Wriggle coastalmanagement

Havelock Estuary 2014

Broad Scale Habitat Mapping

Prepared for

Marlborough District Council

October 2014

Cover Photo: Havelock Estuary, 2014.

Saltmarsh between Pelorus River and Havelock.

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by

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HAVELOCK ESTUARY - EXECUTIVE SUMMARY

Havelock Estuary is an ~800ha, tidal river plus delta estuary located near Havelock in the Marlborough District. It is part of Marlborough District Council's coastal State of the Environment (SOE) monitoring programme. This report summarises the results of 2014 broad scale habitat mapping of the estuary. The following sections summarise 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

- Soft mud (75ha) and very soft mud (202ha) covered 77% of the unvegetated intertidal habitat (35% of the total estuary), and was concentrated mostly in the mid-upper intertidal basins and quiescent zones in both arms. Mud cover was very extensive compared with other similar NZ estuaries.
- Very soft mud had increased 34ha since 2001 (from 168ha to 202ha), while the combined area of soft/very soft mud had also expanded by 6ha indicating the estuary has got muddier over the past 13 years.
- Seagrass cover (15ha, 2% of the estuary) was very low. This limited cover is highly likely due to poor water clarity due to excessive mud.
- Opportunistic macroalgal growth was sparse (11% of the available intertidal habitat) and dominated by *Ulva*. Overall, low average biomass and sediment entrainment indicate the estuary is not expressing significant eutrophication symptoms. No gross eutrophic zones were present.
- Saltmarsh covered 25% of the estuary (203ha) of which 95% was rushland and 3% herbfield. A 15% decline in saltmarsh since 1999 (240ha to 203ha) occurred primarily as a result of eradication of the introduced cordgrass *Spartina*.
- The densely vegetated 200m margin (scrub and forest) cover of the estuary was relatively high (53%), of which 49% was mixed native and exotic scrub/forest predominantly on steeper hills in the lower estuary, and 3% pine forest. Remaining cover comprised grassland and pasture (38%), and residential/commercial/industrial areas near Havelock (8%). No significant change since 1999 was apparent.

RISK INDICATOR RATINGS (indicate risk of adverse ecological impacts) *estimated value

Major Issue	Indicator	2001	2014	Change from Baseline
Sediment	Soft mud (% cover)	VERY HIGH	VERY HIGH	Increase in extent and muddiness
Eutrophication	Macroalgal Growth (EQC)	LOW*	LOW	No significant change*
	Gross Eutrophic Conditions (ha)	VERY LOW*	VERY LOW	No significant change*
Habitat Modification	Seagrass Coefficient (SC)	HIGH*	HIGH	No significant change*
	Saltmarsh (% cover)	VERY LOW	VERY LOW	Decrease in saltmarsh
	200m Vegetated Terrestrial Margin	LOW*	LOW	No significant change*

ESTUARY CONDITION AND ISSUES

In relation to the key issues addressed by the broad scale monitoring (i.e. sediment, eutrophication, and habitat modification), the 2014 broad scale mapping results show that fine sediment is the major issue present in the estuary, with a "very high" risk of adverse impacts to the estuary ecology occurring, including seagrass loss.

Eutrophication is not currently a significant concern, although muddy estuaries are very susceptible to opportunistic macroalgal growths and problems can quickly arise. Saltmarsh loss since 2001 is primarily due to *Spartina* removal.

The large increase in very soft mud since 2001 shows significant deposition of fine sediments over the past 13 years. Over this period there have been three major (>1 in 10 year) storm events in 2008, 2010, and 2012, and commencement of first rotation forest harvesting in the Pelorus/Rai/Wakamarina catchments. Development of landuse/sediment load relationships, and associated estuary sedimentation rates, are needed to quantify human derived inputs.

Notwithstanding, soft mud is likely contributing to losses of seagrass and shellfish, and adverse impacts to the sediment macroinvertebrate community which will become dominated by mud tolerant species, as evident in the fine scale monitoring results (Robertson and Robertson 2014). Such conditions limit food availability for fish and birdlife, and show the ability of the estuary to assimilate sediment loads is currently exceeded.

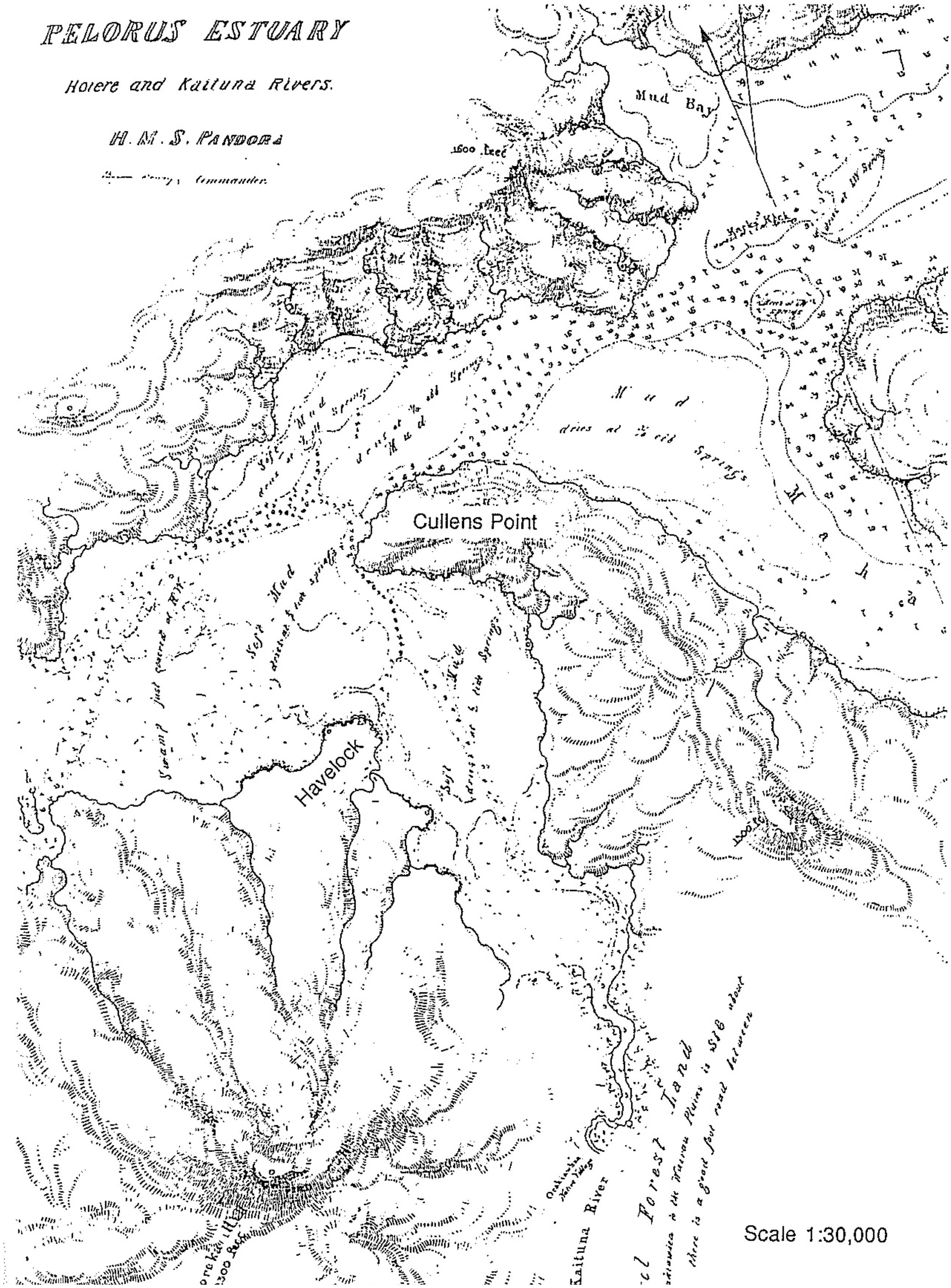
RECOMMENDED MONITORING AND MANAGEMENT

Excessive fine sediment is the major issue identified in Havelock Estuary. While likely to have been occurring since the first human development in the catchment, the monitored increase in estuary muddiness from 2001-2014 highlights recent inputs have exceeded the estuary's assimilative capacity. 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 biannually (Jan/Feb), with annual broad scale macroalgal mapping initiated if conditions appear to be worsening.

Fine scale monitoring (data only) is recommended in 2015, 17, and 19 at the existing two sites, and at two new sites established in the dominant intertidal habitat type (very soft muds). Sedimentation rate monitoring should continue annually with additional sites deployed in eutrophic/high sediment deposition zones, supported by dating of sediment cores to determine the timing and rate of past sediment inputs to the estuary.

Targeted investigations are also recommended to address fine sediment knowledge gaps as follows:

- **Sediment Source Identification**. What are the main sources of fine sediments depositing in the estuary, and what is the relative influence of natural compared to human derived inputs?
- **Ecological Condition/Sediment Load Relationship**. What is the predicted ecological condition of the estuary (pristine to poor) along a full gradient of catchment sediment loads, infilling rates and within-estuary management actions (e.g. dredging, saltmarsh planting).
- **Explore catchment management and restoration options.**



1854 map of Havelock Estuary prepared by Dury on the *H.M.S. Pandora* (reproduced from Lauder 1987).

1. INTRODUCTION

Developing an understanding of the condition and risks to coastal and estuarine habitats is critical to the management of biological resources. These objectives, along with understanding change in condition/trends, are key objectives of Marlborough District Council's State of the Environment Estuary monitoring programme. Recently, Marlborough District Council (MDC) prepared a coastal monitoring strategy which established priorities for a long-term coastal and estuarine monitoring programme (Tiernan 2012). The assessment identified Havelock Estuary as a priority for monitoring.

The estuary monitoring process consists of three components developed from the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002) as follows:

1. **Ecological Vulnerability Assessment** (EVA) of estuaries in the region to major issues (see Table 1) and appropriate monitoring design. To date, neither estuary specific nor region-wide EVAs have been undertaken for the Marlborough region and therefore the vulnerability of Havelock to issues has not yet been fully assessed. However, in 2009 a preliminary vulnerability assessment was undertaken of the Havelock Estuary for the NZ Landcare Trust (Robertson and Stevens 2009), and a recent report has documented selected ecologically significant marine sites in Marlborough (Davidson et al. 2011).
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 Havelock Estuary was undertaken in 2001 (Robertson et al. 2002). 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 Havelock Estuary, was first undertaken in 2001 (Robertson et al. 2002) and repeated in 2014 (Robertson and Robertson 2014). Because the NEMP requires 3-4 consecutive years of data for establishing a defensible baseline, the single year of data that exists for the Havelock Estuary is insufficient for use in trend analysis (i.e. trends in change between 2001 and 2014 data).

In 2014, MDC commissioned Wriggle Coastal Management to undertake a repeat of the broad scale monitoring of Havelock Estuary previously undertaken in 2001 when the NEMP was being developed. The current report describes the following work undertaken between February 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.

Havelock Estuary is a relatively large-sized (~800ha, Robertson et al. 2002), macrotidal (2.17m spring tidal range), poorly-flushed, delta estuary situated at the head of Pelorus Sound. It has one opening, one main basin, and several tidal arms. The catchment (1,149km^2) is partially developed and dominated by native forest (72%), exotic forestry (14%), dairying (4%), other pasture (8%) and scrub (2%). Part of the estuary margin is directly bordered by developed urban and rural land, roads, and seawalls.

The estuary is formed by the sediment output from the Kaituna and Pelorus Rivers (mean flows 3.7 and 45 $m^3.s^{-1}$ respectively). Although the catchment is dominated by native forest and hard sedimentary rock types which don't erode very easily, the terrain is often steep, and therefore erosion can be elevated from developed areas. This erosion is exacerbated by the frequent and high rainfall in the catchments, which in a typical year has several rainfall events that deliver between 50-200mm of rain in one day. As a consequence, freshwater inputs to Havelock Estuary tend to include intermittent pulses that carry elevated loads of suspended sediments, nutrients and faecal bacteria. The bulk of the sediment and nutrient loads settle in the estuary, resulting in a muddy estuary, with low clarity water. The cloudy waters and muddy bed result in the loss of high value seagrass from intertidal and shallow subtidal areas, and reduced phytoplankton production, seabed life and fish communities. However, due to the relatively large area of upper intertidal shallows, the estuary has extensive beds of high value saltmarsh (predominantly jointed wire rush and sea rush), that provide important habitat for birdlife, macroinvertebrates and, at high water, fish.

The highly elevated mud content of the estuary has also provided ideal habitat for the invasion of opportunists (both plant and animal) such as the introduced cordgrass *Spartina townsendii* and the Pacific oyster (*Crassostrea gigas*), both acting as stabilisers of the mud. Both species established new habitat on unvegetated estuary flats and therefore caused limited displacement of native species. Currently Pacific oyster growth is expanding in the estuary but *Spartina* has been eradicated, releasing a large amount of mud to the water column for redistribution within the estuary e.g. through erosion of fine sediments previously bound up in root masses.

The estuary has high use and is valued for its aesthetic appeal, biodiversity, shellfish collection, bathing, waste assimilation, whitebaiting, fishing, boating, walking, and scientific appeal. It 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 and marina is located at Havelock near the Kaituna River mouth.

A 2009 synoptic catchment impact assessment (Robertson and Stevens 2009) identified excessive muddiness, localised eutrophication, and moderate disease risk as the most significant catchment-related issues in the estuary.

Havelock Estuary 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 of fine sediments is common. These changes to water and sediment result in negative impacts to estuarine ecology that are difficult to reverse. They include;

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

Recommended Key Indicators:

Issue	Recommended Indicators	Method
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.

Figure 1. Havelock Estuary, including location of fine scale monitoring sites.

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; i. the wide diversity of habitats they offer, and ii. their natural ability to collect and assimilate sediment and nutrients from the surrounding catchment and inflowing tidal waters. If either of these features are degraded, then the estuary condition deteriorates and the value to humans and estuary plants and animals is lessened. The condition of an estuary is commonly reflected by the extent and intensity of development in the surrounding catchment. They are typically in one of three contrasting states: PRISTINE, MODERATE, OR DEGRADED.

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

MODERATE: Following initial catchment development, sediment, nutrient, and faecal bacteria 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 e.g. bank stabilisation, decreased flow velocity, temporal spreading of flow peaks. Protection of developed margins from erosion and inundation becomes an increasing issue.

Although not yet formally assessed for vulnerability to key stressors, Havelock Estuary is currently in a MODERATE state due to excessive muddiness, habitat loss and, to a lesser extent, disease risk and eutrophication.

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).

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

Although the transitional estuarine waters of Havelock Estuary extend well into Pelorus Sound, the extent mapped in 2014 has applied an arbitrary seaward boundary based on that of Robertson et al. (2002). The mapped extent includes the extensive intertidal margins of the upper estuary, as well as the deltas present at the confluence of the Pelorus and Kaituna River deltas. In future it is envisaged that hydrodynamic models of Pelorus Sound, and the estuaries within it, will enable integrated assessment of the seaward boundaries and linkages between the various Pelorus Sound estuary systems under a range of different flow conditions.

For the current study, MDC supplied rectified ~0.4m/pixel resolution colour aerial photos flown in 2012. Photos covering the estuary at a scale of 1:5,000 were laminated, and experienced scientists ground-truthed the spatial extent of dominant habitat and substrate types over 3 days in March and 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.

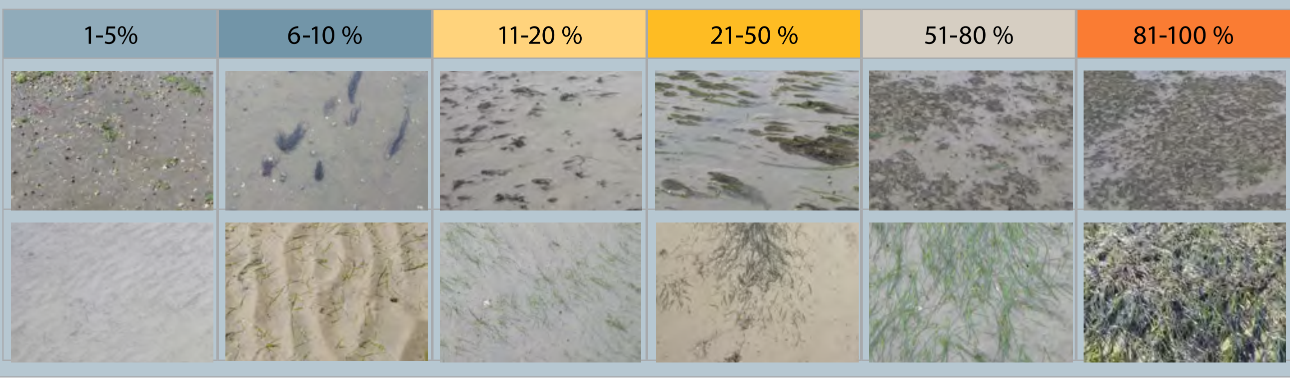
When present, macroalgae and seagrass were mapped using a 6 category percent cover rating scale (see Figure 2 below) to describe density. Macroalgae were additionally assessed using a modification of the WFD-UKTAG (2014) Opportunistic Macroalgal Blooming Tool (OMBT) described in detail in Appendix 2. 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 multi-metric 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*), 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 the previous 2001 broad scale survey, noting in some instances that improvements have been made in the classification and mapping of key parameters like seagrass and macroalgae since 2001.

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



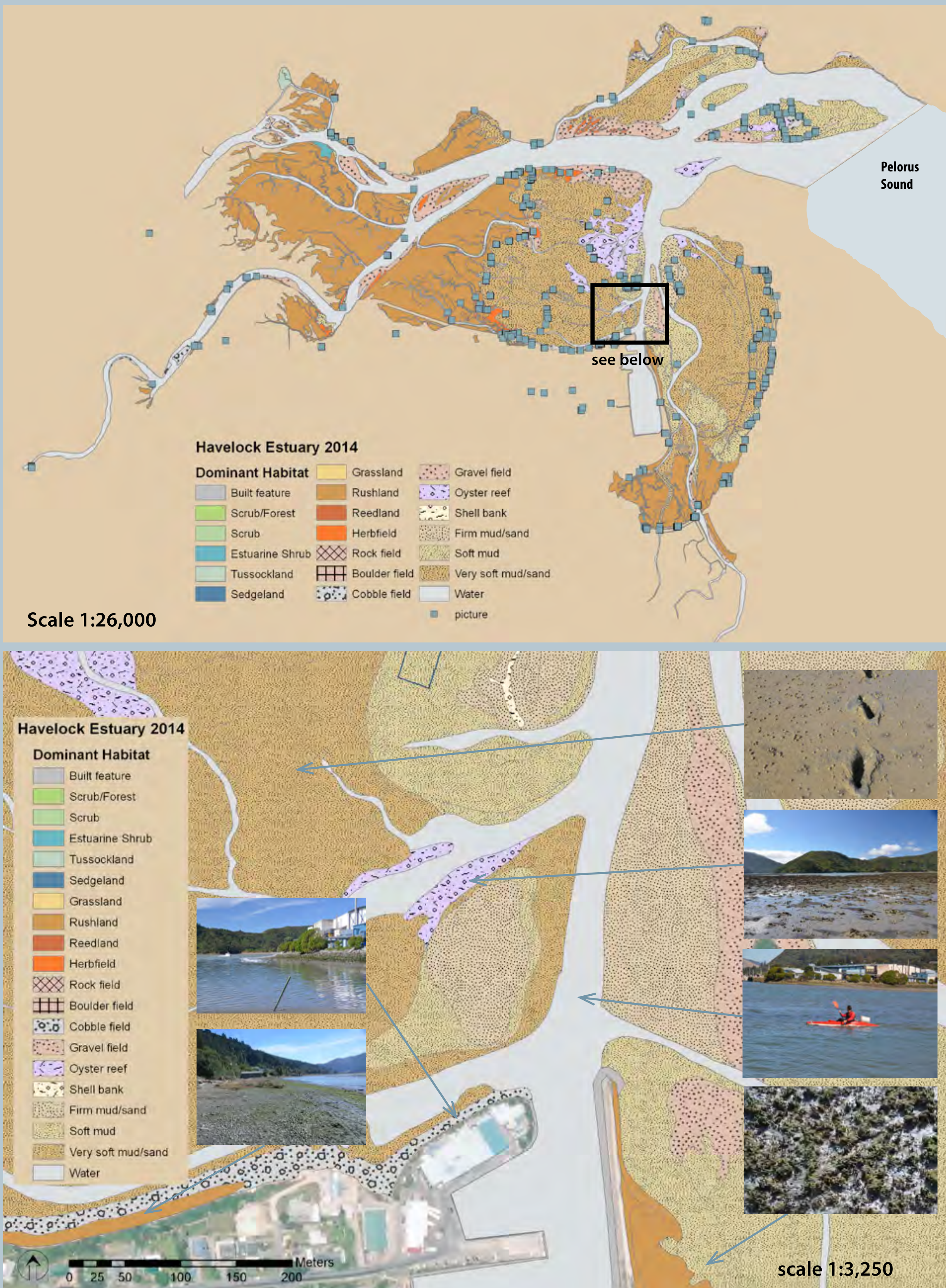


Figure 3. Location of 2014 ground-truthing photographs (top), and example of the more detailed GIS mapping and photos that underpin this summary report (bottom).

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 2 below). Each risk indicator rating is designed to be used in combination with relevant information and other risk indicator ratings, and under expert guidance, to assess overall estuarine condition in relation to key issues, and make monitoring and management recommendations. When interpreting risk indicator results we emphasise:

- The importance of taking into account other relevant information and/or indicator results before making management decisions regarding the presence or significance of any estuary issue.
- 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 Havelock Estuary broad scale monitoring programme are summarised in Tables 2 and 3, 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 2. 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 (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%	>25-50%	>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:

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 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 2).

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 3) 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 3. Summary of estuary condition risk indicator "change" ratings used in the present report.

<table>
<tr><th rowspan="2">INDICATOR</th><th colspan="5">RISK RATING BASED ON PERCENT CHANGE FROM BASELINE</th></tr>
<tr><th>Very Low</th><th>Low</th><th>Moderate</th><th>High</th><th>Very High</th></tr>
<tr><td>Soft mud extent</td><td rowspan="3">0% (or decline)</td><td rowspan="3"><5% increase</td><td rowspan="3">5-15% increase</td><td rowspan="3">16-50% increase</td><td rowspan="3">>50% increase</td></tr>
<tr><td>Dense (>50%) Macroalgal Cover</td></tr>
<tr><td>Gross Eutrophic Conditions</td></tr>
<tr><td>Seagrass</td><td rowspan="3">0% (or increase)</td><td rowspan="3"><5% decrease</td><td>5-15% decrease</td><td>16-50% decrease</td><td rowspan="3">>50% decrease</td></tr>
<tr><td>Saltmarsh</td><td rowspan="2">5-10% decrease</td><td rowspan="2">11-50% decrease</td></tr>
<tr><td>200m Vegetated Terrestrial Margin</td></tr>
</table>

NOTES:

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.

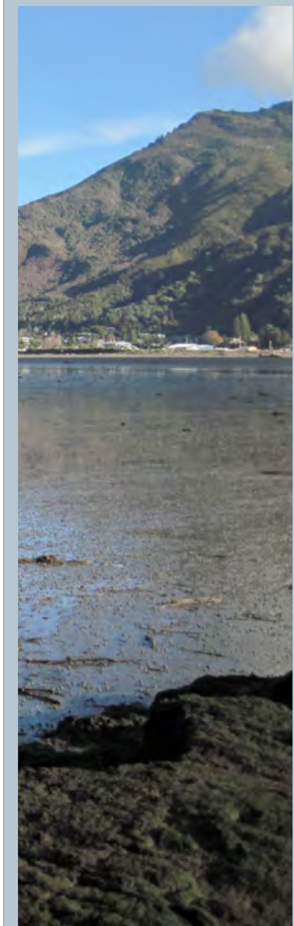
Seagrass is vulnerable to fine sediments in the water column, rapid sediment deposition, poor sediment quality (particularly reduced oxygen or production of sulphide), excessive macroalgal growth, high nutrient concentrations, and reclamation. Decreases in seagrass extent is likely to indicate an increase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



Havelock Estuary, 2014.

Of the six dominant estuary features summarised in Table 4, the 2014 broad scale habitat mapping ground-truthed and mapped all intertidal and margin features, but not subtidal substrate or vegetation. As expected for a dual river delta estuary situated at the head of a shallow sound, habitats were dominated by intertidal flats (45% of estuary), subtidal water (30%) and saltmarsh (25%). In comparison, the extent of dense opportunistic macroalgal growth (3%) and seagrass (2%) within intertidal habitat was relatively small. The mapping also showed that 53% 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, 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 4. Summary of dominant broad scale features in Havelock Estuary, 2014.

Dominant Estuary Feature		Ha	% of Estuary
1.	Intertidal flats (excluding saltmarsh)	362	45%
2.	Opportunistic macroalgal beds (>50% cover) [included in 1. above]	27.4	3%
3.	Seagrass (>50% cover) [included in 1. above]	15.2	2%
4.	Saltmarsh	203	25%
5.	Subtidal waters	236	30%
Total Estuary		**801**	**100%**
6.	Terrestrial Margin - % of 200m wide estuary buffer densely vegetated (e.g. scrub, shrub, forest)		53%

4.1. INTERTIDAL FLATS (EXCLUDING SALTMARSH)

Results (summarised in Table 5 and Figure 4) show very soft mud (56%) and soft mud (21%) were by far the most dominant unvegetated intertidal substrates in Havelock Estuary. Other prominent habitats included cobble and gravel fields (13%) and oyster beds (6%). Firm sands (4%) and rock and boulder features (<1%) were relatively uncommon. In general terms, mud-dominated substrates and oyster reefs tended to be most common in the mid/upper intertidal basins and embayments (Figure 4) where salinity driven flocculation zones are located. Soft mud areas were also common among the decaying root systems of the introduced cordgrass *Spartina* which has been progressively eradicated from the estuary since 2003. Gravel, cobble and sand features were predominantly located in the lower reaches of the estuary and adjacent to channels that have a high degree of flushing from river and tidal flows, while rock and boulder habitat was most commonly located near terrestrial margins.

Table 5. Summary of dominant intertidal substrate, Havelock Estuary, 2014.

Dominant Substrate	Area Ha	Percentage	Comments
Rock field	0.4	0.1%	Prominent along upper intertidal margins on the eastern shoreline leading to Cullen Point.
Boulder field	0.6	0.2%	Steep shorelines within Timahau Bay - often associated with cobbles and oysters.
Boulder field man-made	1.1	0.3%	Surrounding Havelock marina and also common adjacent to reclaimed shorelines.
Cobble field	6.2	1.7%	Shorelines near Havelock township, Kaiuma and Shag Point.
Gravel field	41.8	11.6%	Predominantly within the Pelorus River channel and delta.
Oyster reef	20.2	5.6%	Predominantly in muddy low tide reaches of the main settling basins and lower estuary.
Shell bank	0.1	0.04%	Near the well flushed tidal delta of the Kaituna River.
Firm mud/sand	13.5	3.7%	Near the well flushed tidal delta of the Kaituna River and the lower estuary.
Soft mud	75.4	20.9%	Settling areas in the lower estuary and Timahau Bay, and on flats adjacent to Kaituna River.
Very soft mud	202.1	55.9%	Within intertidal settling basins east and west of Kaituna River and in Wakaretu Bay.
TOTAL	**361.5**	**100%**	

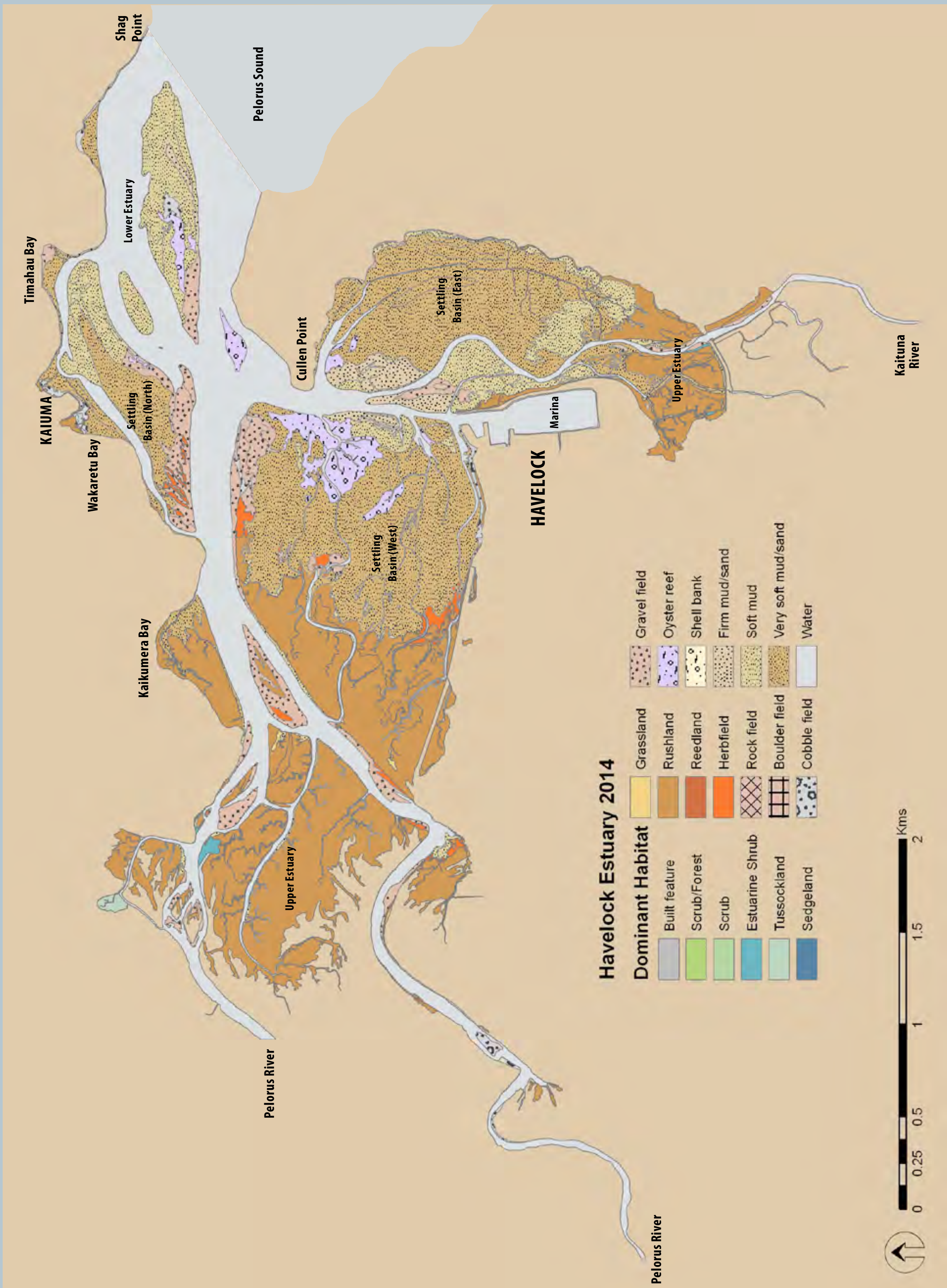


Figure 4. Map of dominant habitat types - Havelock Estuary, 2014.

Soft Mud Habitat.

Of the intertidal habitat outside of saltmarsh, the combined extent of soft mud (SM) and very soft mud (VSM) habitats have been chosen as the primary indicator of fine sediment (or increased muddiness) impacts. This choice reflects the facts 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), alterations to fish and invertebrate communities, and the establishment of invasive species 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.

Figure 4 shows that SM and VSM, along with Pacific oyster beds which have become a dominant cover in some SM and VSM habitats, were concentrated where the Pelorus and Kaituna River flows enter the estuary and deposit sediment in the mid-upper intertidal basins and the lower estuary settling zones. Although such zones are now common in NZ estuaries with developed catchments, the proportion of the intertidal area accumulating fine sediment in Havelock (77%) is the highest of 33 NZ tidal lagoon and delta estuaries for which data are currently available (Figure 5), and exceedingly high when compared to the <1% found in Freshwater Estuary, an undeveloped reference estuary of a similar size and type - a risk indicator rating of "VERY HIGH".

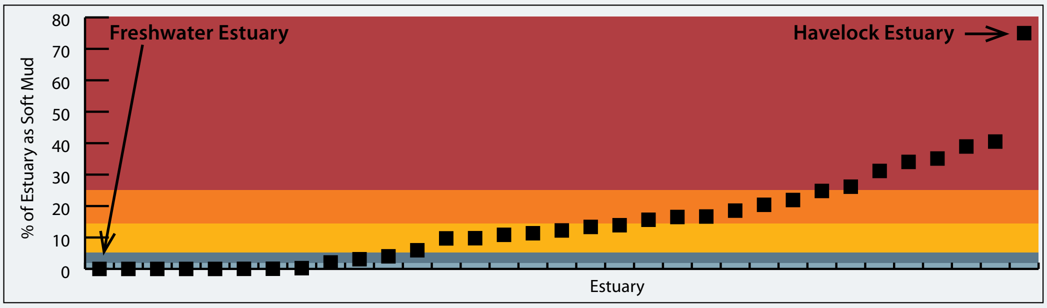
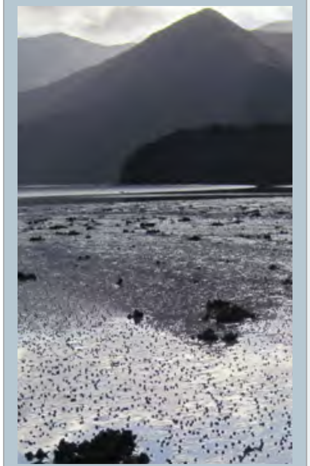


Figure 5. Percentage of estuary with soft mud habitat for 33 typical NZ tidal lagoon and delta estuaries. **(intertidal dominated, shallow, residence time <3 days - data from Wriggle monitoring reports 2006-2013 and Robertson et al. 2002).**

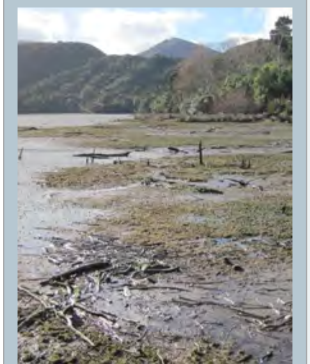
Figure 6. Examples of fine sediment deposition in Havelock Estuary, 2014. Top photos: settling basin east, bottom photos: lower estuary (among oysters) and within seagrass near Shag Point.

SOFT MUD % COVER RISK INDICATOR RATING
2001 VERY HIGH
2014 VERY HIGH



Deep soft muds and clumps of Pacific oysters in the eastern Kaituna settling basin, Cullen Point in the background.

Soft muds in the upper western settling basin.



Remnant root systems of *Spartina* in the eastern Kaituna settling basin.

Changes in Estuary Soft Mud 2001, 2014.

An analysis of the percent cover of major substrate classes in Havelock Estuary (comparing the current results to revised 2001 broad scale mapping results) showed that the combined extent of SM and VSM habitat (i.e. deposition zones) has been relatively consistent over the last 13 years (2001, 272ha; 2014, 278ha) (Table 6). This predominantly reflects a hydrodynamic boundary, with both salinity driven flocculation, and changes in flow velocities in the main estuary basins, promoting settling of fine sediments, and is consistent with the results of earlier studies by Davidson and Brown (1998, 2000). Historically, intertidal mud deposition zones would have been relatively small due to lower sediment inputs from the undeveloped catchment, but channel areas would have been muddy. The 1854 map of the estuary (see page viii) confirms channels were muddy. While intertidal flats are marked as "muddy", this most likely reflects both common terminology of the time, and an extrapolation of channel sampling results. Consequently it is an unreliable indicator of intertidal mud extent.

Table 6. Broad substrate categories, Havelock Estuary, 2001 and 2014.

Substrate Class	2001		2014	
	Area (ha)	%	Area (ha)	%
Boulder/Cobble/Gravel	40.5	12.4%	50.1	13.9%
Shell/Oyster/Mussel/Tubeworm	9.7	3.0%	20.2	5.6%
Firm Sands and Muddy Sands	-	-	13.5	3.7%
Soft Muds	107.7	33.1%	75.4	20.9%
Very Soft Muds	167.6	51.5%	202.1	55.9%
TOTAL	325	100%	362	100%

Although the total area of combined SM and VSM has not changed appreciably since 2001, there has been a notable (35ha) increase in the extent of the VSM component. In addition, the extent of oyster habitat as a dominant cover (which overlies very soft mud habitat) has increased by ~10ha. These results, combined with fine scale monitoring within the estuary showing a 28% increase in the mud content of sediments at Site A (see Figure 1, also Robertson and Robertson 2014) show that the estuary has got muddier over the past 13 years. During this period there have been three major (>1 in 10 year) storm events (2008, 2010, and 2012), and commencement of first rotation forest harvesting in the Pelorus/Rai/Wakamarina catchments.

Our scientific understanding at present suggests that increasing muddiness (in this instance a shift from SM to VSM) will change sediment physicochemical conditions (e.g. increase mud content, reduce oxygenation, increase cohesiveness), with consequent adverse impacts to macroinvertebrates expected. Detailed investigations would be required to quantify specific differences between SM and VSM habitat, and validate the expected changes, but there is little doubt that they would be detrimental to the community present.

A likely contributor increased muddiness in the estuary is the progressive eradication since 2003 of the introduced common cordgrass, *Spartina*. *Spartina* was first introduced into Havelock Estuary in 1952 and grew to occupy 50.6ha of previously unvegetated mid-highwater habitat (Brown 2002). Its primary action in terms of estuary muddiness was to encourage mud deposition and reduce subsequent resuspension and therefore improve water clarity. The 2014 broad scale mapping showed that the mounds of accumulated mud and root systems of the old *Spartina* beds were still obvious (see lower sidebar photo), but clearly eroding, with sediment from the mounds likely transported to nearby deposition zones. Pages 14 and 15 provide further discussion of *Spartina* issues.

Within sediment deposition zones, there had been an increased presence of the invasive Pacific oyster (*Crassostrea gigas*) as a dominant habitat in the estuary since 2001 of ~10ha. Pacific oysters appear to preferentially establish in the muddy areas, and once established, their reef-forming structures filter and trap fine muds creating localised conditions that promote cumulatively greater mud trapping and retention.

In terms of other unvegetated habitat changes, the 2001-2014 comparison shows a 37ha increase in the extent of unvegetated substrate which reflects the combined effects of eradication of 51ha of *Spartina* (and the subsequent reclassification of this habitat from saltmarsh to unvegetated intertidal substrate), reclamation of land adjacent to the marina for industrial purposes (~6ha), expansion of the marina (~8ha), and deposition of marina dredge spoil in intertidal areas to create bird roosting sites (~2ha).

Extensive unvegetated soft mud flats in the eastern Kaituna settling basin. Eroding *Spartina* roots in the foreground.

Soft muds and macroalgal growths in the upper Kaituna settling basin between the road causeway and dense beds of rushland.

Soft muds with numerous mud snails (*Amphibola crenata*) and sparse seagrass cover in the eastern settling basin.

Deep soft muds and clumps of Pacific oysters in the western settling basin, Timahau Bay in the background.

Turbid water in the lower estuary resulting from fine sediment resuspension from small wind waves. Note the relative clarity of the deeper water just offshore.

Deep soft muds and clumps of entrained macroalgae in the western settling basin.

Introduced cord grass *Spartina*: an overview

The exotic cord grass *Spartina* was initially introduced to NZ to promote the reclamation and stabilisation of estuary margins. It did this very effectively e.g. Bascand 1970, Partridge 1987), exhibiting often rapid and aggressive growth in unvegetated tidal flat areas where it trapped large amounts of sediment, providing an important filter of fine sediments from the catchment. Despite this benefit, concerns were raised that its introduction may have unwanted ecological consequences to native ecosystems, and subsequently legislation prohibiting further introductions was passed in 1975 and efforts made to eradicate it wherever possible (e.g. Shaw 1999, Brown 2002).

Havelock Estuary is a good case example where *Spartina,* following its introduction in 1952 to prevent siltation of the shallow boat channel, steadily established throughout the middle/upper intertidal zone before under going a very rapid (25%) expansion in dense beds, and a quadrupling in size of edge zones, over 3 years from Feb. 1979 to Feb. 1981 (Campbell et al. 1991). Such rapid expansion, in response to marina development where dredge spoil was deposited on the channel margins, lead to ecological concerns over *Spartina's* spread, and culminated in eradication initiatives commencing in Havelock Estuary in 2003.

However, the basis for the eradication decision is not well documented, even if the concerns regarding its invasive nature are well founded. Knox et al. (1999), in one of the very few detailed *Spartina* investigations undertaken by expert estuary ecologists in NZ, concluded that “although there is a widespread belief in NZ that the presence of *Spartina* is harmful to the coastal ecosystem in which it occurs, this view is not based on sound scientific data”. Further, a comprehensive ecosystem study of *Spartina* in Havelock Estuary by Odum et al. (1983) concluded, that “there was little justification for a policy of eradication”, a stance reiterated by Campbell et al. (1991). Campbell et al. (2009) further found the new *Spartina* marsh system in Havelock to be much higher in primary productivity than the mudflat it was replacing, with its growth related to its capacity to respond to altered (increased) inputs of sediment related to human activities.

Outside of these expert conclusions, there appears to have been virtually no serious treatment of the main issues regarding why *Spartina* is able to readily flourish in NZ, and the relative benefits and drawbacks of its presence at an ecosystem level. In recommending eradication, significant weight appears to have instead been given to anecdotal concerns about *Spartina*'s **potential** ecological impact. Examples commonly cited to support eradication include Asher (1991) who reported that *Spartina's* sediment trapping and rapid growth were seen as the cause of raised flood plains and restricted waterways, and that it would endanger areas valuable for recreation and food collection, native and migrating bird sanctuaries, and scenic and native qualities. The Southland Acclimatisation Society, cited in Lee and Partridge (1983), state that “dense *Spartina* is little used by animals, and its spread is rapidly destroying habitats formerly occupied by a range of faunal species”. Brown (2002) lists a range of potential *Spartina* impacts that may cause large-scale physical modification of estuaries including the loss of saltmarsh and mudflat habitat for a wide range of marine life, including shellfish, fish and wading birds in Havelock Estuary. In each case, the source references present no substantive evidence to support the claims made.

While it is clear that *Spartina* will alter both estuary habitat and biodiversity in the ways mentioned above, it is equally likely, if not more so, that excessive sedimentation (which *Spartina* helps mitigate) would have similar or even greater impacts. Campbell et al. (2009) emphasise that native ecosystems cannot be restored completely unless the underlying conditions upon which the success of the invader (*Spartina)* is predicated are remediated. Therefore, it is clear that eradicating *Spartina* without altering the input of sediment is addressing the response to this stressor, not its cause. Understanding the primary drivers of change, as well as the response of the ecosystem to such drivers, is needed to reach defensible decisions and understand the potential consequences of *Spartina* eradication.

As it stands, *Spartina* has been declared an invasive weed and nationwide efforts to eradicate it continue (e.g. Brown and Raal 2013). *Spartina* is a ‘total control’ plant in the MDC Regional Pest Management Strategy, and DOC estimated ~$160K was required for annual eradication in the South Island in 2012 (Brown and Raal 2013).

Spartina **prior to eradication in the eastern Kaituna settling basin - photo Phillip Clerke, (DOC).**

Residual *Spartina* root systems in the eastern Kaituna settling basin.

Erosion of *Spartina* root systems along a channel edge in the western Kaituna settling basin.

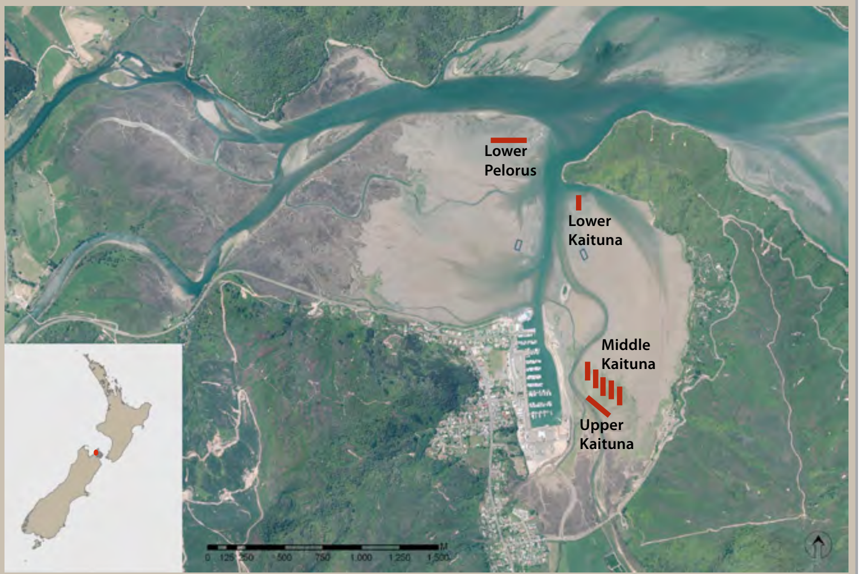
Introduced cord grass *Spartina*: an overview

In Havelock Estuary, spray eradication of *Spartina* has been undertaken since 2003, along with annual monitoring of sediment levels within sprayed root beds (DOC unpublished consent data). Monitoring sites, and the results of sediment levels measured, are presented in the Figures below. Because measures of sediment accumulation prior to spraying are not available, the rate of sediment retention within *Spartina* in Havelock remains unknown, but monitoring after spraying shows sediment deposition continued at ~5mm/yr in sheltered upper estuary root zones (middle and upper Kaituna sites) for 1-2 years (top graph), before a relatively slow and variable release of sediment to the main estuary body, presumably as the root systems break down. Sites in the lower estuary (bottom graph), are subjected to greater wave action and current flows and show more rapid and variable erosion. These results, and knowledge of *Spartina's* trapping ability elsewhere in NZ (e.g. Lee and Partridge 1983), indicate that *Spartina* most likely contributed significantly to the retention of fine sediment entering Havelock Estuary. It is well understood that excessive sediment inputs are detrimental to estuarine systems, and consequently, the presence of *Spartina* within Havelock was beneficial in this respect.

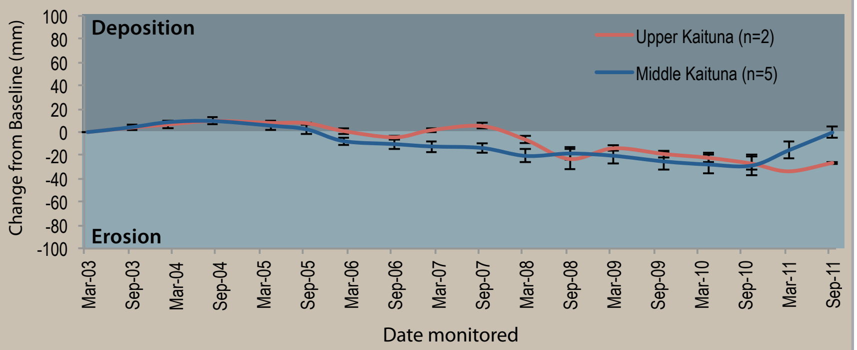
Eradicating *Spartina* without addressing the key driver of sediment inputs, and without monitoring ecological changes or tracking sediment re-deposition related to the spray programme, mean it is not possible to assess the actual consequences of eradication, or the potential benefits from *Spartina's* presence.

While widespread acute impacts from the release of trapped sediment appear unlikely, secondary impacts (e.g. organic breakdown of roots causing localised sediment enrichment, reduced sediment oxygenation, macroalgal blooms on dead root masses) remain un-quantified, as do the impacts of greater sediment inputs to the estuary following the removal of this important sediment trapping habitat. Until such aspects have been enumerated, a predicted response following *Spartina* eradication is put forward as follows:

1. Lost trapping capacity means sediments that would otherwise have been trapped, and sediments released from the decaying root systems, are deposited into the main body of the estuary, concentrating in settling basins, increasing sediment muddiness, altering the sediment dwelling community, and increasing turbidity.
2. Increased turbidity and deposited mud degrades or displaces high value habitat, in particular seagrass and shellfish beds, and diminishes human use values.
3. Altered ecosystem dynamics facilitate the establishment and proliferation of introduced species like Pacific oyster which further trap and concentrate fine muds in the lower intertidal areas (including pseudo-faeces from filtering water column sediment). This again alters ecosystem functioning, displacing native species, altering substrate types, and impacting on human uses.
4. At a localised level, plant death stops nutrient uptake and sediment oxygenation through root systems.
5. Root systems decay causing a switch to largely anoxic sediment conditions contributing to direct organic enrichment of sediments, the promoting the release of sediment-bound nutrients. Sediment de-nitrification is inhibited under the anoxic conditions established.
6. The subsequent release of nutrients fuels the growth of opportunistic macroalgae that are able to establish on the decaying root mats or other suitable substrate.
7. Macroalgae trap and concentrate fine sediments and nutrients, perpetuating a localised cycle of nutrient release from anoxic sediments, with adverse ecological impacts where nuisance growths occur.
8. Where nuisance conditions establish (e.g. excessive algal growth, poor sediment oxygenation), sediment communities are detrimentally impacted with subsequent impacts on secondary feeders including birds and fish.



Location of DOC sediment level monitoring sites (2003-2011) within sprayed *Spartina* beds in Havelock Estuary. Source: DOC unpublished consent monitoring data.



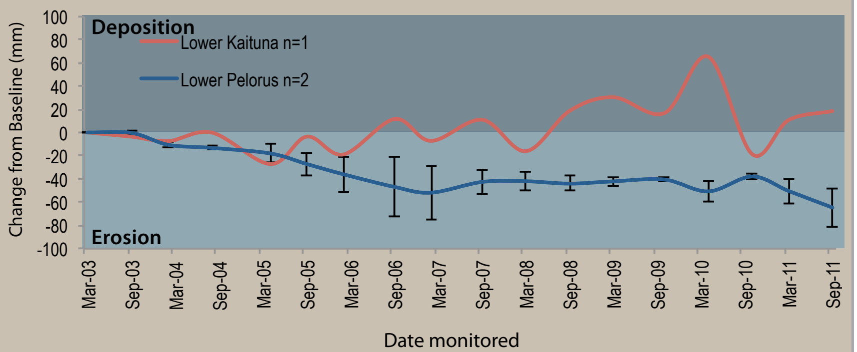


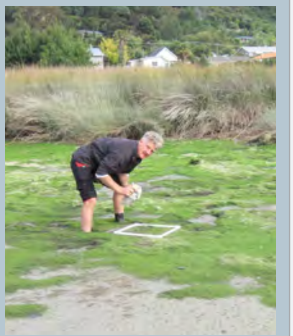
Figure showing changes in sediment levels (mm +-SE) within sprayed *Spartina* beds in Havelock Estuary, (2003-2011). Source: DOC unpublished consent monitoring data.

4. RESULTS AND DISCUSSION (CONTINUED)

4.2. OPPORTUNISTIC MACROALGAE

OPPORTUNISTIC MACROALGAE RISK INDICATOR RATING

2014 LOW (EQR = 0.64)



Assessment of opportunistic macroalgal %cover, and wet weight (biomass) of macroalgae.

GROSS EUTROPHIC AREA RISK INDICATOR RATING

2014 VERY LOW

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.

To assess the condition of opportunistic macroalgal blooms, the spatial spread and density of macroalgae was mapped (Figure 7), and an "Ecological Quality Rating" (EQR) calculated using the Opportunistic Macroalgal Blooming Tool (OMBT) which is fully described in Appendix 2.

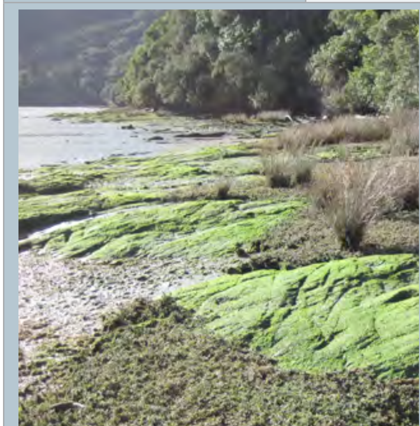
The EQR score can range from zero (major disturbance) to one (reference/minimally disturbed) and the estuary EQR score is placed within a quality status threshold band (i.e. bad, poor, good, moderate, high - Section 3, Table 2). The individual metrics that are used to calculate the EQR (spatial extent,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

The opportunistic macroalgal EQR for Havelock Estuary in March 2014 was 0.64, a quality status of "GOOD". This "GOOD" rating was driven primarily by the vast bulk of the estuary exhibiting few opportunistic macroalgal problems (271ha, 75% of the intertidal area having <5% cover of macroalgae). However, there were extensive areas (27ha, 7%) where macroalgal growth exceeded 50% cover (see photos below).

The dominant cover was species of the green alga *Ulva* which was growing throughout the estuary and in channel areas wherever firm stable substrate was present. Also present, but to a lesser extent, was the red alga *Gracilaria chilensis* which was growing most commonly at low densities in soft muds within deposition zones.

The biomass of macroalgae was relatively uniform in different parts of the estuary with *Ulva* growing on rocky substrate on the upper shores of the settling basins and river channels generally having a low biomass (~50g.m^2), the root masses of sprayed *Spartina* beds having a moderate biomass (~2500g.m^2), and growths among saltmarsh flanking the Kaituna River having the highest biomass (~4000g.m^2).

These results indicate that the estuary overall is not expressing significant symptoms of eutrophication, and that while there are localised areas where nuisance conditions are beginning to establish, there are no gross eutrophic zones in the estuary. Studies on other estuaries indicate muddy estuaries are more susceptible to eutrophication, therefore ongoing monitoring of change is recommended.



Eastern basin shoreline.

Old Spartina beds opposite the marina.

Upper Kaituna.

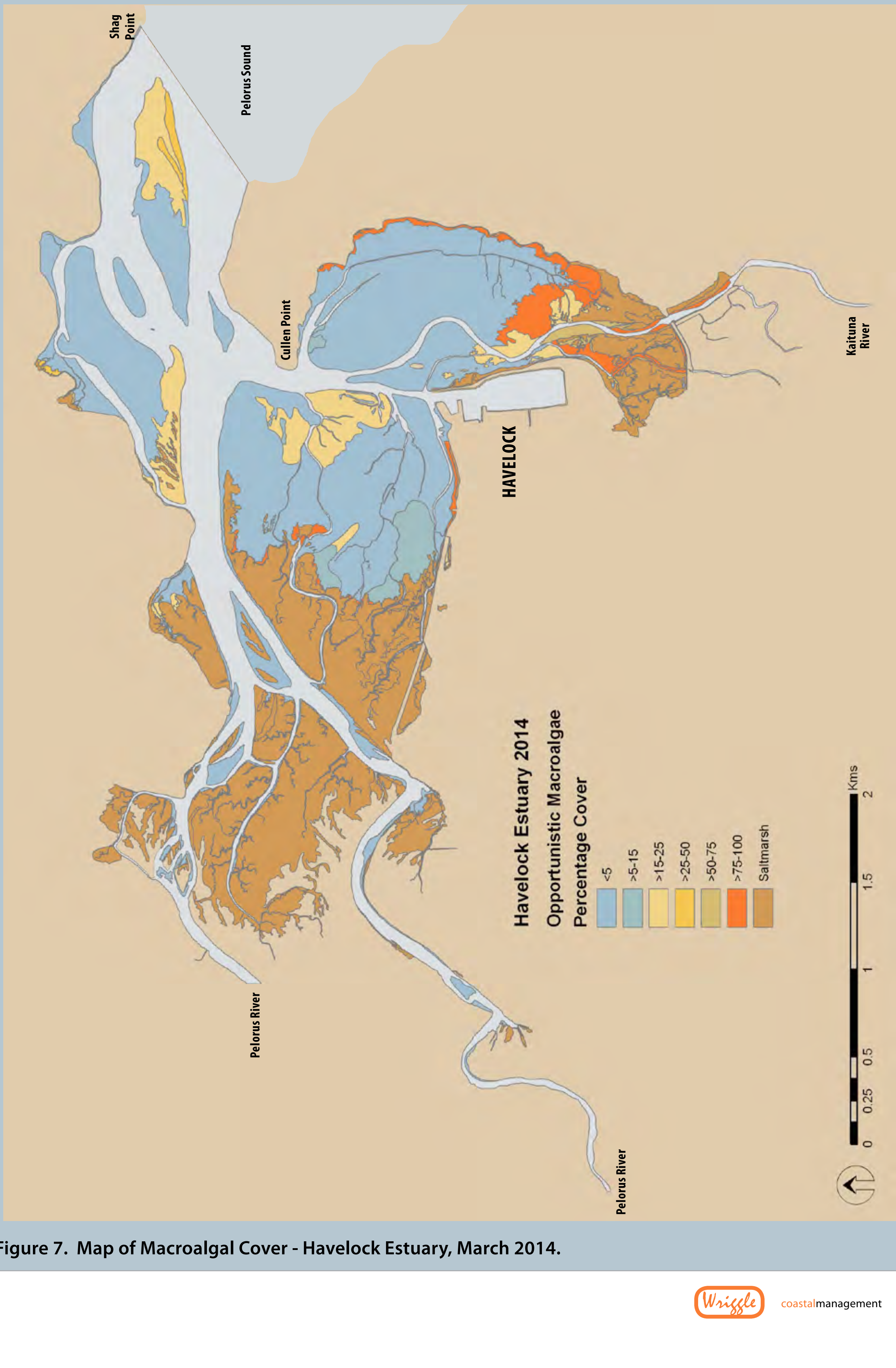


Figure 7. Map of Macroalgal Cover - Havelock Estuary, March 2014.

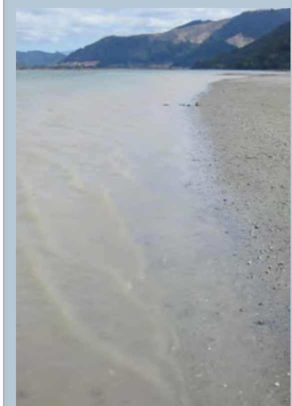
4. RESULTS AND DISCUSSION (CONTINUED)

4.3 SEAGRASS

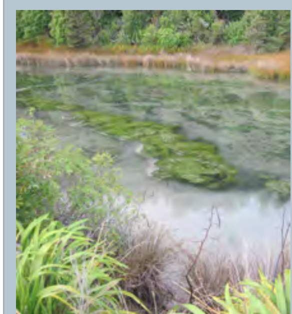
SEAGRASS COEFFICIENT RISK INDICATOR RATING

2014 HIGH (0.6)

***Zostera* beds covered in fine sediment in the lower estuary.**



Fine sediment, re-suspended by very small wind generated waves, flooding into *Zostera* beds in the lower estuary.



Patches of the submerged macrophyte *Ruppia megacarpa* in embayments adjacent to the state highway on the southern edge of the estuary.

Extensive seagrass beds in the lower estuary.

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 7 and Figure 8 summarise the results of the 2014 survey of the available seagrass habitat (mapped intertidal estuary area minus saltmarsh).

- Most of the intertidal estuary (94%) was found to have no seagrass growing.
- 15.2ha of seagrass beds with >50% cover were present. These beds were located primarily near the well flushed lower estuary channels.
- When present, seagrass beds appeared in relatively good condition, although in March 2014, most of the seagrass beds in the lower estuary were overlain with soft mud (sidebar photo).
- Seagrass within estuary deposition zones was scarce and appeared highly stressed, most likely due to a combination of excessive muddiness and associated poor water clarity.
- Localised patches of the submerged macrophyte (seagrass) *Ruppia megacarpa* were present in flow restricted embayments adjacent to the state highway along the estuary's southern edge.

The Seagrass Coefficient (SC) was 0.6, a risk indicator rating of "HIGH" based on the small area of cover relative to the available habitat area. It is not possible to accurately determine historical changes in seagrass cover as the methods used for seagrass in the 2001 broad scale mapping preclude its use as a suitable baseline. However, a review of aerial photographs used in the 2001 mapping indicates the current seagrass extent appears similar to that present in 2001.

Table 7. Summary of seagrass *(Z. muelleri)* cover,Havelock Estuary, March 2014.

Percentage Cover	Area (ha)	Percentage
0	340	94.0
1-5%	0.0	0.0
5-10%	0.0	0.0
10-20%	3.3	0.9
20-50%	3.2	0.9
50-80%	0.8	0.2
>80%	14.4	4.0
	362	**100**

4. RESULTS AND DISCUSSION (CONTINUED)

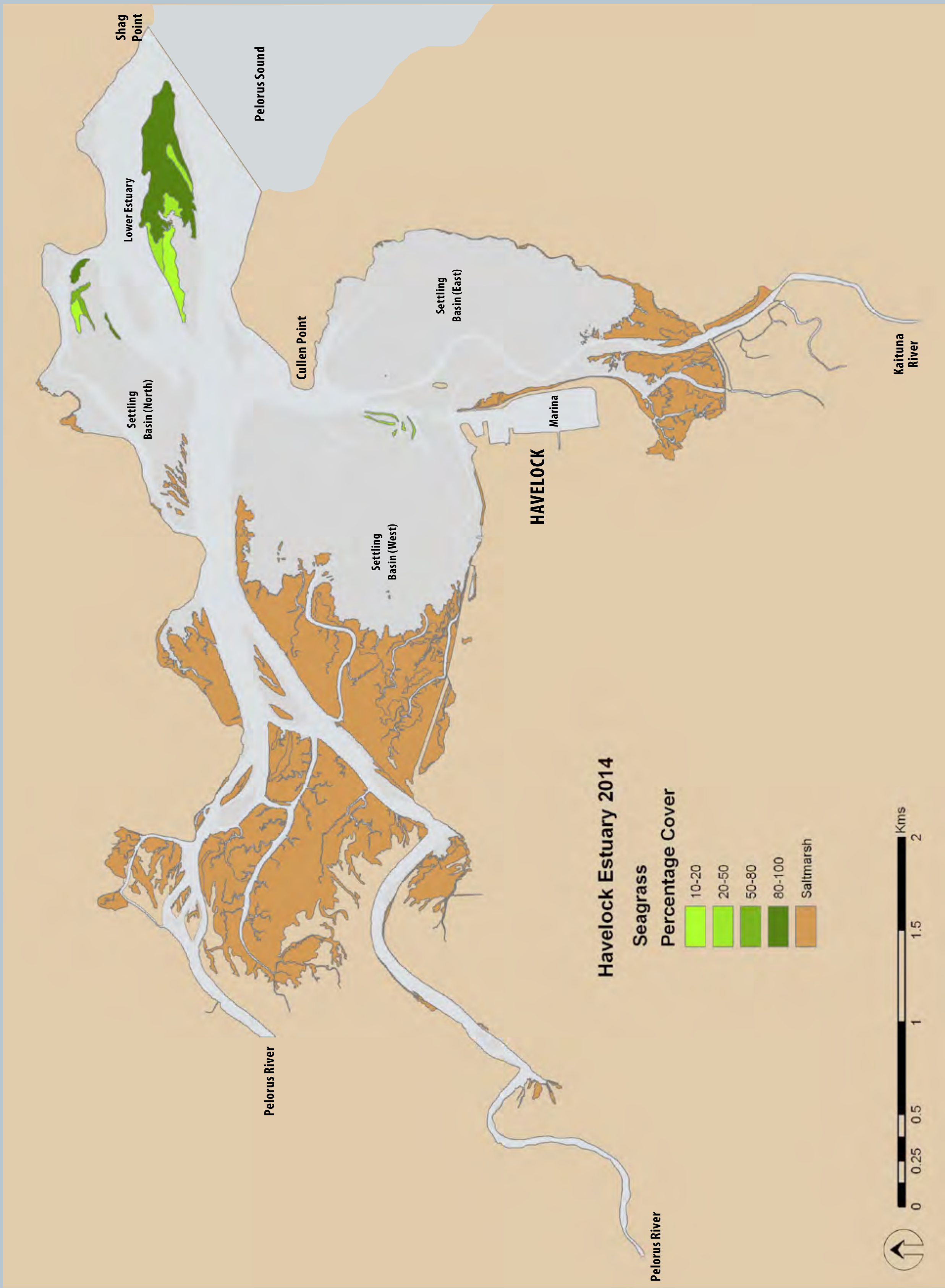


Figure 8. Map of Seagrass Cover - Havelock Estuary, 2014.

4.4 SALTMARSH

SALTMARSH % COVER RISK INDICATOR RATING

2014 VERY LOW

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 8 and Figure 9 summarise the results of the 2014 saltmarsh mapping. The large area of remaining saltmarsh (203ha, 25% of the estuary) fits the risk indicator rating of "VERY LOW". Key findings were:

- The most extensive saltmarsh areas were located in the upper river deltas of the Pelorus and Kaituna Rivers.
- The overwhelmingly dominant saltmarsh cover was rushland (95%), which comprised a relatively even mix of jointed wire rush and searush. Herbfield (4%) was the next most dominant.
- 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. Greatest historical losses have been in the Kaituna arm (~120ha) (see Lauder 1987). Such activities are ongoing in terrestrial margin areas, most noticeably on farmland near upper tidal reaches between the Pelorus River channels where drainage and infilling is apparent.

Table 8. Dominant saltmarsh cover, Havelock Estuary, 2014.

Class	Dominant Vegetation	Area (ha)	Percentage
Estuarine Shrub		1.2	0.6%
	Plagianthus divaricatus (Saltmarsh ribbonwood)	1.2	0.6%
Tussockland		1.1	0.6%
	Cortaderia sp. (Toetoe)	1.1	0.6%
Sedgeland		0.1	0.03%
	Schoenoplectus pungens (Three square)	0.03	0.02%
	Isolepis cernua (Slender clubrush)	0.02	0.01%
	Carex litorosa (Estuary sedge)	0.01	0.002%
Grassland		0.7	0.4%
	Festuca arundinacea (Tall fescue)	0.7	0.4%
Rushland		192.0	94.6%
	Apodasima similis (Jointed wirerush)	98.7	48.7%
	Juncus kraussii (Searush)	93.3	46.0%
	Schoenoplectus tabernaemontani (Lake clubrush)	0.02	0.01%
Reedland		0.03	0.01%
	Typha orientalis (Raupo)	0.03	0.01%
Herbfield		7.8	3.8%
	Samolus repens (Primrose)	7.7	3.8%
	Selliera radicans (Remuremu)	0.1	0.0%
TOTAL		**203**	**100%**

Upper Pelorus arm.

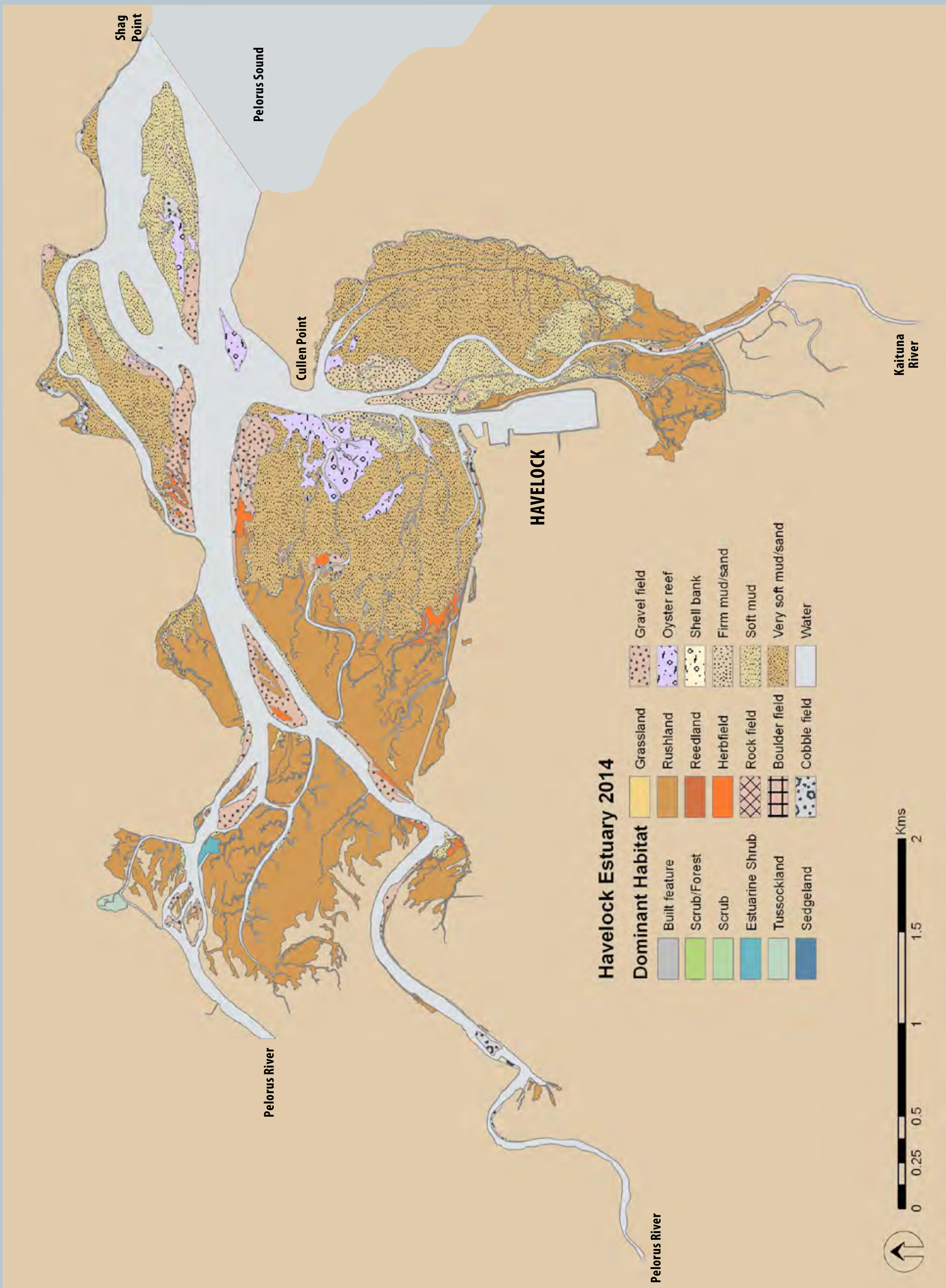


Figure 9. Map of Saltmarsh Vegetation - Havelock Estuary, 2014.

The saltmarsh in Havelock was dominated by wide and extensive beds of rushland in the upper reaches of each arm which were readily visible from the road approaches in and out of Havelock. These large beds are predominantly free of introduced weeds and grasses, with the exception of terrestrial margins which often contain a mix of saltmarsh ribbonwood, gorse, and introduced grass and weeds. Upstream, along the upper river margins leading into the main body of the estuary, saltmarsh was generally confined to narrow strips with the elevated banks and surrounding farmland providing limited habitat, while in the middle and lower sections, naturally steep landforms commonly flank the estuary and saltmarsh is restricted to small pockets or narrow bands along the upper tide range. Such areas are highly susceptible to sea level rise (SLR) related impacts and, where inland migration is not possible, saltmarsh will be eroded or inundated and displaced over time.



Around Havelock township, much of the upper margins have been modified through reclamation or drainage and the shoreline armoured to prevent erosion. These modified margins create extensive barriers to the migration of saltmarsh in response to SLR, and directly disrupts any connectivity to natural terrestrial habitat.



Other notable features within rushland were small herbfields either among sparse rushes in the upper Kaituna arm, or at the edge of rush beds in the Pelorus arm.


Several small patches of the endemic estuary sedge *Carex litorosa*, were present. This plant, while a very minor saltmarsh component, has a declining status in Marlborough (Davidson et al. 2011). In Havelock this appears to be driven primarily by the impact of reclamation or encroachment by terrestrial species into its upper estuary habitat.

SALTMARSH AREA RISK INDICATOR "CHANGE" RATING

2001-2014 HIGH (15%DECREASE)

CHANGES IN SALTMARSH COVER 2001 - 2014

The risk indicator "change" rating for saltmarsh measures a percentage change from an established baseline. Table 9 summarises the reported extent of saltmarsh in Havelock Estuary in 2001 and 2014. The 2001 data are used here as the baseline, but it is acknowledged that by this time significant saltmarsh losses had already occurred, along with the drainage of flanking freshwater wetlands.

The saltmarsh risk indicator rating of change from 2001 to 2014 was "HIGH" reflecting a 15% decrease in saltmarsh. This change was almost solely due to the eradication of 51ha of *Spartina* (reedland) through the combined impact of spraying and, to a lesser extent, reclamation undertaken during expansion of the marina area. To date, there has been no expansion of native saltmarsh into areas where *Spartina* was previously growing.

Rushland in front of old *Spartina* beds (delineated by the bright green growths of opportunistic macroalgae) in the east arm.

The apparent increase in rushland from 2001 to 2014 shown in Table 10 is an artefact of more accurate mapping of saltmarsh features in 2014 and does not represent a meaningful change. In reality, there have been ongoing losses of rushland in the upper Pelorus arm as a consequence of drainage and grazing within paddocks. A transition to more terrestrial species is expected in these areas in the future, including an increase in weed species among rushland and estuarine shrub habitat as a result of reduced tidal emersion.

Although large and dense beds of rushland remain in the heads of both arms, saltmarsh around the estuary has been greatly reduced historically and further reductions of this important habitat are highly undesirable. Margin drainage and infilling is also undesirable from an ecological perspective as predicted sea level rise 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 displaced.

Table 9. Summary of saltmarsh cover, Havelock Estuary 1999, 2014.

Vegetation Class	2001[1]		2014	
	ha	%	ha	%
Estuarine Shrub	*	*	1.2	1%
Tussockland	-	-	1.1	1%
Sedgeland	-	-	0.1	0.05%
Grassland	-	-	0.7	0.3%
Reedland	50.6	21%	0.03	0.01%
Rushland	188.4	79%	192.0	95%
Herbfield	1.4	1%	7.8	4%
SALTMARSH (ha)	240	41%	203	36%
INTERTIDAL (ha)	322	-	362	-

[1]Robertson et al. (2002).

*The reported 1999 estuarine shrub values have been excluded as they were dominated by gorse and manuka.

4.5 200m TERRESTRIAL MARGIN

VEGETATED MARGIN RISK INDICATOR RATING

2014 LOW

VEGETATED MARGIN RISK INDICATOR "CHANGE"RATING

Margin areas by the Havelock marina, pasture in the upper Kaituna arm, and scrub/forest cover in the lower Pelorus arm.

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 margin of the terrestrial mainland and larger islands within the estuary (Table 10 and Figure 10) showed:

- The mapped 200m wide terrestrial margin buffer was dominated by mixed native and exotic scrub and forest (49%) and grassland/pasture (38%). Pasture dominated around the upper estuary river areas on flood plains, while the steeper hills surrounding the lower estuary were dominated by scrub and forest. Plantation forestry (3%) was present in the upper Pelorus.
- Residential (5%), commercial (2%), roads (1%) and industrial development (0.3%) were centred around Havelock township.
- The vast majority of the estuary margin between the Pelorus and Kaituna Rivers on the southern side of the estuary been modified by roading, causeways, seawalls, reclamations, or land clearance.

The relatively extensive densely vegetated buffer (53% native and exotic scrub and forest) fits the risk rating of "LOW". Aerial photos indicate no significant change in the terrestrial margin cover since 2001.

A dominant feature of the southern estuary margin was the extensive presence of roading or infrastructure, and associated erosion protection, along the estuary edge. These developments have 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. The shoreline hardening, combined with associated drainage of wetland areas and channelisation of streams, and the creation of several flow restricted embayments, significantly adversely impacts on native fish spawning and bird habitat, and greatly compromises the 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 near Havelock marina, most of the low lying estuary fringes, where there was once a gentle natural transition from the estuarine to terrestrial habitat, have been significantly modified by human development.

The initiatives being undertaken to improve the quality of the estuary margin, particularly the planting of native trees and creation of bird roosting islands, and protection of saltmarsh on private land should be encouraged wherever possible.

Table 10. Summary of 200m terrestrial margin land cover, Havelock Estuary, 2014.

Class	Dominant Cover	Percentage
Exotic Forest	*Pinus radiata* (Pine tree)	3%
Scrub/Forest	Mixed native and exotic	39%
Scrub	Mixed native and exotic	11%
Estuarine Shrub	*Plagianthus divaricatus* (Saltmarsh ribbonwood)	0.06%
Pasture		36%
Unmanaged Grassland		2%
Roads		1%
Commercial		2%
Industrial		0.3%
Residential		5%
Total		**100%**

4. RESULTS AND DISCUSSION (CONTINUED)

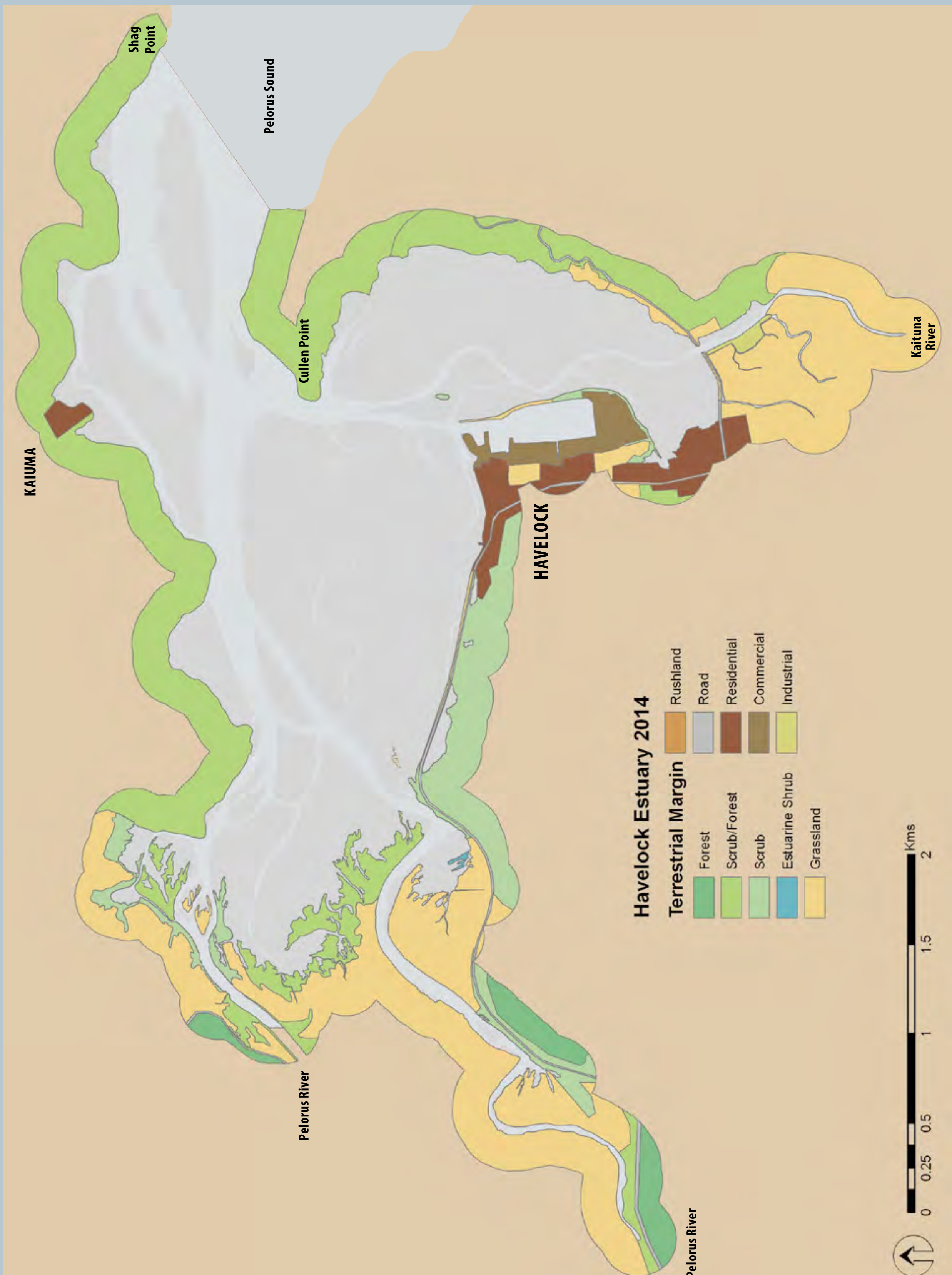


Figure 10. Map of 200m Terrestrial Margin - Dominant Land Use, Havelock Estuary, 2014.

5. SUMMARY AND CONCLUSIONS

Table 11 summarises risk indicator ratings in relation to the key issues addressed by the 2001 and 2014 broad scale monitoring (i.e. sediment, eutrophication and habitat modification).

Table 11. Summary of broad scale risk indicator ratings for Havelock Estuary, 2014, and changes from baseline conditions.

Major Issue	Indicator	Risk Rating		Change from Baseline
		2001	2014	
Sediment	Soft mud (% cover)	VERY HIGH	VERY HIGH	Increase in extent and muddiness
Eutrophication	Macroalgal Growth (OMBT)	LOW*	LOW	No significant change*
	Gross Eutrophic Conditions (ha)	VERY LOW*	VERY LOW	No significant change*
Habitat Modification	Seagrass Coefficient (SC)	HIGH*	HIGH	No significant change*
	Saltmarsh (% cover)	VERY LOW	VERY LOW	Decrease in saltmarsh
	200m Vegetated Terrestrial Margin	LOW*	LOW	No significant change*

*estimated value

The results, which highlight that sediment is a major issue in the estuary ("VERY HIGH" risk rating), are driven by two major findings:

- **Soft mud sediments occupied 77% of the unvegetated intertidal area in 2014** (an increase of 6% since the baseline survey in 2001), and were concentrated in deposition zones in the mid-upper intertidal basins and quiescent zones in both arms. Compared with other developed NZ estuaries, such cover was very large, and well above the <1% mud expected for an undeveloped reference estuary of a similar size and type.
- **The estuary sediments have become muddier** (i.e. higher mud content) since the baseline survey in 2001. In particular, the area classified as very soft mud increased by 34ha (168ha in 2001 to 202ha in 2014). In addition, the extent of the introduced Pacific oyster habitat as a dominant cover (which overlies very soft mud habitat) has increased by ~10ha.

Such changes have significant ecological consequences, in particular to high value seagrass and saltmarsh habitat, and to sediment and water column biology.

Seagrass mapping results found dense seagrass beds were limited to a relatively small area (~15ha) near the well flushed lower estuary channels and flats ("HIGH" risk rating), but were covered by extensive fine mud deposits. Its absence over the majority of the estuary likely reflects the influence of excessive soft mud and reduced water clarity, limiting where seagrass can grow.

Until the post 2003 eradication of the 51ha of introduced cordgrass (*Spartina)* in the estuary, saltmarsh habitat had been rapidly expanding as a result of both the availability of muddy habitat, and the action of *Spartina* in facilitating mud deposition. Subsequently, the now unvegetated, midwater *Spartina* habitat has reverted to soft muds with a high potential for resuspension and exacerbation of detrimental water clarity impacts. Above the midwater habitat, the natural saltmarsh (203ha, 25% of the estuary) was generally the same in both 2001 and 2014 (VERY LOW" risk rating) and was dominated by wide and extensive beds of rushland (192ha), and small herbfields (8ha). However, small changes in saltmarsh area were noted, due to reclamation undertaken during expansion of the marina area and drainage on private land adjacent to the estuary.

Multiple studies have shown estuarine macroinvertebrate communities to be adversely affected by the accumulation of muddy sediments, both through direct and indirect mechanisms including: declining sediment oxygenation, smothering and compromisation of feeding habits (e.g. see Mannino and Montagna 1997; Rakocinski et al. 1997; Peeters et al. 2000; Norkko et al. 2002; Ellis et al. 2002; Thrush et al. 2003; Lohrer et al. 2004; Sakamaki and Nishimura 2009; Jones et al. 2011; Wehkamp and Fischer 2012; Robertson 2013). Generally, increased muddiness results in a community dominated by species tolerant of muddy conditions, with species like cockles and pipi being displaced.

Such ecological changes are expected to have a direct and cascading effect on a range of organisms including fish, birdlife, other primary producers and human uses as a result of changes to physicochemical conditions (e.g. increased mud content, reduced sediment oxygenation, and lower water clarity). The current symptoms and monitoring results serve a warning that such problems are likely to persist without management intervention.

These results show the estuary's capacity to assimilate sediment loads and maintain a healthy ecosystem have been exceeded. Unless loads are kept to levels the estuary can assimilate, Havelock Estuary will continue to infill at a high rate, and become muddier and less biodiverse.

At the present time, the primary source of the sediment loads causing the observed changes between 2001 and 2014 is unclear. However, based on available information, it is likely to be either or both of the following:

- fine sediment delivered to the estuary as a result of erosion from land in the catchment, and
- release of previously trapped sediments from decaying *Spartina* root masses.

Currently, no targeted monitoring or modelling has been undertaken to assess the extent of either of these inputs, but it is acknowledged that such investigations are feasible and would provide valuable input to future management of the estuary.

The mapping also identified more positive results for two other indicators (additional to saltmarsh) which highlight that large sections of the estuary still remain in relatively good condition with low or very low risks of adverse ecological change. In particular, opportunistic macroalgae (the key indicator of eutrophication or excessive nutrient inputs) and vegetated 200m terrestrial margin were in the "LOW" risk category.

- Opportunistic macroalgal growth was sparse throughout most of the estuary (10.6% of the available intertidal habitat). Combined with a relatively low average biomass (~528g.m^{-2}), and a low percentage of algae entrained in underlying sediment (13%), the results indicate the estuary overall is not expressing significant eutrophication symptoms. However, dense beds of *Ulva* were present in localised areas and ongoing macroalgal monitoring is recommended because of the heightened susceptibility of muddy estuaries to opportunistic nuisance macroalgal growths.
- The 200m terrestrial margin was dominated by native and exotic scrub and forest (49%) on the steep hills flanking the lower estuary, and grassland/pasture (38%) on the river flood plains. Artificial structures (e.g. rockwalls, floodbanks, causeways) were a dominant feature around Havelock township, and restrict the area available for saltmarsh growth or expansion in response to predicted sea level rise. The relatively high proportion of naturally vegetated margin surrounding the estuary indicates a propensity for strong buffering actions and enhanced biodiversity.

The monitoring results also raise areas of uncertainty and knowledge gaps, particularly in relation to:

- **Source Identification**. What are the main sources of fine sediments depositing in the estuary?
- **Ecological Condition/Sediment Load Relationship.** What is the predicted ecological condition of the estuary (pristine to poor) along a full gradient of catchment sediment loads, infilling rates, and within estuary management actions (e.g. dredging).

Targeted investigations are recommended to address such issues so that appropriate catchment management and restoration options can be explored. The most cost effective approach is through the application of a catchment based landuse/sediment yield model to predict sediment sources (e.g. CLUES Model) under different landuse patterns, combined with development of a conceptual outline of what the estuary would look like under various sediment load scenarios (e.g. low, medium, high, and existing). This would enable past modifications in estuary condition to be defined and related to natural or human influenced processes influencing the estuary, and provide important information upon which to base future management decisions. It would also provide a basis, through stakeholder involvement, to agree on an appropriate "target" estuary condition, and development of a plan to identify sediment input load guideline criteria. The outcome would help address, early in the process, such important questions as;

- If input loads are reduced, will mud 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?

This conceptual approach would then determine the need for any detailed investigations such as fine sediment source, transport, deposition, and export within the estuary.

6. MONITORING

Havelock Estuary has been identified by MDC as a priority for monitoring, and is a key part of MDC's coastal monitoring programme being undertaken in a staged manner throughout Marlborough 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 MDC:

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 biannually, and initiate broad scale macroalgal mapping if conditions appear to be worsening over the 5 years before broad scale mapping is repeated.

Fine Scale Monitoring
Given the magnitude of the muddiness changes between 2001 and 2014, and to establish whether the deteriorating results observed in 2014 are truly representative of current conditions, monitoring is recommended as follows: Sites A and B continue to be monitored, but two new sites be established in the dominant intertidal habitat type (very soft muds) and all 4 sites be monitored (data collection only) in February 2015, 2017 and 2019 to establish both a multi-year baseline and relationships between soft mud and very soft mud habitats so that the value of previous monitoring is not lost. A full report of all data should then be undertaken at the next scheduled 5 yearly monitoring interval (2019). This change is supported by the 2014 broad scale mapping results of dominant substrate types, opportunistic macroalgae, and seagrass beds in the estuary.

Sedimentation Rate Monitoring
Because sedimentation is a priority issue in the estuary it is recommended that sediment plate depths (established at the two existing fine scale sites in 2014) be measured annually, and new plates be deployed in the dominant very soft mud locations where sediment appears to be rapidly accumulating.

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

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) identify fine sediment as the major issue in Havelock Estuary. Although elevated fine sediment inputs have likely been occurring since the first human development of the catchment, the monitored increase in estuary muddiness from 2001-2014 highlights recent inputs have exceeded the estuary's assimilative capacity. 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 sources through the application of a catchment based landuse/sediment yield model to predict sediment sources under different landuse patterns. Although much of the sediment trapped among *Spartina* roots is likely to have already been released, this source should also be considered.
- Using the results of the above investigations, and other appropriate monitoring data, identify sediment input load guideline criteria to reduce fine sediment infilling to the target state.
- Explore catchment management and estuary restoration options, and develop a plan to achieve targets.

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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.

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 (2012a)
	Very Soft Mud	>5cm		
Hutt Estuary	Firm Muddy Sand	0-2cm	21%	Stevens and Robertson (2014a)
	Soft Mud	2-5cm	28-51%	Robertson and Stevens (2012b)
	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 (2014b)
	Soft Mud	2-5cm	>25%	
	Very Soft Mud	>5cm		
Havelock Estuary	Firm Muddy Sand	0-2cm	17%	Stevens and Robertson (current report)
	Soft Mud	2-5cm	>25%	
	Very Soft Mud	>5cm		

APPENDIX 2. ESTUARY CONDITION RISK RATINGS (CONTINUED)

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).

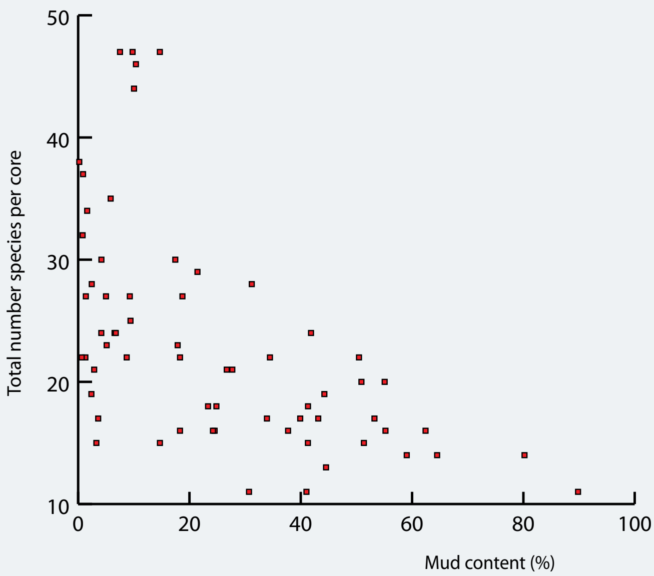

Figure 1. Sediment mud content and number of macrobenthic species per core from 12 estuaries scattered throughout NZ, and representing most NZ shallow, short residence time estuary types. (Wriggle Coastal Management database 2009-14).

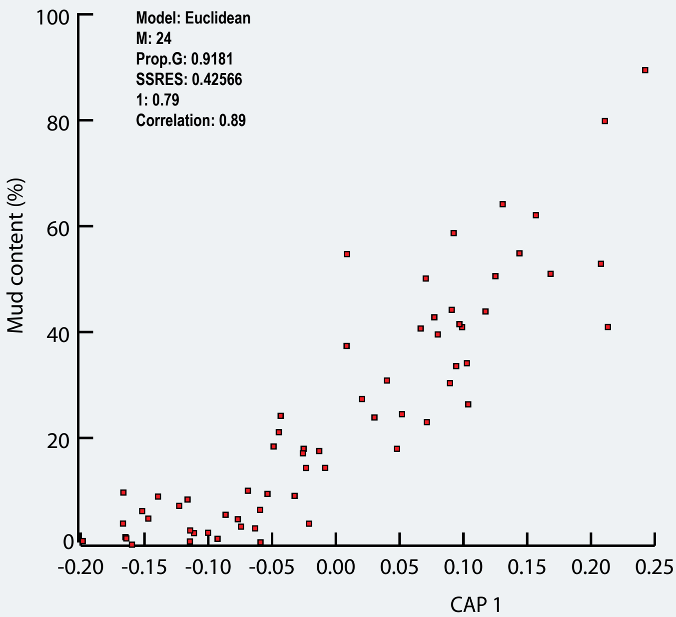

Figure. 2. Canonical analysis of the principal coordinates (CAP) for the effect of sediment mud content (exclusively) on the macroinvertebrate assemblages from 25 typical NZ estuaries (i.e. CAP1) among sites. Note: M = the number of PCO axes used for the analysis, Prop.G = the proportion of the total 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.

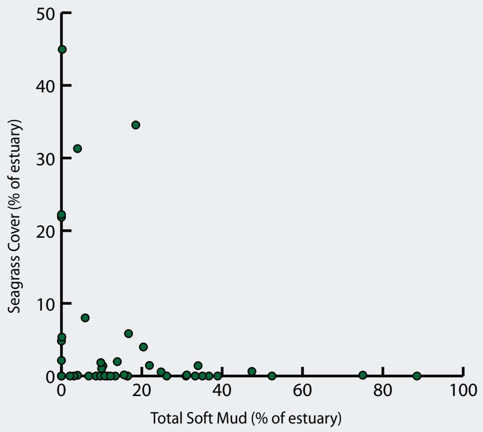

Figure 3. Percentage soft mud and seagrass cover of 45 typical NZ tidal lagoon and tidal river) estuaries (shallow, residence time <3 days) (data sourced from Wriggle Coastal Management monitoring reports 2006-2013 and Robertson et al. 2002).

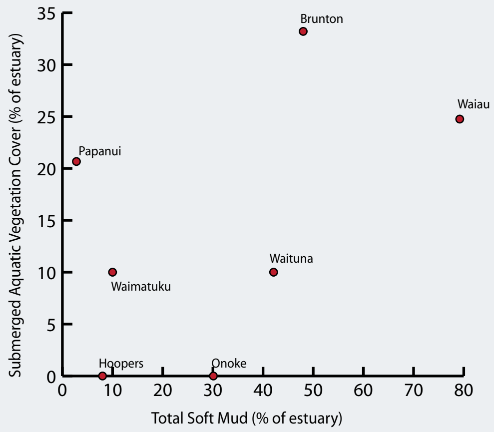

Figure 4. Percentage soft mud and seagrass cover of 7 typical NZ ICOLL estuaries (shallow, residence time variable) (data sourced from Wriggle Coastal Management monitoring reports 2006-2013).

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, 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 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 magnitude 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 magnitude 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.

APPENDIX 2. ESTUARY CONDITION RISK RATINGS (CONTINUED)

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

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 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.

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, HAVELOCK ESTUARY 2014 WORKED EXAMPLE.

Monitoring of Havelock Estuary 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, Havelock Estuary, 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%	270.8	0	0.0	0	0	0	0
>5-15%	14.0	10	1.4	100	14000	12.9	1.3
>15-25%	45.6	20	9.1	264	120384	17.3	3.5
>25-50%	4.3	40	1.7	390	16770	0	0.0
>50-75%	4.5	75	3.4	190	8550	0.2	0.2
>75%	22.9	100	22.9	1408	322432	0.2	0.2
TOTALS	362	-	38.5	-	482136	30.6	5.1

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

AIH - Available Intertidal Habitat (ha)	362	ha
Percentage cover of AIH (%) = (Total % Cover / AIH} x 100 - *where Total % cover = Sum of {(patch size) / 100} x average % cover for patch*	10.6	%
Biomass of AIH ($g.m^{-2}$) = Total biomass / AIH - *where Total biomass = Sum of (patch size x average patch biomass)*	133.2	$g.m^{-2}$
Biomass of Affected Area ($g.m^{-2}$) = Total biomass / AA - *where Total biomass = Sum of (>5% cover patch size x average patch biomass)*	528	$g.m^{-2}$
Presence of Entrained Algae = (No. quadrats or area (ha) with entrained algae / total no. of quadrats or area (ha)) x 100	13	%
Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%). Highlighted in yellow cells in Table 9 above.	91.3	ha
Size of AA in relation to AIH (%) = (AA / AIH) x 100	25.2	%

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 (%)	10.6	GOOD	FEDS:0.8-(10.6-5)/9.999)*0.2=		0.69
Biomass of AIH ($g.m^{-2}$)	133.2	GOOD	FEDS:0.8-((133.2-100)/399.9999)*0.2=		0.78
Biomass of Affected Area ($g.m^{-2}$)	528	MODERATE	FEDS:0.6-((528-500)/499.9999)*0.2=		0.59
Presence of Entrained Algae (%)	13.2	MODERATE	FEDS:0.6-((13-5)/14.9999)*0.2=		0.69
Affected Area (use the lowest of the following two metrics)		MODERATE			0.43
Affected Area (ha)	91.3	MODERATE	FEDS:0.6-((91.3-50)/49.9999)*0.2=	0.43	
Size of AA in relation to AIH (%)	25.2	MODERATE	FEDS:0.6-((25.2-15)/34.9999)*0.2=	0.54	
Ecological Quality Rating - EQR (Average of FEDS)		**GOOD**			**0.64**

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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