coastalmanagement

Waimea Inlet 2014

Broad Scale Habitat Mapping

Prepared for

Tasman District Council

August 2014

Cover Photo: Waimea Inlet, 2014.


Mobile sands opposite Nelson Airport

Waimea Inlet 2014

Broad Scale Habitat Mapping

Prepared for
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by

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All photos by Wriggle except where noted otherwise.

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WAIMEA INLET - EXECUTIVE SUMMARY

This report summarises the results of the 2014 broad scale habitat mapping of Waimea Inlet, one of the South Island's largest tidal lagoon estuaries (~3307ha intertidal area), located near Nelson City and Richmond in the Nelson/Tasman District. It is one of the key estuaries in Tasman District Council's long-term coastal monitoring programme. The following sections summarise the broad scale monitoring results (from the current report and previous studies), risk indicator ratings, overall estuary condition, and monitoring and management recommendations.

BROAD SCALE RESULTS

- Sand substrate dominated the estuary (49%, 1477ha), mostly in the central estuary towards the estuary entrances.
- Soft and very soft mud cover was extensive (40%, 1195ha), mostly in the upper parts of the central basin and sheltered arms. Very soft mud had increased dramatically since 1999 (from 10ha to 551ha), a likely consequence of fine sediment inputs from natural and human-related catchment land disturbance.
- Opportunistic macroalgal growth was low overall (2.7% of the available intertidal habitat), but dense beds of both *Gracilaria* and *Ulva* were present in localised areas. The biomass, size of affected area (158ha), and degree of macroalgal entrainment, reflected relatively poor conditions in these areas.
- Gross eutrophic conditions (combined symptoms of: a high mud content, a shallow apparent Redox Potential Discontinuity (aRPD) depth, elevated nutrient and total organic carbon concentrations, displacement of invertebrates sensitive to organic enrichment, and high (>50% cover) macroalgal growth) affected 28ha and reflected an estimated increase of >50% since 1990.
- Seagrass cover (34ha, 1% of estuary) was very low and had declined by 41% since 1990. Losses are attributed primarily to excessive fine mud.
- Saltmarsh covered 9% of the estuary (303ha) of which 56% was herbfield and 34% rushland. A 14% decline in saltmarsh since 1946 was attributed primarily to reclamation from road construction and margin development, with significant displacement of saltmarsh habitat also occurring prior to 1946.
- The densely vegetated margin (scrub and forest) cover of the estuary was relatively low (22%), of which 20% was plantation forestry on Rabbit and Rough Islands. Remaining cover comprised grassland and grass-dominated amenity areas (38%), residential/rural residential (22%), and industrial development (16%). Although no significant overall change since 1999 was evident, projects to help restore the vegetated margin e.g. "Plant Right Now" and Cycleway Trust, are being undertaken e.g. Bells Island and Stringer Creek.

RISK INDICATOR RATINGS (indicate risk of adverse ecological impacts)

Major Issue	Indicator	Baseline *estimated value		2014	Change from Baseline
Sediment	Soft mud (% cover)	1990	VERY HIGH	VERY HIGH	Increase in very soft mud
Eutrophication	Macroalgal Growth (OMBT)	1990	LOW*	MODERATE	Increase in nuisance macroalgae
	Gross Eutrophic Conditions (ha)	1990	MODERATE	HIGH	Increase in gross eutrophic conditions
Habitat Modification	Seagrass Coefficient (SC)	1990	HIGH*	VERY HIGH	Decrease in seagrass
	Saltmarsh (% cover)	1946	LOW	MODERATE	Decrease in saltmarsh
	200m Vegetated Terrestrial Margin	1999	HIGH	HIGH	No significant change

ESTUARY CONDITION AND ISSUES

In relation to the key issues addressed by the broad scale monitoring (i.e. sedimentation, eutrophication, and habitat modification), the 2014 broad scale mapping results show that while large sections of the estuary remain in good condition, the ratings indicate "moderate" to "very high" risks of adverse impacts to the estuary ecology from these issues, particularly muddiness. The change ratings highlight a decline in most estuary condition indicators since the baseline (1946 or 1990), the exception being the extent of densely vegetated margin which had largely already been lost. These results confirm that the dominant ongoing issues in the estuary were excessive muddiness of natural settlement areas in the main estuary basins and sheltered arms, and to a lesser extent, localised but significant areas of nuisance macroalgal growth. The large increase in very soft mud since 1999 shows significant deposition of catchment derived fine sediments over the past 15 years. This is likely contributing to losses of seagrass and shellfish, and will adversely impact on the sediment macroinvertebrate community which will become dominated by mud tolerant species. Such conditions limit food availability for fish and birdlife, and show the ability of the estuary to assimilate catchment sediment loads is currently exceeded.

RECOMMENDED MONITORING AND MANAGEMENT

Excessive fine sediment is the major issue identified in Waimea Inlet. Consequently it is recommended that broad scale habitat mapping be repeated every 5 years (next due in 2019) focussing on the main issue of fine sediment, with saltmarsh and the terrestrial margin assessed on a 10 yearly cycle unless obvious changes are observed. A rapid visual assessment of macroalgal growth should be undertaken annually (Jan/Feb), with annual broad scale macroalgal mapping initiated if conditions appear to be significantly worsening.

Fine scale monitoring (data only) is recommended annually for the next 2 years (2015-16) to establish a multi-year baseline, and then 5-yearly. Sedimentation rate monitoring should continue annually with additional sites deployed in eutrophic/high sediment deposition zones.

It is also strongly recommended that a detailed estuary investigation of fine sediment source, transport, deposition and export be undertaken. This would provide important information upon which to base future sediment load management decisions, but should be preceded by a conceptual broad scale outline of what the estuary would look like under various sediment load scenarios (e.g. low, medium, current, high), which is then used to identify, through stakeholder involvement, an appropriate "target" estuary condition. These results, and other appropriate monitoring data, could then be used to identify sediment input load guideline criteria to reduce fine sediment infilling to the target state and develop a plan to achieve such targets.

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, Motueka Delta, Motupipi, Ruataniwha and Whanganui estuaries as priorities for monitoring.

For Waimea Inlet, 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. Both estuary-specific (Stevens and Robertson 2010) and region-wide EVA's have been undertaken (Robertson and Stevens 2012) providing specific recommendations for Waimea 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. Broad scale mapping of Waimea Inlet was undertaken in ~1990 (Davidson and Moffat 1990), 1999 (Robertson et al. 2002), 2006 (Clarke et al. 2008), and historical vegetation cover assessed from 1946 and 1985 aerial photographs (Tuckey and Robertson 2003). The current report describes a repeat of broad scale habitat mapping undertaken in early 2014.
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 Waimea Inlet, was undertaken in 2001 (Robertson et al. 2002) and 2006 (Gillespie et al. 2007), with Sites A and C included in the 2011 regional sewerage compliance monitoring. Additionally, sedimentation rates in the estuary have been monitored annually by TDC at ten sites since 2008.

In 2013, TDC commissioned Wriggle Coastal Management to undertake broad scale monitoring of Waimea Inlet. The current report describes the following work undertaken between Feb. and May 2014:

- 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.

Waimea Inlet has previously been described as a relatively large (~3,460ha), macrotidal (3.66m spring tidal range), shallow (mean depth ~1-2m at high water), well-flushed (residence time <1 day), seawater-dominated, tidal lagoon type estuary (Figure 1, Table 2, Robertson et al. 2002). It has two tidal openings, two main basins, and several tidal arms separated by causeways. The catchment ($812km^2$) is extensively developed and dominated by high producing pasture, cropping/horticulture and exotic forestry, while much of the estuary margin is directly bordered by developed urban and rural land, roads, cycleway/walkway (Great Taste Trail), causeways and seawalls.

The estuary, given its complex shape, contains a wide variety of intertidal habitats. Data from previous mapping (Robertson et al 2002) include soft muds (1105ha), firm mud sands (801ha), firm and mobile sands (341ha), saltmarsh (234ha), seagrass (~34ha), cobble and gravel fields (252ha) and oyster and cockle beds (32ha). While dominated by intertidal sand and mudflats, the well flushed and often steeply incised estuary channels are deep and, particularly near the entrances, support a variety of cobble, gravel, sand, and biogenic (oyster, mussel, tubeworm) habitats.

Previously reported historical loss of high value vegetated habitat has been estimated for seagrass as 40% from 1990 to 1999, and native saltmarsh as 15% from 1946-2006 (based on Davidson and Moffat 1990, Tuckey and Robertson 2003, Clark et al. 2008). The loss of saltmarsh habitat has been attributed primarily to reclamation and drainage around margin areas, with shoreline modification (e.g. seawalls, bunds, roads) now greatly limiting natural saltmarsh expansion and restricting its capacity to migrate inland in response to predicted sea level rise. Consequently, future saltmarsh loss is highly likely. The cause of the seagrass loss is likely attributable to the unusually large extent of soft mud in the estuary (see later sections of this report) and its role in both smothering seagrass, and reducing available light through poor water clarity.

The estuary has high use and is valued for its aesthetic appeal, rich biodiversity, shellfish collection, bathing, waste assimilation, whitebaiting, fishing, boating, walking, and scientific appeal. The inlet is recognised as a valuable nursery area for marine and freshwater fish, an extensive shellfish resource, and is very important for birdlife. A small port is located at Mapua near the north western entrance.

A recent vulnerability assessment (Robertson and Stevens 2012) identified habitat loss, excessive muddiness, moderate disease risk, and changes in biota as a result of climate change, as the most significant issues in the estuary. Excessive muds and increasing eutrophication and sedimentation are most evident in the presence of localised areas of excessive macroalgal blooms with low sediment oxygenation and muddy, sulphide-rich sediments.

The Waimea Inlet is currently being monitored every five years and the results will help determine the extent to which the estuary is affected by major estuary issues (Table 1), both in the short and long term.

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

1. Sedimentation

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 is common. These changes to water and sediment result in negative impacts to estuarine ecology that are difficult to reverse. They include:

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

Recommended Key Indicators:

Issue	Recommended Indicators	Method
Sedimentation	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	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 Potenial Depth - aRPD) and/or redox probe. Note: Total Sulphur is also currently under trial.
	Biodiversity of Bottom Dwelling Animals	Type and number of animals living in the upper 15cm of sediments (infauna in $0.0133m^2$ replicate cores), and on the sediment surface (epifauna in $0.25m^2$ replicate quadrats).

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

3. Disease Risk

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

Recommended Key Indicators:

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

4. Toxic Contamination

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

Recommended Key Indicators:

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

5. Habitat Loss

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

Recommended Key Indicators:

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

1. INTRODUCTION (CONTINUED)

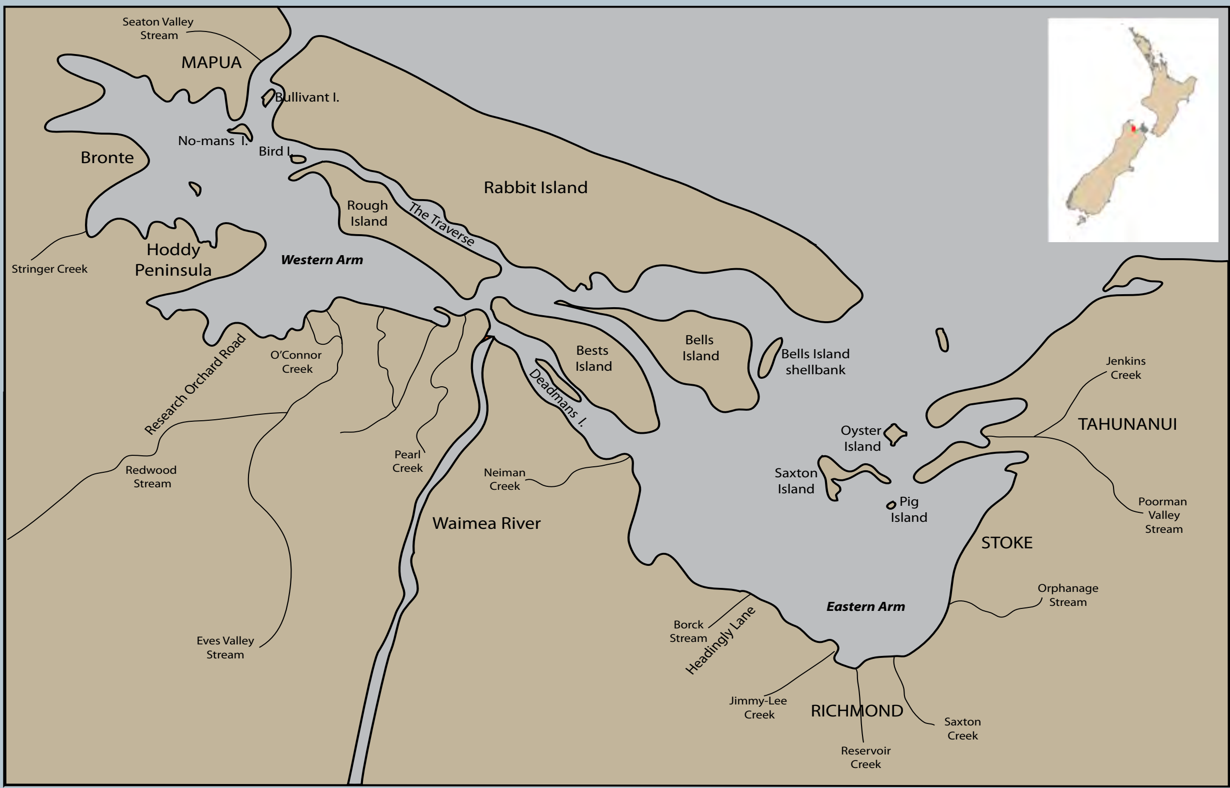


Figure 1. Waimea Inlet, including location of islands and major freshwater streams.

Table 2. Characteristics of tidal lagoon estuaries.

Waimea Inlet (Figure 1) is an example of a "tidal lagoon" type estuary. Such estuaries have the following general characteristics (McLay 1976, Kirk & Lauder 2000, Hume et al. 2007):

- Broad shallow circular to slightly elongate basins, narrow mouths, usually enclosed by a sand spit (hence sometimes called "barrier enclosed lagoons").
- Simple or complex shorelines - some have more than one arm (Waimea Inlet has a complex shoreline with two main arms, numerous smaller ones (drowned valleys) and numerous islands).
- An entrance to the sea which is always open.
- Funnel-shaped entrance (if alongshore movement of sand due to waves breaking at a angle to the shoreline is small - as is the case for the Waimea).
- Extensive intertidal areas which are cut by channels draining the arms.
- A large tidal prism (i.e. a large difference in the volume of water in the estuary between low and high tides).
- The volume of river water inflow is generally small in comparison to marine inputs, and most of the estuary drains on each tidal cycle. Hence they have low water residence times (often <3 days), and good flushing, particularly in the lower estuary. Most of the Waimea Inlet drains at low tide and residence time is <1 day.
- Salinities tend to be high and close to that of seawater.
- Resuspension of sediment by waves at high tide can be high if arms are broad and exposure to wind fetch is elevated. Waimea Inlet has moderate-high wind exposure and high sediment resuspension.
- Mainwater bodies are well flushed and dominated by sandy sediments with a shift to muds in the sheltered arms and upper reaches where flushing and resuspension is less active, as well as where freshwater inputs, often with elevated sediment loads, enter the estuary. The upper reaches, margins of drainage channels, and sheltered arms, are commonly the muddiest parts of Waimea Inlet.
- A well-mixed water column due to strong tidal flushing, wind mixing and shallow depths. In the Waimea Inlet, the only area unlikely to always be well-mixed is where the Waimea River channel enters the estuary. Here more buoyant freshwater is expected to float on top of tidal salt water.
- The coastal plumes from tidal lagoon estuaries are generally much cleaner than from tidal river lagoons and estuaries, although ocean swell can resuspend sediment in the entrance of estuaries.
- High habitat diversity and ecological richness (in their natural state).

1. INTRODUCTION (CONTINUED)

OVERVIEW 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:

- The wide diversity of habitats they offer, and
- 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.

Well flushed tidal lagoon estuaries like Waimea Inlet (see Table 2 for a description of physical characteristics) are typically in one of three contrasting states (PRISTINE, MODERATE, or DEGRADED), and the state of the estuary is commonly related directly to 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, assimilate sediment and nutrients, and provide 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 initial catchment development, sediment, nutrient, and disease-causing organism inputs typically increase, and modification of the estuary margin (primarily by drainage and reclamation) is common. Increased nutrients cause a shift to increased eutrophication, evident in low-moderate nuisance macroalgal growth, and increased phytoplankton production. This, along with increased fine sediment deposition, starts to reduce sediment oxygenation and water clarity. The increasing inputs of fine sediment may also lead to a reduction in seagrass populations and a shift in the macroinvertebrate community to one more tolerant of fine muds.

DEGRADED: With more intensive catchment development, soft muds commonly accumulate in the upper estuary and on sheltered tidal flats, and water clarity decreases further. The combined effects of sediment smothering and reduced light levels may contribute to the loss of seagrass and shellfish beds. 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. Protection of developed margins from erosion and inundation becomes an increasing issue.

Waimea Inlet is currently in a MODERATE state due to high sediment inputs, habitat loss, and to a lesser extent disease risk and eutrophication (Stevens and Robertson 2010, Robertson and Stevens 2012).

2. 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 aerial photography, detailed ground-truthing, and GIS-based digital mapping used to record the primary habitat features present. Very simply, the method involves three key steps:

- Obtaining laminated aerial photos for recording dominant habitat features.
- Carrying out field identification and mapping (i.e. ground-truthing).
- Digitising the field data into GIS layers (e.g. ArcMap).

Although the transitional estuarine waters of Waimea Inlet extend into Tasman Bay, the extent mapped in 2014 has applied an arbitrary seaward boundary based on that of Davidson and Moffat (1990). This primarily reflects the physical intertidal margins of the estuary, with nominal features (e.g. seawalls, road ends) used to mark the seaward edge of the mapped area. In future it is envisaged that hydrodynamic models of Tasman Bay will enable integrated assessment of the seaward boundaries, and linkages between the various estuarine systems within Tasman Bay, under a range of different flow conditions.

For the current study, Land Information NZ (LINZ) supplied rectified ~0.5m/pixel resolution colour aerial photos flown in late 2012/early 2013. Photos covering the estuary at a scale of 1:3,000 were laminated, and experienced scientists ground-truthed the spatial extent of dominant habitat and substrate types over 20 person days from February to May 2014 by walking the area (Figure 3) and recording features directly on the laminated aerial photos. Ipads with “iGIS HD” app. were used to show live position tracking on aerial photos (via an inbuilt GPS accurate to ~5m), and to log field notes. Appendix 1 lists the definitions used to classify substrate and saltmarsh vegetation.

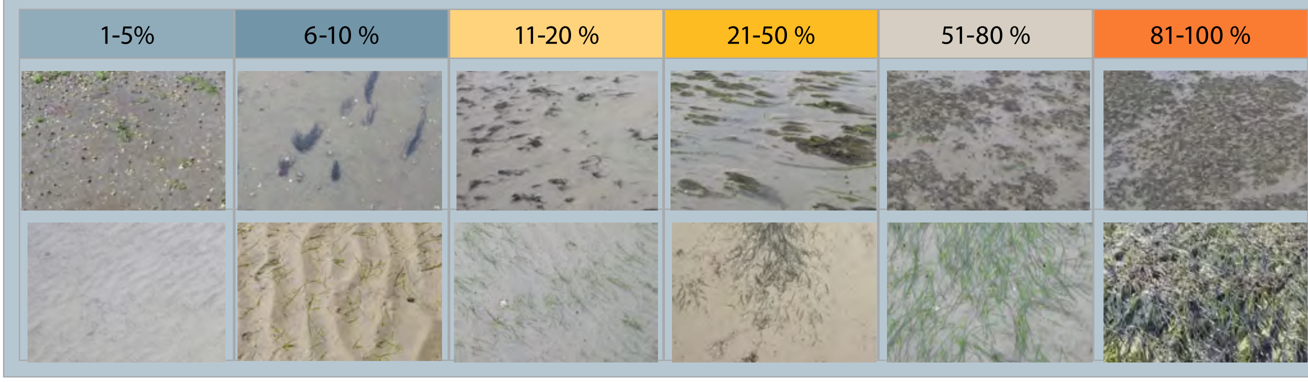
When present, macroalgae and seagrass were mapped using a six category percent cover rating scale (see Figure 2 below) to describe density. Macroalgae were additionally assessed using a modification of the WFD-UKTAG (2014) Opportunistic Macroalgal Blooming Tool (OMBT) described in detail in Appendix 2. This tool, supported by extensive studies of the macroalgal condition in relation to ecological responses in a wide range of estuaries, is the most comprehensive currently available rating tool. It uses measures of the spatial extent, density, biomass, and degree of sediment entrainment of opportunistic macroalgae within a multimetric index composed of five metrics that each have a band of quality status thresholds, and combine to produce an overall Ecological Quality Rating (EQR) ranging from zero (major disturbance) to one (reference/minimally disturbed). Quality status thresholds and EQR bands are presented in Section 3, Table 4.

Broad scale habitat features were subsequently digitised from aerial photos into ArcMap 9.3 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*), gross eutrophic conditions, 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 on a separate CD) providing a much more detailed data set designed for easy interrogation to address specific monitoring and management questions. An example of the detail available on the GIS files is presented in Figure 3.

The 2014 georeferenced spatial habitat maps provide a robust baseline of key indicators. Wherever possible the 2014 results have been compared to previous broad scale surveys (1990, 1990, 2006), noting that differences exist in the previous mapping extent or accuracy of some key parameters like seagrass, macroalgae or soft mud. These particularly relate to errors in the 2006 mapping of substrate and seagrass that preclude their use. It is noted that the mapping results of Davidson and Moffat (1990) are currently being digitised by DOC and more accurate calculations of habitat features from 1990 will subsequently be available in future.

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



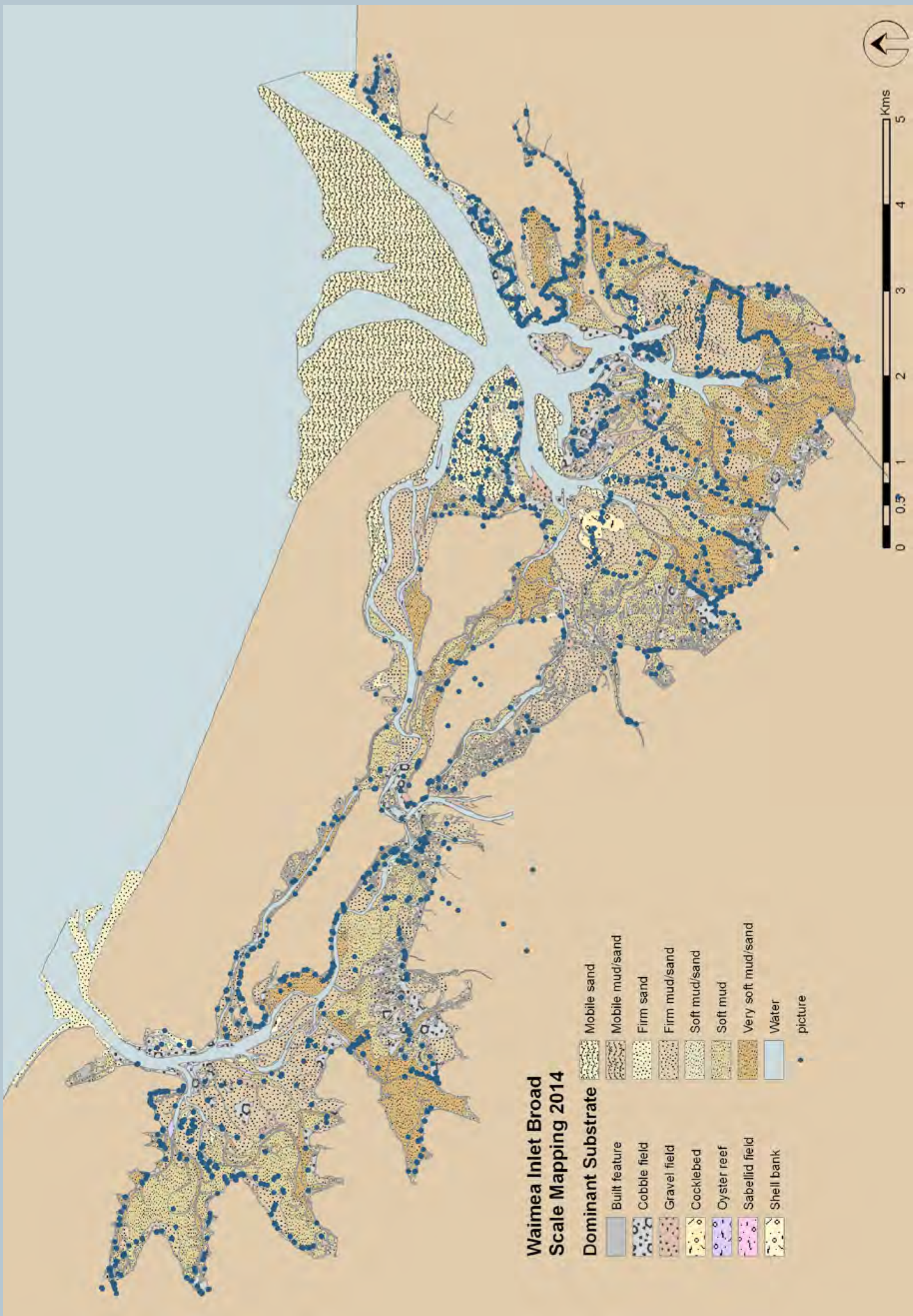


Figure 3. Location of 2014 field photographs indicating groundtruthing extent.

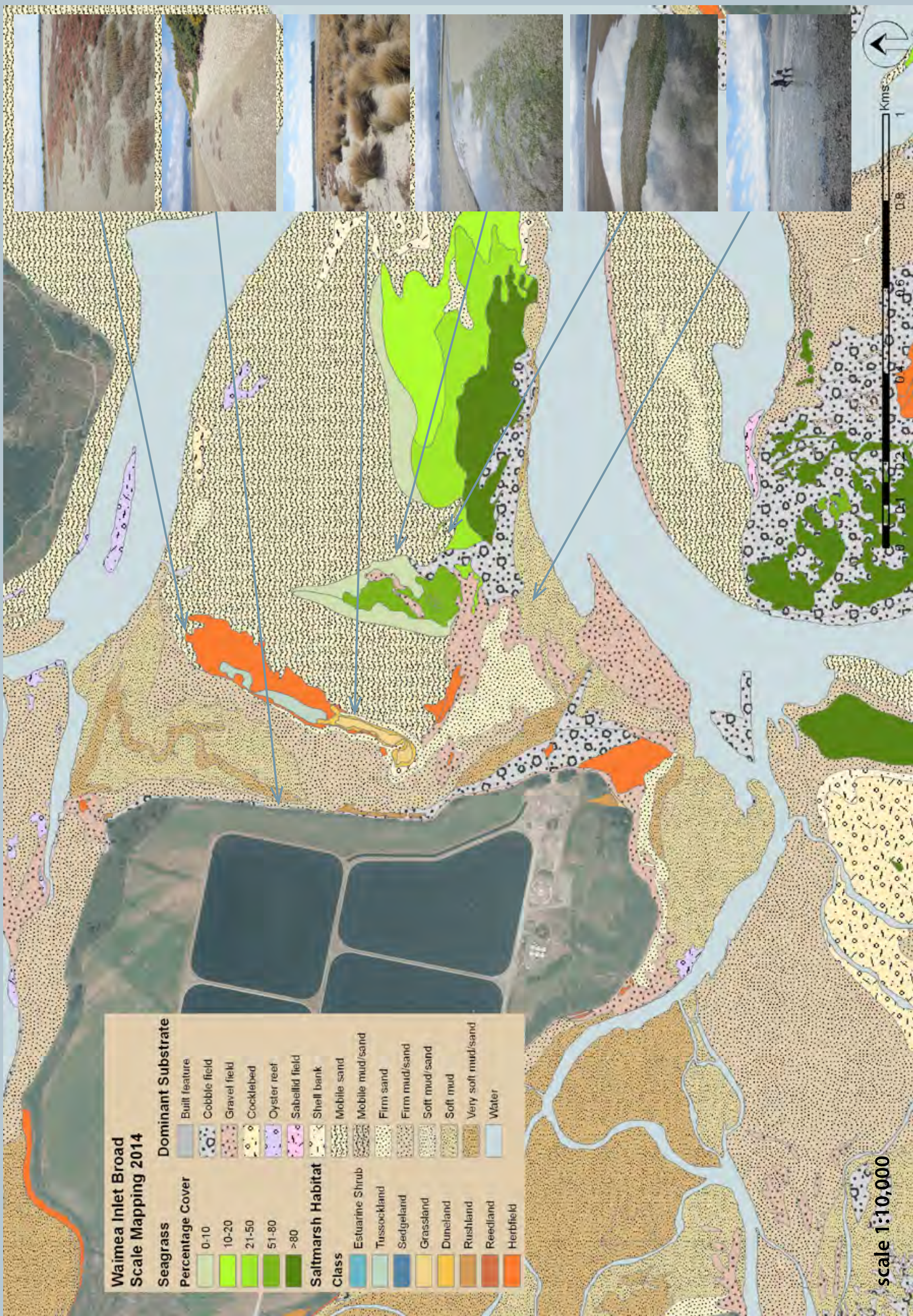


Figure 3a. Example of the detailed GIS mapping and field photos that underpin this summary report.

3. 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” that assign a relative level of risk (e.g. very low, low, moderate, high, very high) of specific indicators adversely affecting intertidal estuary condition have been proposed (see Table 3 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.
- That rating and ranking systems can easily mask or oversimplify results. For instance, large changes can occur within a 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 secondary ratings, primary ratings being given more weight in assessing the significance of indicator results. It is noted that many secondary 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. 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 risk ratings used for the Waimea Inlet broad scale monitoring programme are summarised in Tables 3, 4 and 5, along with supporting notes explaining the use and justifications for each indicator. The basis underpinning most of the following ratings is the observed correlation between an indicator and the presence of degraded estuary conditions from a range of tidal lagoon estuaries throughout NZ. Work to refine and document these relationships is ongoing.

Table 3. Summary of estuary condition risk indicator ratings used in the present report.

INDICATOR	RISK RATING				
	Very Low	Low	Moderate	High	Very High
Soft mud (% cover)	<2%	2-5%	>5-15%	>15-25%	>25%
Sedimentation Rate (mm/yr)	<1mm/yr	>1-2mm/yr	>2-5mm/yr	>5-10mm/yr	>10mm/yr
Apparent Redox Potential Discontinuity (aRPD) depth[2] (cm)	>10cm depth below surface	3-10cm depth below sediment surface	1-<3cm depth below sediment surface	0-<1cm depth below sediment surface	Anoxic conditions at surface
Gross Eutrophic Conditions (ha)	<0.5ha	0.5-5ha	6-20ha	20-30ha	>30ha
Seagrass Coefficient (SC)	>7.0	>4.5-7.0	>1.5-4.5	>0.2 - 1.5	0.0 - 0.2
Saltmarsh (% cover)	>20%	11-20%	6-10%	2-5%	<2%
200m Vegetated Terrestrial Margin	>80-100%	>50-80%	>25-59%	>5-25%	<5%
MACROALGAL INDICATORS (OBMT approach - WFD_UKTAG 2014 - see Appendix 2 for details)					
	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 ($g.m^2$) 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 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 - see Appendix 2 for further detail.

Notes for Table 3:

Soft Mud Percent Cover. Estuaries are a sink for sediments. Where large areas of soft mud are present, they are likely to lead to major and detrimental ecological changes that could be very difficult to reverse, and indicate where changes in land management may be needed. Justifications for these ratings are presented in Appendix 2.

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.

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 apparent Redox Potential Discontinuity (aRPD) 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.

Seagrass Coefficient. Seagrass (*Zostera muelleri*) grows in soft sediments in NZ estuaries where its presence enhances estuary biodiversity. Though tolerant of a wide range of conditions, it is vulnerable to fine sediments in the water column and sediment quality (particularly if there is a lack of oxygen and production of sulphide) (see Appendix 4).

A continuous index (the seagrass coefficient - SC) has been developed to rate seagrass condition based on the percentage cover of seagrass in defined categories using the following equation: ***SC=((0 x %seagrass cover <1%)+(0.5 x %cover 1-5%)+(2 x %cover 6-10%)+(3.5 x %cover 11-20%)+(6 x %cover 21-50%)+(9 x %cover 51-80%)+(12 x %cover >80%))/100.*** The "early warning trigger" for initiating management action is a trend of a decreasing Seagrass Coefficient.

Saltmarsh. A variety of saltmarsh species (commonly dominated by rushland but including scrub, sedge, tussock, grass, reed, and herb fields) grow in the upper margins of most NZ estuaries where vegetation stabilises fine sediment transported by tidal flows. Saltmarshes have high biodiversity, are amongst the most productive habitats on earth and have strong aesthetic appeal. Where saltmarsh cover is limited, these values are decreased. The "early warning trigger" for initiating management action is <5% of the estuary as saltmarsh.

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 protects against introduced weeds and grasses, naturally filters sediments and nutrients, and provides valuable ecological habitat. The "early warning trigger" for initiating management action is <50% of the estuary with a densely vegetated margin.

In addition to the above ratings, a suite of arbitrary "change" indicators are proposed (Table 4) based on the common sense basis that an increase in problem expressions, or the loss of valued habitat features, is undesirable, and that the greater the loss, the more undesirable the change. The change ratings are primarily intended to highlight trends in condition and act as a trigger for targeted investigation as appropriate. In the future, development of comprehensive indicator-response relationships are envisaged for a range of estuary types.

Table 4. Summary of estuary condition risk indicator "change" ratings used in the present report.

INDICATOR	RISK RATING BASED ON PERCENT CHANGE FROM BASELINE				
	Very Low	Low	Moderate	High	Very High
Soft Mud Extent	0% (or decline)	<5% increase	5-15% increase	16-50% increase	>50% increase
Dense (>50%) Macroalgal Cover					
Gross Eutrophic Conditions					
Seagrass	0% (or increase)	<5% decrease	5-15% decrease	16-50% decrease	>50% decrease
Saltmarsh			5-10% decrease	11-50% decrease	
200m Vegetated Terrestrial Margin					

Notes for Table 4:

Soft mud in estuaries decreases water clarity, lowers biodiversity and affects aesthetics and access. Increases in the area of soft mud indicate where changes in catchment land use management may be needed.

Increases in the area of **dense (>50%) macroalgal cover** indicate changes in catchment land use management are likely to be needed. Because extensive cover of dense macroalgae is commonly associated with gross eutrophic conditions that can be very difficult to reverse, even relatively small changes from baseline conditions should be evaluated as a priority.

Increases in the area of **gross eutrophic conditions** indicate changes in catchment land use management are likely to be needed. Because of the highly undesirable and often rapidly escalating decline in estuary quality associated with gross eutrophic conditions, even relatively small changes from baseline conditions should be evaluated as a priority.

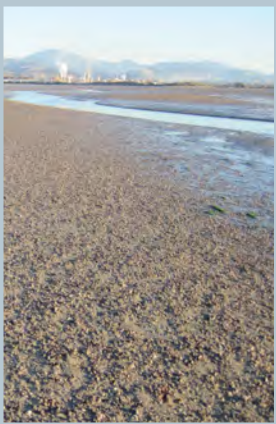
Seagrass is vulnerable to fine sediments in the water column, rapid sediment deposition, poor sediment quality (particularly reduced oxygen or production of sulphide), excessive macroalgal growth, high nutrient concentrations, and reclamation. Decrease in seagrass extent is likely to indicate an increase in these types of pressures.

Saltmarshes are sensitive to a wide range of pressures including land reclamation, margin development, flow regulation, sea level rise, grazing, wastewater contaminants, and weed invasion. Decrease in saltmarsh extent is likely to indicate an increase in these types of pressures.

Estuaries are sensitive to a wide range of pressures including land reclamation, margin development, flow regulation, sea level rise, grazing, wastewater contaminants, and weed invasion. Reduction in the **vegetated terrestrial buffer** around the estuary is likely to result in a decline in estuary quality.

4. RESULTS AND DISCUSSION

BROAD SCALE MAPPING



Soft mud, extensive cockle flats, and tubeworm/mussel reef - Waimea Inlet, 2014.

Six main habitats were identified in the 2014 broad scale habitat mapping (Table 5). As expected for a shallow tidal lagoon estuary, the habitats were dominated by unvegetated intertidal flats (77% of estuary), subtidal waters (15%) and saltmarsh (8% of estuary). In comparison, the extent of opportunistic macroalgal beds (2%) and seagrass (1%) habitat was relatively small. The mapping also showed that only 22% of the 200m wide terrestrial margin was densely vegetated.

- 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.
- In addition, it is acknowledged that underlying this written report, are the supporting GIS files that provide a highly 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.

Table 5. Summary of dominant broad scale features in Waimea Inlet, 2014.

Dominant Estuary Feature		Ha	% of Estuary
1.	Intertidal flats (excluding saltmarsh)	3005	77%
2.	Opportunistic macroalgal beds (>50% cover) [included in 1. above]	59	2%
3.	Seagrass (>50% cover) [included in 1. above]	34	1%
4.	Saltmarsh	303	8%
5.	Subtidal water	602	15%
Total Estuary		**3910**	**100%**
6.	Terrestrial Margin - % of 200m wide estuary buffer that is densely vegetated (shrub, forest)		22%

NOTE: Previous broad scale results all differ slightly due to the use of variable methods and estuary boundaries, so have not been included here.

4.1. INTERTIDAL FLATS (EXCLUDING SALTMARSH)

Results (summarised in Table 6 and Figure 4) show firm sand and soft muds were the dominant substrates in Waimea Inlet (49% and 40% of the intertidal area respectively), Other prominent habitats included; cobble/gravel fields (10%), biogenic features e.g. worm, oyster, and shell beds (0.6%), and large cockle beds (0.7%). In general terms, the sand dominated substrates and biogenic reefs tended to be most common near both estuary entrances and around lower estuary channels that have a high degree of flushing. Soft muds tended to be concentrated in the mid-upper intertidal basins and embayments in both arms (Figure 5). Cobble and gravel fields were more common in the upper tidal reaches, particularly near river and stream deltas (Figure 4).

Table 6. Summary of dominant intertidal substrate, Waimea Inlet, 2014.

Dominant Substrate	Area Ha	Percentage	Comments
Artificial Structures	7.2	0.2%	Predominantly steep faced rock and earth margins of reclaimed land and roads.
Cobble field	222.6	7.4%	Extensive throughout the upper reaches and near river and stream deltas.
Gravel field	61.0	2.0%	As above. Also common adjacent to reclaimed shorelines.
Oyster reef	11.8	0.4%	Most extensive near estuary entrances, and along muddy channel margins
Sabellid field	1.8	0.1%	Narrow reefs on channel banks, mostly in the lower eastern arm of the estuary.
Shell bank	5.7	0.2%	Predominantly in upper tidal reaches near established cockle beds.
Cockle bed	20.2	0.7%	Most extensive in the eastern arm, in sandy habitat near well flushed tidal channels.
Mobile sand	608.3	20.3%	Most common near channel margins by the estuary entrances.
Mobile mud/sand	29.7	1.0%	Most common near channel margins by the estuary entrances.
Firm sand	156.7	5.2%	Most common near channel margins by the estuary entrances.
Soft sand	0.2	0.0%	Predominantly in the upper intertidal zone by the eastern estuary entrance.
Firm mud/sand	682.0	22.7%	Commonly raised, well flushed, mid-intertidal tidal flats, and among saltmarsh.
Soft mud/sand	645.8	21.5%	Most common as tidal flats in the mid-upper tidal reaches of the estuary.
Very soft mud/sand	551.1	18.3%	Concentrated in deposition zones in the mid-upper tidal reaches, and channel margins.
TOTAL	**3005**	**100**	

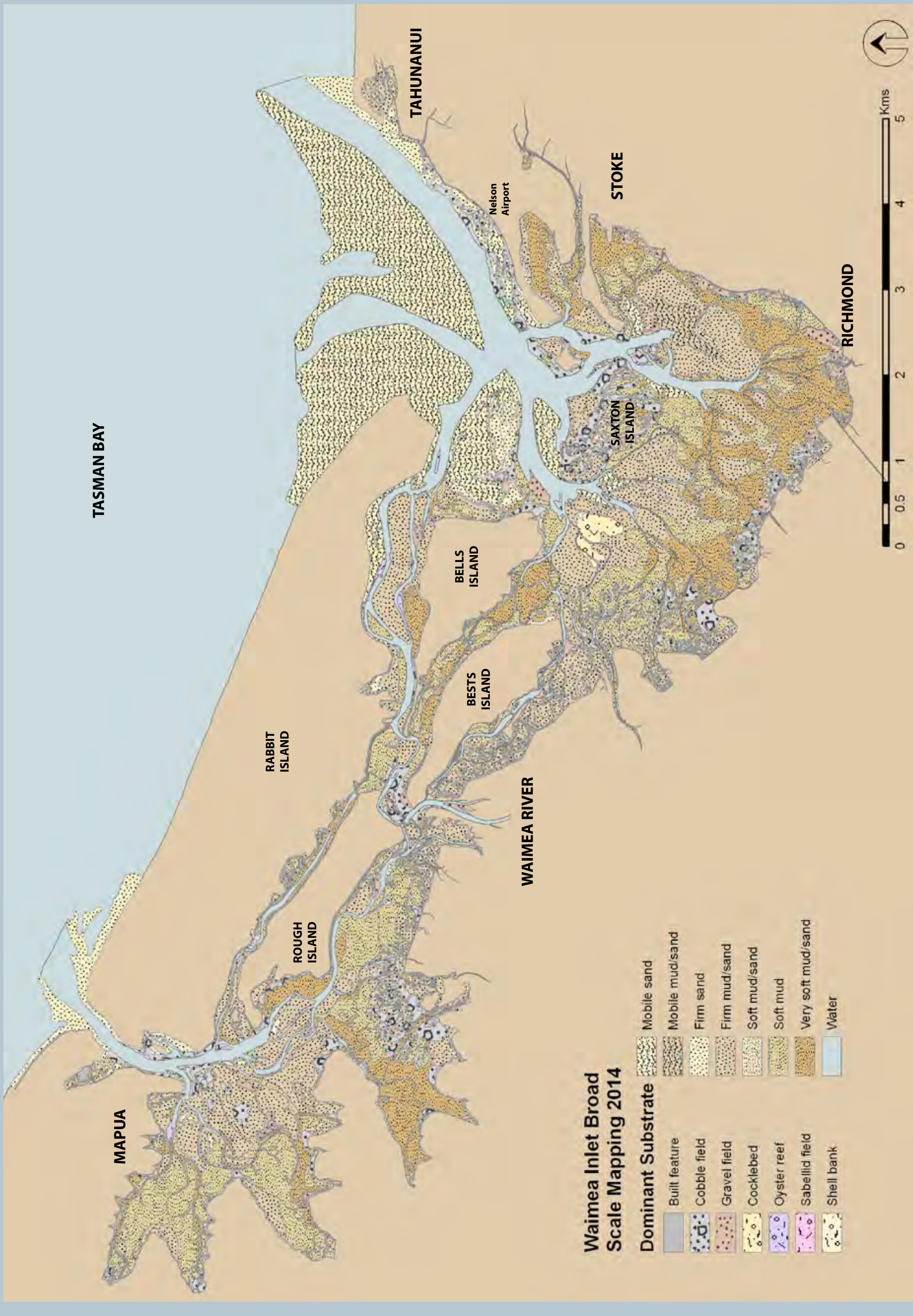


Figure 4. Map of dominant substrate types - Waimea Inlet, 2014.

Soft Mud Habitat

Of the unvegetated intertidal habitats, the combined extent of the soft mud (SM) and very soft mud (VSM) habitats have been chosen as the primary indicator of fine sediment (or increased muddiness) impacts and used to delineate deposition zone boundaries. This choice reflects the fact that where soil erosion from catchment development exceeds the assimilative capacity of an estuary, impacts such as increased muddiness and turbidity, shallowing, increased nutrients, changes in saltmarsh and seagrass habitats, reduced sediment oxygenation, increased organic matter degradation by anoxic processes (e.g. sulphide production), and alterations to fish and invertebrate communities can result. Also, because contaminants are most commonly associated with finer sediment particles, extensive areas of fine soft muds provide a sink which concentrate catchment contaminants.

As indicated above, SM and VSM habitats were concentrated in deposition zones in the mid-upper intertidal basins and embayments in both arms (Figure 5) and, although such zones are now common in NZ estuaries with developed catchments, the proportion of the intertidal area accumulating fine sediment in Waimea Inlet was very high compared with other NZ tidal lagoon and delta estuaries (Figure 6) - risk indicator rating "very high".

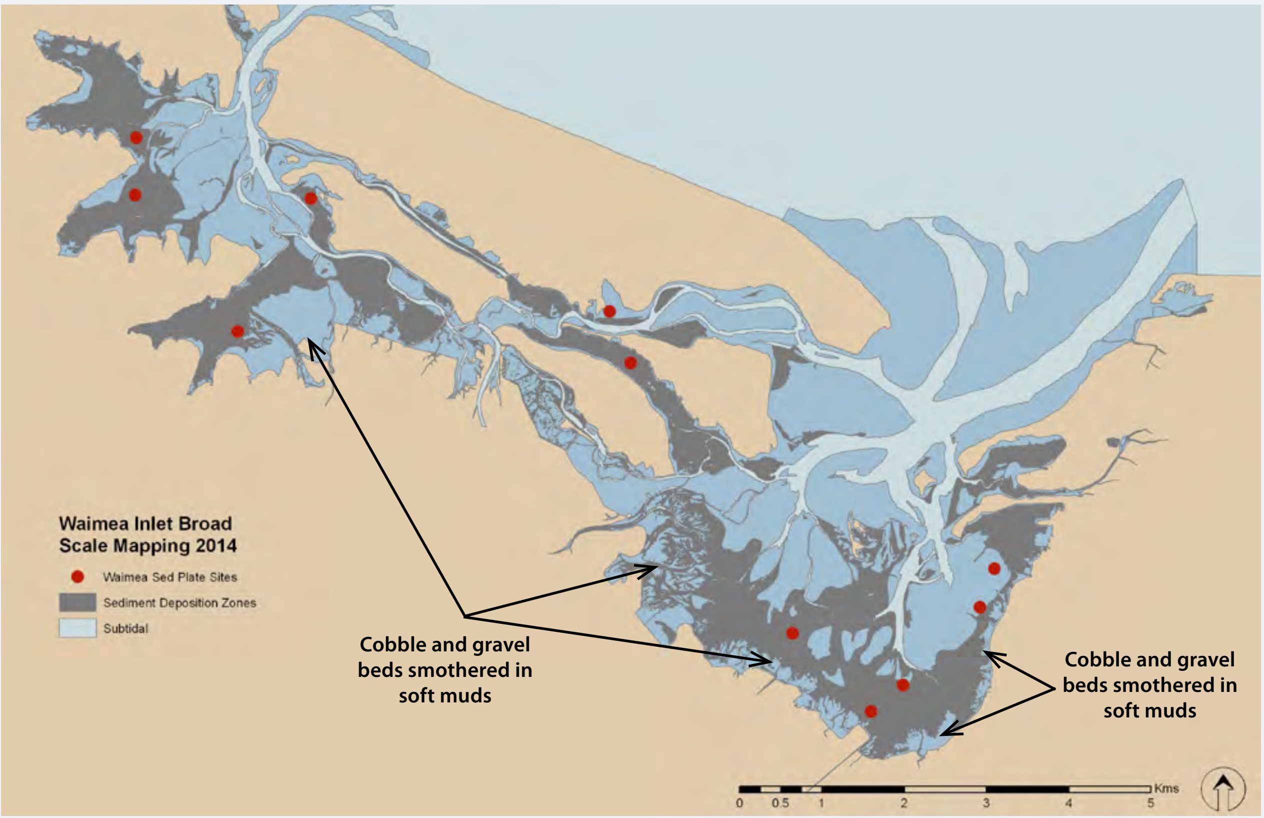


Figure 5. Dominant sediment deposition zones and sediment rate monitoring sites - Waimea Inlet, 2014.

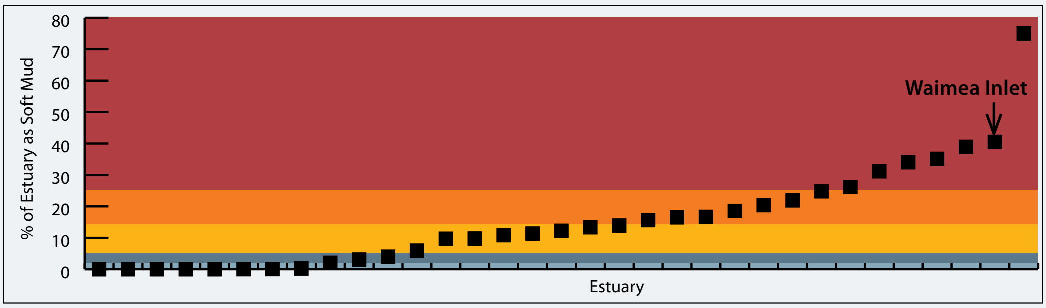


Figure 6. Percentage of estuary with soft mud habitat for 33 typical NZ tidal lagoon and delta estuaries. (intertidal dominated, shallow, residence time <3 days - data from Wriggle monitoring reports 2006-2013 and Robertson et al. 2002).

Examples of fine sediment deposition over gravel beds (a,b,c), firm sands (d), mobile sands (e), cockle beds (f) and deep accumulations of mud in the airport embayment (g) - Waimea Inlet, 2014.

SOFT MUD % COVER RISK INDICATOR RATING
1990 VERY HIGH (43%)
1999 VERY HIGH (43%)
2014 VERY HIGH (40%)

Changes in Estuary Soft Mud 1990, 1999, 2014

An analysis of the percent cover of major substrate classes in Waimea Inlet (using 1990, 1999 and 2014 broad scale mapping results) showed that the extent of the combined SM and VSM habitat (i.e. deposition zones) has been generally consistent for at least the last 25 years (1990, 1137ha; 1999, 1105ha; 2014, 1197ha) (Table 7). This likely reflects a hydrodynamic boundary, with tidal flushing maintaining the majority of the lower estuary in a predominantly sandy condition.

Table 7. Broad substrate categories, Waimea Inlet, 1990, 1999 and 2014.

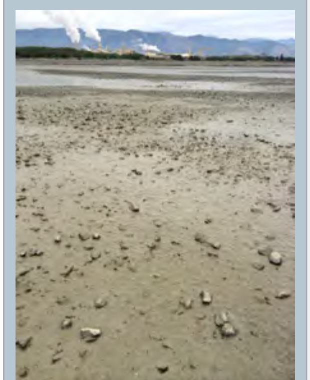
Substrate Class	1990		1999		2014	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Boulder/Cobble/Gravel	197	7%	253	10%	291	10%
Shell/Oyster/Mussel/Tubeworm	-	-	38	1%	40	1%
Firm Sands and Muddy Sands	1333	50%	1157	45%	1477	49%
Soft Muds	1137	43%	1095	43%	646	22%
Very Soft Muds			10	<1%	551	18%
TOTAL	2667	100%	2552.3	100%	3005	100%

However, while the total area of combined SM and VSM appeared to be relatively stable, there has been a notable shift from SM to VSM substrate since 1999 (10ha of VSM in 1999, to 551ha of VSM in 2014). Our limited understanding at present suggests that a shift from SM to VSM indicates a change in physicochemical conditions (e.g. increased mud content, reduced oxygenation, etc.) and consequent adverse impacts to macroinvertebrates. It follows therefore that detailed investigations, aimed at quantifying differences between SM and VSM habitat, are required to validate the expected detrimental changes.

Supporting the likelihood of increases in mud content in Waimea was the fact that a shift in muddiness was also measured (as a change in % mud content) at the four fine scale sites in the estuary. At these sites mud content increased by 24-176% since 2001 (Robertson and Robertson 2014). In addition, anecdotal observations over the past 5 years indicate that, after rain events, there are regular fresh mud deposits on the tidal flats adjacent to many of the smaller streams discharging into the eastern arm. In such locations, at least 30ha of cobble/gravel/cockle habitat was noted as covered in fine muds during the 2014 broad scale mapping. The photos on page 13 highlight the types of fine sediment impacts observed, including burial of cockle beds.

In terms of impacts to estuarine biology from the increase in mud, the broad scale mapping clearly identified several affected habitats:

- Increased presence of the invasive pacific oyster (*Crassostrea gigas*) as a dominant habitat in the estuary since 1999. Pacific oysters appear to preferentially establish in the muddy areas of Waimea Inlet, and once established, their reef structures filter and trap fine muds creating localised conditions that promote cumulatively greater mud trapping and retention.
- Seagrass beds have declined considerably since 1990 (see subsequent seagrass section).
- The introduced common cordgrass, *Spartina anglica*, was introduced into Waimea Estuary in 1948 and grew to occupy ~100ha of previously unvegetated mid-highwater habitat. Its primary action in terms of estuary muddiness was to facilitate mud deposition and reduce subsequent resuspension, and therefore improve water clarity. It was progressively eradicated in the late 1980's and early 1990's. In 1990 it was still present on 29ha (Davidson and Moffat 1990). Since 2001, it has been virtually absent from the estuary. In 2014, the broad scale mapping showed that the eroding mounds of accumulated mud and root systems of the old *Spartina* beds were relatively sparse, indicating that the eroded sediment from the mounds had likely been transported to nearby unvegetated sediment deposition zones.



Deep soft muds in the eastern basin, and soft muds within oyster reef, and cobble in the Bark Processors declamation.

In terms of other unvegetated habitat changes, a relatively small but significant substrate change has been the removal of ~6.5ha of reclaimed land adjacent to the Bark Processor's site in Lower Queen Street in ~2009. Following its return to intertidal cobble habitat, the 2014 survey showed some fringing saltmarsh was establishing (both naturally and following planting initiatives), although the margins of the declamation were covered in fine mud.

Rate of Infilling

Although not measured in the 2014 broad scale assessment, the rate of infilling of the estuary is an important factor in the soft mud accumulation analysis, particularly in the deposition basins. Estimates from three sources indicate that the current rate is approximately 1-2mm/yr, but one source indicates rates pre 1964 were much higher, as follows:

1. Radio-isotope dating estimates from 2 sediment cores from sediment deposition zones within the estuary in 2011 indicate an infilling rate of 1-2mm/yr since 1964, and >10mm/yr in the western arm in the 1950's-1960's when catchment orchard blocks were being developed (Stevens and Robertson (2011).
2. Since 2008, sedimentation rate monitoring of multiple sediment plates at sites throughout Waimea Inlet (including some within sediment deposition zones - Figure 5) shows an average sedimentation rate of <1mm/yr.
3. A "ballpark" prediction of the mean rate of infilling of 1-3mm/yr was estimated from the predicted suspended sediment (SS) input load (121kt.yr^{-1} CLUES Model, default settings), minus the estimated SS export load to the sea (this is currently unknown, but based on expert opinion is likely to vary between 20-80% of the input load). Based on these assumptions, a "ballpark" mean infilling rate of between 0.7-2.6mm/yr is predicted.

Note: actual rates in particular locations in the estuary are likely to vary over a larger range, with the dominant sediment deposition zones (including saltmarsh) accumulating more (3-8mm/yr), and the other areas less (0.5-1mm/yr).

Such findings indicate that the current "ballpark" infilling rate is in the "moderate" category, and that most of the fine sediment entering the estuary is historical (pre-1964).

Catchment Sources of Sediment

In terms of the source of the fine sediments to the estuary, the current study was not designed to address this aspect. Previous investigations (Stevens and Robertson 2010) however, suggest that the main inputs were from historical catchment development and areas with ongoing inadequate soil conservation practices, and that the muddiness is exacerbated by the presence of post-glacial silt deposits within the catchment. Recent large flood events in December 2011 and April 2013 are also likely to have transported significant loads of sediment to the estuary and Tasman Bay.

Overall, the results clearly indicate a significant muddiness issue in Waimea Estuary which requires further attention. A summary of the issue, and recommended actions to address it, are presented in Sections 7, 8 and 9.

4. RESULTS AND DISCUSSION (CONTINUED)

4.2. OPPORTUNISTIC MACROALGAE

100% macroalgal (*Gracilaria*) cover in the eastern arm of Waimea Inlet March, 2014.

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

The spatial cover of intertidal macroalgae in Waimea Inlet in March 2014 is presented in Figure 7, with the Opportunistic Macroalgal Blooming Tool (OMBT) used to measure and rate the spatial extent, density, biomass, and degree of sediment entrainment of macroalgae within the affected intertidal area. The measures each have quality status threshold bands (i.e. bad, poor, good, moderate, high - Section 3, Table 3) that combine to produce an overall "Ecological Quality Rating (EQR)" ranging from zero (major disturbance) to one (reference/minimally disturbed). Appendix 2 provides a detailed description of the methods, definitions, and fully worked EQR calculations. Summary results and definitions are presented in Tables 8 and 9, and the final scoring and quality ratings in Table 10.

Table 8. Results of opportunistic macroalgal cover, biomass, and entrainment, Waimea Inlet, 2014.

Percentage Cover Band	Area (ha)	Nominal % Cover	Algal Area (ha)	Average biomass (g.m^{-2})	Total Biomass (kg)	Area Containing Entrained Algae (ha)	Area of Entrained Algae (ha)
0-5%	44.6	1	0.4	70	31220	0	0
>5-15%	66.0	10	6.6	193	127380	36.2	3.6
>15-25%	14.6	20	2.9	226	32979	11.5	2.3
>25-50%	18.0	37.5	6.8	240	43227	6.1	2.3
>50-75%	9.1	62.5	5.7	871	79075	8.3	5.2
>75%	50.1	87.5	43.9	2287	1146510	18.7	16.4
TOTALS	202.4	-	66.3	-	1460391	80.8	29.8

Table 9. Values used in the normalisation and re-scaling of face values to EQR metric for Waimea Inlet.

AIH - Available Intertidal Habitat (ha)*	2451	ha
Percentage cover of AIH (%) = (Total % Cover / AIH} x 100 - *where Total % cover = Sum of {(patch size) / 100} x average % cover for patch*	2.7	%
Biomass of AIH (g.m^{-2}) = Total biomass / AIH - *where Total biomass = Sum of (patch size x average patch biomass)*	59.6	g.m^{-2}
Biomass of Affected Area (g.m^{-2}) = Total biomass / AA - *where Total biomass = Sum of (>5% cover patch size x average patch biomass)*	906	g.m^{-2}
Presence of Entrained Algae = (No. quadrats or area (ha) with entrained algae / total no. of quadrats or algal area (ha)) x 100	45	%
Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%). Highlighted in yellow cells in Table 9 above.	157.8	ha
Size of AA in relation to AIH (%) = (AA / AIH) x 100	6.4	%

*= mapped intertidal total (3910ha) minus: saltmarsh (303ha), coastal mobile sand deltas (554ha), and subtidal habitat (602ha)

Table 10. Results of the normalisation and re-scaling of face values to EQR metric for Waimea Inlet.

Metric	Face Value	Quality Status	Calculation of Final Equidistant Score (FEDS) using Table A4-3		FEDS
% Cover of AIH (%)	2.7	HIGH	FEDS:1-(2.7-0)/5)*0.2=		0.89
Biomass of AIH (g.m^{-2})	59.6	HIGH	FEDS:1-((59.6-0)/100)*0.2=		0.88
Biomass of Affected Area (g.m^{-2})	906	MODERATE	FEDS:0.6-((906-500)/499.9999)*0.2=		0.44
Presence of Entrained Algae (%)	45	POOR	FEDS:0.4-((45-20)/29.9999)*0.2=		0.23
Affected Area (use the lowest of the following two metrics)		POOR			0.32
Affected Area (ha)	157.8	POOR	FEDS:0.4-((157.8-100)/149.9999)*0.2=	0.32	
Size of AA in relation to AIH (%)	6.4	GOOD	FEDS:0.8-((6.4-5)/9.9999)*0.2=	0.77	
Ecological Quality Rating - EQR (Average of FEDS)		**MODERATE**			**0.55**

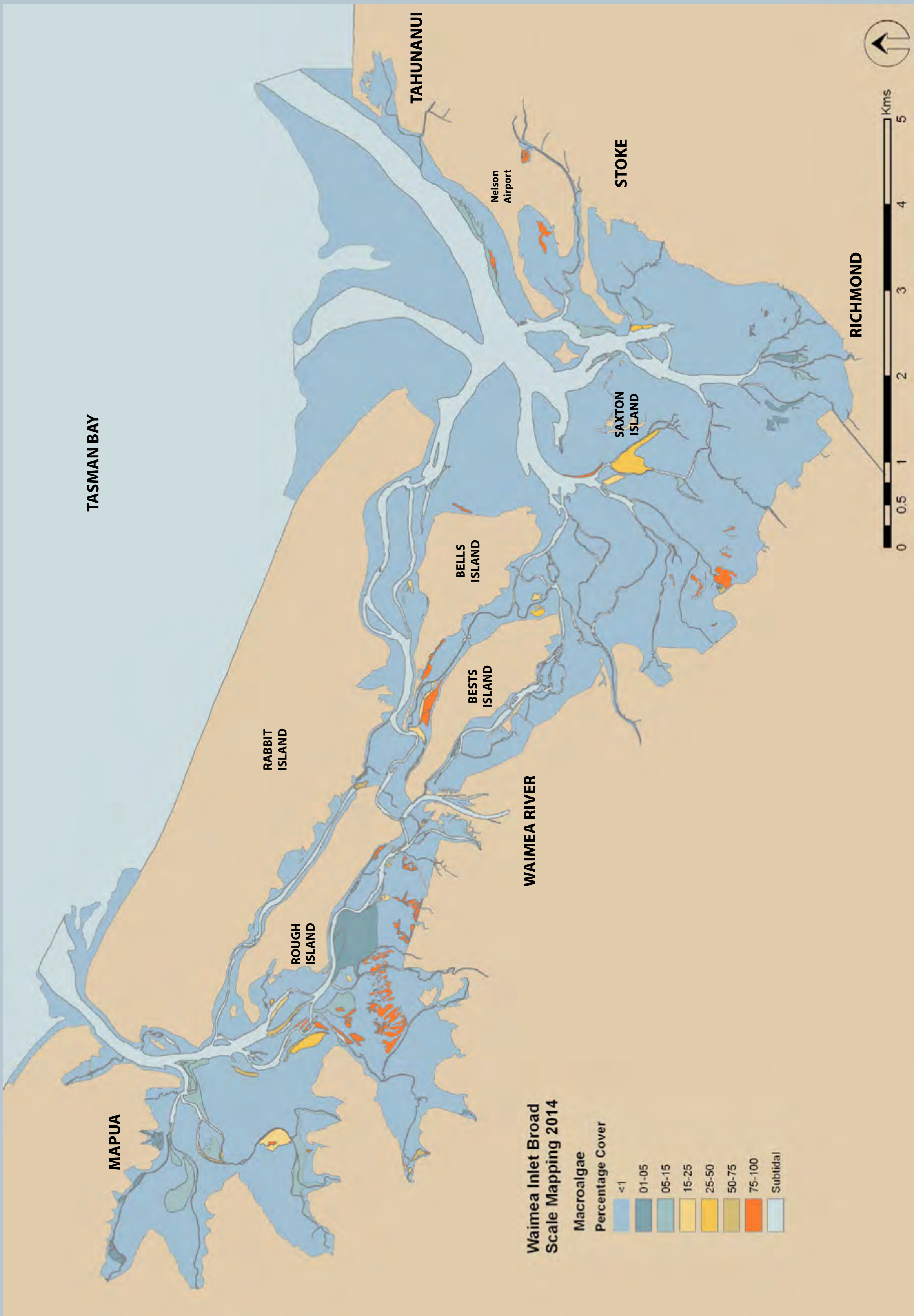


Figure 7. Map of Macroalgal Cover - Waimea Inlet, March 2014.

OPPORTUNISTIC MACROALGAL BLOOMING TOOL RISK INDICATOR RATING

2014 MODERATE (0.55)

DENSE MACROALGAE RISK INDICATOR "CHANGE" RATING

1990-2014 VERY HIGH

OMBT assessment of %cover, wet weight (biomass), and extent of macroalgal entrainment in sediment.

Overall, the results of the opportunistic macroalgal mapping show:

- The majority of the intertidal area (94%) had <5% macroalgal percentage cover.
- There was a significant area of high-very high (>50%) nuisance macroalgal cover (59ha) at various locations throughout the estuary - see Figure 7.
- The dominant macroalgae were the green alga *Ulva lactuca* (which grows rapidly throughout the estuary and in channel areas wherever substrate allows and growing conditions are favourable), and the red alga *Gracilaria chilensis* (growing predominantly in soft muds within deposition zones).
- High density macroalgal cover commonly coincided with the presence of soft, poorly oxygenated muds, particularly among dense beds of *Gracilaria* growing in the upper intertidal reaches of both arms.
- Growths of low density macroalgae were greater in the lower eastern arm compared to the western arm and were generally concentrated near channel areas in the lower tidal reaches.

The Opportunistic Macroalgae Blooming Tool results (Table 10) rated the overall influence of macroalgae in Waimea Inlet at the upper end of the "MODERATE" category. This rating was driven primarily by the vast bulk of the estuary not exhibiting opportunistic macroalgal problems (reflected in the "HIGH" quality status of low average % cover and biomass in the available intertidal habitat, and the "GOOD" rating of the affected area (AA) in relation to the available intertidal habitat (AIH)). These values were then offset by the "MODERATE" and "POOR" quality status in areas where opportunistic macroalgae have established in the estuary (e.g. a relatively large area affected, high degree of entrainment in sediment, and high biomass). These results indicate that while the estuary overall is not expressing significant symptoms of eutrophication, there are localised nuisance areas causing adverse impacts. These areas of gross nuisance condition are discussed on page 18.

Changes in Opportunistic Macroalgal Cover 1990 - 2014

Although the EQR cannot be applied retrospectively due to data insufficiencies, the summary results of Davidson and Moffat (1990) indicate that dense growths of opportunistic macroalgae were likely to have been present over ~15ha of the estuary in 1990, located predominantly in the mid-lower reaches of the western arm. In contrast, the 2014 coverage of ~60ha was 4x higher and concentrated in the eastern arm. Although macroalgal cover was not accurately mapped in 1999 and 2006, a quick review of the 1999 and 2006 aerial photographs indicate dense beds of opportunistic macroalgae were present in the eastern arm in 1999, had increased in extent from 1999 to 2006, and increased again from 2006 to 2014. Remapping and reanalysing the previous results would enable indicative areas of growth to be enumerated.

The most significant expansion of macroalgae appeared adjacent to the MDF plant/ Bark Processor's sites in the eastern arm with dense beds of *Gracilaria* establishing and expanding in the upper tidal reaches. Additional areas of nuisance growth are in the causeway constricted embayments near Nelson Airport, between Bests and Bells Islands, and in settlement basins east of Bests Island and Hoddy Peninsula. North of Jimmy-Lee Creek, sparse growths are becoming entrained in sediment and have the potential to develop into nuisance areas.

The dense macroalgal beds in the estuary are currently in a poor condition with 100% cover of algae smothering anoxic (oxygen starved) sediments which smell strongly of hydrogen sulphide. These conditions indicate rotting algae are creating nuisance conditions toxic to most animals, and are also likely to be releasing sediment bound nutrients that will fuel further opportunistic growths and ongoing nuisance conditions.

The steady expansion of dense nuisance macroalgal growth since 1990, primarily in soft sediment depositions areas in the eastern arm, fits within a risk indicator "change" rating of "VERY HIGH".

GROSS EUTROPHIC AREA RISK INDICATOR RATING

2014 HIGH (28ha)

GROSS EUTROPHIC AREA RISK INDICATOR "CHANGE"RATING

1990-2014 VERY HIGH

Gross Eutrophic Conditions

When sediments exhibit combined symptoms of high macroalgal growth (>50% cover), a high mud content, a shallow RPD, elevated nutrient and organic concentrations, and displacement of invertebrates sensitive to organic enrichment, they represent gross eutrophic conditions. These conditions will kill or displace most estuarine animals and shellfish, and also release sulphides and nutrients (primarily ammonia and dissolved phosphorus, which are much more readily available to fuel macroalgal growth) from the sediments, leading to a cycle of increasing habitat deterioration which is very difficult to reverse. These conditions are most likely to occur on the relatively sheltered tidal flats of an estuary, areas that are also those most favourable for high value habitat including seagrass and shellfish beds.

A risk indicator rating has been developed that recognises that gross eutrophic conditions should not be present in short residence time estuaries (like Waimea Inlet), with their presence providing a clear signal that the assimilative capacity of the estuary is being exceeded. The 2014 risk rating places the estuary in the "HIGH" category with 28ha of the estuary in a degraded state. The most degraded sites are concentrated in natural deposition zones within the estuary (Figures 8 and 9), where the combined influence of flocculation at the saltwater/freshwater interface, relatively sheltered tidal flats (dissipating flow velocities), and limited tidal flushing, all serve to concentrate catchment inputs of sediments and nutrients, and provide suitable conditions for the growth of opportunistic macroalgae. While not formally enumerated due to a lack of previous ground-truthed data, personal observations of changes within the estuary, combined with historical aerial photographs, indicate that the extent of gross eutrophic areas has increased by >50% since 1990, a risk indicator "change" rating of "VERY HIGH". It is recommended that any localised sources potentially contributing to the development of degraded conditions be assessed.

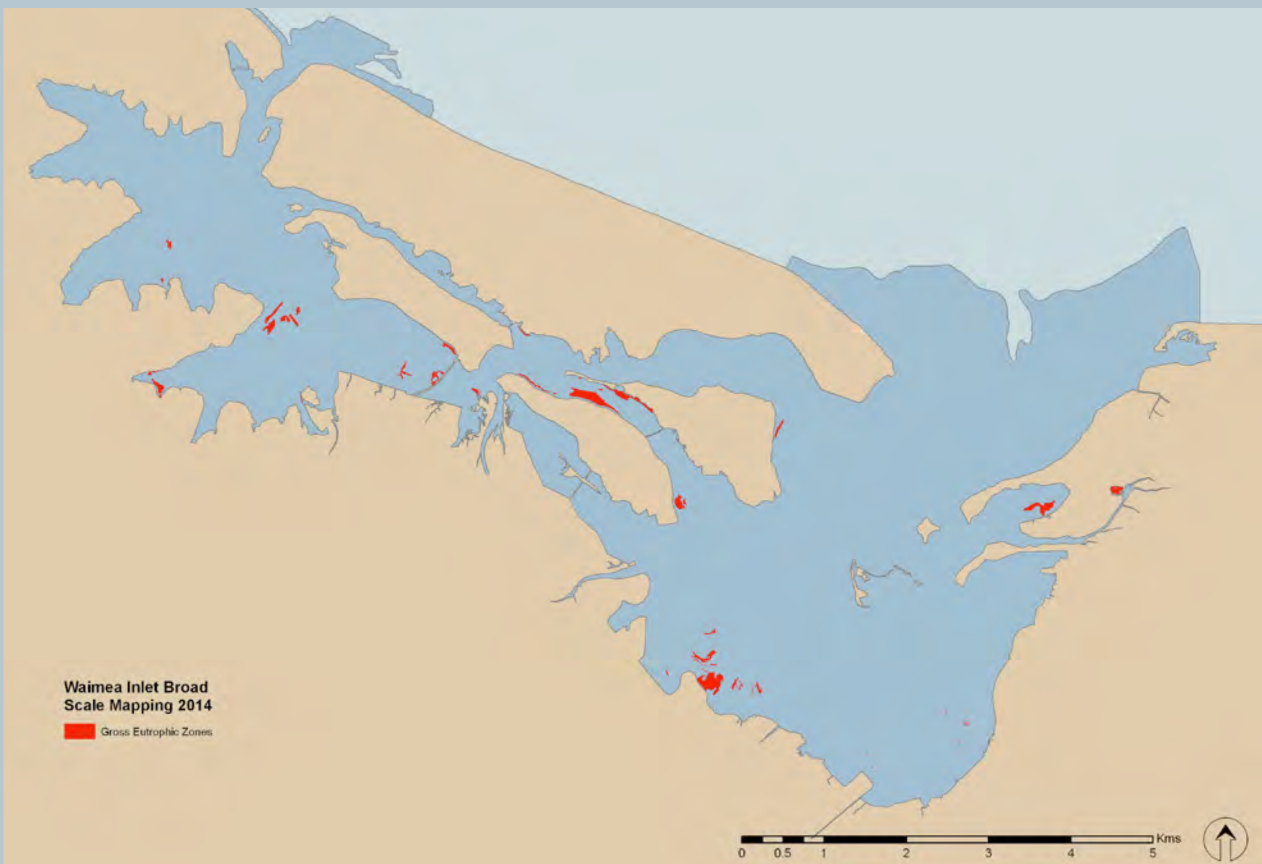
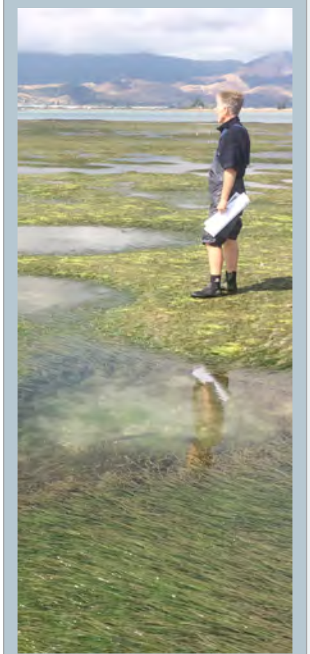


Figure 8. Location of gross eutrophic zones - Waimea Inlet, 2014.

Figure 9. Examples of gross eutrophic zones within Waimea Inlet showing extensive cover (top), excessive muddiness and high sulphide/low oxygen sediment conditions (middle), and smothering by dense macroalgal growth (bottom).

4.3. SEAGRASS

Seagrass beds adjacent to Saxton Island.



Seagrass beds adjacent to Bells Island, with localised area of mud covered 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 11 and Figure 10 summarise the results of the 2014 survey of the available seagrass habitat (mapped estuary area minus saltmarsh).

- The majority of the estuary (97%) had no seagrass growing.
- 34ha of seagrass beds with >50% cover were present. These beds were located primarily near the well flushed entrance channels and central basin of the eastern arm (e.g. west of Saxton Island, east of Bells Island, west of the Nelson airport peninsula).
- When present, seagrass beds appeared in relatively good condition, although in March 2014, ~3ha of seagrass beds on the Bells Island sandflats were overlain with soft mud (lower sidebar photo).
- Seagrass appears unable to establish within estuary deposition zones, most likely due to a combination of excessive muddiness and associated poor water clarity.

The Seagrass Coefficient (SC) was 0.13, a risk indicator rating of "VERY HIGH", signifying a very small area of seagrass in relation to the available habitat in the estuary.

Table 11. Summary of seagrass *(Z. muelleri)* cover, Waimea Inlet, March 2014.

Percentage Cover	Area (ha)	Percentage
0	3497	97.0
1-5%	61.4	1.7
5-10%	0.0	0.0
10-20%	6.2	0.2
20-50%	7.6	0.2
50-80%	10.7	0.3
>80%	23.5	0.7
	3607	**100**

SEAGRASS COEFFICIENT RISK INDICATOR RATING
2014 VERY HIGH (0.13)

SEAGRASS AREA RISK INDICATOR "CHANGE"RATING
1990-2014 HIGH (41%DECREASE)

Changes in Seagrass Cover 1990 - 2014

Mapping of the estuary using aerial photos from 1946 and 1985 was unable to distinguish seagrass boundaries due to poor photo resolution (Tuckey and Robertson 2003). The most accurate baseline of seagrass cover is therefore the mapping undertaken by Davidson and Moffat (1990), acknowledging that due to the already much modified nature of the estuary by 1990 the seagrass extent would have been significantly reduced from its natural state. In 1990 ~58ha of seagrass was reported, located predominantly in the eastern arm near the estuary mouth which is well flushed, largely free of mud, and regularly bathed with clean seawater. Robertson et al. (2002) reported 28ha of seagrass in 1999, although a quick review of the data and aerial photos indicates an additional 6-8ha of seagrass was present in lower channel areas but not mapped. The estimated 1999 cover is therefore ~35ha. Estimates of 2006 seagrass cover and losses reported in Clark et al. (2008) should not be used due to mapping errors. The 2014 seagrass mapping found that the location and extent (34ha) of dense seagrass beds was similar to 1999, but compared to 1990 had reduced in area by ~41%. One area of significant change was the loss since 1999 of ~4ha of seagrass fringing an area south/southwest of Saxton Island, with previously continuous beds now present only as small unconnected patches. Additionally a small area (<0.1ha) of seagrass was lost following the Monaco-Bells Island pipeline upgrade in 2012. Efforts by TDC to transplant seagrass disturbed during the upgrade were unsuccessful.

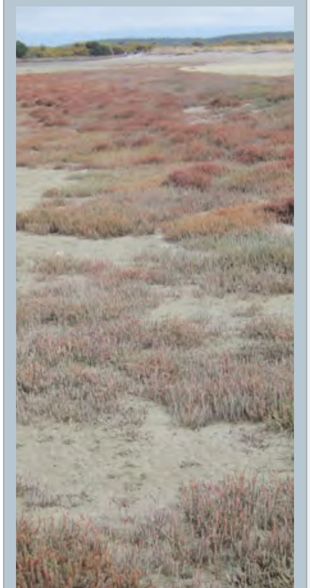
Based on the ~41% decline in dense (>50%) seagrass cover since 1990, a risk indicator "change" rating of "HIGH" has been estimated. If compared to a change from likely natural state conditions, the rating would be "VERY HIGH".

Figure 10. Map of Seagrass Cover - Waimea Inlet, 2014.

4.4. SALTMARSH

SALTMARSH % COVER RISK INDICATOR RATING

2014 MODERATE

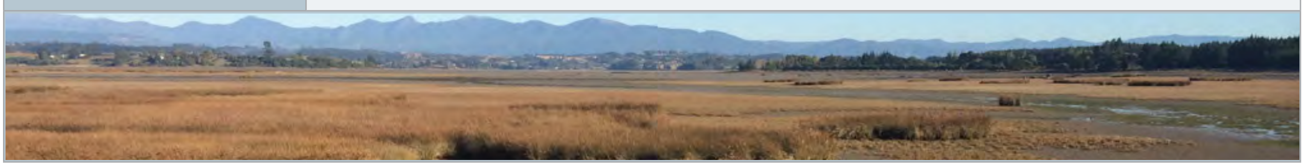


Saltmarsh (vegetation able to tolerate saline conditions where terrestrial plants are unable to survive) is important as it is highly productive, naturally filters and assimilates sediment and nutrients, acts as a buffer that protects against introduced grasses and weeds, and provides an important habitat for a variety of species including fish and birds. Table 12 and Figure 11 summarise the results of the 2014 saltmarsh mapping. The area of remaining saltmarsh (303ha, 9% of the intertidal area) fits the risk indicator rating of "MODERATE". Key findings were:

- The most extensive saltmarsh areas were located in the relatively narrow arms either side of the Waimea River.
- The dominant saltmarsh was herbfield (56%), and rushland (34%), although estuarine tussock (5%) and saltmarsh ribbonwood (4%) dominated areas were also common.
- Introduced weeds were a common subdominant cover near the terrestrial margin.
- Saltmarsh extent has been significantly reduced by largely historical estuary drainage, reclamation and channelisation. Such activities are ongoing in terrestrial margin areas, and include bunding for the cycleway.
- Saltmarsh and margin reinstatement following recent realignment of SH60 has been completed in the northwest of the estuary (~0.3ha of the estuary directly affected).
- The filtering potential of the remaining saltmarsh is significantly compromised by the widespread presence of bunds and drains that direct terrestrial runoff directly into tidal channels.

Table 12. Summary of saltmarsh cover, Waimea Inlet, 2014.

Class	Dominant Vegetation	Area (ha)	Percentage
Estuarine Shrub		11.4	4%
	Plagianthus divaricatus (Saltmarsh ribbonwood)	11.4	4%
Tussockland		15.4	5%
	Austrostipa stipoides (Buggar grass)	15.4	5%
Sedgeland		0.1	0.04%
	Cyperus eragrostis (Umbrella sedge)	0.01	0.002%
	Schoenoplectus pungens (Three square)	0.1	0.04%
Grassland		3.5	1%
	Festuca arundinacea (Tall fescue)	3.5	1%
Duneland		1.5	0.5%
	Ammophila arenaria (Marram grass)	1.5	0.5%
Rushland		102.0	34%
	Juncus kraussii (Searush)	87.3	29%
	Apodasmia similis (Jointed wirerush)	14.7	5%
Reedland		0.01	0.004%
	Typha orientalis (Raupo)	0.01	0.004%
Herbfield		170.2	56%
	Sarcocornia quinqueflora (Glasswort)	169.1	56%
	Suaeda novaeûzelandiae (Sea blite)	0.8	0.3%
	Carpobrotus edulis (Ice plant)	0.2	0.1%
	Selliera radicans (Remuremu)	0.03	0.01%
	Samolus repens (Primrose)	0.02	0.01%
TOTAL		**303**	**100%**



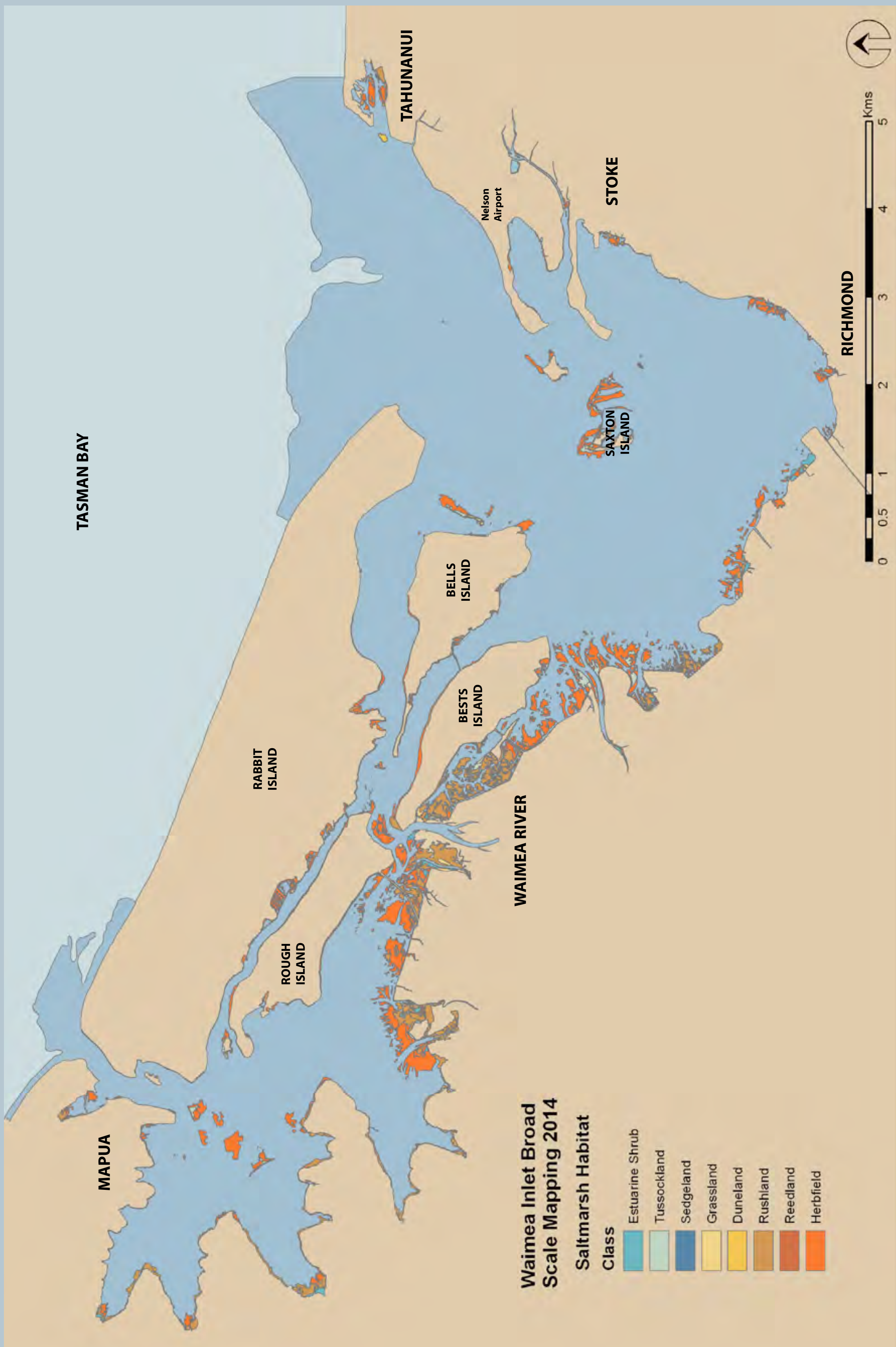


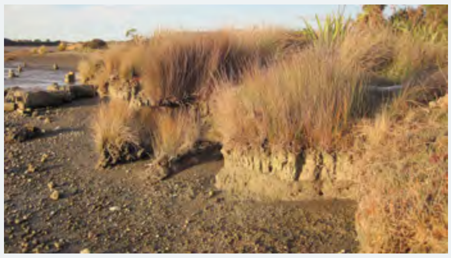
Figure 11. Map of Saltmarsh Vegetation - Waimea Inlet, 2014.

4. RESULTS AND DISCUSSION (CONTINUED)

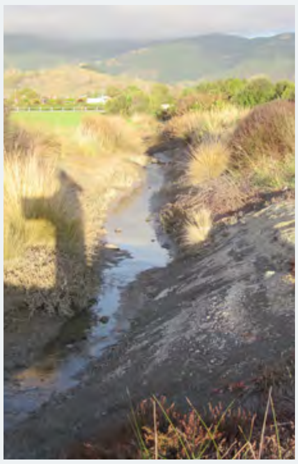
The estuary saltmarsh was characterised primarily by rushland in the upper intertidal reaches (often with a mix of saltmarsh ribbonwood, gorse, and introduced grass and weeds at the margins), and extensive glasswort herbfields common seaward of the rushland. There has been widespread planting of native trees at the estuary margin.

Because most of the eastern arm has been modified through reclamation or drainage, the now armoured shoreline prevents saltmarsh from establishing in many areas through a combination of inundation and wave erosion. Consequently, these modified margins create extensive barriers to the migration of saltmarsh in response to sea level rise (SLR), and are apparent around most of the eastern estuary.

Elsewhere naturally steep landforms flank the estuary with saltmarsh also likely to be eroded or inundated and displaced over time where inland migration is not possible.

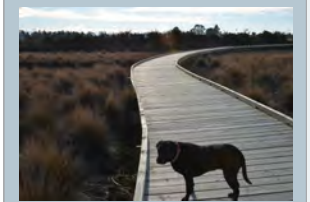


Other saltmarsh impacts have resulted from roading/ cycleway developments, causeways, embayments, and flapgating, culverting and stream channelisation.



SALTMARSH AREA RISK INDICATOR "CHANGE"RATING

1946-2014 HIGH (14% DECREASE)



Changes in Saltmarsh Cover 1946 - 2014

The risk indicator "change" rating for saltmarsh measures a percentage change from an established baseline. Table 13 summarises the reported extent of saltmarsh in Waimea Inlet at specified times since 1946. The 1946 data are used as the first documented baseline, but it is acknowledged that by this time only tiny fragments of the once extensive and continuous coastal forest, wetland and saltmarsh would have remained (Davidson and Moffat 1990).

The saltmarsh risk indicator rating of change from 1946 to 2014 is "HIGH" reflecting a 14% decrease in the area (ha) of saltmarsh. The key changes since 1946 appear predominantly associated with the loss of estuarine shrub, tussockland, rushland, and herbfield, primarily through reclamation and margin development. In particular, the industrial developments and construction of the Stoke - Richmond expressway through the east of the estuary displaced significant areas of saltmarsh and now presents a barrier to any subsequent expansion of saltmarsh habitat, a situation repeated in low-lying areas between lower Queen Street and the Waimea River developed for industrial, commercial, farming, and recreational uses.

The findings indicate no large recent losses of saltmarsh which is consistent with a changing appreciation of the values of retaining/enhancing saltmarsh and wetland habitat for a multitude of ecological reasons, as well as human ecological service purposes including erosion protection, sediment trapping, and nutrient assimilation.

Because saltmarsh around the estuary has already been greatly reduced, further reductions of this important habitat are highly undesirable. However, ongoing margin development is obvious on private land adjacent to the estuary in many areas and further drainage and reclamation, or expansion of the already extensive flood protection bunds, will see the loss of remaining low lying areas needed by saltmarsh and flanking wetlands. Such areas will be very important in the future as predicted sea level rise (SLR) will force saltmarsh inland, and if it is unable to migrate into suitable areas, then the saltmarsh which buffers the estuary from sediment and nutrients, provides high value wildlife habitat, and mitigates flooding impact, will be lost. Disruption to the natural supply of gravel to the estuary from surrounding streams is also evident and if the reduced input of this substrate, essential for many saltmarsh plants, continues it may significantly impact on saltmarsh resilience to SLR.

It is also clear that there are a large number of private initiatives being undertaken to improve the quality of the estuary margin, particularly through the planting of native trees. Such actions should be encouraged wherever possible.

Table 13. Summary of reported saltmarsh cover, Waimea Inlet, 1946, 1985, 1990, 1999, 2006, 2014.

Vegetation Class	1946[1]		1985[1]		1990[2]		1999[3]		2006[4]		2014	
	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
Estuarine Shrub	16.0	0.6%	3.2	0.1%	-	-	3.3	0.2%	22.6	0.8%	11.4	0.3%
Tussockland	6.9	0.2%	7.0	0.3%	4.8	0.2%	9.5	0.5%	19.0	0.6%	15.4	0.5%
Sedgeland	-	-	-	-	-	-	0.1	0.0%	0.1	0.0%	0.1	0.0%
Grassland	-	-	-	-	-	-	0.4	0.0%	3.7	0.1%	3.5	0.1%
Reedland	-	-	43.5	1.6%	29.0	1.0%	0.01	0.0%	-	-	0.01	0.0%
Rushland	126.0	4.3%	96.0	3.5%	75.0	2.6%	98.0	5.2%	102.0	3.5%	102.0	3.1%
Herbfield	165.0	5.7%	120.0	4.4%	93.0	3.2%	123.0	6.5%	154.0	5.2%	170.2	5.1%
Unknown	38.5	1.3%	-	-	-	-	-	-	-	-	-	-
SALTMARSH (ha)	352	12%	270	10%	202	7%	234	12%	301	10%	303	9%
Corrected area (ha)[5]	352		uncertain		uncertain		~300		301		303	
INTERTIDAL (ha)	2909	-	2758	-	2869	-	1886	-	2940	-	3308	-

[1]Tuckey and Robertson (2003), [2]Davidson and Moffat (1990), [3]Robertson et al. (2002), [4]Clark et al (2008). Differences in classifications precludes direct comparison between different surveys. [5]Areas estimated from a synoptic revision of past mapping coverage/extent, reported results, and aerial photos.

4.5. 200M TERRESTRIAL MARGIN

VEGETATED MARGIN RISK INDICATOR RATING

2014 HIGH

VEGETATED MARGIN RISK INDICATOR "CHANGE"RATING

1999-2014 VERY LOW NO SIGNIFICANT CHANGE

Margin areas by the Stoke Expressway, Nelson airport, Monaco, Saxton Creek mouth, and the cycleway near Ravensdown.

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 mapping (Table 14 and Figure 12) showed:

- The mapped 200m wide terrestrial margin buffer was dominated by grassland (28%) and grass dominated parks and amenity areas (10%), residential/rural residential (22%), exotic forest (20%, located on Rabbit and Rough Islands), and industrial development (16%).
- Dense plantings of mixed native and exotic scrub and forest were sparse (2%).
- The vast majority of the estuary margin had been modified by roading, causeways, seawalls, reclamations, or land clearance - the eastern margin being almost completely modified from Tahanuanui to ~2km west of the Waimea River.

These results showed that only 22% of the terrestrial margin was densely vegetated in 2014 (fits the risk rating of "HIGH"), however this was likely an overestimate given that the majority was plantation forestry which has a much lower ecological value than the historical naturally vegetated margin. Aerial photos indicate no significant change in the terrestrial margin cover since 1999.

A dominant feature of the estuary margin was the extensive presence of roading or infrastructure, and associated erosion protection, along the estuary edge, particularly in the east. These developments have commonly resulted in a steepened and hardened shoreline, often with a vertical face along the edge of past reclamations, of which very little buffering vegetation remains on the landward side or seaward side. This shoreline hardening, combined with associated drainage of wetland areas and channelisation of streams, significantly adversely impacts on native fish spawning and bird habitat, and greatly compromises any natural capacity of the estuary to respond to climate change related sea level rise, and to assimilate and buffer against inputs of sediment and nutrients.

While there have been significant amenity planting initiatives along parts of the developed estuary margin, there is no escaping the fact that most of the low lying estuary fringes, where there was once a gentle natural transition from the estuarine to the terrestrial habitat, has been lost due to human development.

Table 14. Summary of 200m terrestrial margin land use, Waimea Inlet, 2014.

Class	Dominant Cover	Percentage
Forest		20.1%
	Exotic forest	19.8%
	Mixed native and exotic forest	0.3%
Scrub/Forest		0.3%
	Mixed native and exotic scrub/forest	0.3%
Scrub		1.7%
	Mixed native and exotic scrub	1.3%
	Native scrub	0.4%
Grassland		27.5%
	Pasture	24.1%
	Unmaintained introduced grass	3.4%
Park	Maintained park/amenity area	10.2%
Horticulture		2.8%
Industrial		15.6%
Residential		7.3%
Rural Residential		14.5%
Total		**100%**

Figure 12. Map of 200m Terrestrial Margin - Dominant Land Use, Waimea Inlet, 2014.

5. SUMMARY AND CONCLUSIONS

Table 15 summarises risk indicator ratings in relation to the key issues addressed by the broad scale monitoring (i.e. sediment, eutrophication and habitat modification).

Table 15. Summary of broad scale risk indicator ratings for Waimea Inlet, 2014, and changes from baseline conditions.

Major Issue	Indicator	Risk Rating			Change from Baseline
		Baseline		2014	
Sediment	Soft mud (% cover)	1990	VERY HIGH	VERY HIGH	Increase in very soft mud
Eutrophication	Macroalgal Growth (OMBT)	1990	LOW*	MODERATE	Increase in nuisance macroalgae
	Gross Eutrophic Conditions (ha)	1990	MODERATE	HIGH	Increase in gross eutrophic conditions
Habitat Modification	Seagrass Coefficient (SC)	1990	HIGH*	VERY HIGH	Decrease in seagrass
	Saltmarsh (% cover)	1946	LOW	MODERATE	Decrease in saltmarsh
	200m Vegetated Terrestrial Margin	1999	HIGH	HIGH	No significant change

*estimated value

The 2014 broad scale mapping results showed that while large sections of the estuary remain in good condition, risk ratings for key indicators range from “MODERATE” to “VERY HIGH”. The change ratings highlight a decline in most estuary condition indicators since the baseline (1946 or 1990), the exception being the extent of densely vegetated margin which was cleared very early after European settlement.

Clearly, the most significant issue was fine sediment, with the primary indicator results (i.e. soft mud and very soft mud habitat) showing the following:

- The area occupied by soft and very soft mud habitats (1197ha, 40%) was large compared with other NZ estuaries.
- Mud habitats were concentrated in deposition zones in the mid-upper intertidal basins and embayments in both arms, which in future could provide a valuable guide for any future investigations of sediment transport and deposition patterns in the estuary, and the establishment of monitoring priorities.
- The total area of soft mud appeared to be relatively stable, but there had been a large shift from soft mud to very soft mud substrate since 1999.
- The mean rate of infilling was tentatively categorised in the moderate range, with more detailed investigations required to improve its accuracy.

Also rated as a highly significant issue was seagrass loss, with a decline in seagrass cover of 41% since 1990 attributed to a likely restriction in its range due to excessive muddiness in the mid-upper estuary. In 2014, dense seagrass beds (34ha) were situated primarily near the well flushed entrance channels and central basin of the eastern arm (e.g. west of Saxton Island, east of Bells Island, west of the Nelson airport peninsula).

Opportunistic macroalgal growth was rated as a slightly less significant issue given that it was low throughout most of the estuary (2.7% of the available intertidal habitat), indicating a low overall trophic status (or level of nutrient enrichment). However, because dense beds of opportunistic macroalgae, and accompanying poor sediment conditions, were present in localised areas in 2014 (158ha), and had expanded by >50% since 1990, the estuary was rated as having a high risk of localised adverse ecological impacts from gross eutrophic zones.

The 200m terrestrial margin was also rated as a high issue given the fact that it included only 22% of its area as densely vegetated (mainly plantation forestry on Rabbit and Rough Islands). No significant change since 1999 was evident. Artificial shoreline structures (e.g. rockwalls, floodbanks, causeways) were a dominant feature around the estuary.

Saltmarsh was rated as a low to moderate issue in 2014, given that saltmarsh vegetation was still prominent (303ha, 9% of the estuary), of which 56% was herbfield and 34% rushland around much of the estuary margins. However, a 15% reduction in saltmarsh habitat between 1947 and 2014, was recorded (primarily due to reclamation and road development on the eastern side of the estuary), and ongoing reclamation and drainage is evident on private land adjacent to the estuary.

The dominance of muddy habitats, some of which were enriched with opportunistic macroalgae, indicate likely adverse impacts to key biota (e.g. seagrass, macroinvertebrates, fish and birds (Robertson and Stevens 2014)) and human uses and values within the estuary, as a direct result of changes to physicochemical conditions (e.g. increased mud content, reduced sediment oxygenation, and lower water clarity).

5. SUMMARY AND CONCLUSIONS (CONTINUED)

The findings also raise areas of uncertainty and knowledge gaps, particularly in relation to rates of sediment infilling; catchment sources of sediment; losses of sediment to the ocean; water column impacts; and the main drivers of sediment transport and deposition within the estuary (particularly since 1999). Addressing these gaps, for example, by undertaking a detailed investigation of fine sediment source, transport, deposition, and export within the estuary, would provide important information upon which to base future management decisions. Existing information collected by TDC would significantly contribute to such work, e.g. TDC LIDAR data to provide detailed bathymetry of the estuary.

However, prior to the instigation of detailed investigations, it is recommended that a conceptual outline of what the estuary would look like under various sediment load scenarios (e.g. low, medium, high and existing) be provided, and used to identify, through stakeholder involvement, an appropriate "target" estuary condition. The outcome would help address, early in the process, such important questions as;

- Will the mud that is already in the estuary gradually dissipate and be replaced by sand, or will it always be muddy?
- Can we get rid of existing mud in the estuary through dredging or some other artificial means?
- Can we stabilise the existing mud habitat and grow vegetation to improve ecology?

These results, and other appropriate monitoring data, could then be used to identify sediment input load guideline criteria to reduce fine sediment infilling to the target state and develop a plan to achieve such targets.

6. MONITORING

Waimea 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 the Tasman district. Based on the 2014 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 Macroalgae
Continue with the programme of 5 yearly broad scale habitat mapping, focussing on the main issue of sediment, with saltmarsh and the terrestrial margin assessed on a 10 yearly cycle unless obvious changes are observed. Next monitoring recommended in February/March 2019. Undertake a rapid visual assessment of macroalgal growth annually, and initiate broad scale macroalgal mapping if conditions appear to be significantly worsening over the 5 years before broad scale mapping is repeated.

Fine Scale Monitoring
Sampling of fine scale sites A, B, C and D have now been completed for 2001, 2006 and 2014). It is recommended that for the next two years TDC collect data only (no reporting) from sites A, C and D (excluding heavy metals, SVOCs, mercury and arsenic) to establish a multi-year baseline, and undertake a full report of all data at the next scheduled 5 yearly monitoring interval (2020/21).

Sedimentation Rate Monitoring
Because sedimentation is a priority issue in the estuary it is recommended that sediment plate depths be measured annually, and additional plates be deployed to improve spatial coverage, particularly in the highly eutrophic locations where sediment appears to be most rapidly accumulating.

Sediment Source Monitoring
Identify potential catchment sources of fine sediment, and likely loads to the estuary, using a combination of modeling and monitoring methods.

Sediment Transport and Deposition Monitoring Within Estuary
Assess transport/deposition patterns of sediment within the estuary and losses to the ocean using modeling and monitoring methods, and use this and other appropriate monitoring data to identify sediment input load guideline criteria to reduce fine sediment infilling to a more natural rate.

Terrestrial Margin Saltmarsh
Because of ongoing margin development around the estuary it is recommended that saltmarsh areas located on private land be identified and landowners be encouraged to protect these remaining, but vulnerable, stands. Where LIDAR data are available they should be used to identify the areas most likely to be influenced by sea level rise to assist in planning for the future managed retreat of saltmarsh.

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

7. MANAGEMENT

The combined results from the 2014 and broad scale and fine scale reports (Robertson and Robertson 2014) identified fine sediment as the major issue in Waimea Inlet. To address this issue, it is recommended that the following be considered:

- Develop a conceptual outline of what the estuary would look like under various sediment load scenarios (e.g. low, medium, high and existing) and, through stakeholder involvement, identify an appropriate "target" estuary condition.
- Following this initial step undertake, a detailed investigation of fine sediment source, transport, deposition and export within the estuary, to provide underpinning information upon which to base future management decisions. Existing information collected by TDC would significantly contribute to such work, e.g. use of LIDAR data recently collected by TDC being used to accurately define the tidal prism and bathymetry of the estuary. The LIDAR data will also highlight the estuary margin areas most likely to be impacted by predicted sea level rise and should be used to underpin planning of any replanting initiatives and to facilitate the expansion of estuary margins in response to predicted sea level rise.
- Using the results of the above investigations, and other appropriate monitoring data, to identify sediment input load guideline criteria to reduce fine sediment infilling to the target state and develop a plan to achieve such targets.
- Where possible, seek opportunities for community based saltmarsh restoration to enhance ecological and landscape values e.g. between Jimmy-Lee and Reservoir Creeks (where there are existing stockpiles of river gravels suitable for substrate enhancement), and adjacent to the Waimea cycleway/walkway.

8. ACKNOWLEDGEMENTS

Many thanks to Trevor James (Resource Scientist, Tasman District Council) for his support with this work and comments on the report.

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APPENDIX 1. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS

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

Forest: Woody vegetation in which the cover of trees and shrubs in the canopy is >80% and in which tree cover exceeds that of shrubs. Trees are woody plants ≥10 cm diameter at breast height (dbh). Tree ferns ≥10cm dbh are treated as trees. Commonly sub-grouped into native, exotic or mixed forest.
Treeland: Cover of trees in the canopy is 20-80%. Trees are woody plants >10cm dbh. Commonly sub-grouped into native, exotic or mixed treeland.
Scrub: Cover of shrubs and trees in the canopy is >80% and in which shrub cover exceeds that of trees (c.f. FOREST). Shrubs are woody plants <10 cm dbh. Commonly sub-grouped into native, exotic or mixed scrub.
Shrubland: Cover of shrubs in the canopy is 20-80%. Shrubs are woody plants <10 cm dbh. Commonly sub-grouped into native, exotic or mixed shrubland.
Tussockland: Vegetation in which the cover of tussock in the canopy is 20-100% and in which the tussock cover exceeds that of any other growth form or bare ground. Tussock includes all grasses, sedges, rushes, and other herbaceous plants with linear leaves (or linear non-woody stems) that are densely clumped and >100 cm height. Examples of the growth form occur in all species of *Cortaderia, Gahnia,* and *Phormium*, and in some species of *Chionochloa, Poa, Festuca, Rytidosperma, Cyperus, Carex, Uncinia, Juncus, Astelia, Aciphylla,* and *Celmisia*.
Duneland: Vegetated sand dunes in which the cover of vegetation in the canopy (commonly Spinifex, Pingao or Marram grass) is 20-100% and in which the vegetation cover exceeds that of any other growth form or bare ground.
Grassland: Vegetation in which the cover of grass (excluding tussock-grasses) in the canopy is 20-100%, and in which the grass cover exceeds that of any other growth form or bare ground.
Sedgeland: Vegetation in which the cover of sedges (excluding tussock-sedges and reed-forming sedges) in the canopy is 20-100% and in which the sedge cover exceeds that of any other growth form or bare ground. "Sedges have edges." Sedges vary from grass by feeling the stem. If the stem is flat or rounded, it's probably a grass or a reed, if the stem is clearly triangular, it's a sedge. Sedges include many species of *Carex, Uncinia,* and *Scirpus*.
Rushland: Vegetation in which the cover of rushes (excluding tussock-rushes) in the canopy is 20-100% and where rush cover exceeds that of any other growth form or bare ground. A tall grasslike, often hollow-stemmed plant, included in rushland are some species of *Juncus* and all species of *Leptocarpus*.
Reedland: Vegetation in which the cover of reeds in the canopy is 20-100% and in which the reed cover exceeds that of any other growth form or open water. Reeds are herbaceous plants growing in standing or slowly-running water that have tall, slender, erect, unbranched leaves or culms that are either round and hollow – somewhat like a soda straw, or have a very spongy pith. Unlike grasses or sedges, reed flowers will each bear six tiny petal-like structures. Examples include *Typha, Bolboschoenus, Scirpus lacutris, Eleocharis sphacelata,* and *Baumea articulata*.
Cushionfield: Vegetation in which the cover of cushion plants in the canopy is 20-100% and in which the cushion-plant cover exceeds that of any other growth form or bare ground. Cushion plants include herbaceous, semi-woody and woody plants with short densely packed branches and closely spaced leaves that together form dense hemispherical cushions.
Herbfield: Vegetation in which the cover of herbs in the canopy is 20-100% and where herb cover exceeds that of any other growth form or bare ground. Herbs include all herbaceous and low-growing semi-woody plants that are not separated as ferns, tussocks, grasses, sedges, rushes, reeds, cushion plants, mosses or lichens.
Lichenfield: Vegetation in which the cover of lichens in the canopy is 20-100% and where lichen cover exceeds that of any other growth form or bare ground.
Introduced weeds: Vegetation in which the cover of introduced weeds in the canopy is 20-100% and in which the weed cover exceeds that of any other growth form or bare ground.
Seagrass meadows: Seagrasses are the sole marine representatives of the Angiospermae. They all belong to the order Helobiae, in two families: Potamogetonaceae and Hydrocharitaceae. Although they may occasionally be exposed to the air, they are predominantly submerged, and their flowers are usually pollinated underwater. A notable feature of all seagrass plants is the extensive underground root/rhizome system which anchors them to their substrate. Seagrasses are commonly found in shallow coastal marine locations, salt-marshes and estuaries.
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.
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: The substrate is clearly recognised by the granular beach sand appearance and the often rippled surface layer. Mobile sand is continually being moved by strong tidal or wind-generated currents and often forms bars and beaches. When walking on the substrate you'll sink <1 cm.
Firm sand: Firm sand flats may be mud-like in appearance but are granular when rubbed between the fingers, and solid enough to support an adult's weight without sinking more than 1-2 cm. Firm sand may have a thin layer of silt on the surface making identification from a distance difficult.
Soft sand: Substrate containing greater than 99% sand. When walking on the substrate you'll sink >2 cm.
Firm mud/sand: A mixture of mud and sand, the surface appears brown, and may have a black anaerobic layer below. When walking you'll sink 0-2 cm.
Soft mud/sand: A mixture of mud and sand, the surface appears brown, and may have a black anaerobic layer below. When walking you'll sink 2-5 cm.
Very soft mud/sand: A mixture of mud and sand, the surface appears brown, and may have a black anaerobic layer below. When walking you'll sink >5 cm.
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 FOR KEY INDICATORS

Developed by Wriggle Coastal Management

June 2014

GUIDELINES FOR USE

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), 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 process, "risk indicator ratings" have been proposed that assign a relative level of risk of adversely affecting estuarine conditions (e.g. very low, low, moderate, high, very high) to each indicator. 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.
- That rating and ranking systems can easily mask or oversimplify results. For instance, large changes can occur within a 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 secondary ratings, primary ratings being given more weight in assessing the significance of indicator results. It is noted that many secondary 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. 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 risk ratings used in the Waimea Inlet broad scale monitoring programme, and their justifications, are summarised in the following sections.

APPENDIX 2. ESTUARY CONDITION RISK RATINGS (CONTINUED)

1. SEDIMENT: PERCENT SOFT MUD COVER

Estuaries are a sink for sediments. However, where large areas of "soft mud" are present in estuaries that are not naturally prone to such impacts, they are likely to lead to major and detrimental ecological changes that could be very difficult to reverse, and indicate where changes in land management may be needed. "Total Soft Mud" is defined as the combination of the "soft mud" and "very soft mud" which are two indicators used to assess broad scale estuary condition in the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002). These are defined as follows:

- Soft Mud: A mixture of mud and sand, the surface appears grey-brown (may have a black anaerobic layer below) and when a human walks on it they sink 2-5cm.
- Very Soft Mud: A mixture of mud and sand, the surface appears grey-brown and may have a black anaerobic layer below and when a human walks on it they sink >5cm.

Subsequent to the development of NEMP, the characteristics of "total soft mud" has been further defined and related to; percentage mud content (i.e. grain size), the macroinvertebrate community, and seagrass cover (see supporting evidence below). As a consequence, the characteristics of "total soft mud" are generally as follows:

"Total Soft Mud" Characteristics

- Sediments are relatively incohesive at mud contents below 20-30% (i.e. are not sticky and are relatively firm to walk on), but become cohesive and "sticky" at higher mud contents (i.e. you begin to sink into the muds).
- There is a marked shift in the macroinvertebrate assemblage when mud content exceeds 25-30% to one dominated by mud tolerant and/or species of intermediate tolerance. This shift is most apparent when elevated mud content is contiguous with high total organic carbon (TOC) concentrations.
- Seagrass (*Zostera muelleri*) cover is often absent or less than 1% for estuaries with greater than 20-30% soft mud.

These characteristics indicate that the presence of extensive areas of soft mud sediments (i.e. greater than 20-30% of the estuary as soft mud) in typical NZ tidal lagoon and tidal river estuaries means that seagrass cover is likely to be absent, the macroinvertebrate community degraded and the soft mud areas overlain with the dense nuisance beds of the red macroalga *Gracilaria* sp. in enclosed embayments or sheltered areas. Following on from these findings, a preliminary rating to reflect the likely risk of adverse impacts to the estuarine ecology was therefore developed (see following section).

SUPPORTING EVIDENCE

1. Total Soft Mud - Relationship to Mud Content

Based on the results from a selection of typical NZ tidal lagoon and tidal river estuaries (Table 1), the percent mud content of "Total Soft Mud" generally equates to estuarine sediments with a % mud content in the 25-100% range (i.e. the range where sediments become "cohesive" or sticky - Houwing 2000).

Table 1. Relationship between "muddiness category" and % mud content of intertidal habitat of various typical NZ estuaries.

Estuary	Muddiness Category	Human Footprint Depth (cm)	% Mud Content	Source
Porirua Harbour	Firm Muddy Sand	0-2cm	1.7-11.1%	Stevens and Robertson (2013)
	Soft Mud	2-5cm	37-49%	
	Very Soft Mud	>5cm		
Waikanae Estuary	Soft Mud	2-5cm	27-47%	Robertson and Stevens (2012)
	Very Soft Mud	>5cm		
Hutt Estuary	Firm Muddy Sand	0-2cm	21%	Stevens and Robertson (2014)
	Soft Mud	2-5cm	28-51%	Robertson and Stevens (2012
	Very Soft Mud	>5cm		
Whareama Estuary	Firm Muddy Sand	0-2cm	21%	Stevens and Robertson (2013)
	Soft Mud	2-5cm	39-86%	
	Very Soft Mud	>5cm		
Waimea Estuary	Firm Muddy Sand	0-2cm		Stevens and Robertson (2014a)
	Soft Mud	2-5cm	>25%	
	Very Soft Mud	>5cm		
Havelock Estuary	Firm Muddy Sand	0-2cm	17%	Stevens and Robertson (2014b)
	Soft Mud	2-5cm	>25%	
	Very Soft Mud	>5cm		

1. SEDIMENT: PERCENT SOFT MUD COVER (CONTINUED)

2. Mud Content - Relationship to Macroinvertebrate Community

A review of monitoring data from 25 typical NZ estuaries (shallow, short residence time estuaries) (Wriggle database 2009-2014) confirmed a "high" risk of reduced macrobenthic species richness for NZ estuaries when mud values were >25-30% mud and a "very high" risk at >55% (this last value is more tentative given the low number of data-points beyond this mud content) (Figure 1). This is supported statistically (canonical analysis of the principal coordinates (CAP) for the effect of mud content) by the increasing dissimilarity in the macrobenthic community as mud contents increase above 25-30% mud (Figure 2).

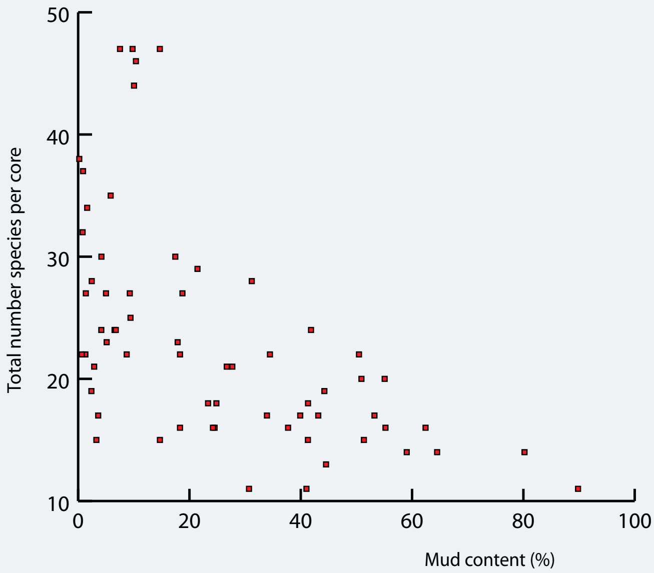

Figure 1. Sediment mud content and number of macrobenthic species per core from 12 estuaries scattered throughout NZ, and representing most NZ shallow, short residence time estuary types. (Wriggle Coastal Management database 2009-14).

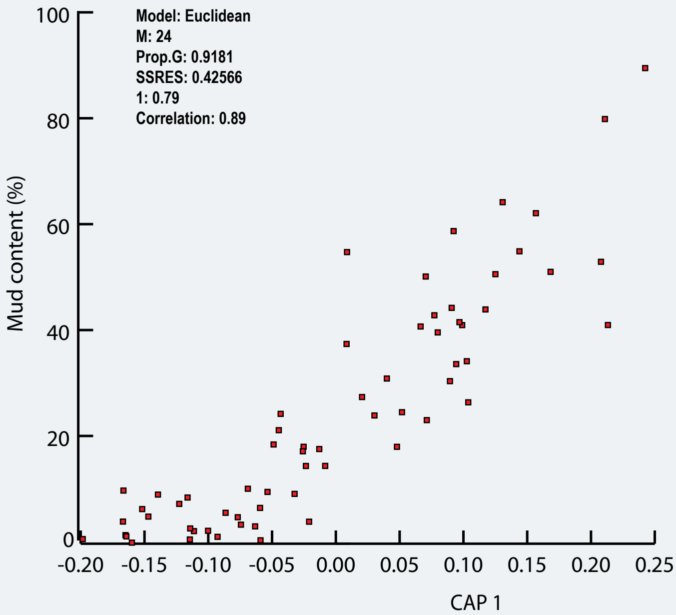

Figure. 2. Canonical analysis of the principal coordinates (CAP) for the effect of sediment mud content (exclusively) on the macroinvertebrate assemblages from 25 typical NZ estuaries (i.e. CAP1) among sites. Note: M = the number of PCO axes used for the analysis, Prop.G = the proportion of the total variation in the dissimilarity matrix explained by the first m PCO axes, SSRES = the leave-one-out residual sum of squares, 1 = the squared canonical correlation for the canonical axis, Correlation = the correlation between the canonical axis and the sediment mud content or pollution gradient.

APPENDIX 2. ESTUARY CONDITION RISK RATINGS (CONTINUED)

1. SEDIMENT: PERCENT SOFT MUD COVER (CONTINUED)

3. Total Soft Mud - Relationship to Seagrass Cover

- Tidal Lagoon and Tidal River Estuaries: Seagrass (Zostera *muelleri*) typically requires sandy sediments with a low mud content for healthy growth. Extensive broad scale mapping of seagrass cover for 45 typical NZ tidal lagoon and tidal river estuaries (shallow, residence time <3 days) indicate that seagrass cover is absent or less than 1% cover for estuaries with greater than 20-30% of the estuary area as soft mud (Figure 3). It is expected that this is primarily caused by reduced water clarity, and hence light availability, as a result of resuspension and elevated suspended sediment input loads.
- ICOLLS: Submerged aquatic vegetation (SAV) in intermittently open and closed lagoons/lakes (i.e. brackish waterbodies) in NZ can survive in some ICOLLs that are dominated by muddy sediments (Figure 4). This occurs primarily as a result of the ability of SAV (unlike Zostera) to grow up to the surface and hence obtain sufficient light for growth. ICOLLs with low SAV are generally SAV limited by reasons other than soft muds, unless the SAV is Zostera (such as in Papanui Inlet). For example, in Lake Onoke, SAV is limited by the short period opening/closing regime: in Waimatuku, SAV is limited by the very long opening period and short closed period, in Waituna SAV is limited by a combination of macroalgal/epiphyte cover and muddiness and the opening/closing regime.

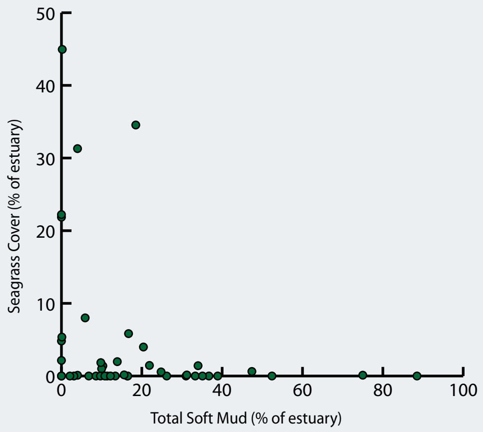

Figure 3. Percentage soft mud and seagrass cover of 45 typical NZ tidal lagoon and tidal river estuaries (shallow, residence time <3 days) (data sourced from Wriggle Coastal Management monitoring reports 2006-2013 and Robertson et al. 2002).

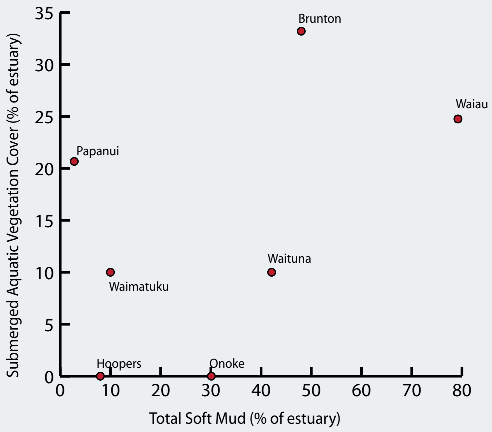

Figure 4. Percentage soft mud and seagrass cover of 7 typical NZ ICOLL estuaries (shallow, residence time variable) (data sourced from Wriggle Coastal Management monitoring reports 2006-2013).

RECOMMENDED SEDIMENT SOFT MUD PERCENT COVER RISK RATING (INTERIM)

The following rating specifies the magnitude of likely risk that the measured % soft mud will cause adverse impacts to estuarine ecology and is based on data for a wide range of NZ estuary types. These results showed that most estuaries in a dataset of 50 typical NZ estuaries fit the <10% soft mud category (Wriggle data 2001-2013).

Estuary Condition Risk Rating (Interim): Sediment Soft Mud Percent Cover

Risk Rating	Very Low	Low	Moderate	High	Very High
Soft Mud Percent Cover	<2%	2-5%	>5-15%	>15-25%	>25%

RECOMMENDED RESEARCH

Undertake extensive grain size validation monitoring of the following habitat types: firm muddy sand, soft mud, and very soft mud to confirm and refine the measured range of % mud found in each these broad scale monitoring categories from estuaries throughout NZ.
Undertake further studies in typical NZ estuaries on % cover of mud and the incidence of gross eutrophic conditions, and adverse impacts to macroinvertebrates, seagrass, saltmarsh, fish, and/or birds.

References

Houwing, E.J. 2000. Sediment dynamics in the pioneer zone in the land reclamation area of the Wadden Sea, Groningen, The Netherlands. PhD thesis, University of Utrecht, Utrecht.

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

2. OPPORTUNISTIC MACROALGAE - RATIONALE

Opportunistic macroalgae are species that survive well in conditions in which other species often struggle to survive or compete. Blooms in NZ estuaries form principally of species of green algae *Ulva* (this includes taxa formerly known as *Enteromorpha*), and *Cladophora*, red algae *Gracilaria*, and brown algae (e.g. *Ectocarpus, Pilayella, Bachelotia*). These bloom-forming species are a natural component of intertidal ecosystems (Adams 1994), but they only grow to bloom proportions when nutrient levels are elevated and sufficient light reaches the bed of the estuary (or the water column where macroalgae are suspended). As a consequence, they generally only reach nuisance conditions in shallow estuaries, or the margins of deeper, estuaries. In relation to the common estuary types, nuisance macroalgal blooms can be found in the following habitats:

Table A2-1. Relationship between estuary type and habitat where nuisance macroalgae proliferate given excess nutrients.

Estuary Type	Habitat Where Nuisance Macroalgae Proliferate
Tidal Lagoon	Intertidal Flats (especially poorly flushed arms near nutrient inflows)
	Subtidal channels with solid substrate for attachment
Tidal River	Intertidal areas that are poorly flushed e.g. lagoon separated from main flow
	Subtidal channels with solid substrate for attachment
Coastal Embayment	Intertidal Flats close to river inflows
	Intertidal and shallow subtidal areas with solid substrate for attachment or sheltered from currents
ICOLLs	Intertidal flats and shallow subtidal areas
Fiords and Sounds	Intertidal flats and shallow subtidal areas

Blooms of rapidly growing macroalgae can have deleterious effects on intertidal and shallow subtidal communities, and can cause an undesirable imbalance with effects such as:

- blanketing of the surface causing a hostile physico-chemical environment in the underlying sediment,
- sulphide poisoning of infaunal species,
- anoxic gradient at the water sediment interface,
- effects on birds including changes in the feeding behaviour of waders,
- smothering of seagrass beds - Duarte (1995), Taylor et al. (1995), Valiella et al. (1997),
- excessive algal growths, or rafts of floating or detached weed causing interference with water use activities,
- aesthetic effects such as nuisance odours or deposition in bathing waters.

The macroalgal response to nutrient loads generally increases with water residence times (Painting et al. 2007), either of the whole estuary (as is often the case for many NZ short residence time estuaries), or part of the estuary (e.g. a poorly flushed upper estuary arm where nutrient-rich muds accumulate). There is some evidence this response may also be significantly modified by the presence of fringing saltmarsh, due to reductions in nutrient loading through processes such as denitrification (Valiela et al. 1997).

Such findings are supported by widespread monitoring of NZ shallow estuaries which indicate that excessive macroalgal cover in poorly flushed parts of these estuaries can result in "gross nuisance conditions" (i.e. high mud content, surface sediment anoxia, elevated organic matter and nutrient concentrations, an imbalanced benthic invertebrate community dominated and seagrass dieoff (Robertson and Stevens 2012a and b). Similar gross eutrophic conditions occur in shallow coastal lagoons or ICOLLs where conditions are not too turbid, but it is expected that the minimum mud content at which they occur is much less than for tidal lagoon estuaries.
However, if the estuary is sandy and relatively pristine, macroalgal growth can be elevated but not cause nuisance sediment conditions and associated seagrass and macroinvertebrate loss (Robertson and Stevens 2013). In narrow tidal river estuaries, such gross eutrophic conditions are rare.
As a consequence, the use of macroalgal abundance as a trophic state indicator must be used alongside other secondary indicators, such as mud content and RPD, in order to accurately predict the trophic status of such estuaries. The presence of persistent and extensive areas of "gross nuisance conditions" in estuaries, however, provides a clear signal that the assimilative capacity of the estuary is being exceeded.

APPENDIX 2. ESTUARY CONDITION RISK RATINGS (CONTINUED)

OPPORTUNISTIC MACROALGAE - NEW ZEALAND AND INTERNATIONAL RATINGS

Ideally, an effective macroalgal condition rating would address the following:

- include only habitats in an estuary that are able to effectively grow nuisance macroalgae.
- include a weighting to account for macroalgae that are lodged within sediment and therefore have improved survival, i.e sediment-entrained macroalgae (commonly this is *Gracilaria* within NZ).
- include both percent cover and biomass metrics for nuisance species so that depth of macroalgal cover is accounted for.
- be underpinned by macroalgal condition/ecological response relationships.

1. US - ASSETS APPROACH, (BRICKER ET AL. 2007)

The ASSETS approach is relatively simple, but lacks standard methods and fails to differentiate between abundance and relative size of bloom patches, species composition (including sediment-entrained algae) and ecological response.
Rating:
High (periodic or persistent macroalgal bloom problems have been observed),
Moderate (Episodic macroalgal bloom problems have been observed),
Low (no macroalgal problems observed).
Definitions; Frequency of problem: Episodic (occasional/random); Periodic (seasonal, annual, predictable); Persistent (always/continuous).

2. NZ - WRIGGLE APPROACH (STEVENS AND ROBERTSON 2013)

Wriggle Coastal Management have developed a two part macroalgae condition rating (1. for low density (<50%) macroalgal cover throughout the estuary, and 2. a warning indicator for hotspots of high density (>50%) cover). The ratings estimate the risk of macroalgal condition causing adverse ecological impacts on an estuary. The approach includes a standard method and adequately differentiates between the relative size of bloom patches, species composition, and ecological response. However, it does not adequately account for sediment-entrained macroalgae and the influence of macroalgal biomass. Also it includes all intertidal habitat in its assessment rather that just intertidal habitat that can effectively grow macroalgae.
The methodology uses percent cover of nuisance species (primarily *Ulva* and *Gracilaria* sp.) and the presence of hotspots or gross nuisance conditions (>50% macroalgal cover, combined sediments with >30% mud content, elevated TOC, and a degraded macroinvertebrate community).
The first rating (low density macroalgal condition) is a continuous index (the macroalgae coefficient - MC) based on the weighted percentage cover of macroalgae in defined categories throughout the estuary. The equation used is: MC=((0 x %macroalgal cover <1%)+(0.5 x %cover 1-5%)+(1 x %cover 5-10%)+(3 x %cover 10-20%)+(4.5 x %cover 20-50%)+(6 x %cover 50-80%)+(7.5 x %cover >80%))/100.
The second (hotspot) rating targets areas of heavy growth and is applied where the percentage cover of intertidal macroalgal exceeds 50%. The highest of the ratings (presented below) is applied to determine recommended responses.

Rating	Very Low	Low	Moderate	High	Very High
Total Macroalgal Cover (MC)	<0.2	0.2-1.5	1.5-4.5	4.5-7	>7
Hotspot Risk (%cover >50%)	<1	1-5%	6-10	11-30%	>30%

3. OPPORTUNISTIC MACROALGAL BLOOMING TOOL - OMBT (UK - WFD 2014)

The UK-WFD (Water Framework Directive) approach for opportunistic macroalgal condition is the most comprehensive of the available rating tools. It is supported by extensive studies of the macroalgal condition in relation to ecological responses in a wide range of estuaries. It considers composition, macroalgal cover, abundance, and disturbance-sensitive taxa. The OMBT is a comprehensive 5 part multimetric index described below.

OPPORTUNISTIC MACROALGAL BLOOMING TOOL - OMBT (CONTINUED)

The Available Intertidal Habitat (AIH) - the estuary area between high and low water spring tide able to support opportunistic macroalgal growth - is defined. 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 is 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.

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 was established. This 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 waterbody. 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.

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

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.

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.

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.

Timing: The OMBT has been developed to classify data over the maximum growing season so sampling should target the peak bloom in summer (Dec-March), although peak timing may vary among water bodies, so 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.

OPPORTUNISTIC MACROALGAL BLOOMING TOOL - OMBT (CONTINUED)

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 A2-2).

- **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 a 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 quadrat or error to be made). 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 had started.

Each metric in the OMBT has equal weighting and is combined to produce the ecological quality ratio score (EQR).

Table A2-2. 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.

APPENDIX 2. ESTUARY CONDITION RISK RATINGS (CONTINUED)

OPPORTUNISTIC MACROALGAL BLOOMING TOOL - OMBT (CONTINUED)

EQR calculation

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

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

The EQR calculation process is as follows:

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

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

2. Normalisation and rescaling to convert the face value to an equidistant index score (0-1 value) for each index (Table A2-3).

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 A2-3 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.

APPENDIX 2. ESTUARY CONDITION RISK RATINGS (CONTINUED)

OPPORTUNISTIC MACROALGAL BLOOMING TOOL - OMBT (CONTINUED)

Table A2-3. 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.

APPENDIX 2. ESTUARY CONDITION RISK RATINGS (CONTINUED)

OPPORTUNISTIC MACROALGAL BLOOMING TOOL - OMBT, WAIMEA INLET 2014 WORKED EXAMPLE

Monitoring of Waimea Inlet collected detailed results for opportunistic macroalgal percentage cover, and more limited data on biomass and percentage entrainment from within defined percentage cover categories. Summary results are presented in Table A2-4, and A2-5.

Table A2-4. Results of opportunistic macroalgal algal cover, biomass, and entrainment, Waimea Inlet, 2014.

Percentage Cover Band	Area (ha)	Nominal % Cover	Algal Area (ha)	Average biomass ($g.m^{-2}$)	Total Biomass (kg)	Area Containing Entrained Algae (ha)	Area of Entrained Algae (ha)
0-5%	44.6	1	0.4	70	31220000	0	0
>5-15%	66.0	10	6.6	193	127380000	36.2	3.6
>15-25%	14.6	20	2.9	226	32978854	11.5	2.3
>25-50%	18.0	37.5	6.8	240	43226727	6.1	2.3
>50-75%	9.1	62.5	5.7	871	79074987	8.3	5.2
>75%	50.1	87.5	43.9	2287	1146509787	18.7	16.4
TOTALS	202.4	-	66.3	-	1460390354	80.8	29.8

Table A2-5. Data values for use in the normalisation and re-scaling of face values to EQR metric, Waimea Inlet.

AIH - Available Intertidal Habitat (ha)*	2451	ha
Percentage cover of AIH (%) = (Total % Cover / AIH} x 100 - *where Total % cover = Sum of {(patch size) / 100} x average % cover for patch*	2.7	%
Biomass of AIH ($g.m^{-2}$) = Total biomass / AIH - *where Total biomass = Sum of (patch size x average patch biomass)*	59.6	$g.m^{-2}$
Biomass of Affected Area ($g.m^{-2}$) = Total biomass / AA - *where Total biomass = Sum of (>5% cover patch size x average patch biomass)*	906	$g.m^{-2}$
Presence of Entrained Algae = (No. quadrats or area (ha) with entrained algae / total no. of quadrats or area (ha)) x 100	45	%
Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%). Highlighted in yellow cells in Table 9 above.	157.8	ha
Size of AA in relation to AIH (%) = (AA / AIH) x 100	6.4	%

*= mapped intertidal total (3910ha) minus: saltmarsh (303ha), coastal mobile sand deltas (554ha), and subtidal habitat (602ha)

The Final Ecological Quality Rating (EQR) is then calculated using the following equation for each of the metrics and the appropriate values from Table A2-3. The results are summarised in Table A2-6.

Final EQR = Upper Equidistant range value – ({Observed Value - Upper Face Value Range/Face Value Class Width} * Equidistant Band Width).

The final result using UK-WFD Opportunistic Macroalgae Blooming Tool indicates an overall "MODERATE" category status for opportunistic macroalgal blooming in Waimea Inlet. This is driven primarily by the "POOR" condition status (Table A4-6) of macroalgae within the affected area (relatively high biomass and degree of entrainment). In other words, while the vast bulk of the estuary is not exhibiting opportunistic macroalgal problems (reflected in the low average % cover and biomass in the AIH), localised growths of macroalgae are present and nuisance conditions exist in these areas.

As a note, the rating using the Wriggle Approach for the same estuary, was in the "Very High" category, indicating a very high risk of adverse ecological impacts as a result of the macroalgal blooms in the estuary.

Table A2-6. Results of the normalisation and re-scaling of face values to EQR metric for Waimea Inlet.

Metric	Face Value	Quality Status	Calculation of Final Equidistant Score (FEDS) using Table A4-3		FEDS
% Cover of AIH (%)	2.7	HIGH	FEDS:1-(2.7-0)/5)*0.2=		0.89
Biomass of AIH ($g.m^{-2}$)	59.6	HIGH	FEDS:1-((59.6-0)/100)*0.2=		0.88
Biomass of Affected Area ($g.m^{-2}$)	906	MODERATE	FEDS:0.6-((906-500)/499.9999)*0.2=		0.44
Presence of Entrained Algae (%)	45	POOR	FEDS:0.4-((45-20)/29.9999)*0.2=		0.23
Affected Area (use the lowest of the following two metrics)		POOR			0.32
Affected Area (ha)	157.8	POOR	FEDS:0.4-((157.8-100)/149.9999)*0.2=	0.32	
Size of AA in relation to AIH (%)	6.4	GOOD	FEDS:0.8-((6.4-5)/9.9999)*0.2=	0.77	
Ecological Quality Rating : EQR (Average of FEDS)		**MODERATE**			**0.55**

APPENDIX 2. ESTUARY CONDITION RISK RATINGS (CONTINUED)

OPPORTUNISTIC MACROALGAE

RECOMMENDED RISK RATING THRESHOLDS FOR OPPORTUNISTIC MACROALGAE (INTERIM)

The following table summarises the thresholds for opportunistic macroalgae in narrative form:

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
Narrative for Opportunistic Macroalgae	Algal cover <5% and low density. Macroalgae shows no persistence including lack of entrained algae. Little impact on surrounding ecology.	Limited cover (5-15%) and low biomass (<500gm-2) of opportunistic macroalgal blooms and with no growth of algae in the underlying sediment. Little impact on surrounding ecology.	Moderate % cover (15-25%) and/or biomass (500-1000g/m2), often with entrainment in sediment. Slightly detrimental to the surrounding ecology with some signs of persistence.	Persistent, high % cover (25-75%) and/or biomass (1000-3000g/m2), often with entrainment in sediment. Significant adverse impacts to sediment macroafauna and fish and birdlife.	Persistent very high % cover (>75%) and/or biomass (>3000g/m2), with entrainment in sediment. Strong adverse impacts to sediment macroafauna and fish and birdlife.

RECOMMENDED RESEARCH

- Opportunistic macroalgae thresholds developed to date have been primarily for use in deeper, predominantly subtidal, longer residence time estuaries, rather than shallow, intertidally dominated estuaries, with very short residence times (SSRTEs) (i.e. NZ's dominant estuary type). It is therefore recommended that further studies be undertaken to establish the macroalgal cover and biomass versus ecosystem condition (i.e. macroinvertebrate, fish, seagrass, saltmarsh) relationships for key NZ estuary types.
- Because NZ estuaries have only been exposed to a very short period of anthropomorphic influence, they are more susceptible to the influence of fine sediments (increased muddiness) than their overseas counterparts. Research is required to investigate the combined influence of increased muddiness and nutrients on opportunistic macroalgal growth and high value estuarine biota in NZ shallow estuaries.
- Because of the requirement by Regional Councils to predict the susceptibility of estuaries to macroalgal blooms and associated sedimentation, it is recommended that nutrient load thresholds be derived for key estuary types and estuary habitats (particularly SSRTEs).

References

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