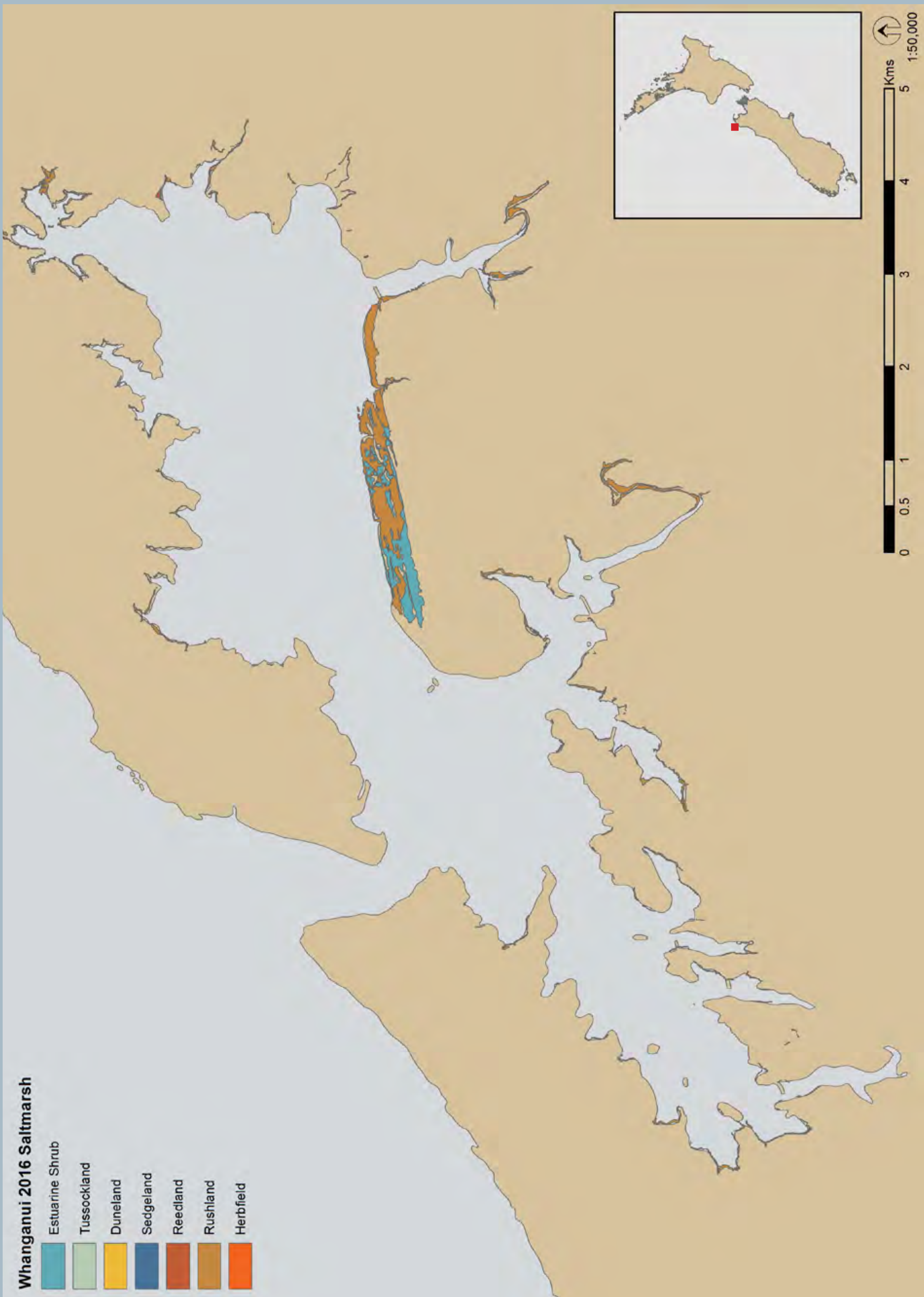


Figure 12. Map of dominant saltmarsh cover - Whanganui Inlet, 2016.

4. Results and Discussion (continued)

The saltmarsh around Whanganui Inlet was commonly characterised by narrow strips of rushland located between MHWN and constraining natural landforms at the upper tidal reaches e.g. hillsides, (below left), terrestrial wetlands (below centre), or cliffs (below right). Saltmarsh was largely free of exotic weeds.

Saltmarsh was also common in the heads of small arms where streams entered the estuary and where rushland extended across tidal flats, often transitioning to herbfields, or directly abutting seagrass beds.

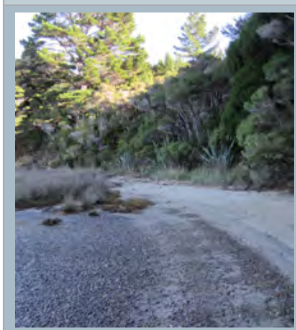
Many arms, where small cliffs surrounded the estuary margin, had no saltmarsh at all.

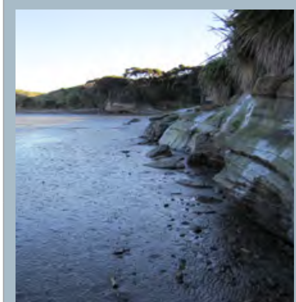
Herbfields were relatively sparse as a dominant cover but were occasionally present flanking rushland.

The most extensive saltmarsh beds were on the southern shore of the northern arm margin and were rushland-dominated. Their terrestrial edge was a mix of saltmarsh ribbonwood and gorse dominant to rushland.

4. Results and Discussion (continued)

4.5. 200m TERRESTRIAL MARGIN





Above: Margin areas around Whanganui Inlet highlighting forest, pasture, causeways, and natural landform barriers.
Right: Rushland backing onto native forest and scrub.

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, Figure 13) showed:

- Dense buffering vegetation covered 85% of the 200m margin and comprised predominantly native scrub and forest. Much of this is forest protected under the Department of Conservation estate (Northwest Nelson Conservation Park and Kahurangi National Park).
- A small amount of duneland (1%) was present near the estuary entrance and central basin.
- The remaining 200m wide terrestrial margin was dominated by sheep and beef pasture (15%) concentrated on freehold land near Rakopi, and along the northeastern boundary of the estuary.
- At the immediate upper tidal range of the estuary margin, much of the estuary has hardened edges. The vast majority are natural landforms, although there are also extensive road causeways crossing most of the smaller arms of the estuary.

The extensive densely vegetated buffer (85%) fits the risk indicator rating of "VERY LOW". There appears to have been no significant change since 1990, and future change is also not expected to significantly alter this given the current level of protection for forest areas. Freehold land areas are the most likely to change although much of this land has already been converted to pasture so again significant changes are not expected.

This presence of hardened estuary margins, often a naturally steep or vertical face along the estuary edge, constrains the areas in which the estuary has a natural capacity to respond to climate change related sea level rise. Consequently, the relatively few low-lying areas where saltmarsh can expand in response to such pressure will be important to manage effectively in the future to protect saltmarsh vegetation, fish spawning and bird habitat. It is recommended that these be identified through the use of LIDAR or similar methods. Where significant areas are identified on freehold land, it is recommended advice be provided to land owners on management options to ensure ongoing estuary modification such as shoreline armouring and saltmarsh drainage is appropriately assessed and managed on a site specific basis.

Table 8. Summary of 200m terrestrial margin land cover, Whanganui Inlet, 2016.

Class	Dominant features	Percentage
Forest	Native forest on southwestern hills.	42%
Scrub/Forest	Predominantly regenerating native scrub and forest on northeastern and central southern margin hillsides.	24%
Scrub	Gorse, flax, and ribbonwood at estuary edge, native scrub on hillsides.	18%
Grassland	Sheep and beef pasture.	15%
Duneland	Marram grass near entrance and central basin area.	1%
Total		**100%**

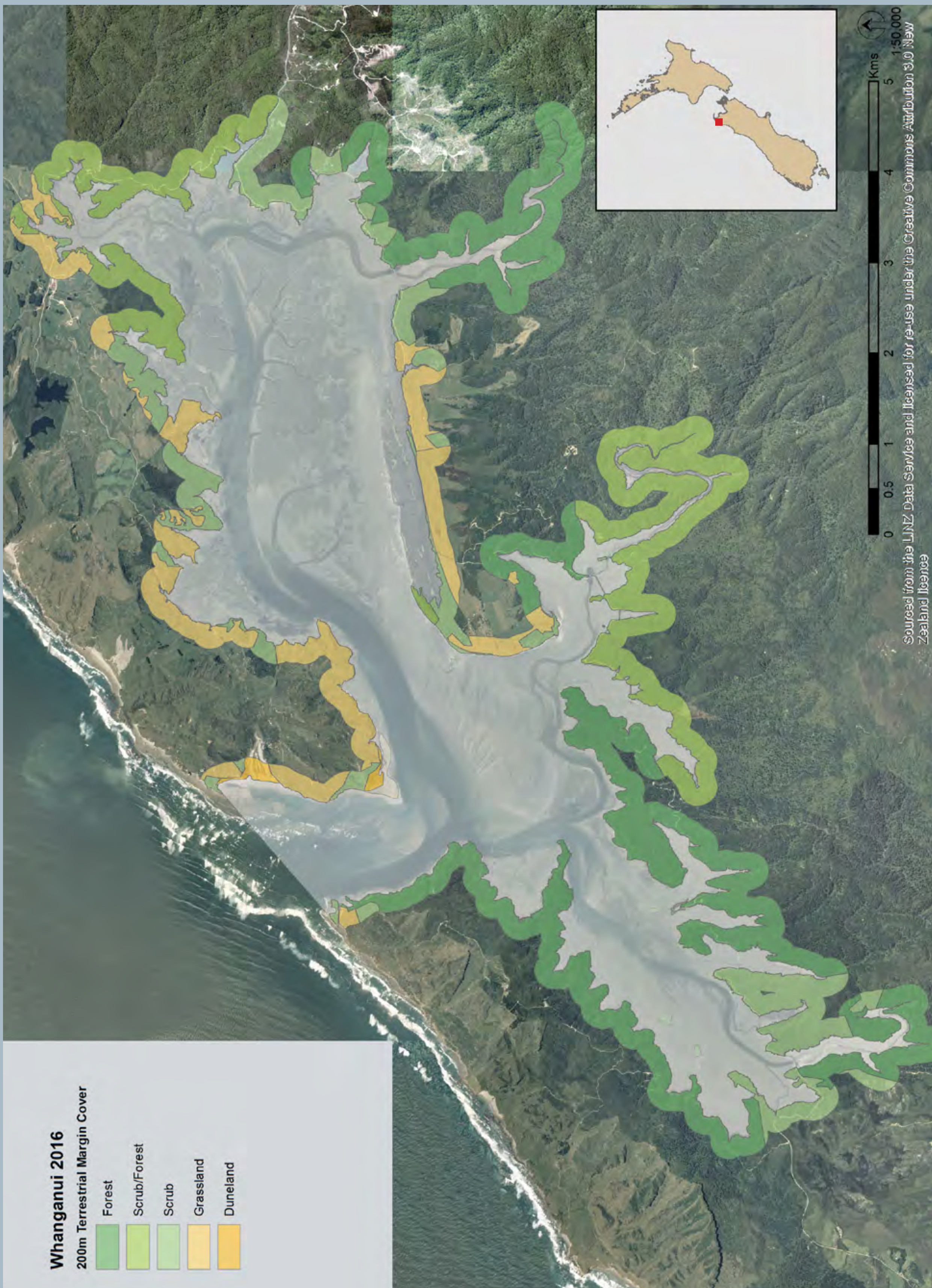


Figure 13. Map of 200m Terrestrial Margin - Dominant Land Cover, Whanganui Inlet, 2016.

5. SUMMARY AND CONCLUSIONS

Broad scale habitat mapping undertaken in early 2016 showed Whanganui Inlet is a large and relatively unmodified estuary set within a native forest dominated catchment. It supports very extensive areas of seagrass, but also has large areas dominated by muds. Risk indicator ratings were used in relation to the key estuary stressors (i.e. sedimentation, eutrophication and habitat modification), and changes from 1990 baseline conditions, to assess overall condition (Table 9).

The risk of adverse impacts occurring to estuary ecology was rated "HIGH". This is a reflection of the current extent of fine mud in the estuary (54%, 1061ha), combined with a very rapid and dramatic decrease in seagrass extent (estimated at ~403ha, 56%) that occurred between 2012/13 and 2015/16. Prior to this there had been a relatively small decrease in seagrass extent between 1990 and 2012/13 (~84ha, 10%). The primary cause of seagrass decline is likely to be excessive muddiness, but there is a possibility of it being part of a natural cycle of die back.

Eutrophication, expressed through indicators of macroalgal growth and the presence of gross eutrophic conditions, and habitat modification, primarily localised historical saltmarsh drainage and reclamation, and construction of road causeways, were not considered to be significant ongoing estuary stressors.

The key consequence of increased muddiness and seagrass loss, and to a lesser extent habitat modification, is a reduction in the ecological value of these important habitat features, particularly a reduced capacity to assimilate sediment and nutrient inputs, and reduced supporting habitat to birds, fish (whitebait) and shellfish.

Table 9. Summary of broad scale risk indicator ratings for Whanganui Inlet, 2016, and changes from 1990 baseline mapping.

Major Issue	Indicator	2016 risk rating	Change since 1990 baseline
Sedimentation	Soft mud (% cover)	HIGH	Undetermined increase
Eutrophication	Macroalgal Growth (EQC)	LOW	No significant change
	Gross Eutrophic Conditions (ha)	VERY LOW	No significant change
Habitat Modification	Seagrass (% change from 1990 baseline)	HIGH	Large decrease
	Saltmarsh (% of intertidal area)	LOW	Small decrease
	200m Vegetated Terrestrial Margin	VERY LOW	No significant change

At present, the primary source of fine sediment causing excessive estuary muddiness is unclear, however it is almost certainly terrestrial sediment delivered to the estuary as a result of catchment erosion. However, because the majority of the catchment surrounding the estuary is in native forest (~91%), it is unclear how much of the mud in the estuary is from local sources, and how much may be contributed by west coast catchments or coastal erosion. The increase in the area of soft mud since 1990, and the extent of soft mud present in the estuary, means it is a significant issue and macrobenthic ecology will be compromised in muddy areas.

In response to the combined issues of muddiness and seagrass loss it is recommended that natural and current state sediment inputs to the estuary be estimated to determine the likely local catchment contribution (and the extent of human influenced change within this), and an assessment be made of whether fine sediment inputs from outside the local catchment (i.e. coastal inputs from west coast sources) require assessment.

6. MONITORING

Whanganui Inlet has been identified by TDC as a priority for monitoring, and is a key part of TDC's coastal monitoring programme being undertaken in a staged manner throughout Tasman district. Based on the 2016 monitoring results and risk indicator ratings, particularly those related to fine sediment, the following monitoring recommendations are proposed by Wriggle for consideration by TDC:

Broad Scale Habitat Mapping, Including Seagrass and Macroalgae.
Continue broad scale habitat mapping at 5-10 yearly intervals, unless obvious changes are observed in the interim, focusing on the main issue of fine sediment. Next monitoring recommended for consideration in Jan-Mar 2021. It is also recommended that saltmarsh and seagrass extent be mapped based on existing aerial photos from 1948, and the natural state cover of saltmarsh be estimated from historical records of the estuary.

Fine Scale Monitoring.
Baseline fine scale monitoring commenced in December 2015 and a 3 year annual baseline is recommended, followed by repeat monitoring at five yearly intervals.

6. Monitoring (continued)

Sedimentation Rate Monitoring.
Because fine sediment is a priority issue in the estuary it is recommended that the sediment plates established at the three fine scale monitoring sites be measured annually for both sediment deposition rate and grain size.

Terrestrial Margin Saltmarsh.
Because natural barriers to saltmarsh migration are present around much of the estuary, it is recommended that the areas most likely to be influenced by sea level rise be identified to assist in planning for the managed retreat of saltmarsh. LIDAR data, where available, should be used to assist this process. Where such saltmarsh areas are identified on private land, landowners should be encouraged to protect these remaining, but vulnerable, stands.

Intensive Investigations.
In addition to the above routine SOE monitoring of long term fine scale and broad scale elements, to defensibly address issues of increasing muddiness and loss of seagrass in the estuary, it is recommended that the following intensive investigations be considered:

- Identify the potential source and magnitude and timing of fine sediment (mud) inputs impacting seagrass beds and intertidal flats i.e. recent or historical inputs, and the origin of the dominant source mud inputs in terms of landuse (e.g. sheep/beef, native forest landuse) and catchments.
- If recent increases in muddiness are not explained by predicted catchment inputs, assess whether fine sediment inputs from outside the local catchment (i.e. coastal inputs from west coast sources, erosion of estuary margins) require assessment.
- Determine the magnitude of any changes required to maintain health estuary functioning by comparing current catchment loads (whether they are indirectly from the ocean or from the estuary catchment or margins) with what could be achieved under best landuse soil conservation practices.

These investigations are usually undertaken using a combination of:

- Forensic techniques applied to estuary sediments to assess historical sedimentation rates (e.g. isotope based ageing of sediment cores) and to identify the primary sources contributing to sediment accumulating in the estuary (e.g. compound specific stable isotope source tracking).
- Existing catchment models such as CLUES, and extensions incorporating refined sediment yields for specific land use activities (e.g. Green et al. 2014), and validated by monitoring sediment loads in rivers draining major subcatchments.

7. MANAGEMENT

Using the results of the above investigations, it is recommended that the Council identify through stakeholder involvement an appropriate "target" estuary condition and determine any catchment management changes needed to achieve the target. For example, ensuring Best Management Practices (BMPs) are being implemented both within the catchment, and potentially outside the estuary catchment, if significant mud contributions come from there. 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.

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.

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 first two 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 an adult sinks 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 yan adult sinks 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 an adult sinks >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 multi-metric index approach suitable for characterising the different types of estuaries and related macroalgal issues found in NZ. The tool allows the simple adjustment of underpinning threshold values to calibrate it to the observed relationships between macroalgal condition and the ecological response of different estuary types. It incorporates sediment entrained macroalgae, a key indicator of estuary degradation, and addresses limitations associated with percentage cover estimates that do not incorporate biomass e.g. where high cover but low biomass are not resulting in significantly degraded sediment conditions. It is supported by extensive studies of the macroalgal condition in relation to ecological responses in a wide range of estuaries.

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

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

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

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

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

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

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

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

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

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

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

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

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

Timing: 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 the 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.

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

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

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

EQR calculation

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

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

The EQR calculation process is as follows:

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

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

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

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

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

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

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

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Appendix 2. Estuary Condition Risk Ratings (continued)

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

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

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

Table A3. 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. WHANGANUI INLET MACROALGAL DATA

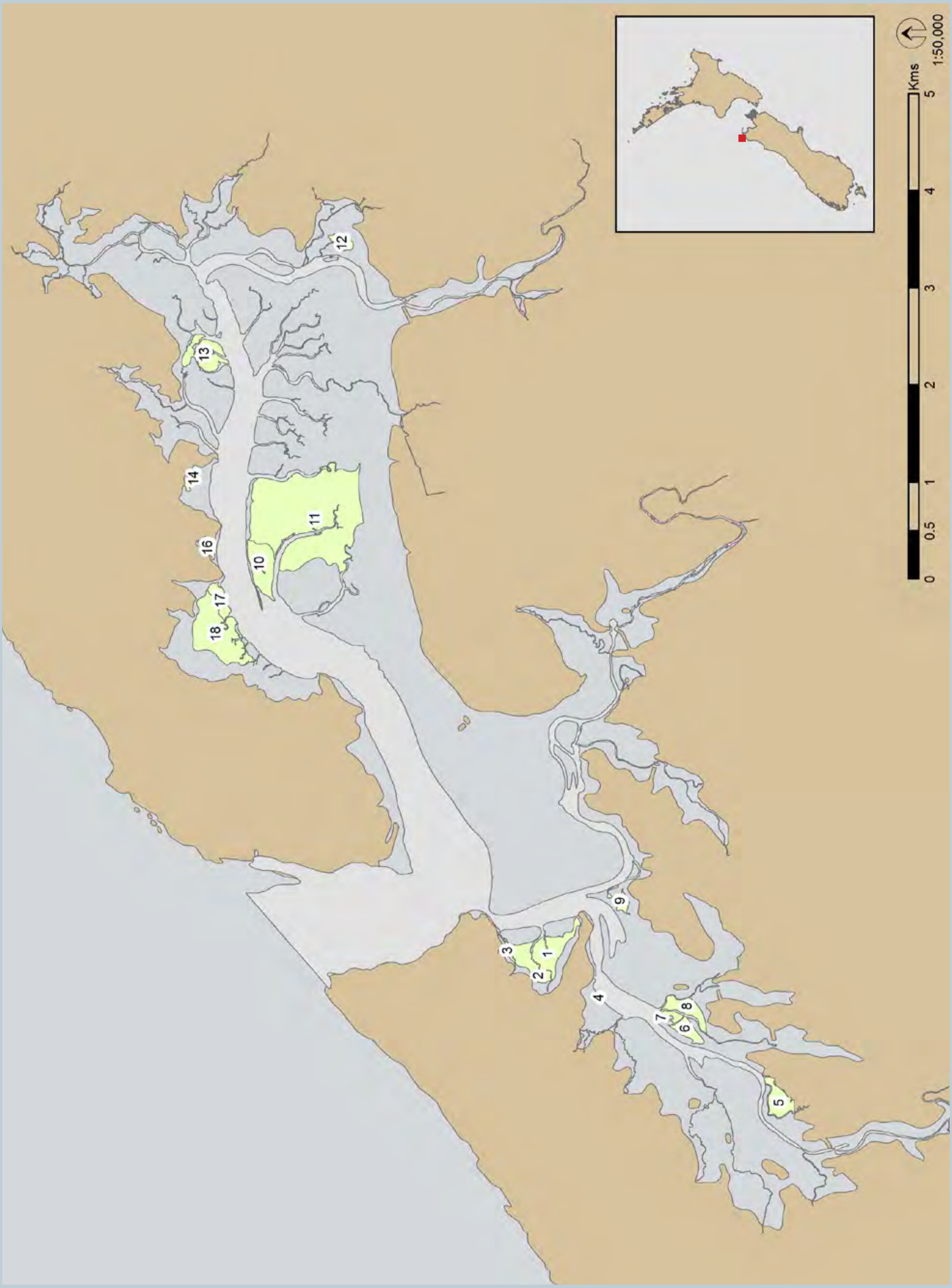

Figure A1. Location of macroalgal patches (>5% cover) used in assessing Whanganui Inlet, March 2016.

Appendix 3. Whanganui Inlet Macroalgal Data (continued)

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

Patch ID	Dominant species	Patch area (ha)	Percent cover of macroalgae	Presence (1) or absence (0) of entrained algae	Mean Biomass (g.m^{-2} wet weight)	aRPD depth (cm)	Presence (1) or absence (0) of soft mud
1	*Gracilaria chilensis*	10.8	30	1	800	1	1
2	*Gracilaria chilensis*	8.0	50	1	2000	1	1
3	*Gracilaria chilensis*	0.9	80	1	1500	1	1
4	*Gracilaria chilensis*	0.1	100	1	2500	1	1
6	*Ulva intestinalis*	4.2	20	0	150	3	0
7	*Ulva intestinalis Gracilaria chilensis*	2.1	80	0	800	1	0
8	*Ulva intestinalis Gracilaria chilensis*	6.4	40	0	200	1	1
9	*Gracilaria chilensis*	2.4	60	1	1000	1	0
10	*Gracilaria chilensis*	11.9	10	0	120	3	0
12	*Gracilaria chilensis*	2.6	10	1	150	1	1
14	*Gracilaria chilensis*	0.9	80	1	1000	1	1
15	*Gracilaria chilensis*	0.6	40	1	300	1	1
16	*Gracilaria chilensis*	1.9	10	1	100	1	1
18	*Gracilaria chilensis*	24.9	10	1	150	1	1

Macroalgal cover <15% not included when calculating the OMBT EQR.

Patch ID	Dominant species	Patch area (ha)	Percent cover of macroalgae	Presence (1) or absence (0) of entrained algae	Mean Biomass (g.m^{-2} wet weight)	aRPD depth (cm)	Presence (1) or absence (0) of soft mud
5	*Gracilaria chilensis*	7.0	1	0	10	3	1
11	*Gracilaria chilensis*	92.4	5	0	50	2	0
13	*Gracilaria chilensis*	10.2	5	1	20	1	1
17	*Ulva lactuca Gracilaria chilensis*	4.0	5	0	20	3	0

APPENDIX 4. WHANGANUI INLET SEDIMENT GRAIN SIZE DATA

Sampling locations and grain size results used to validate broad scale substrate classifications (see Figure 3).

Site	NZTM East	NZTM North	Field Code	Dry Matter g/100g as rcvd	MUD <63 µm	SAND <2 mm, ≥63 µm	GRAVEL ≥2 mm
WH_00	1566111	5508102	sM	71	74.4	25.6	< 0.1
WH_01	1568360	5507992	fMs	81	24.6	70.3	5.1
WH_02	1568215	5507993	vsM	64	81.2	18.3	0.6
WH_03	1567843	5507375	fMs	75	24.1	75.5	0.4
WH_04	1567629	5507424	fM	71	56.1	43.8	< 0.1
WH_05	1568377	5508631	vsM	61	85.3	14.6	0.1
WH_06	1558536	5503050	sM	63	92.8	7.0	0.2
WH_07	1558501	5503237	sM	74	72.5	26.6	0.9
WH_08	1558621	5502162	sM	69	68.3	29.9	1.7
WH_09	1558247	5504407	sM	75	63.7	36.3	< 0.1
WH_10	1559414	5502870	vsM	66	62.7	34.3	2.9
WH_11	1560123	5502391	vsM	61	85.6	12.8	1.5
WH_12	1560138	5503021	sM	62	90.2	9.7	0.1
WH_13	1560550	5504321	sM	69	48.7	49.1	2.3
WH_14	1560789	5503754	fM	69	47.1	52.6	0.3
WH_15	1560737	5503700	sM	69	68.6	28.7	2.7
WH_16	1565912	5507695	vsM	63	80.2	19.5	0.3
WH_17	1566831	5507298	sM	72	58.2	41.7	0.2
WH_18	1567521	5506843	sM	75	49.6	50.4	< 0.1
WH_19	1566947	5507637	vsM	65	79.6	20.2	0.2
WH_20	1567434	5507394	vsM	70	65.9	32	2.1