coastalmanagement

# Tokomairiro Estuary

## Broad Scale Habitat Mapping 2018

Prepared for

**Otago Regional Council**

**June 2018**

**Cover Photo: Tokomairiro Estuary, view upstream from near the entrance, February 2018.**


Tokomairiro Estuary - upper estuary channel confined within incised banks 0.5-1m high

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Prepared for
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by

Leigh Stevens

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

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# TOKOMAIRIRO ESTUARY - EXECUTIVE SUMMARY


Tokomairiro Estuary is a modified, moderate-large sized (150ha), mesotidal, shallow (mean depth ~1.75m at high water), tidal river type estuary located downstream of Milton, Otago. The mouth is nearly always open, but often has a constricted tidal mouth that very infrequently closes, and the upper estuary is at times poorly flushed, stratified and susceptible to phytoplankton blooms.

The estuary substrate is dominated by muddy sediments but supports large areas of saltmarsh, subtidal macrophyte growth, and small beds of nuisance macroalgae. The 398km$^2$ catchment is dominated by high producing exotic pasture (54%) and plantation forestry (35%).

Tokomairiro is one of the key estuaries in Otago Regional Council's (ORC's) long-term coastal monitoring programme. This report presents the results of broad scale estuary habitat mapping undertaken in February 2018 with monitoring results, overall estuary condition and issues, and monitoring recommendations summarised below.

## BROAD SCALE RESULTS

- Intertidal flats comprised 26% of the estuary, saltmarsh 38%, and subtidal waters 36%.
- Intertidal substrates (outside of saltmarsh) were dominated by soft and very soft mud (69%), with smaller areas of mobile sand (22%), firm sand (6%) and firm muddy sand (2%).
- Sediment mud content measured within soft and very soft mud habitat was high (20-65%).
- Opportunistic macroalgal growth had an Ecological Quality Rating of GOOD. It was not widespread, but growths of *Gracilaria* entrained in sediment are likely to be persistent. Phytoplankton concentrations were high, particularly in deeper stratified upper estuary areas with over 5km of the upper estuary reported as eutrophic (Robertson and Robertson 2018).
- Large parts of the intertidal estuary (23%) were adversely impacted by low sediment oxygenation.
- Intertidal seagrass was scarce (20m$^2$) but 16ha of native macrophyte *Ruppia* was mapped growing subtidally.
- Saltmarsh cover was relatively extensive 57ha (38% of the intertidal area) and was dominated by rushland (53%).
- The 200m terrestrial margin was 58% pasture, with 40% remaining in a densely vegetated buffer zone, including plantation forest.

## ESTUARY CONDITION AND ISSUES

In relation to the key issues addressed by the broad scale monitoring (i.e. muddiness, eutrophication, and habitat modification), the 2018 broad scale mapping results show that the estuary supported a variety of substrate types, extensive areas of saltmarsh, very small areas of intertidal seagrass (*Zostera*), but large subtidal macrophyte beds (*Ruppia*). It was expressing symptoms of excessive muddiness throughout most of the upper and middle estuary, a moderate level of eutrophication (i.e. entrained macroalgae and high phytoplankton concentrations), and large areas with low sediment oxygenation. Historically, there has been significant modification and loss (~90-100ha) of estuary saltmarsh through drainage and reclamation and the 200m terrestrial buffer is now dominated by pasture and plantation forest.

The combined results place the estuary in a MODERATE state in relation to ecological health with an ETI score of 0.59, Band C, reflecting a moderate degree of eutrophic symptoms.

## RECOMMENDED MONITORING

Tokomairiro Estuary has been identified by ORC as a priority for monitoring because it has high ecological and human use values and is situated in a developed catchment, and therefore vulnerable to excessive sedimentation and eutrophication. Broad scale habitat mapping, in conjunction with fine scale monitoring and sedimentation rate monitoring, provides valuable information on current estuary condition and trends over time. The following broad scale monitoring recommendations are proposed by Wriggle for consideration by ORC:

- To characterise any issues from changes in habitat (e.g. saltmarsh area, soft mud extent), undertake broad scale habitat mapping at 10 yearly intervals (next scheduled for 2028) unless obvious changes are observed in the interim.
- Install sediment plates to monitor annual sediment accrual at two sites in the key deposition zone of the middle estuary.
- Because of the potential for intertidal macroalgal growth to quickly transition to nuisance conditions it is recommended that macroalgae be mapped 5 yearly.

# 1. INTRODUCTION

Developing an understanding of the condition of and risks to coastal and estuarine habitats is critical to the management of biological resources. The Otago Regional Council's "Regional Policy Statement and Regional Plan: Water" demonstrates the Council's determination to maintain estuaries in good condition. In the period 2005-2008 Otago Regional Council (ORC) undertook preliminary (one-off) monitoring of the condition of seven Otago estuaries in its region. In 2016, ORC began a more comprehensive long-term estuary monitoring programme designed to particularly address the key NZ estuary issues of eutrophication and sedimentation within their estuaries, as well as identifying any toxicity and habitat change issues. The estuaries currently included in the programme are the Shag, Waikouaiti, Catlins, Kaikorai and Tokomairiro estuaries.

Within NZ, the approach for monitoring estuary condition follows the National Estuary Monitoring Protocol (NEMP) (Robertson et al. 2002) and the NZ Estuary Trophic Index (ETI) (Robertson et al. 2016a and b). It consists of three components as follows:

1. **Ecological Vulnerability Assessment (EVA**) of estuaries in the region to major issues (see Table 1) and appropriate monitoring design. This component has not yet been undertaken on a regional scale for Otago and hence relative vulnerabilities of their estuaries to the key issues have not been formally identified.
2. **Broad Scale Habitat Mapping (NEMP approach).** This component (see Table 1) maps the key habitats within the estuary, determines their condition, and assesses changes to these habitats over time. Preliminary broad scale intertidal mapping of Tokomairiro Estuary was undertaken in 2009 (Stewart and Bywater 2009) with a comprehensive survey undertaken in February 2018 (Stevens 2018). This latter monitoring is the subject of this report.
3. **Fine Scale Monitoring (NEMP approach).** Monitoring of physical, chemical and biological indicators (see Table 1). This component, which provides detailed information on sediment condition, was undertaken in a partial form in 2009 (Stewart and Bywater 2009), with the first year of comprehensive baseline monitoring undertaken in December 2017 (Robertson 2018).

**Report Structure:** The current report presents an overview of key estuary issues in NZ and recommended monitoring indicators (Section 1). This is followed by risk indicator ratings (Section 2) and the sampling methods used in this broad scale assessment (Section 3). Summarised broad scale results of the February 2018 field sampling are then presented and discussed (Section 4) for the following:

Sediment types in particular muddiness, sediment oxygenation, macroalgae and phytoplankton, seagrass, Gross Eutrophic Zones (GEZs), saltmarsh vegetation, and the 200m terrestrial margin surrounding the estuary.

To help the reader interpret the findings, results are related to relevant risk indicator ratings to facilitate the assessment of overall estuary condition (summarised in Section 5), and to guide monitoring recommendations (Section 6).

**TOKOMAIRIRO ESTUARY**

Situated at the mouth of the Tokomairiro River (mean flow ~3.7$m^3.s^{-1}$), Tokomairiro Estuary drains a 398$km^2$ catchment containing high producing exotic pastures (54%) and plantation forestry (35%). Since the late 1990s there has been a shift from sheep and beef farming to intensive dairy farming, especially on the Milton (Tokomairiro) Plain. The estuary is a 150ha shallow, short residence time tidal river estuary (SSRTRE) with several intertidal flats in the lower reaches (Figure 1). It discharges to the Pacific Ocean via a broad embayment at Toko Mouth, 16km southeast of Milton, Otago. The mouth is nearly always open, but often has a constricted tidal mouth that very infrequently closes. The impact of mouth restriction has contributed to siltation within the estuary, with mud substrate dominating intertidal areas in the upper and middle estuary. Ecologically, habitat diversity is moderate and although large areas of the natural vegetated margin and saltmarsh have been lost through historical drainage and reclamation for grazing, saltmarsh (57ha, 38% of estuary) remains a significant feature of the estuary.

The Tokomairiro Swamp, located in the middle estuary, is listed as a 'Significant Wetland' by ORC, with a lot of shallow ponds in addition to tidal habitat. The estuary provides excellent habitat for estuarine and freshwater fish and birds. Birds include very high numbers of pied stilt, and waterfowl species including the mallard, grey duck, NZ shoveller, grey teal, black swan, royal spoonbill, white faced heron, marsh crake and South Island fernbird are also present. Fish include brown trout, whitebait/inanga, koaro, common smelt, eel, lamprey, common bully, redfinned bully, mullet, 3 species of flounder, and blue moki.

The presence of deeper sections in the upper estuary that can trap dense saline water under a surface layer of more buoyant freshwater make the estuary susceptible to phytoplankton blooms under low flow conditions when flushing is limited. This will be exacerbated where nutrients inputs to the estuary are elevated.

The main recreational uses in the Tokomairiro River catchment are waterfowl shooting and angling, bird watching, swimming, picnicking, and boating in the estuary. Wastewater is also discharged to the river at Milton. Historical monitoring of the Tokomairiro River has shown that water quality is degraded, particularly in its lower reaches.

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

### 1. Sediment Changes

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

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

**Recommended Key Indicators:**

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

### 2. Eutrophication

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

**Recommended Key Indicators:**

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

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

### 3. Disease Risk

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

**Recommended Key Indicators:**

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

### 4. Toxic Contamination

In the last 60 years, NZ has seen a huge range of synthetic chemicals introduced to the coastal environment through urban and agricultural storm-water runoff, groundwater contamination, industrial discharges, oil spills, antifouling agents, leaching from boat hulls, and air pollution. Many of them are toxic even in minute concentrations, and of particular concern are polycyclic aromatic hydrocarbons (PAHs), heavy metals, polychlorinated biphenyls (PCBs), endocrine disrupting compounds, and pesticides. 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. Tokomairiro Estuary, showing main estuary zones and fine scale water quality sites.

# 2. ESTUARY RISK INDICATOR RATINGS

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

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

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

The indicators and interim risk ratings used for the Tokomairiro Estuary broad scale monitoring programme are summarised in Table 2, with supporting notes explaining the use and justifications for each indicator in Appendix 2. The basis underpinning most of the ratings is the observed correlation between an indicator and the presence of degraded estuary conditions from a range of tidal lagoon and tidal river estuaries throughout NZ. Work to refine and document these relationships is ongoing.

**Table 2. Summary of estuary condition risk indicator ratings used in broad scale assessments.**

| **RISK INDICATOR RATINGS / ETI BANDS*** (indicate risk of adverse ecological impacts) | | | | | |
|---|---|---|---|---|---|
| **BROAD AND FINE SCALE INDICATORS** | | Very Low - Band A | Low - Band B | Moderate - Band C | High - Band D |
| **Soft mud (% of unvegetated intertidal substrate)** | | <1% | 1-5% | >5-15% | >15% |
| **Sediment Mud Content (% mud)** | | <5% | 5-10% | >10-25% | >25% |
| **Apparent Redox Potential Discontinuity (aRPD)**** | | Unreliable | Unreliable | 0.5-2cm | <0.5cm |
| **Redox Potential (RP mV) upper 3cm***** | | >+100mV | +100 to -50mV | -50 to -150mV | <-150mV |
| **Sediment Oxygenation (aRPD <0.5cm or RP@3cm <-150mV)*** | | <0.5ha or <1% | 0.5-5ha or 1-5% | 6-20ha or >5-10% | >20ha or >10% |
| **Macroalgal Ecological Quality Rating (OMBT)** | | ≥0.8 - 1.0 | ≥0.6 - <0.8 | ≥0.4 - <0.6 | 0.0 - <0.4 |
| **Phytoplankton Biomass (chl-a 90th percentile)** | | <2ug/l | 5-10ug/l | >10-16ug/l | >16ug/l |
| **Seagrass (% change from baseline)** | | <5% decrease | 5%-10% decrease | >10-20% decrease | >20% decrease |
| **Gross Eutrophic Zones (ha or % of intertidal area)** | | <0.5ha or <1% | 0.5-5ha or 1-5% | 6-20ha or >5-10% | >20ha or >10% |
| **Saltmarsh Extent (% of intertidal area)** | | >20% | >10-20% | >5-10% | 0-5% |
| Supporting indicator | **Extent** (% remaining from est. natural state) | >80-100% | >60-80% | >40-60% | <40% |
| **Vegetated 200m Terrestrial Margin** | | >80-100% | >50-80% | >25-50% | <25% |
| **Percent Change from Monitored Baseline** | | <5% | 5-10% | >10-20% | >20% |
| **NZ ETI score*** | | 0-0.25 | 0.25-0.50 | 0.50-0.75 | 0.75-1.0 |

*NZ ETI (Robertson et al. 2016b), **Hargrave et al. (2008), ***Robertson (PhD in prep.), Keeley et al. (2012). See NOTES in Appendix 2 for further information.

# 3. METHODS

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

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

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

Estuary boundaries were set seaward from an imaginary line closing the mouth to the upper extent of saline intrusion (i.e. where ocean derived salts during average annual low flow are <0.5ppt), the latter confirmed by Ben Robertson (pers. comm. April 2018) as matching the boundaries used by Stewart and Bywater (2009). LINZ rectified colour aerial photos (~0.25m/pixel resolution) flown in 2014/15 were sourced from ESRI online, laminated (scale of 1:3,000), and used by experienced scientists who walked the area in Feb.2018 to ground-truth the spatial extent of dominant vegetation and substrate types. From representative broad scale substrate classes, 6 grain size samples were analysed to validate substrate classifications (Figure 3, Table 5). When present, macroalgae and seagrass patches were mapped to the nearest 5% using a 6 category percent cover rating scale as a guide to describe density (see Figure 2). Notes on sampling, resolution and accuracy are presented in Appendix 3.

Macroalgae was further assessed by identifying patches of comparable growth, and enumerating each patch by measuring:

- % cover of opportunistic macroalgae (the spatial extent and density of algal cover providing an early warning of eutrophication issues).
- macroalgal biomass (wet weight) (providing a direct measure of areas of excessive growth).
- extent of algal entrainment in sediment (highlighting where nuisance condition have a high potential for establishing and persisting).
- gross eutrophic zones (highlighting significant sediment degradation by measuring where there is a combined presence of high algal cover or biomass, low sediment oxygenation, and soft muds).

Where macroalgal cover exceeded 5% of the Available Intertidal Habitat (AIH), a modified Opportunistic Macroalgal Blooming Tool (OMBT) is used to rate macroalgal condition. The OMBT, described in detail in Appendix 4, is a 5 part multimetric index that produces an overall Ecological Quality Rating (EQR) ranging from 0 (major disturbance) to 1 (minimally disturbed) and which is placed within overall quality status threshold bands (i.e. bad, poor, good, moderate, high - Appendix 4). This integrated index provides a comprehensive measure of the combined influence of macroalgal growth and distribution.

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

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

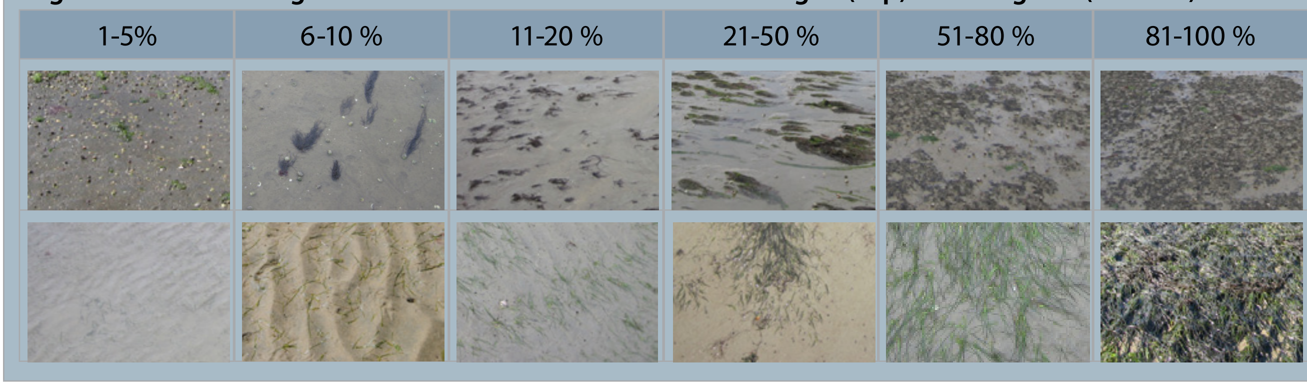



**Figure 3. Tokomairiro Estuary - lower estuary showing ground-truthing coverage, field photos and location of grain size samples used to validate substrate classifications.**

# 4. RESULTS AND DISCUSSION

## 4.1. BROAD SCALE MAPPING SUMMARY

The 2018 broad scale habitat mapping ground-truthed and mapped all intertidal substrate and vegetation including the dominant land cover of the 200m terrestrial margin, with the dominant estuary features summarised in Table 3. The estuary comprises a long and narrow enclosed tidal river estuary with a relatively even balance of saltmarsh (38%) and subtidal water (36%) and a smaller area of intertidal flats (26%) located predominantly in the lower estuary reaches.

Intertidal seagrass was very scarce (although dense beds of submerged macrophytes were present in the upper estuary), and dense (>50% cover) opportunistic macroalgae was present but not a prominent intertidal feature (<2ha). No intertidal Gross Eutrophic Zones (GEZ's) were identified. The dominant land cover of the 200m wide terrestrial margin was pasture (58%). 40% remained densely vegetated, although 22% of this was exotic forest and subject to cyclical harvesting.

In the following sections, various factors related to each of the key habitats in the estuary (e.g. area of soft mud) are used in conjunction with risk ratings to assess key estuary issues of sedimentation, eutrophication, and habitat modification. The supporting GIS files underlying this written report provide a detailed spatial record of the key features present throughout the estuary. These are intended as the primary supporting tool to help the Council address a wide suite of estuary issues and management needs, and to act as a baseline to assess future change.

**Table 3. Summary of dominant broad scale features, Tokomairiro Estuary, Feb. 2018.**

| Dominant Estuary Feature | | 2018 ha | 2018 % of intertidal area | 2018 % of total estuary area |
|---|---|---|---|---|
| 1. | Intertidal flats (excluding saltmarsh) | 39.4 | 41.0 | 26.3 |
| 2. | Saltmarsh | 56.8 | 59.0 | 37.9 |
| 3. | Subtidal waters | 53.7 | | 35.8 |
| **Total Estuary** | | **150** | | **100** |
| 4. | 200m wide densely vegetated Terrestrial Margin (e.g. scrub, shrub, forest) | | | 40% |

While broad scale mapping of the estuary was undertaken in 2009 (Stewart and Bywater 2009), only high level comparisons could be made with the current results due to variability in the way features were previously classified, and limitations with the accuracy of the 2009 GIS files.

## 4.2. INTERTIDAL SUBSTRATE

Results (summarised in Table 4 and Figure 4) show intertidal substrate comprised three major sediment types. The lower estuary was dominated by sands, and the central and upper estuary intertidal flats by soft and very soft mud, while firm muds dominated among saltmarsh vegetation. Artificial boulder field was relatively scarce (<1%) and located near reclaimed and eroding estuary margins by the settlement at Toko Mouth.

This sediment sequence is relatively predictable and is in many instances driven by past modification of the estuary. Channelisation and drainage around the river margins has reduced its capacity to regularly flow into low-lying wetland and saltmarsh areas at the estuary edge. This is historically where raised river flow events would be naturally mitigated, and where much of the catchment-derived sediments and nutrients would have been be deposited and assimilated. Reducing the area in which such natural processes can occur serves to concentrate river flows within the main channel, often contributing to increased bank erosion and the movement and deposition of sediments further down the estuary towards the sea. Where river flows mix with seawater, and the estuary widens and flow velocity reduces, sediment flocculation and deposition contribute to the accumulation of finer sediments on the bed and margins of the middle and lower estuary. Consequently this area is muddy and in relatively poor condition (see following section). Closer to the sea, tidal exchange in the lower estuary provides good flushing and maintains this part of the estuary in a sandy condition both through the deposition of marine sands, and the tidal flushing and export of terrestrial derived muds from the estuary to the coast.

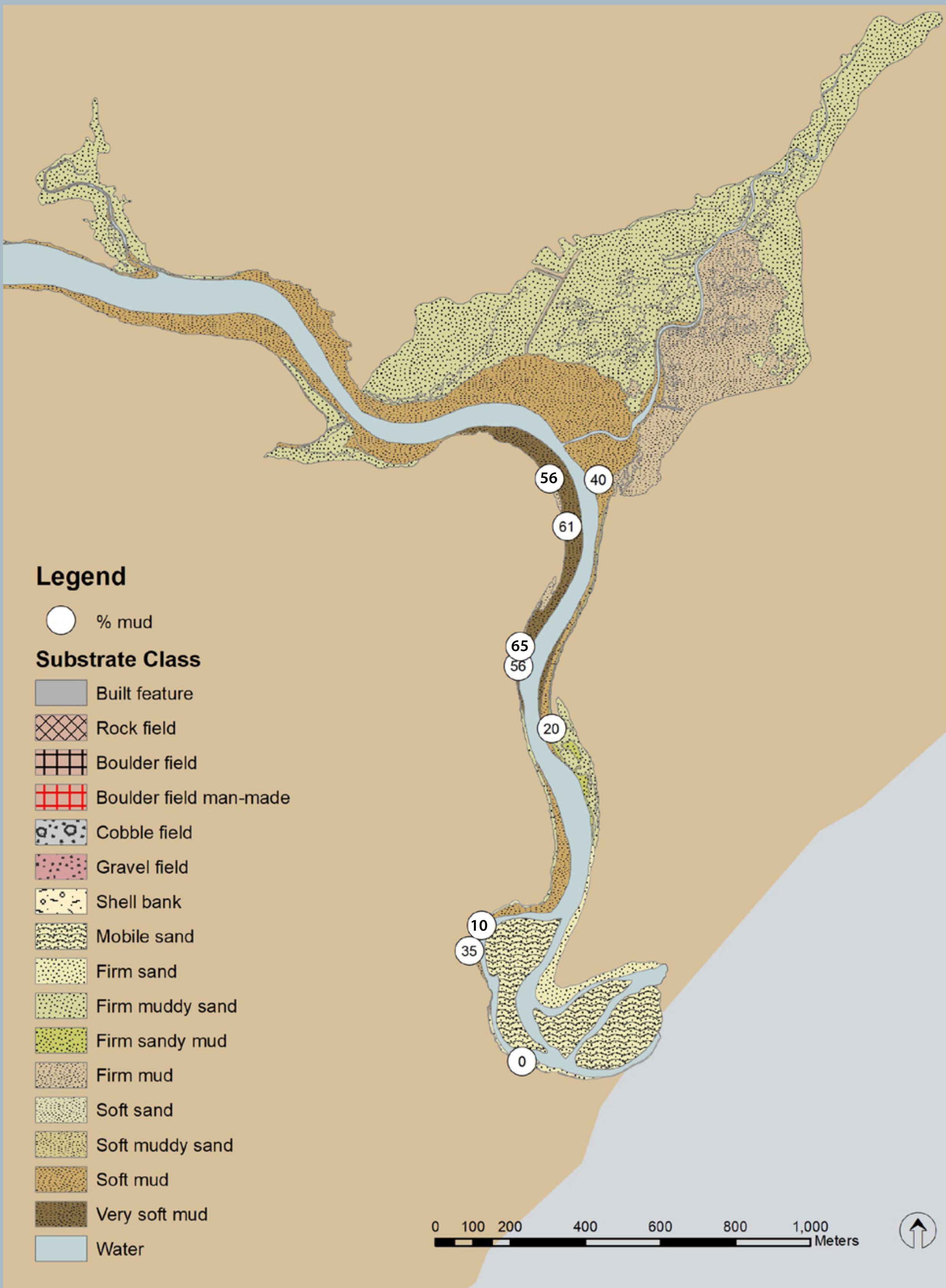



**Figure 4. Map of dominant intertidal substrate types - Tokomairiro Estuary, Feb. 2018.**

In the upper tidal zone of the estuary, extensive reclamation and drainage of wetlands and saltmarsh has contributed to sediments becoming relatively dry and firm due to rapid drainage and drying. Many areas remain regularly inundated by saltwater at high tide and this tidal inundation prevents the establishment of terrestrial plants and weeds. In the absence of seawater flows, saltmarsh vegetation has become dominated by terrestrial or freshwater plants.

**Table 4. Summary of dominant intertidal substrate, Tokomairiro Estuary, Feb. 2018.**

| Dominant Substrate | Within Saltmarsh | | Intertidal Flats | | Total Estuary | |
|---|---|---|---|---|---|---|
| | Ha | % | Ha | % | Ha | % |
| Rock field | | | 0.003 | 0.01 | 0.003 | 0.003 |
| Boulder field man-made | | | 0.1 | 0.2 | 0.1 | 0.1 |
| Mobile sand | | | 8.7 | 22.1 | 8.7 | 9.0 |
| Firm sand | | | 2.2 | 5.6 | 2.2 | 2.3 |
| Firm muddy sand | 43.4 | 76.4 | 0.7 | 1.8 | 44.1 | 45.8 |
| Firm sandy mud | | | 0.6 | 1.6 | 0.6 | 0.7 |
| Firm mud | 13.4 | 23.5 | | | 13.4 | 13.9 |
| Soft mud | 0.1 | 0.1 | 23.5 | 59.4 | 23.5 | 24.4 |
| Very soft mud | | | 3.7 | 9.3 | 3.7 | 3.8 |
| **Grand Total** | **56.8** | **100** | **39.5** | **100** | **96.3** | **100** |

## 4.3. EXTENT OF SOFT MUD

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

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

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

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

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

The area (horizontal extent) of intertidal soft mud is the primary sediment indicator used in the current broad scale report, with sediment mud content a supporting indicator. Sediment plates have been established at three fine scale sites (see Robertson and Robertson 2018 for details) to monitor sediment accrual. The plates are primarily to help understand potential changes in the biological community at fine scale sites so are not always located within the primary deposition zones of the estuary.

Figure 4 and Table 4 shows that of the intertidal area not supporting saltmarsh, soft or very soft muds covered 27.1ha (69%), a risk indicator rating of HIGH, and had a mud content measured in representative areas of 20-65%, a supporting risk indicator rating of HIGH (Table 5). Within the dominant sandy substrate near the entrance, grain size reflected a LOW risk rating (0-10% mud content). Very coarse sands were present on the outer coast at the estuary entrance.

The 2018 soft mud extent (27.1ha) was less than the 38ha reported by Stewart and Bywater (2009). This difference is attributable to more extensive intertidal flats in the upper estuary being exposed and included in the 2009 mapping, likely as a consequence of mouth constriction limiting drainage in 2018.

**Table 5. Grain size results from representative sediments, Tokomairiro Estuary, Feb. 2018.**

| Broad Scale Classification | Site # | % mud | % sand | % gravel | aRPD cm | RP@3cm | NZTM East | NZTM North |
|---|---|---|---|---|---|---|---|---|
| Firm Sand | 6 | 0 | 99 | 1 | >5 | 135 | 1372031 | 4877340 |
| Firm Muddy Sand | FS A* | 10 | 89 | 1 | na | 13 | 1371992 | 4877703 |
| Soft Mud | 5 | 20 | 74 | 6 | 1 | -80 | 1372109 | 4878227 |
| | 1 | 35 | 64 | 1 | 3 | 160 | 1371890 | 4877635 |
| Very Soft Mud | 4 | 40 | 60 | 0 | 0.5 | -144 | 1372234 | 4878891 |
| | 2 | 56 | 41 | 3 | 0.5 | -157 | 1372020 | 4878394 |
| | FS C* | 56 | 41 | 3 | na | -203 | 1372104 | 4878894 |
| | 3 | 61 | 31 | 8 | 0.5 | -140 | 1372150 | 4878766 |
| | FS B* | 65 | 35 | 0 | na | -211 | 1372026 | 4878446 |

# See Figure 3 for site locations. *Data sourced from Robertson and Robertson (2018) FS=Fine Scale, na=not assessed.

## 4.4. SEDIMENT OXYGENATION

The primary indicators used to assess sediment oxygenation are apparent Redox Potential Discontinuity (aRPD) depth and Redox Potential (RPmV) measured at 3cm. These indicators were measured at representative sites throughout the dominant sand and mud substrate types. From these measurements, broad boundaries have been drawn of estuary zones where sediment oxygen is depleted to the extent that adverse impacts to macrofauna (sediment and surface dwelling animals) are expected (Figure 5). Because macrofauna are used as an indicator of ecological impacts to other taxa, it is expected that these zones will also be exerting adverse impacts on associated higher trophic communities including birds and fish.

These results show that there is a large part (22.2ha 23%) of the total intertidal area identified as having depleted sediment oxygen, a NZ ETI risk rating of HIGH. This was largely confined to soft and very soft muds located in the middle and lower estuary (Figure 5). Elsewhere the majority of the estuary sediments are well to moderately well oxygenated and appeared in good (healthy) ecological condition, with the aRPD depth at 2-5cm and the RP above -150mV at 3cm in most sand dominated sediments in the lower estuary, and also among saltmarsh where oxygen exchange through plant roots contributed to good but variable sediment oxygenation.

Sediment oxygenation was not recorded outside of fine scale sites in 2009 so the broad scale patterns of sediment oxygenation cannot be determined from these earlier studies.

**Thin layer of oxygenated sediment overlying anoxic muds in the middle-lower estuary.**

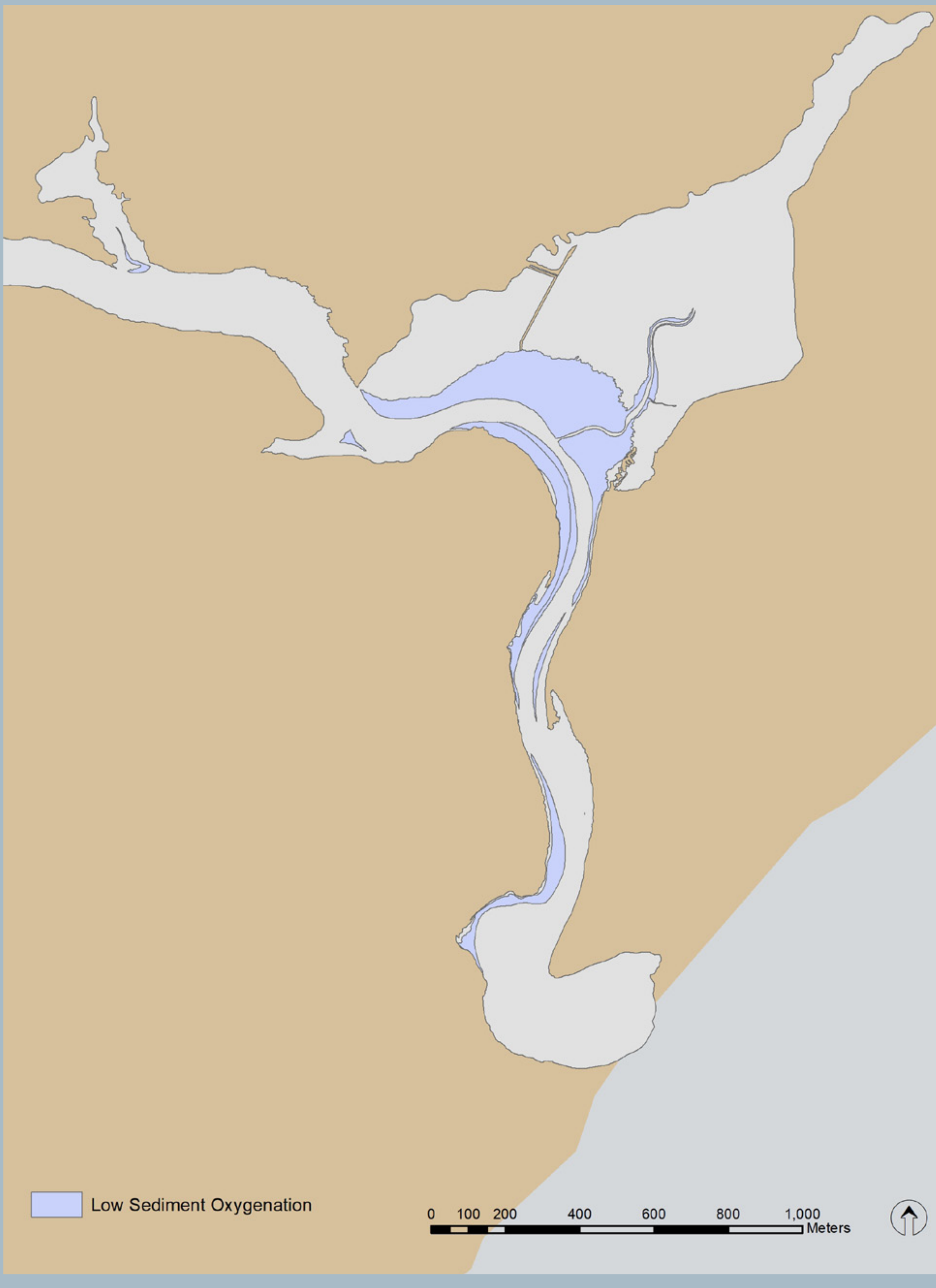



**Figure 5. Map of areas with low sediment oxygenation - Tokomairiro Estuary, Feb. 2018.**

## 4.5. OPPORTUNISTIC MACROALGAE

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

Opportunistic macroalgal growth was assessed by mapping the spatial spread and density of macroalgae in the Available Intertidal Habitat (AIH) (Figure 6), and calculating an "Ecological Quality Rating" (EQR) using the Opportunistic Macroalgal Blooming Tool (OMBT). The EQR score can range from zero (major disturbance) to one (reference/minimally disturbed) and relates to a quality status threshold band (i.e. bad, poor, good, moderate, high - Section 2, Table 2, Appendix 4). 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. If the estuary supports <5% opportunistic macroalgal cover within the AIH, the overall quality status is reported as HIGH with no further sampling required.

The overall opportunistic macroalgal EQR for Tokomairiro Estuary in Feb. 2018 was 0.62 (Table 6), a quality status of "Good" and indicates that the estuary overall is expressing limited symptoms of macroalgal degradation (MODERATE risk rating). This is reflected in the "Good" Quality Status scores for the affected area of the estuary and the relatively low overall percentage cover and biomass in available intertidal habitat ("High" status), although sediment entrained algae was present ("Bad" quality status). In other words, macroalgal growth is not widespread, but when it is present, it is entrained in sediment and therefore likely to be persistent (e.g. Figure 6).

Growths were dominated by the red alga *Gracilaria chilensis* growing in the lower estuary, and to a lesser extent by the green alga *Ulva* which was present in the more sheltered arms of the middle estuary, both as drift algal deposits as well as localised growths. The highest density growths were *Gracilaria* on the edge of the main river channel. A constant flow of waters containing elevated nutrients appears sufficient to stimulate growth, but the absence of hard substrate to adhere to and regular physical scouring may be limiting the extent that persistent nuisance macroalgae beds can establish. The combined overall risk rating was assessed as LOW at the time of sampling. Stewart and Bywater (2009) reported 0.6ha of macroalgae in the estuary.

**Table 6. Summary of intertidal opportunistic macroalgal cover, Tokomairiro Estuary, Feb. 2018.**

| Metric | Face Value | Final Equidistant Score (FEDS) | Quality Status |
|---|---|---|---|
| AIH - Available Intertidal Habitat (ha) | 36 | | |
| Percentage cover of AIH (%) = (Total % Cover / AIH} x 100<br>*where Total % cover = Sum of {(patch size) / 100} x average % cover for patch* | 3.101 | 0.876 | High |
| Biomass of AIH (g.m$^{-2}$) = Total biomass / AIH<br>*where Total biomass = Sum of (patch size x average patch biomass)* | 25.573 | 0.949 | High |
| Biomass of Affected Area (g.m$^{-2}$) = Total biomass / AA<br>*where Total biomass = Sum of (>5% cover patch size x average patch biomass)* | 503.625 | 0.399 | Poor |
| Presence of Entrained Algae = (No. quadrats or area (ha) with entrained algae / total no. of quadrats or area (ha)) x 100 | 84.179 | 0.063 | Bad |
| Affected Area (use the lowest of the following two metrics) | | 0.798 | Good |
| Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%) | 1.818 | 0.964 | High |
| Size of AA in relation to AIH (%) = (AA / AIH) x 100 | 5.078 | 0.798 | Good |
| | | | |
| **OVERALL MACROALGAL ECOLOGICAL QUALITY RATING - EQR (AVERAGE OF FEDS)** | | **0.62** | **GOOD** |

Currently, entrained macroalgae is limited to narrow strips in the middle and lower estuary located low in the tidal range where it remains covered by water for most of the tidal cycle. There are also submerged beds growing in the middle of the river channel. Where growths remain submerged for much of the tidal cycle, underlying sediments generally remain sufficiently well oxygenated to prevent anaerobic sediment conditions from developing at the sediment surface. However, if macroalgal growth expands onto the intertidal flats, dense growths can smother the surface and cause underlying sediments to become anaerobic thereby releasing sediment bound nutrients and creating a negative feedback loop where released nutrients fuel macroalgal growth across the entire tidal cycle, which in turn contributes to anaerobic conditions, which in turn fuels macroalgal growth. The shift to significantly degraded conditions through such processes can be rapid and difficult to reverse.

Because the mouth of the estuary is at times constricted and there are deeper parts of the upper estuary known to stratify, phytoplankton blooms are likely to be an issue in subtidal parts of the estuary if catchment nutrients and sediments accumulate and do not get flushed out to sea. This component is more thoroughly addressed in the fine scale report (Robertson and Robertson 2018). Synoptic sampling, undertaken as part of fine scale monitoring on 18 February 2018, recorded chl-a concentrations throughout the surface waters of the estuary of 3-5mg/$m^3$ (an ETI rating of Band A - LOW). In two sites in deeper waters in the upper estuary, Robertson and Robertson (2018) identified very high chl-a concentrations e.g. 2-3m deep: 40-41mg/$m^3$ (ETI Band D - VERY HIGH). These deeper waters were stratified with buoyant fresh water trapping eutrophic high salinity waters on the bottom of the upper estuary as far as 12km from the open coast. These high chl-a concentrations, while a 1 day snapshot, show that deeper parts of the subtidal estuary are adversely impacted by elevated phytoplankton growth. Under prolonged low flow summer conditions, these conditions will get progressively worse and can be expected to have a significant adverse effect on the biological health of the estuary. This will be primarily as a consequence of extreme daily changes in oxygen levels, oxygen being produced during the day, but being consumed by alga at night with low oxygen conditions causing significant biological stress to fish and invertebrates.

Because in-stream nutrient measures vary by orders of magnitude seasonally and even daily in relation to flow and uptake by macroalgae and phytoplankton, synoptic nutrient monitoring needs to be considered alongside algal biomass assessments and annual catchment load estimates. The former are a direct measure of the expression of nutrient related problems, while the latter broadly characterise nutrient inputs independent of smaller scale spatial and temporal variances. An assessment of nutrient and sediment loads from available Council water quality inflow data (e.g. Milton wastewater treatment plant discharge) and land runoff for Tokomairiro Estuary under both natural state/reference conditions and the current land use derived from the Landcare Research Land Cover Data Base (LCDB4 2012/13) is in Robertson and Robertson (2018). These predicted catchment nutrient load inputs are expected to place the upper estuary at a relatively high risk of macroalgal and phytoplankton impacts.

Also, because of the strong affinity of nutrients to adhere to fine sediments, and because sediment inputs to the estuary are likely to be elevated (current inputs are estimated as 3.9 x the natural state loading (Robertson and Robertson 2018) and will likely increase where there is significant land disturbance e.g. forest harvesting or roading activities), there is potential for sediment entrained macroalgal problems in the estuary to increase, particularly in response to changes to land use in the catchment e.g. increased or intensified pastoral farming or forest harvesting that lead to increased sediment and nutrient inputs.

The importance of maintaining the currently extensive *Ruppia* beds in the estuary (see following section) is also emphasised because of their important role in nutrient uptake and maintaining water clarity.


*Gracilaria* entrained in soft muds in the lower estuary.

Deposited clumps of *Ulva* on soft muds in the middle estuary.

**Figure 6. Map of intertidal opportunistic macroalgal biomass ($g.m^{-2}$) - Tokomairiro Estuary, Feb. 2018.**

### 4.6. SEAGRASS

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

Figure 7 presents the results of the intertidal seagrass extent. Only three small patches were located on the true left channel edge in the middle estuary. The total area comprised 20m$^2$, 0.01% of the intertidal area not supporting saltmarsh and was confined to areas that have strong tidal flushing and are subsequently not prone to excessive fine mud deposition. In the absence of any comprehensive rating of seagrass extent within NZ estuaries, which can be highly variable in the extent of seagrass that they support, changes from a documented baseline currently represent the most reliable method for monitoring seagrass extent and assessing change. The current study has provided a high resolution GIS map of seagrass extent for this purpose.

Large beds of the native macrophyte *Ruppia megacarpa* (Horse's mane weed) were also present growing subtidally in the upper estuary. *Ruppia megacarpa* is a large robust perennial with long, much branched stems that grows in the bottom sediments and favours clear freshwater or brackish water. *Ruppia* has been identified as playing a key role in regulating water quality including oxygen production, nutrient uptake, as well as providing habitat for invertebrates and fish, and as a food source for invertebrates and waterfowl. The presence of such extensive growths in the estuary is a very positive sign. While outside the scope of the contracted work, these beds were quickly mapped. They covered approximately 16ha, 29% of the mapped subtidal estuary area (Figure 7). Within the *Ruppia* beds large trout were plentiful and a single measure of water quality (see Figure 7) in the relatively shallow (1.2m deep) lower reaches of the upper estuary channel recorded clear waters, high oxygenation, low-moderate chlorophyll-a, and mesohaline salinity (>5-18ppt). There was no stratification evident in this part of the estuary with good mixing throughout the water column.

**Table 7. Synoptic water quality data from within *Ruppia* beds, Tokomairiro Estuary, Feb. 2018.**

| Depth m | salinity (ppt) | Temp °C | DO % | DO mg/l | pH units | Chl-a ug/l | NZTM East | NZTM North |
|---|---|---|---|---|---|---|---|---|
| 0.25 | 6.8 | 19.9 | 105 | 8.8 | 8.4 | 5.1 | 1370031 | 4879500 |
| 1.0 | 9.6 | 19.7 | 107 | 9.1 | 8.3 | 5.3 | | |

**Dense beds of the macrophyte *Ruppia megacarpa* growing subtidally in the lower sections of the upper estuary.**

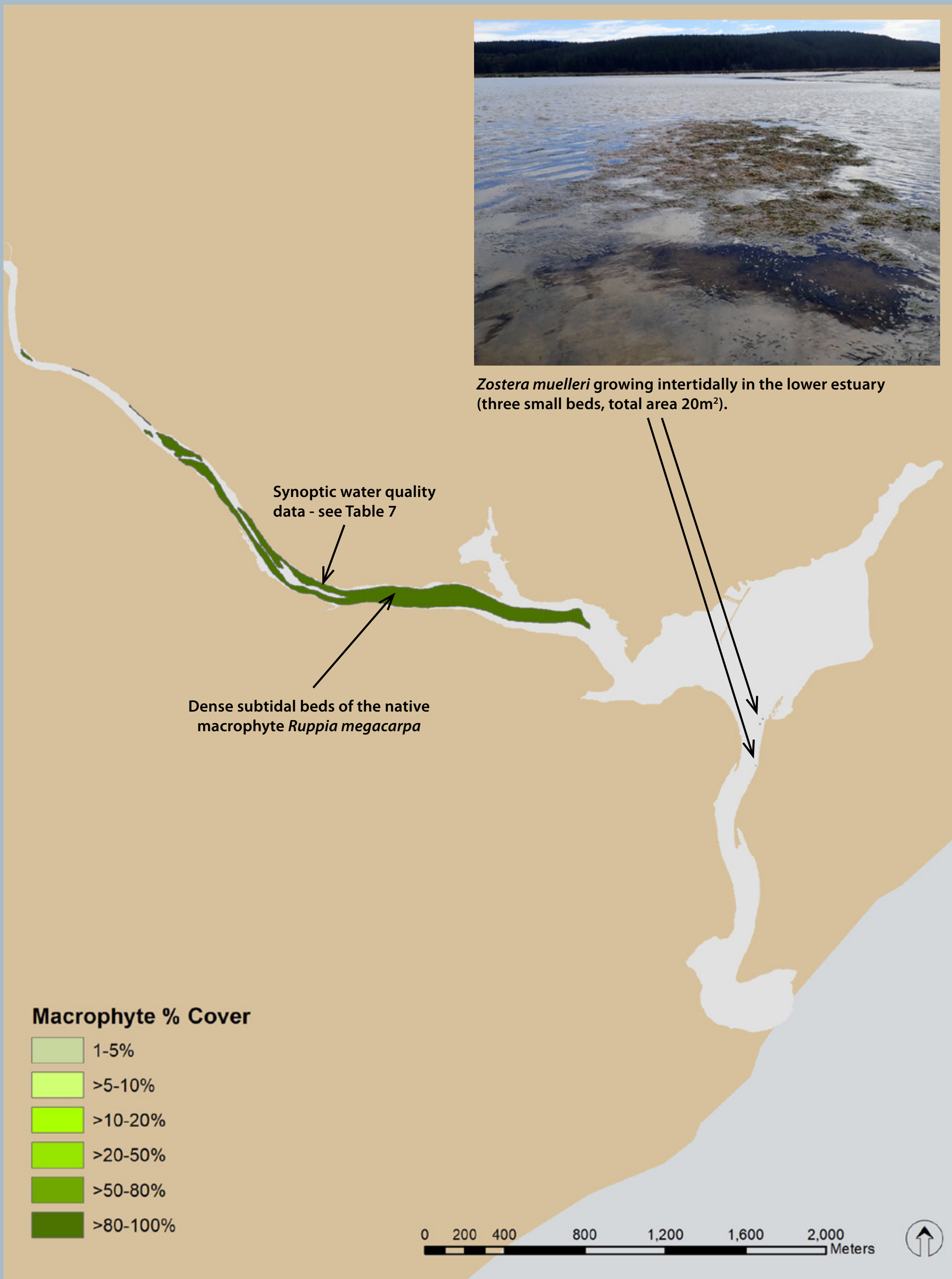



Figure 7. Map of intertidal seagrass percentage cover - Tokomairiro Estuary, Feb. 2018.

## 4.7. SALTMARSH

Herbfield in a narrow strip near in the lower estuary.

Terrestrial vegetation growing to the estuary margin in the upper estuary.

Expansive beds of rushland in the middle estuary.

Herbfields among rushland in the middle estuary.

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

The primary measure to assess saltmarsh condition is the percent cover of the intertidal area. Table 8 and Figure 8 summarise the 2018 results and show saltmarsh was present across 56.8ha (38%) of the intertidal estuary area, a risk indicator rating of LOW. Saltmarsh was dominated by rushland (53%) and herbfields (35%). Rushland comprised primarily jointed wire rush often with a subdominant cover of saltmarsh ribbonwood, and an understory of herbfield (primrose, remuremu, glasswort, bachelor's button and shore leptinella). The former two were the dominant herbfield species.

Within the lower estuary, saltmarsh was limited to a narrow strip in front of raised estuary margins (top sidebar photo), while the upper estuary had terrestrial vegetation extending to the very edge of the river bank (upper middle photo). The largest intact saltmarsh was in the middle estuary (lower two photos). Despite much of this area having extensive drainage channels throughout them (see photo below), introduced weeds and grasses were uncommon below the upper tidal margins, indicating regular flushing with seawater.

A supporting measure also applied is saltmarsh loss compared to estimated natural state cover. While the historical extent of the estuary has not been specifically mapped as part of the current work, it is evident that extensive areas in the upper estuary have been historically drained and converted to pasture. It is estimated that ~90-100ha of saltmarsh has been lost from the estuary, a supporting risk rating of HIGH. The combined overall risk rating was assessed as LOW recognising that while historical losses have been significant, saltmarsh remains a significant feature of the estuary and further reclamation and drainage is unlikely.

Hump and hollow styled drainage through herbfields in the middle estuary.

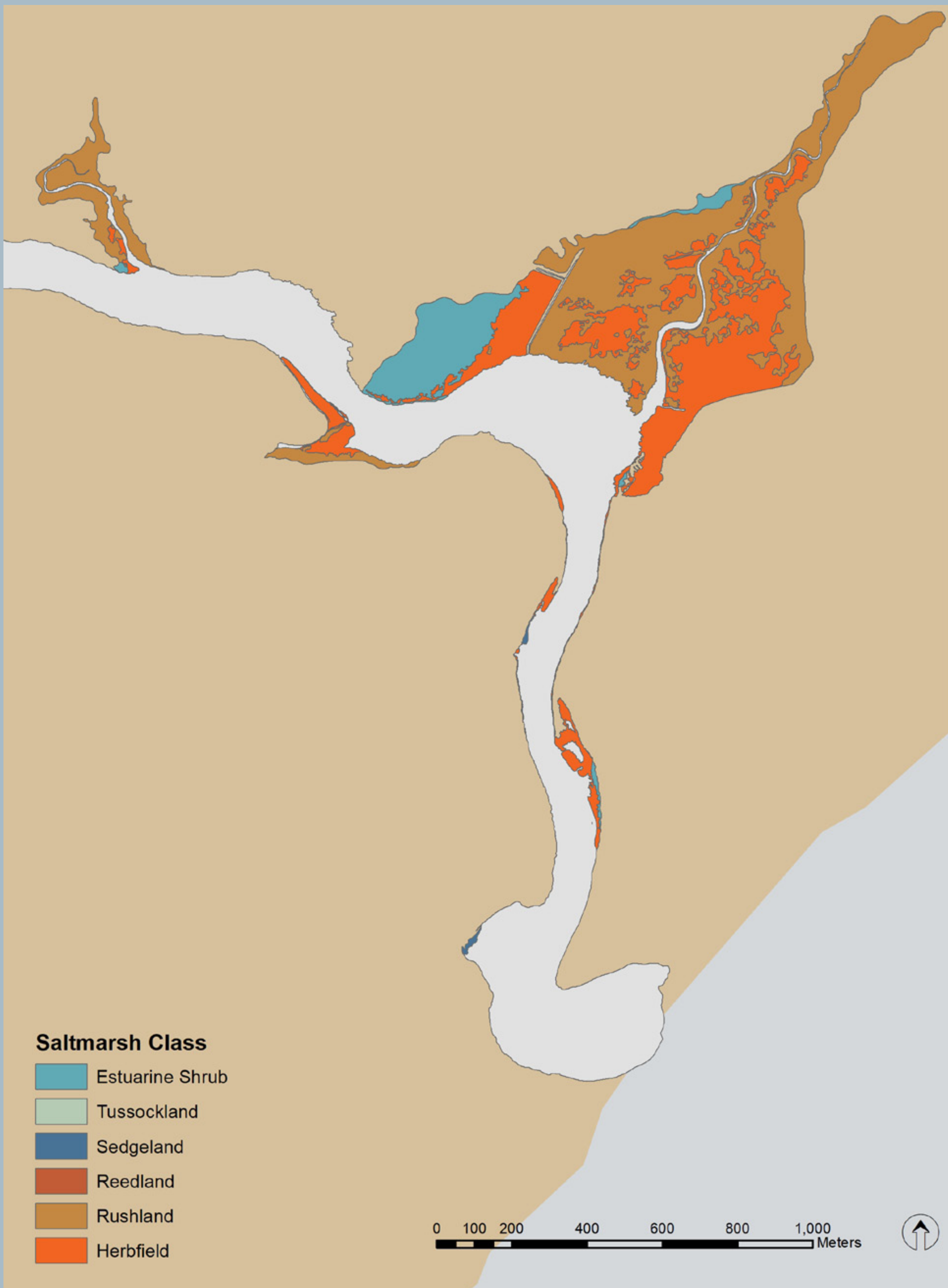



**Figure 8. Map of dominant saltmarsh cover - Tokomairiro Estuary, Feb. 2018.**

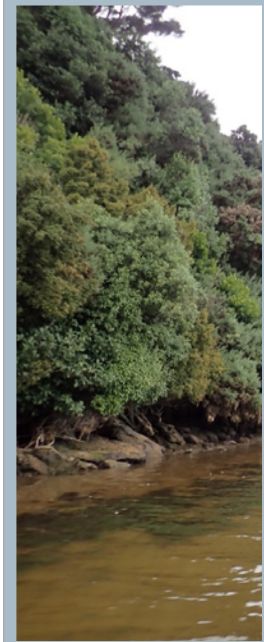
**Table 8. Summary of dominant saltmarsh cover, Tokomairiro Estuary, Feb. 2018.**

| Saltmarsh Class, Dominant and subdominant specie | Ha | % |
|---|---|---|
| Estuarine Shrub | 6.7 | 11.8 |
| Plagianthus divaricatus (Saltmarsh ribbonwood) | | |
| Apodasmia similis (Jointed wirerush) | | |
| Festuca arundinacea (Tall fescue) | 6.0 | |
| Festuca arundinacea (Tall fescue) | | |
| Festuca arundinacea (Tall fescue) | 0.1 | |
| Leptospermum scoparium (Manuka) | 0.5 | |
| Phormium tenax (New Zealand flax) | 0.05 | |
| Grassland | 0.1 | 0.1 |
| Festuca arundinacea (Tall fescue) | 0.0 | |
| Selliera radicans (Remuremu) | 0.1 | |
| Samolus repens (Primrose) | 0.1 | |
| Sedgeland | 0.1 | 0.2 |
| Schoenoplectus pungens (Three-square) | 0.1 | |
| Rushland | 30.0 | 52.9 |
| Apodasmia similis (Jointed wirerush) | 0.2 | |
| Festuca arundinacea (Tall fescue) | 0.4 | |
| Plagianthus divaricatus (Saltmarsh ribbonwood) | 4.6 | |
| Samolus repens (Primrose) | 22.5 | |
| Selliera radicans (Remuremu) | 2.4 | |
| Herbfield | 19.8 | 34.9 |
| Cotula coronopifolia (Bachelor's button) | | |
| Leptinella dioica | | |
| Samolus repens (Primrose) | 0.2 | |
| Samolus repens (Primrose) | | |
| Selliera radicans (Remuremu) | | |
| Sarcocornia quinqueflora (Glasswort) | 1.0 | |
| Sarcocornia quinqueflora (Glasswort) | 0.02 | |
| Selliera radicans (Remuremu) | 0.01 | |
| Samolus repens (Primrose) | 0.5 | |
| Selliera radicans (Remuremu) | | |
| Samolus repens (Primrose) | 0.1 | |
| Cotula coronopifolia (Bachelor's button) | 1.2 | |
| Sarcocornia quinqueflora (Glasswort) | 16.8 | |
| **Grand Total** | **56.8** | 100 |

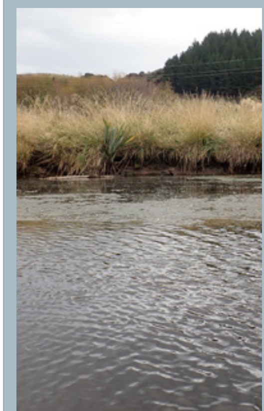
**NZ musk - *Mimulus repens***

**Remuremu - *Selliera radicans* and glasswort - *Sarcocornia quinqueflora***

### 4.8. 200m TERRESTRIAL MARGIN



Forest/scrub cover on steep banks near the middle estuary.



Grassland bordering estuary margins

Like saltmarsh, a densely vegetated terrestrial margin filters and assimilates sediment and nutrients, acts as an important buffer that protects against introduced grasses and weeds, is an important habitat for a variety of species, provides shade to help moderate stream temperature fluctuations, and improves estuary biodiversity. The results of the 200m terrestrial margin mapping of the estuary (Table 9 and Figure 9) showed:

- 40% was densely vegetated, a risk indicator rating of MODERATE.
- 58% was pasture or unmaintained grassland.
- 2% had been developed (residential, road).

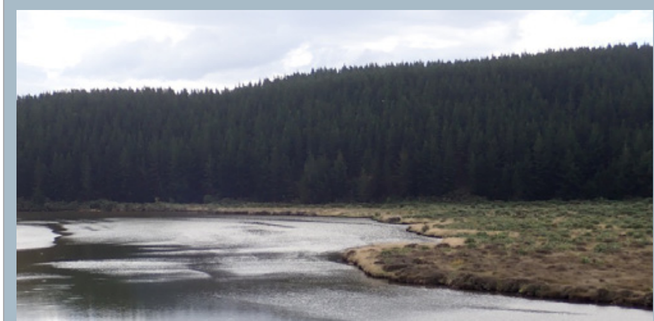
At a catchment-wide scale, a similar pattern is evident with 54% of the catchment in high producing grassland, and 34% exotic forest (Figure 10), some large forestry blocks having been recently clear fell harvested (Figure 9).

Very little native vegetation remains within the 200m terrestrial margin of the estuary as a consequence of land clearance for forestry and farming. The most notable areas are the Tokomairiro swamp on the margins of the middle-upper estuary. Outside of developed pasture and forestry, much of the dense vegetated cover comprises gorse and unmanaged grassland.

The extent of densely vegetated 200m terrestrial margin habitat means there is some buffering against adverse ecological degradation (e.g. localised sediment and nutrient inputs, introduced weeds), but this will be significantly reduced during forest harvesting, particularly in relation to sediments. The 200m terrestrial margin risk indicator rating is therefore MODERATE but subject to change depending on the extent of land disturbance.

**Table 9. Summary of 200m terrestrial margin land cover, Tokomairiro Estuary, Feb. 2018.**

| Class | Dominant features | Percentage |
|---|---|---|
| Forest | Predominantly plantation forestry of *Pinus radiata* (Pine tree) | 23.2 |
| Scrub | Predominantly *Ulex europaeus* (Gorse) and *Phormium tenax* (flax) | 9.2 |
| Tussockland | *Phormium tenax* (flax) | 5.7 |
| Grassland | Developed pasture (47%) and un-maintained grassland (11%) present along much of the estuary edge | 57.6 |
| Duneland | Small area of *Ammophila arenaria* (Marram grass) at the coast | 0.3 |
| Estuarine Shrub | Saltmarsh ribbonwood often with a subdominant mix of jointed wire rush | 1.7 |
| Residential | Toko Mouth | 0.8 |
| Artificial substrate | Roading | 1.5 |
| **Grand Total** | | **100** |



Raised river flats supporting swampland and saltmarsh in the middle estuary with plantation forestry in the background.

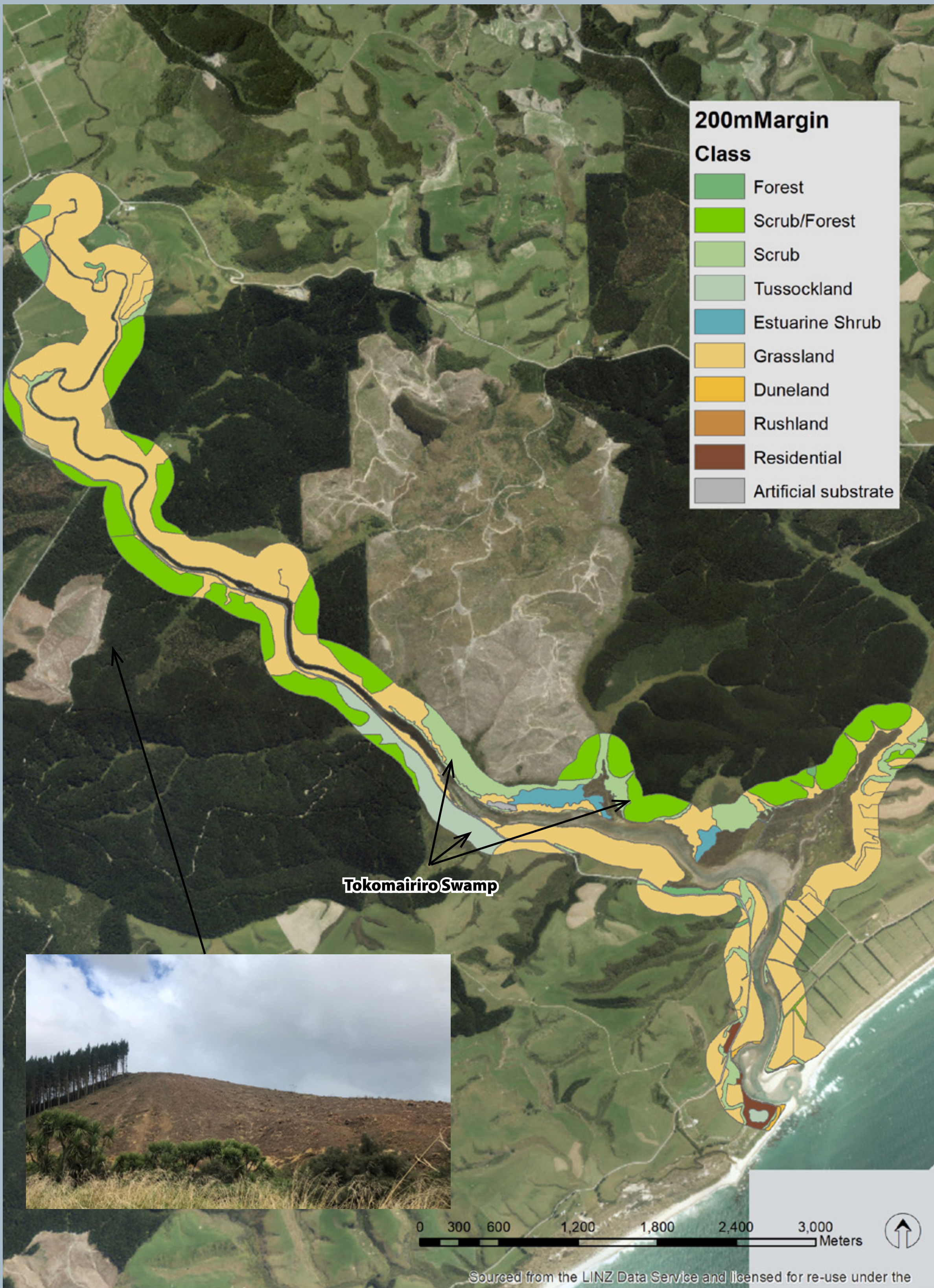
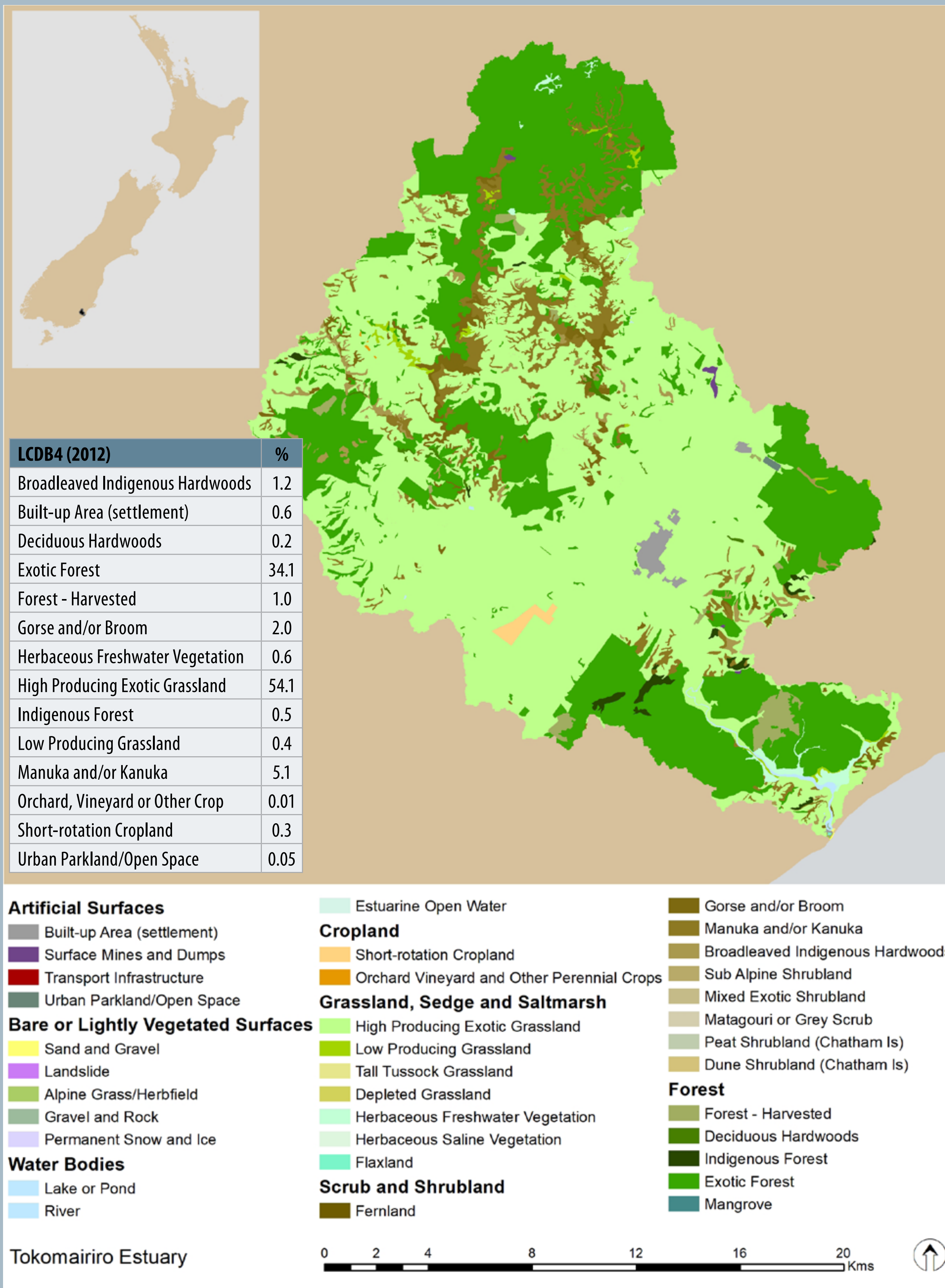



**Figure 9. Map of 200m Terrestrial Margin - Dominant Land Cover, Tokomairiro Estuary, Feb. 2018.**




| LCDB4 (2012) | % |
|---|---|
| Broadleaved Indigenous Hardwoods | 1.2 |
| Built-up Area (settlement) | 0.6 |
| Deciduous Hardwoods | 0.2 |
| Exotic Forest | 34.1 |
| Forest - Harvested | 1.0 |
| Gorse and/or Broom | 2.0 |
| Herbaceous Freshwater Vegetation | 0.6 |
| High Producing Exotic Grassland | 54.1 |
| Indigenous Forest | 0.5 |
| Low Producing Grassland | 0.4 |
| Manuka and/or Kanuka | 5.1 |
| Orchard, Vineyard or Other Crop | 0.01 |
| Short-rotation Cropland | 0.3 |
| Urban Parkland/Open Space | 0.05 |

**Figure 10. Summary of Catchment Land Cover (LCDB4 2012), Tokomairiro Estuary.**

# 5. SUMMARY

Broad scale habitat mapping of the Tokomairiro Estuary undertaken in February 2018, combined with ecological risk indicator ratings in relation to the key estuary stressors (i.e. muddiness, eutrophication and habitat modification), have been used to assess overall estuary condition.

**Muddiness**

Soft or very soft muds covered 27.1ha (69%) of the intertidal area, a risk indicator rating of HIGH. Soft muds were concentrated in the central and upper estuary where muds accumulate on narrow intertidal river banks, and on the larger tidal flats in the middle and lower estuary where the channel widens, flow velocity reduces and salinity driven sediment flocculation occurs. 28% of the estuary had soft mud with a mud content measured in representative areas of 20-63%, a supporting risk indicator rating of HIGH. To inform the broad scale report recommendations, the current state/natural state sediment load (CSSL/NSSL) ratio and the mean annual rate of sediment deposition have been estimated. The CSSL/NSSL ratio is estimated as 3.9, an ETI rating of MODERATE, and the mean annual rate of sediment deposition as ~7mm/yr (assuming 80% of estimated sediment load retained in estuary, sediment density of 1.2, and all sediment is deposited on mud dominated intertidal substrate and subtidal habitat within the estuary), a rating of HIGH. See Robertson and Robertson (2018) for detail on data sources, methods and calculations used to derive specific values for these parameters.

Within the dominant sandy substrate near the entrance, grain size reflected a LOW risk rating (0-10% mud content). 22.2ha (23%) of the intertidal area (including saltmarsh) had sediment oxygenation depleted to a level where adverse impacts to macrofauna (sediment and surface dwelling animals) are expected, an ETI risk indicator rating of HIGH.

**Eutrophication**

The key broad scale indicators used to assess eutrophic expression in the estuary are primary productivity through macroalgal growth and phytoplankton (fuelled by nutrient inputs to the estuary), and supporting indicators of sediment muddiness, oxygenation, and the presence of Gross Eutrophic Zones (a combined presence of dense algal growth, muds and poor sediment oxygenation). Fine scale indicators, reported in Robertson and Robertson (2018) include sediment organic content, nutrients, macroinvertebrates, and mud content.

The OMBT “Ecological Quality Rating” (EQR) score of was 0.62, a risk rating of MODERATE. The presence of the nuisance alga *Gracilaria* entrained in sediments in the lower estuary is a clear warning of the potential for nuisance conditions to develop. While large areas of muddy sediment had low oxygenation and elevated nutrients, these areas had not developed into GEZs. High chl-a concentrations indicate that deeper subtidal parts of the upper estuary are adversely impacted by elevated phytoplankton growth.

The total nitrogen (TN) areal load, not including point source discharges from the catchment, is estimated as ~385mgTN/m$^2$/d. In moderate susceptibility SSRTRE estuaries that have predominantly open mouths, an internal review of data held by Wriggle indicates significant eutrophic symptoms are not expected below loading rates of 500mgTN/m$^2$/d. Exceptions are where the upper estuary is long (i.e. >3km long) or there are deeper holes where stratification can occur. Because the Tokomairiro has a long confined upper estuary (~12km long) with deeper areas that stratify, there is a risk of eutrophication in these sensitive areas under the estimated current loading rates. The conclusion of Robertson and Robertson (2018) that at least 5km of the upper estuary was eutrophic in February 2018 confirms this and highlights that a significant part of the subtidal estuary is currently in a degraded state with current nutrient inputs to the estuary sufficient to fuel nuisance algal growths. At times of prolonged low flows or mouth constriction the estuary is expected to shift to a more degraded state.

The expected nutrient and sediment loads that relate to specific states of ecological condition, and the susceptibility of Tokomairiro Estuary under various nutrient and fine sediment loads (reflecting good, moderate and poor condition) are to be described in detail in Robertson and Robertson (2018) with the results used to provide guidance on what changes to sediment and nutrient loads would be required to shift the estuary towards a different ecological state (e.g. to improve its condition).

## 5. SUMMARY (CONTINUED)

**Habitat modification**

Despite significant historical saltmarsh losses (estimated at ~90-100ha in total), extensive herbfield-and rushland remained in the estuary (56.8ha, 38% of the intertidal area), and there were large and extensive beds of the native macrophyte *Ruppia*. The presence of such large areas of both *Ruppia* and saltmarsh, despite extensive drainage, is very positive, a risk indicator of VERY LOW. The limited extent of seagrass (*Zostera*) most likely reflects poor clarity and high sediment impacts in the lower estuary, although nutrient concentrations are also elevated above thresholds known to impact seagrass growth. The 200m terrestrial margin has been highly modified but 40% supported a densely vegetated buffer of rushland, scrub and forest, although over half of this is plantation forestry and subject to disturbance as a consequence of harvesting.

**Comparison with previous results**

It is difficult to compare the current results directly with the 2009 assessment due to variability in mapping accuracy and the features included (e.g. 2009 saltmarsh included large areas of terrestrial vegetation). However there appears to have been little change from 2009 to 2018 in relation to the area of mud in the estuary, and no significant change obvious in the extent of saltmarsh. The current detailed broad scale mapping will enable future changes to be assessed more reliably.

## 6. CONCLUSION

The combined results place the estuary in a MODERATE state overall in relation to broad scale ecological features. Fine sediment issues are evident throughout most of the estuary, and eutrophication issues are apparent through the presence of entrained nuisance macroalgae, oxygen depleted sediments and elevated phytoplankton concentrations. Extensive areas of saltmarsh remain in good condition, but are largely confined to the upper tidal range of the middle estuary. The NZ Estuary Trophic Index (ETI) score has been calculated using available broad and fine scale indicators (details summarised in Appendix 7). The ETI score for Tokomairiro Estuary was 0.59, Band C, reflecting a moderate degree of eutrophic symptoms. This likely underestimates the extent of eutrophic symptoms as the predominantly subtidal eutrophic upper reaches of the estuary are largely excluded from the ETI scoring assessment.

## 7. MONITORING RECOMMENDATIONS

Tokomairiro Estuary is a moderate-large sized estuary situated in a developed catchment with high ecological and human use values. It is moderately vulnerable to excessive sedimentation and eutrophication and has been identified as a priority for monitoring within ORC's coastal monitoring programme. The present report addresses the broad scale component of the long term monitoring programme. The recommendation for ongoing broad scale monitoring is as follows:

- To characterise any issues of change in habitat (e.g. saltmarsh area, soft mud extent, GEZ's, sediment oxygen depletion, 200m terrestrial margin vegetation), it is recommended that broad scale habitat mapping be undertaken at 10 yearly intervals (next scheduled for 2028) unless obvious changes are observed in the interim.
- Because of the extensive areas of soft mud in the estuary, installation of sediment plates to monitor annual sediment accrual at two sites in the key deposition zone of the middle estuary is recommended.
- Because of the potential for intertidal macroalgal growth to quickly transition to nuisance conditions it is recommended that macroalgae be mapped 5 yearly.

In relation to likely management needs for the estuary, it is recommended that to defensibly address the likely cause of macroalgal and phytoplankton growths and subtidal habitat degradation the following work be considered:

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

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

Mud snails (*Amphibola crenata*) in the lower estuary.

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# APPENDIX 1. BROAD SCALE HABITAT CLASSIFICATION DEFINITIONS.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

**Shell bank:** Area that is dominated by dead shells.

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

# APPENDIX 2. NOTES SUPPORTING RISK INDICATOR RATINGS (TABLE 2)

## NOTES to Table 2: See Robertson et al. (2016a, 2016b) for further information supporting these ratings.

**Soft Mud Percent Cover.** Soft mud (>25% mud content) has been shown to result in a degraded macroinvertebrate community (Robertson et al. 2015, 2016), and excessive mud decreases water clarity, lowers biodiversity and affects aesthetics and access. Because estuaries are a sink for sediments, the presence of large areas of soft mud is likely to lead to major and detrimental ecological changes that could be very difficult to reverse. In particular, its presence indicates where changes in land management may be needed. If an estuary is suspected of being an outlier (e.g. has >25% mud content but substrate remains firm to walk on), it is recommended that the initial broad scale assessment be followed by particle grain size analyses of relevant areas to determine the extent of the estuary with sediment mud contents >25%.

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

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

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

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

**Redox Potential (Eh).** For meter approaches, Eh measurements represent a composite of multiple redox equilibria measured at the surface of a redox potential electrode coupled to a millivolt meter (Rosenberg et al. 2001) (often called an ORP meter) and reflects a system's tendency to receive or donate electrons. The electrode is inserted to different depths into the sediment and the extent of reducing conditions at each depth recorded (RPD is the depth at which the redox potential is ~0mV, Fenchel and Riedl 1970, Revsbech et al. 1980, Birchenough et al. 2012, Hunting et al. 2012). The Eh rating bands reflect the presence of healthy macrofauna communities in sediments below the aRPD depth.

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

**Opportunistic Macroalgae.** The presence of opportunistic macroalgae is a primary indicator of estuary eutrophication, and when combined with gross eutrophic conditions (see previous) can cause significant adverse ecological impacts that are very difficult to reverse. Thresholds used to assess this indicator are derived from the OMBT (see Section 3), with results combined with those of other indicators to determine overall condition.

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

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

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

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

# APPENDIX 3. NOTES ON SAMPLING, RESOLUTION AND ACCURACY

**Sediment sampling and analysis**

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

In addition, at selected sampling sites redox potential (RP) was measured with an oxidation-reduction potential meter at 0, 1, 3, 5 and 10cm depths below the substrate surface, and the aRPD depth and substrate type recorded. These results have been used to generate broad scale maps showing areas where sediment oxygenation is depleted to the extent that adverse impacts to macrofauna (sediment and surface dwelling animals) are expected i.e. where RPD at 3cm <-150mV or aRPD <1cm (Robertson et al. 2016b).

**Sampling resolution and accuracy**

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

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

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

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

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

# APPENDIX 4. OPPORTUNISTIC MACROALGAL BLOOMING TOOL

The UK-WFD (Water Framework Directive) Opportunistic Macroalgal Blooming Tool (OMBT) (WFD-UKTAG 2014) is a comprehensive 5 part multimetric index approach suitable for characterising the different types of estuaries and related macroalgal issues found in NZ. The tool allows simple adjustment of underpinning threshold values to calibrate it to the observed relationships between macroalgal condition and the ecological response of different estuary types. It incorporates sediment entrained macroalgae, a key indicator of estuary degradation, and addresses limitations associated with percentage cover estimates that do not incorporate biomass e.g. where high cover but low biomass are not resulting in significantly degraded sediment conditions. It is supported by extensive studies of the macroalgal condition in relation to ecological responses in a wide range of estuaries.

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

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

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

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

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

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

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

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

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

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

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

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

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

**Timing:** Because the OMBT has been developed to classify data over the maximum growing season, sampling should target the peak bloom in summer (Dec-March), although peak timing may vary among water bodies, therefore local knowledge is required to identify the maximum growth period. Sampling is not recommended outside the summer period due to seasonal variations that could affect the outcome of the tool and possibly lead to misclassification; e.g. blooms may become disrupted by stormy autumn weather and often die back in winter. Sampling should be carried out during spring low tides in order to access the maximum area of the AIH.

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**Suitable Locations:** The OMBT is suitable for use in estuaries and coastal waters which have intertidal areas of soft sedimentary substratum (i.e. areas of AIH for opportunistic macroalgal growth). The tool is not currently used for assessing ICOLLs due to the particular challenges in setting suitable reference conditions for these water bodies.

**Derivation of Threshold Values.**

Published and unpublished literature, along with expert opinion, was used to derive critical threshold values suitable for defining quality status classes (Table A2).

- **Reference Thresholds.** A UK Department of the Environment, Transport and the Regions (DETR) expert workshop suggested reference levels of <5% cover of AIH of climax and opportunistic species for high quality sites (DETR, 2001). In line with this approach, the WFD adopted <5% cover of opportunistic macroalgae in the AIH as equivalent to High status. From the WFD North East Atlantic intercalibration phase 1 results, German research into large sized water bodies revealed that areas over 50ha may often show signs of adverse effects, however if the overall area was less than 1/5th of this, adverse effects were not seen, so the High/Good boundary was set at 10ha. In all cases a reference of 0% cover for truly un-impacted areas was assumed. Note: opportunistic algae may occur even in pristine water bodies as part of the natural community functioning.
  The proposal of reference conditions for levels of biomass took a similar approach, considering existing guidelines and suggestions from DETR (2001), with a tentative reference level of <100g $m^{-2}$ wet weight. This reference level was used for both the average biomass over the affected area and the average biomass over the AIH. As with area measurements a reference of zero was assumed.
  An ideal of no entrainment (i.e. no quadrats revealing entrained macroalgae) was assumed to be reference for un-impacted waters. After some empirical testing in a number of UK water bodies a High / Good boundary of 1% of quadrats was set.
- **Class Thresholds for Percent Cover:**
  **High/Good boundary** set at 5%. Based on the finding that a symptom of the potential start of eutrophication is when: (i) 25% of the available intertidal habitat has opportunistic macroalgae and (ii) at least 25% of the sediment (i.e. 25% in a quadrat) is covered (Comprehensive Studies Task Team (DETR, 2001)). This implies that an overall cover of the AIH of 6.25% (25*25%) represents the start of a potential problem.
  **Good / Moderate boundary** set at 15%. True problem areas often have a >60% cover within the affected area of 25% of the water body (Wither 2003). This equates to 15% overall cover of the AIH (i.e. 25% of the water body covered with algal mats at a density of 60%).
  **Poor/Bad boundary** is set at >75%. The Environment Agency has considered >75% cover as seriously affecting an area (Foden et al. 2010).
- **Class Thresholds for Biomass.** Class boundaries for biomass values were derived from DETR (2001) recommendations that <500 $g.m^{-2}$ wet weight was an acceptable level above the reference level of <100 $g.m^{-2}$ wet weight. In Good status only slight deviation from High status is permitted so 500 $g.m^{-2}$ represents the Good/Moderate boundary. Moderate quality status requires moderate signs of distortion and significantly greater deviation from High status to be observed. The presence of >500 $g.m^{-2}$ but less than 1,000 $g.m^{-2}$ would lead to a classification of Moderate quality status at best, but would depend on the percentage of the AIH covered. >1$kg.m^{-2}$ wet weight causes significant harmful effects on biota (DETR 2001, Lowthion et al. 1985, Hull 1987, Wither 2003).
- **Thresholds for Entrained Algae.** Empirical studies testing a number of scales were undertaken on a number of impacted waters. Seriously impacted waters have a very high percentage (>75%) of the beds showing entrainment (Poor / Bad boundary). Entrainment was felt to be an early warning sign of potential eutrophication problems so a tight High /Good standard of 1% was selected (this allows for the odd change in a quadrat or error to be taken into account). Consequently the Good / Moderate boundary was set at 5% where (assuming sufficient quadrats were taken) it would be clear that entrainment and potential over wintering of macroalgae had started.

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

**Table A2. The final face value thresholds and metrics for levels of ecological quality status in the UK-WFD 2014.**

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

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

# APPENDIX 4. OPPORTUNISTIC MACROALGAL BLOOMING TOOL

## EQR calculation

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

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

The EQR calculation process is as follows:

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

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

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

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

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

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

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

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# APPENDIX 4. OPPORTUNISTIC MACROALGAL BLOOMING TOOL

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

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

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

**Table A4. The final face value thresholds and metrics for levels of ecological quality status used to rate opportunistic macroalgae in the current in the study (modified from UK-WFD 2014).**

| **MACROALGAL INDICATORS** (OBMT approach - WFD_UKTAG 2014) | | | | | |
|---|---|---|---|---|---|
| **QUALITY RATING** | High | Good | Moderate | Poor | Bad |
| **EQR (Ecological Quality Rating)** | ≥0.8 - 1.0 | ≥0.6 - <0.8 | ≥0.4 - <0.6 | ≥0.2 - <0.4 | 0.0 - <0.2 |
| % cover on Available Intertidal Habitat (AIH) | 0 - ≤5 | >5 - ≤15 | >15 -≤25 | >25 - ≤75 | >75 - 100 |
| Affected Area (AA) [>5% macroalgae] (ha)* | ≥0 - 10 | ≥10 - 50 | ≥50 - 100 | ≥100 - 250 | ≥250 |
| AA/AIH (%)* | ≥0 - 5 | ≥5 - 15 | ≥15 - 50 | ≥50 - 75 | ≥75 - 100 |
| Average biomass (g.m$^{2}$ wet wgt) of AIH | ≥0 - 100 | ≥100 - 200 | ≥200 - 500 | ≥500 - 1450 | ≥1450 |
| Average biomass (g.m$^{2}$ wet wgt) of AA | ≥0 - 100 | ≥100 - 200 | ≥200 - 500 | ≥500 - 1450 | ≥1450 |
| % algae entrained >3cm deep | ≥0 - 1 | ≥1 - 5 | ≥5 - 20 | ≥20 - 50 | ≥50 - 100 |

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

# APPENDIX 5. TOKOMAIRIRO ESTUARY MACROALGAL DATA

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

| Patch ID | Patch area (ha) | Quadrat No | Percent cover of macroalgae | Mean Biomass (g.m-$^{2}$ wet weight) | Presence (1) or absence (0) of entrained algae | aRPD depth (cm) | Presence (1) or absence (0) of soft mud | Dominant species |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.31 | 1 | 40 | 250 | 1 | 1 | 1 | *Gracilaria chilensis* |
| 2 | 0.25 | 1 | 50 | 350 | 1 | 1 | 1 | *Gracilaria chilensis* |
| 3 | 0.97 | 1 | 60 | 400 | 1 | 1 | 1 | *Gracilaria chilensis* |
| 4 | 0.10 | 1 | 100 | 1500 | 0 | 1 | 1 | *Ulva sp. (intestinalis)* |
| 5 | 0.04 | 1 | 80 | 900 | 0 | 1 | 1 | *Ulva sp. (intestinalis)* |
| 6 | 0.14 | 1 | 100 | 1200 | 0 | 1 | 1 | *Ulva sp. (intestinalis)* |

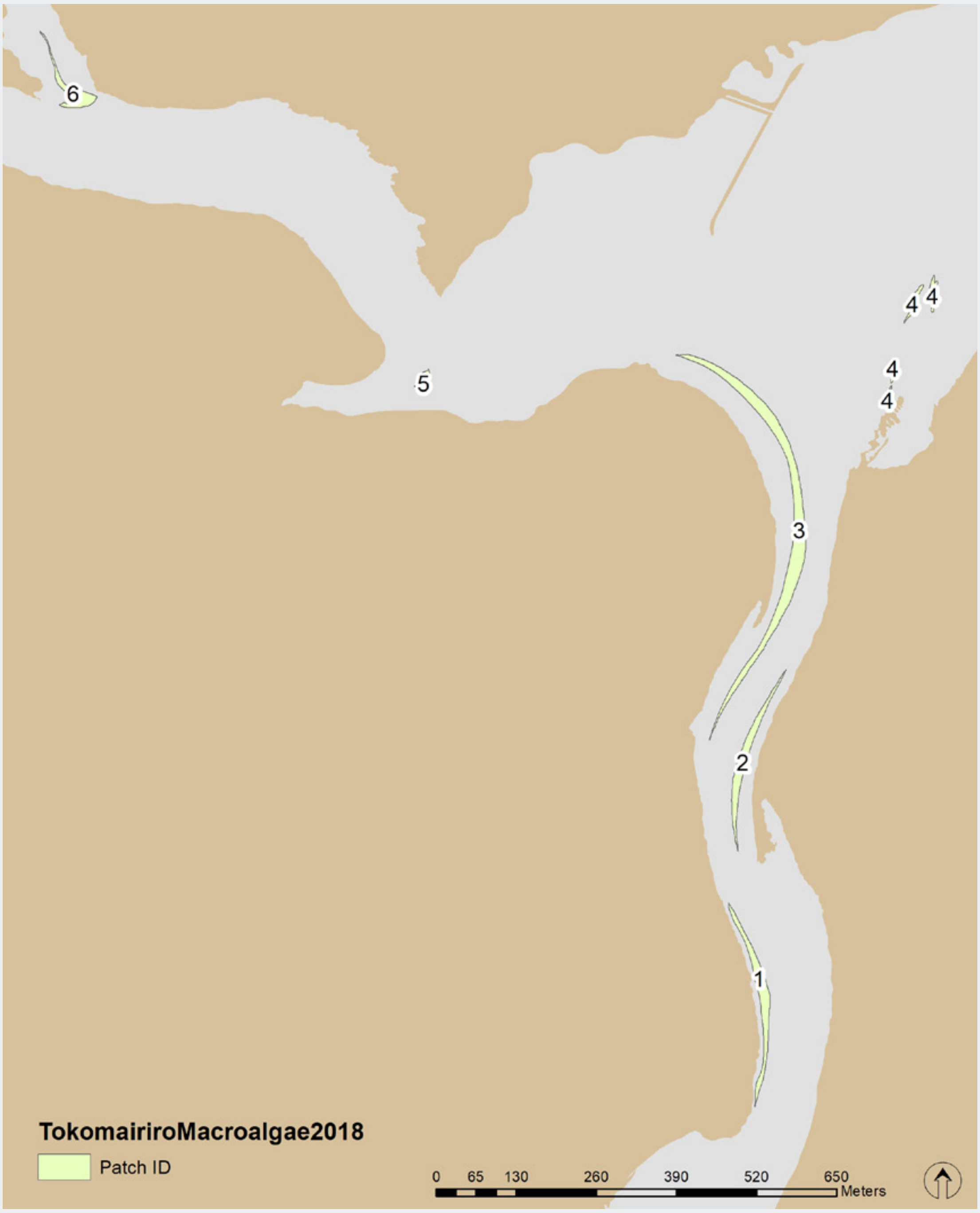


**Figure A1. Location of macroalgal patches (>5% cover) used in assessing Tokomairiro Estuary, Feb 2018.**

**Hill Laboratories**
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R J Hill Laboratories Limited
28 Duke Street Frankton 3204
Private Bag 3205
Hamilton 3240 New Zealand

T 0508 HILL LAB (44 555 22)
T +64 7 858 2000
E mail@hill-labs.co.nz
W www.hill-laboratories.com

# Certificate of Analysis



| | | | |
|---|---|---|---|
| **Client:** | Salt Ecology Limited | **Lab No:** | 1926975 SPv1 |
| **Contact:** | Leigh Stevens | **Date Received:** | 17-Feb-2018 |
| | C/- Salt Ecology Limited | **Date Reported:** | 27-Mar-2018 |
| | 21 Mount Vernon Place | **Quote No:** | 90443 |
| | Washington Valley | **Order No:** | |
| | Nelson 7010 | **Client Reference:** | Tokomairiro Estuary |
| | | **Submitted By:** | Leigh Stevens |

**Sample Type: Sediment**

| **Sample Name:** | | Toko 1 15-Feb-2018 | Toko 2 15-Feb-2018 | Toko 3 15-Feb-2018 | Toko 4 15-Feb-2018 | Toko 5 15-Feb-2018 |
|---|---|---|---|---|---|---|
| **Lab Number:** | | 1926975.1 | 1926975.2 | 1926975.3 | 1926975.4 | 1926975.5 |
| Individual Tests | | | | | | |
| Dry Matter of Sieved Sample | g/100g as rcvd | 62 | 59 | 53 | 66 | 74 |
| 3 Grain Sizes Profile | | | | | | |
| Fraction >/= 2 mm* | g/100g dry wt | 1.1 | 2.7 | 7.8 | 0.3 | 5.5 |
| Fraction < 2 mm, >/= 63 µm* | g/100g dry wt | 63.5 | 41.4 | 31.3 | 60.4 | 74.2 |
| Fraction < 63 µm* | g/100g dry wt | 35.4 | 55.9 | 60.9 | 39.3 | 20.3 |

| **Sample Name:** | | Toko 6 15-Feb-2018 | | | | |
|---|---|---|---|---|---|---|
| **Lab Number:** | | 1926975.6 | | | | |
| Individual Tests | | | | | | |
| Dry Matter of Sieved Sample | g/100g as rcvd | 93 | - | - | - | - |
| 3 Grain Sizes Profile | | | | | | |
| Fraction >/= 2 mm* | g/100g dry wt | 1.1 | - | - | - | - |
| Fraction < 2 mm, >/= 63 µm* | g/100g dry wt | 98.5 | - | - | - | - |
| Fraction < 63 µm* | g/100g dry wt | 0.4 | - | - | - | - |

# Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

**Sample Type: Sediment**

| Test | Method Description | Default Detection Limit | Sample No |
|---|---|---|---|
| Individual Tests | | | |
| Dry Matter for Grainsize samples | Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis). | 0.10 g/100g as rcvd | 1-6 |
| 3 Grain Sizes Profile* | | 0.1 g/100g dry wt | 1-6 |
| 3 Grain Sizes Profile | | | |
| Fraction >/= 2 mm* | Wet sieving with dispersant, 2.00 mm sieve, gravimetry. | 0.1 g/100g dry wt | 1-6 |
| Fraction < 2 mm, >/= 63 µm* | Wet sieving using dispersant, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference). | 0.1 g/100g dry wt | 1-6 |
| Fraction < 63 µm* | Wet sieving with dispersant, 63 µm sieve, gravimetry (calculation by difference). | 0.1 g/100g dry wt | 1-6 |

# APPENDIX 6. ANALYTICAL METHODS AND RESULTS

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.

This certificate of analysis must not be reproduced, except in full, without the written consent of the signatory.

Ara Heron BSc (Tech)
Client Services Manager - Environmental

# APPENDIX 7. NZ ESTUARY TROPHIC INDEX

The NZ ETI (Robertson et al. 2016a,b) is designed to enable the consistent assessment of estuary state in relation to nutrient enrichment, and also includes assessment criteria for sediment muddiness. An integrated online calculator is available [https://shiny.niwa.co.nz/Estuaries-Screening-Tool-1/] to calculate estuary physical and nutrient load susceptibility (primarily based on catchment nutrient loads combined with mixing and dilution in the estuary), as well as trophic expression based on key estuary indicators [https://shiny.niwa.co.nz/Estuaries-Screening-Tool-2/]. The more indicators included, the more robust the ETI score becomes. Where established ratings are not yet incorporated into the NIWA ETI online calculator they are included via spreadsheet calculator. Because the default values in the ETI database have been sourced from high level national data with limited field validation e.g. the Coastal Explorer database, key inputs such as estuary area, depth, volume, tidal prism and flow have been updated using specific estuary measurements and field observations.

The indicators used to derive an ETI score for the estuary are presented below using the broad scale monitoring results (this report) and fine scale monitoring results (Robertson and Robertson 2018). The input values used in the online calculator are presented on the following page.

ETI Tool 1 rates the physical and nutrient load susceptibility of Tokomairiro Estuary as "MODERATE".

ETI Tool 2 online calculator scores the estuary 0.56, Band C, a rating of "MODERATE" for eutrophic symptoms.

| ETI scoring summary for Tokomairiro Estuary, February 2018. | | | | NIWA online calculator | Spreadsheet Calculator |
|---|---|---|---|---|---|
| **PRIMARY SYMPTOM INDICATORS FOR SHALLOW INTERTIDAL DOMINATED ESTUARIES (AT LEAST 1 PRIMARY SYMPTOM INDICATOR REQUIRED)** | | | | **Primary Symptom Value** | |
| Required | Opportunistic Macroalgae | OMBT EQR | shallow inter-tidal | 0.62 | 0.62 |
| Required | Macroalgal GEZ % | % Gross Eutrophic Zone (GEZ)/Estuary Area | shallow inter-tidal | 0 | 0 |
| Required | Macroalgal GEZ Ha | Ha Gross Eutrophic Zone (GEZ) | shallow inter-tidal | 0 | 0 |
| Optional | Phytoplankton biomass | Chl- a (summer 90 pctl, mg/m³) | water column | 4 | 4 |
| Optional | Cyanobacteria (if issue identified) NOTE ETI rating not yet developed | | water column | - | - |
| **SUPPORTING INDICATORS FOR SHALLOW INTERTIDAL DOMINATED ESTUARIES (MUST INCLUDE A MINIMUM OF 1 REQUIRED INDICATOR)** | | | | **Supporting Indicator Value** | |
| Required Indicators | Sediment Oxygenation | Mean Redox Potential (mV) at 1cm depth in most impacted sediments and representing at least 10% of estuary area | shallow inter-tidal | -160 | -160 |
| Required Indicators | Sediment Oxygenation | % of estuary with Redox Potential <-150mV at 3cm or aRPD <1cm | shallow inter-tidal | | 23 |
| Required Indicators | Sediment Oxygenation | Ha of estuary with Redox Potential <-150mV at 3cm or aRPD <1cm | shallow inter-tidal | | 22.2 |
| Required Indicators | Sediment Total Organic Carbon | Mean TOC (%) measured at 0-2cm depth in most impacted sediments and representing at least 10% of estuary area | shallow inter-tidal | 1.55# | 1.55# |
| Required Indicators | Sediment Total Nitrogen | Mean TN (mg/kg) measured at 0-2cm depth in most impacted sediments and representing at least 10% of estuary area | shallow inter-tidal | 1700# | 1700# |
| Required Indicators | Macroinvertebrates | Mean AMBI score measured at 0-15cm depth in most impacted sediments and representing at least 10% of estuary area | shallow inter-tidal | 3.5# | 3.5# |
| Optional Indicators | Muddy sediment | Proportion of estuary area with >25% mud content | shallow inter-tidal | 0.69 | 0.69 |
| Optional Indicators | Sedimentation Rate | Ratio of mean annual Current State Sediment Load (CSSL) relative to mean annual Natural State (NSSL) | shallow inter-tidal | | 3.9# |
| Optional Indicators | Dissolved oxygen | 1 day instantaneous minimum of water column measured from representative areas of estuary water column (including likely worst case conditions) (mg.m³) | water column | 6.3 | 6.3 |
| **NZ ETI Score** | | | | **0.57** | **0.59** |

*Measurements from >1m depth in the upper estuary collected on 16/2/18 were 20-30mg/m³, surface water concentrations throughout the estuary were 5-7mg/m³. Phytoplankton was not used in calculating the ETI scores presented (available data from a single day of synoptic sampling only).

# Data from fine scale site B, Dec 2017 - source Robertson and Robertson (2018).

# APPENDIX 7. NZ ESTUARY TROPHIC INDEX

Input values used in the NZ ETI online calculator (May 2018). See the NIWA online tool metadata spreadsheets for full explanation of terms and abbreviations.

| NZ ETI Tool 1 Input details | Calculator Heading | Unit | Input Value |
|---|---|---|---|
| Estuary Number | Est_no | | 1063 |
| Estuary Name | Est_name | | Tokomairiro River |
| Regional Council | Reg_Council | | ORC |
| Island | Island | | South Island |
| NZCHS geomorphic code | NZCHS_code | | 7A |
| NZCHS geomorphic class | NZCHS_class | | Tidal lagoon (permanently open) |
| ETI Class | ETI_class | | SSRTRE |
| Latitude | LAT | decimal degrees | -46.22270389 |
| Longitude | LON | decimal degrees | 170.0491455 |
| Freshwater inflow | Qf | m3/s | 3.71798 |
| Annual river total nitrogen loading | TNriver | T/yr | 190.240 |
| Annual river total phosphorus loading | TPriver | T/yr | 13.261 |
| Volume | V | m3 | 2646991 |
| Tidal Prism | P | m3 | 537000 |
| Return flow fraction | b | unitless | NA |
| ACExR fitted exponent | A | unitless | -0.48 |
| ACExR fitted constant | B | unitless | 107.87 |
| Ratio NO3 | R_NO3 | unitless | 0.65 |
| Ratio DRP | R_DRP | unitless | 0.73 |
| Ocean salinity | OceanSalinity_mean | ppt | 34.44 |
| Ocean nitrate concentration | NOcean | mg/m3 | 70.85 |
| Ocean DRP concentration | POcean | mg/m3 | 16.34 |
| Intertidal area | Intertidal | % | 51.05 |
| Typical closure length | Tl | days | NA |
| ICOE class | isICOE | one of: TRUE, FALSE | TRUE |
| Closure length | closure_length | one of: days, months | days |
| Estuary Area | est_area_m2 | m2 | 1500000 |
| Mean depth | mean_depth | m | 1.76 |
| Tidal height | tidal_height | m | 1.71 |
| Estuary Area at low tide | LOWTIDEest_area_m2 | m2 | 537000 |
| Mean depth at low tide | LOWTIDEmean_depth | m | 1.0 |
| Estuary volume at low tide | LOWTIDEvolume | m3 | 537000 |

| NZ ETI Tool 2 Input details | | | |
|---|---|---|---|
| Name of estuary | estuary_name | | Tokomairiro Estuary 2018 |
| Phytoplankton Biomass | CHLA | mg/m3 | 4 |
| Macroalgal GNA | macroalgae_GNA_ha | ha | 0 |
| Macroalgal GNA/Estuary Area | macroalgae_GNA_percent | % | 0 |
| Opportunistic Macroalgae | macroalgae_EQR | OMBT EQR | 0.62 |
| Dissolved Oxygen (DO) | DO | mg/m3 | 6.3 |
| Sediment Redox Potential (RP) | REDOX | mV | -160 |
| Total Organic Carbon (TOC) | TOC | % | 1.55 |
| Total Nitrogen (TN) | TN | mg/kg | 1700 |
| Macroinvertebrates | AMBI | NZ AMBI | 3.5 |
| Area of soft mud | soft_mud | Proportion | 0.69 |
| Estuary type | estuary_type | | SSRTRE |
| ICOE status | isICOE | TRUE/FALSE | TRUE |