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Catlins Estuary

Broad Scale Habitat Mapping 2016/17

Prepared for

Otago Regional Council

May 2017

Cover Photo: Catlins Estuary, view over the lower estuary basin, December 2016.

Catlins Estuary entrance

Catlins Estuary

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by

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CATLINS ESTUARY - EXECUTIVE SUMMARY

Catlins Estuary is a relatively modified, large sized (830ha), mesotidal (1.76m spring tidal range), shallow (mean depth ~1-2m at high water), well-flushed (residence time <1 day), seawater-dominated, tidal lagoon type estuary located at Pounawea, Otago. It has a single tidal entrance that is always open, a large lower estuary basin, an upper estuary basin named Catlins Lake, and two dominant freshwater inflows (Catlins and Owaka Rivers). The catchment is dominated by pasture (61%) and indigenous forest (20%). It is one of the key estuaries in Otago Regional Council's (ORC's) long-term coastal monitoring programme. This report presents the results of the December 2016 broad scale estuary habitat mapping with broad scale monitoring results, overall estuary condition and issues, and monitoring recommendations summarised below.

BROAD SCALE RESULTS

- Intertidal flats comprised 75% of the estuary, subtidal waters 23%, and saltmarsh 1.5%.
- Intertidal substrates were dominated by firm muddy sand (45%) and soft and very soft mud (21%), firm sand (20%), with smaller areas of mobile sand (7%), soft muddy sand (4%), rockfield (2%), and shell, gravel, cobble and artificial boulder fields (all <1%). The soft mud risk rating was HIGH.
- Sediment mud content measured within mud habitat was high (27-46%), a risk rating of HIGH.
- Opportunistic macroalgal growth (*Ulva intestinalis* and *Gracilaria chilensis*) was sparse overall (~5% of the available intertidal habitat), an overall Ecological Quality Rating of "GOOD" (a risk rating of LOW). However, gross eutrophic zones (entrained high biomass growths and degraded sediments) appear to have recently established in the Owaka arm and Catlins Lake, a risk rating of MODERATE to HIGH.
- Seagrass (*Zostera muelleri*) covered 5% of the estuary, located in the central basin that has strong tidal flushing.
- Saltmarsh cover was relatively sparse 12ha (1.9% of the intertidal area) and reflected significant (>300ha) historical losses, a risk rating of HIGH.
- The 200m terrestrial margin was 71% pasture or unmaintained grassland with 23% densely vegetated buffer, a risk rating of HIGH.

ESTUARY CONDITION AND ISSUES

In relation to the key issues addressed by the broad scale monitoring (i.e. muddiness, eutrophication, and habitat modification), the 2016 broad scale mapping results show that the estuary supported a variety of substrate types, extensive areas of high value seagrass beds, but very little saltmarsh. It was expressing symptoms of excessive muddiness, a moderate level of eutrophication (i.e. nuisance macroalgal growths and gross eutrophic zones), and historical habitat modification has also been significant.

The combined results place the estuary in a "MODERATE" state overall in relation to ecological health. Fine sediment and eutrophication issues were evident in the relatively sheltered Catlins Lake and Owaka arm, and significant historical modification and loss of estuary saltmarsh.

RECOMMENDED MONITORING

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

To characterise any issues of change in habitat (e.g. saltmarsh or seagrass area, soft mud extent), it is recommended that broad scale habitat mapping be undertaken at 10 yearly intervals (next scheduled for 2026) unless obvious changes are observed in the interim.

Because nuisance opportunistic macroalgae and gross eutrophic conditions appear to have established in the estuary only relatively recently, it is recommended that a strong baseline be established by undertaking an annual macroalgal survey (January/February) over the next three years in conjunction with scheduled fine scale sampling.

1. INTRODUCTION

Developing an understanding of the condition 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; Shag Estuary, Waikouaiti Estuary and Catlins Estuary.

Monitoring of the Catlins Estuary began with preliminary broad and fine scale monitoring undertaken in 2008 and 2012 with the first year of comprehensive baseline monitoring undertaken in December 2016.

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 Catlins Estuary was first undertaken in 2008 (Stewart and Bywater 2009) and the Owaka arm in 2012 (Stewart 2012), with the first comprehensive mapping undertaken in December 2016 and which 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 the condition of Catlins Estuary, was undertaken in a partial form in November 2008 (Stewart and Bywater 2009) and extended to include the Owaka arm in November 2012 (Stewart 2012), with the first year of comprehensive baseline monitoring undertaken on 17 December 2016 (Robertson et al. 2017).

Report Structure: The current report presents an overview of key estuary issues in NZ and recommended monitoring indicators (Section 1). This is followed by risk indicator ratings (Section 2) and the sampling methods (Section 3) used in this broad scale assessment. Summarised results of the December 2016 field sampling are then presented and discussed (Section 4) for the following:

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

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

CATLINS ESTUARY

Catlins Estuary is a large-sized (~830ha and ~12km long), shallow, intertidal dominated, estuary (SIDE) that discharges via one permanent open tidal mouth to the Pacific Ocean via a broad embayment at Pounawea, Otago (Figure 1). The estuary is fed by two rivers, the Catlins (mean flow ~3.7$m^3.s^{-1}$) and the slightly smaller Owaka River (mean flow 3.1$m^3.s^{-1}$) [source NIWA CLUES 10.3, 2016]. The Catlins River catchment is ~415km^2 with land cover dominated by high producing grassland (61%), indigenous forest (23%), and exotic forest (5%). On high producing exotic grassland, sheep and beef grazing represents the majority of recorded land use, with dairy, deer and forestry being less common.

The majority of the estuary is bordered by farmland, mainly sheep and beef, with a large barrier spit to the north of the estuary entrance near the village of New Haven. A small area of virgin podocarp forest (rimu, totara, matai, kahikatea and miro) borders the estuary at Pounawea, a remnant and reminder that the main industry of the Catlins from 1870 to 1970 was logging these giant podocarp trees.

A large wetland is located at the western head of the estuary (Catlins River) which is an important habitat for waterfowl and fish breeding. The estuary itself is also an important habitat for marine and freshwater fish and as a coastal recreation area with boating, swimming, fishing and walking, and is listed as a coastal protection area with Kai Tahu cultural and spiritual values. The estuary falls into two main areas, the eastern basin around Pounawea near the estuary entrance which has strong tidal flushing and is dominated by sands, and the muddier upper reaches to the west of the Hinahina Road bridge, termed Catlins Lake, which is relatively shallow with more restricted flushing.

Overall the estuary has moderate to high ecological habitat diversity with variable substrate types including sand, rock shell, gravel and mud, extensive shellfish beds, but relatively small areas of saltmarsh (1.5% of the estuary), and seagrass (3.5% of the estuary). Historically there has been a significant loss (>300ha) of saltmarsh since c.1850 as a consequence of drainage and reclamation with much of the natural vegetated margin now developed for grazing.

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

Recommended Key Indicators:

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

5. Habitat Loss

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

Recommended Key Indicators:

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

Figure 1. Catlins Estuary, showing main estuary zones and fine scale monitoring 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, "risk indicator ratings" have also been proposed that assign a relative level of risk (e.g. very low, low, moderate, high) of specific indicators adversely affecting intertidal estuary condition (see Table 2 below). Each risk indicator rating is designed to be used in combination with relevant information and other risk indicator ratings, and under expert guidance, to assess overall estuarine condition in relation to key issues, and make monitoring and management recommendations. When interpreting risk indicator results we emphasise:

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

The indicators and interim risk ratings used for the Catlins 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 the present report.

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

*NZ ETI (Robertson et al. 2016b), **Hargrave et al. (2008), ***Robertson (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). For the current study, 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 Dec. 2016 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.

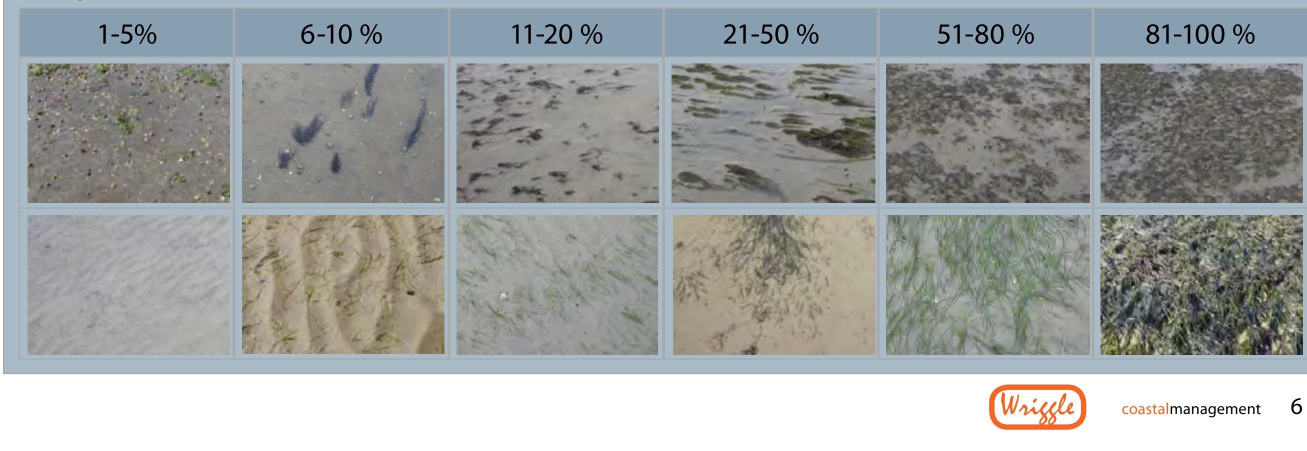
Macroalgae was further assessed by identifying patches of comparable growth, and enumerating each patch by measuring:

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

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

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

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



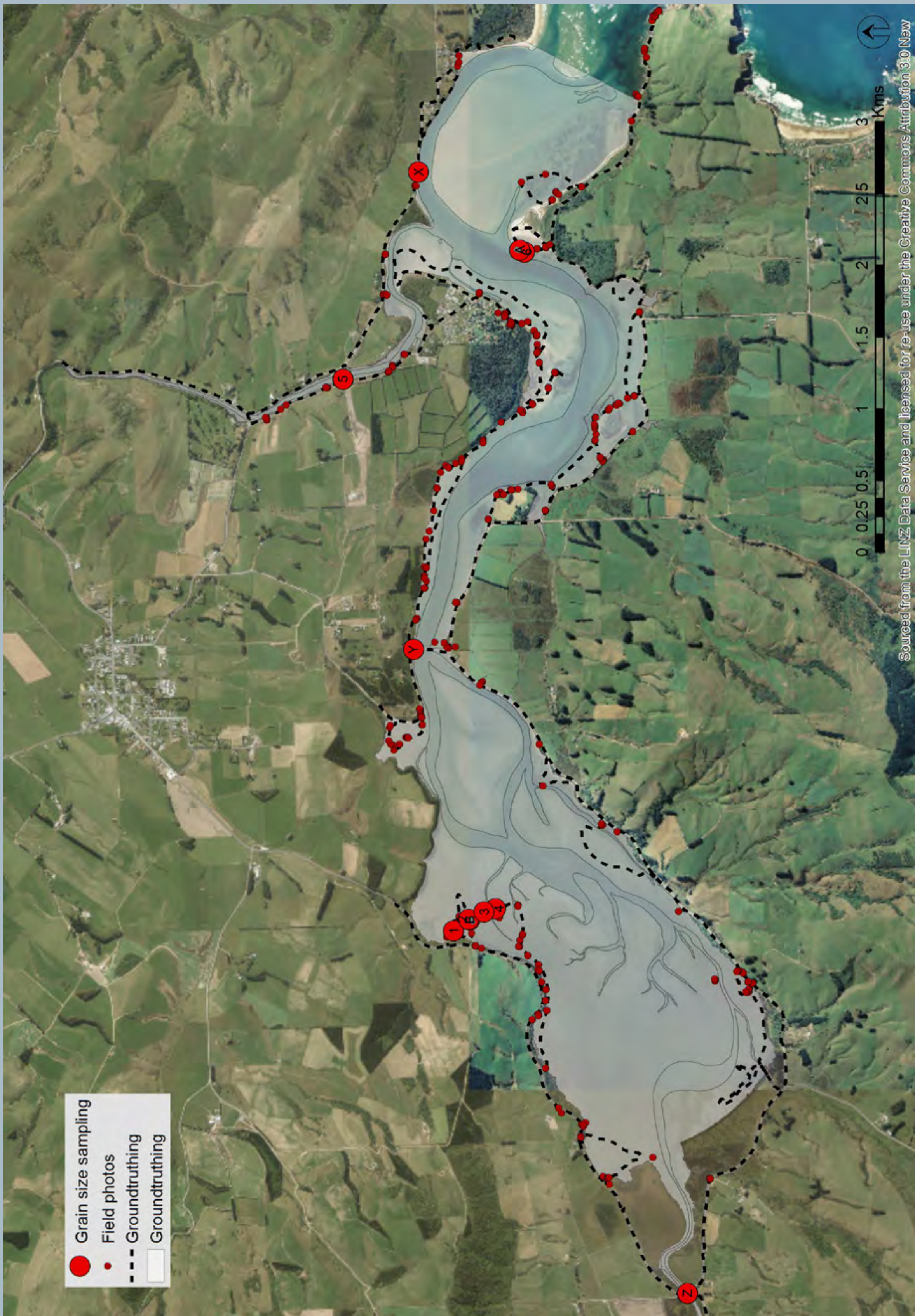


Figure 3. Catlins Estuary - mapped estuary extent showing ground-truthing coverage, field photos and location of grain size samples used to validate substrate classifications.

4. RESULTS AND DISCUSSION

4.0. BROAD SCALE MAPPING SUMMARY

The 2016 broad scale habitat mapping ground-truthed and mapped all intertidal substrate and vegetation including the dominant land cover of the 200m terrestrial margin, with the six dominant estuary features summarised in Table 3 and shown in Figure 4. The estuary comprises an enclosed tidal estuary dominated by intertidal flats (75.3%) with small areas of fringing saltmarsh (1.5%) and a subtidal channel (23%). Intertidal seagrass (3.7%) was relatively sparse, as was dense (>50% cover) opportunistic macroalgae (3.9%). The 200m wide terrestrial margin was dominated by grassland (61%) with 23% densely vegetated buffer. 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.

While mapping of the estuary was previously undertaken in 2008 and 2012 (Stewart and Bywater 2009, Stewart 2012), the ORC supplied GIS files included incomplete coverages and the hard copy reports contain only high level summary detail which limited the extent that detailed comparisons could be made. Further, the retrospective application of risk ratings is precluded by the previous assessments classifying large areas of terrestrial vegetation as being within the estuary, and grouping key features e.g. seagrass and macroalgae together. Table 3 provides a summary of the merged 2008 and 2012 results and 2016 mapping results from the current study.

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

Table 3. Summary of dominant broad scale features in Catlins Estuary, 2008/2012 and 2016.

Dominant Estuary Feature		2008/2012			2016		
		ha	% intertidal	% estuary	ha	% intertidal	% estuary
1.	Intertidal flats (excluding saltmarsh)	728.5	96.3	76.8	624.3	98.1	75.3
2.	Opportunistic macroalgal beds (>50% cover) [on intertidal flats]	53.6	7.1	5.6	32.0	5.0	3.9
3.	Seagrass (>20% cover) [on intertidal flats]				30.3	4.8	3.7
4.	Saltmarsh ([1]excludes obvious terrestrial areas listed in 2008 and 2012)	27.9	3.7	2.9	12.1	1.9	1.5
5.	Subtidal waters ([2]not recorded in 2008 or 2012, 2016 value used)	192.6[2]	-	20.3	192.6	-	23.2
Total Estuary		**949**	**100%**		**829**		**100**
6.	200m wide densely vegetated Terrestrial Margin (e.g. scrub, shrub, forest)						23%

4.1. INTERTIDAL SUBSTRATE (EXCLUDING SALTMARSH)

Results (summarised in Table 4 and Figure 5) show substrates on intertidal flats in 2016 were dominated by firm muddy sand (45%), soft and very soft mud (21%), and firm sand (20%), with smaller areas of mobile sand (7%), soft muddy sand (4%), rockfield (2%), and shell, gravel, cobble and artificial boulder fields (all <1%).

Soft and very soft muds were confined largely to the upper tidal reaches of the relatively sheltered Owaka arm and Catlins Lake which is constricted above the Hinahina road bridge. In contrast, the lower estuary was dominated by sands that are regularly exposed to strong tidal flushing and wave exposure from the outer coast. Between these zones firm muddy sands dominated. This is a common feature within estuaries where mud-dominated sediments in the upper estuary transition to sand dominated sediments in the lower estuary.

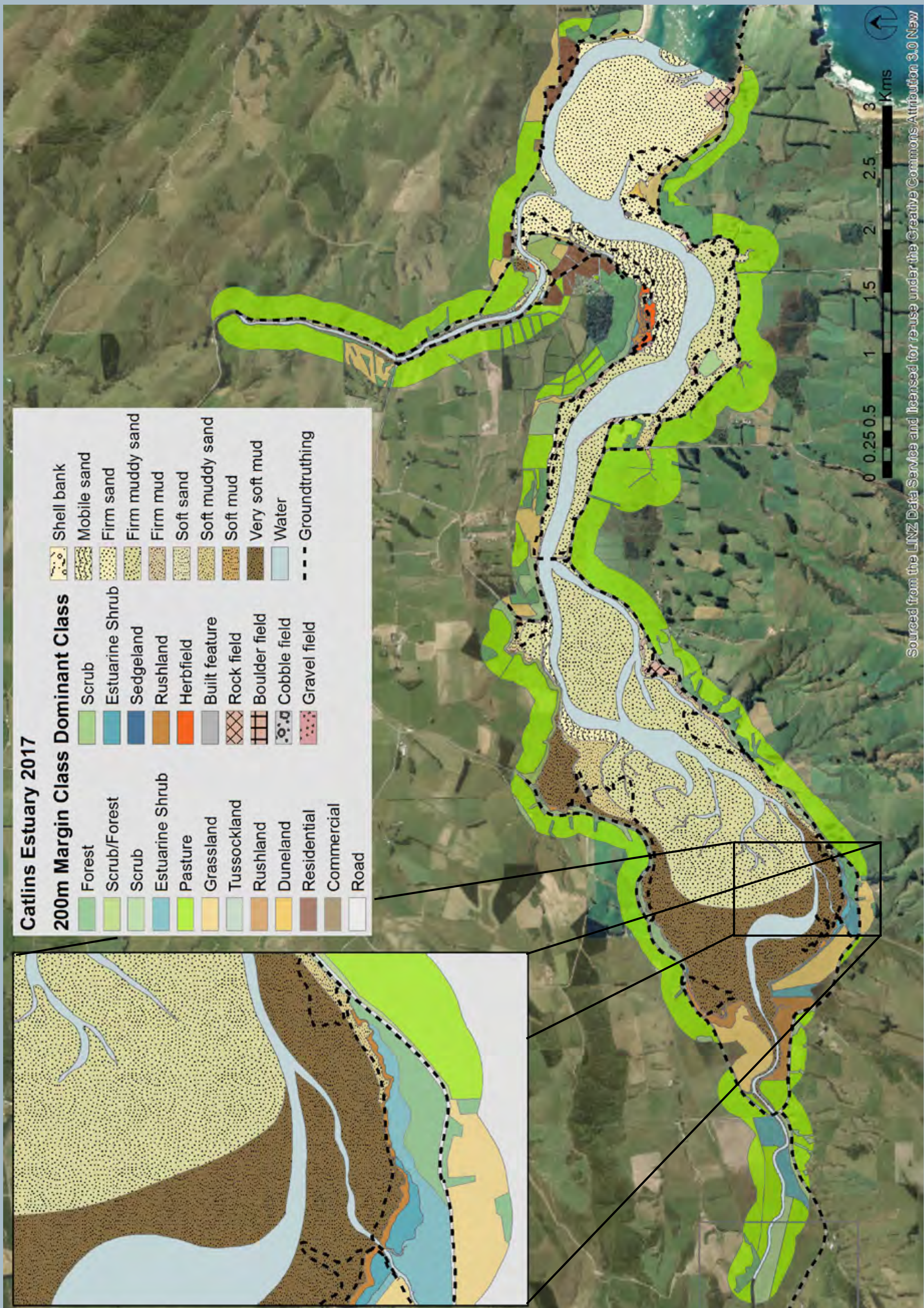


Figure 4. Overview of terrestrial margin and intertidal areas mapped including detail of GIS layers - Catlins Estuary, Dec. 2016.

Table 4. Summary of dominant intertidal substrate, Catlins Estuary, 2016.

Dominant Substrate	Ha	%	Comments
Built feature	1.9	0.3	Artificial boulder fields along reclamation margins
Rock field	10.0	1.6	Predominantly near the entrance
Gravel field	0.8	0.1	Mid estuary along upper channel margins
Cobble field	0.0	0.0	Small pockets in the main basin and near the entrance
Shell bank	1.3	0.2	Small pockets in the main basin near Pounawea
Mobile sand	45.9	7.3	Predominantly near the entrance and in the lower estuary
Firm sand	125.2	20.1	Predominantly near the entrance
Firm muddy sand	283.7	45.4	Mid to upper estuary settlement basins
Soft muddy sand	24.7	4.0	Upper estuary at seaward edge of settlement basins
Soft mud	0.5	0.1	Upper estuary settlement basins and sheltered channels in the Owaka arm
Very soft mud	130.3	20.9	
Grand Total	**624.3**	**100**	

4.2. EXTENT OF SOFT MUD

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

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

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

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

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

The area (horizontal extent) of intertidal soft mud is the primary sediment indicator used in the current broad scale report, with sediment mud content a supporting indicator. Sediment plates have been established at two fine scale sites to enable future monitoring of vertical buildup (see Robertson et al. 2017 for details).

Figure 5 and Table 4 shows that soft or very soft muds covered 131ha (21%) of the intertidal area, a risk indicator rating of HIGH, and had a mud content measured in representative areas of 27-46%, a supporting risk indicator rating of HIGH (Table 5). Soft muds were concentrated in the upper tidal reaches of Catlins Lake and the Owaka arm where mud settlement is thought to predominantly reflect salinity driven flocculation, reduced flow velocities, and sheltered deposition zones. Within the dominant firm sandy mud substrate of the estuary, grain size reflected a LOW risk rating (3-10% mud content).

The 2016 soft mud extent (131ha) was less than half that previously reported (273ha, Stewart and Bywater 2009, Stewart 2012), but was almost entirely classified as very soft mud (130ha) in 2016, compared to 21ha recorded in the 2008/2012 surveys. Future monitoring will determine if this represents an ongoing trend or is related to differences in the assessment methods used.

Table 5. Representative sediment grain size results, 2016.

Classification	Site	% mud	% sand	% gravel
Firm Muddy Sand	6	3.1	96.9	< 0.1
	4	10.1	89.9	< 0.1
Soft Muddy Sand	2	18.4	81.6	< 0.1
	3	21.8	78.2	< 0.1
Very Soft Mud	5	27.2	69.9	2.9
	1	46.7	53.2	< 0.1

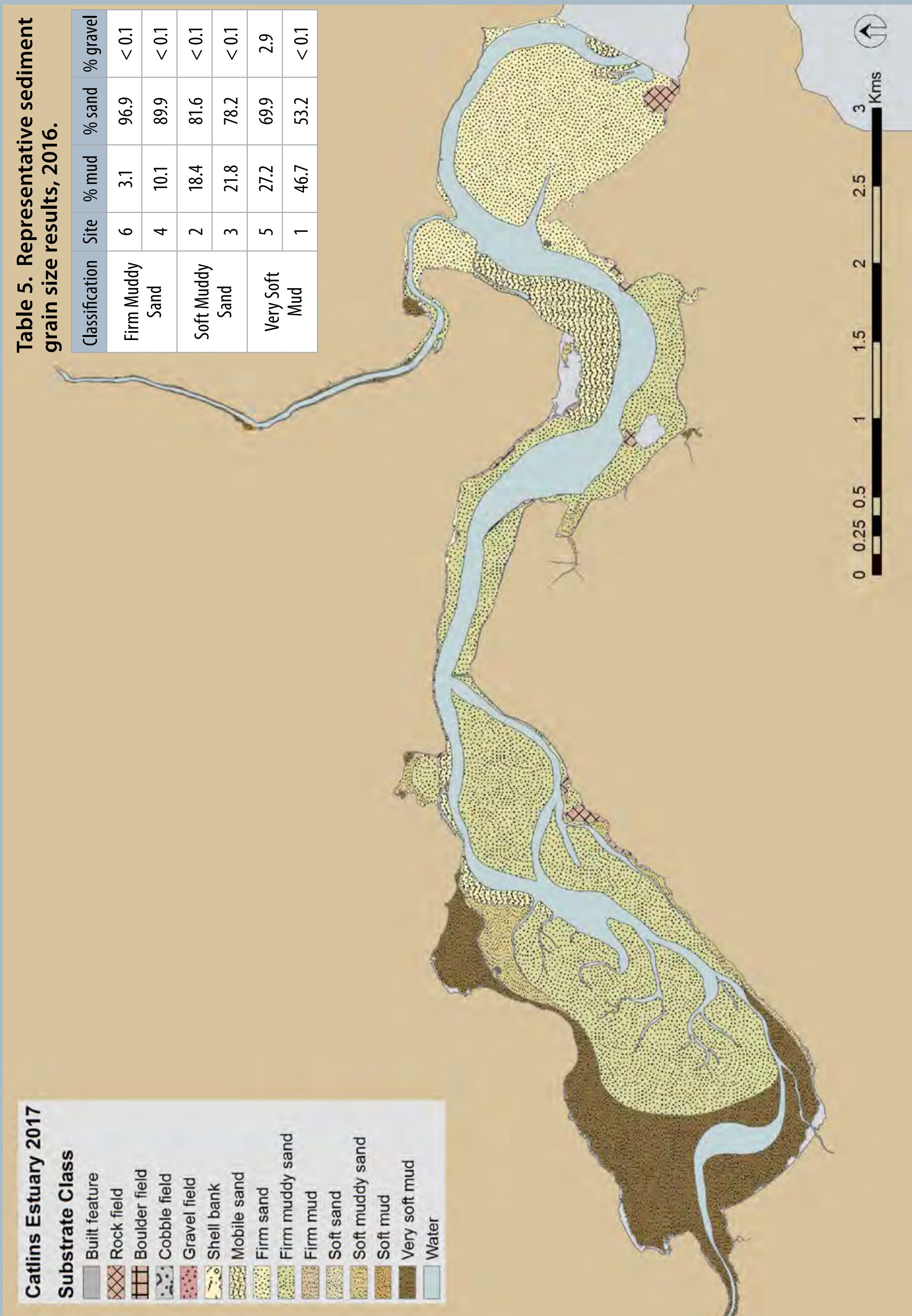


Figure 5. Map of dominant intertidal substrate types - Catlins Estuary, Dec. 2016.

4. RESULTS AND DISCUSSION (CONTINUED)

Clean sand and gravels (left) and rock (right) in the lower estuary near the entrance.

Gravel and cobble near Hinahina Road (left), and very soft mud in the Owaka arm (right).

Firm muddy sand (left) and soft mud (right) in Catlins Lake.


Boulderfield armoured margin near New Haven (left) and mobile sands in the central estuary (right).


Dense macroalgae in soft muds in the Owaka arm (left) and near Hinehine Road bridge (right).

Herbfield and rushland contiguous with native podocarp forest near Pounawea.

4. RESULTS AND DISCUSSION (CONTINUED)

4.3. SEDIMENT OXYGENATION

The primary indicators used to assess sediment oxygenation are aRPD depth and RP measured at 3cm. These indicators were measured at representative sites throughout the dominant sand and mud substrate types, and from a range of sites with variable macroalgal cover and biomass. 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 6). Because macrofauna are used as an indicator of ecological impacts to other taxa, it is expected that these zones will also be exerting adverse impacts on associated higher trophic communities including birds and fish.

These results show that the majority of the estuary sediments are well to moderately well oxygenated and appeared in good (healthy) ecological condition, with the aRPD depth at 2-5cm and the RP above -150mV at 3cm in most sand and gravel dominated sediments. There was 17.1ha (2.7%) of the total intertidal area identified as having depleted sediment oxygen, a NZ ETI risk rating of "MODERATE". These areas were largely confined to very soft muds located in the upper tidal range settlement areas in the Owaka arm and Catlins Lake where dense growths of the red nuisance macroalgae *Gracilaria* had smothered the estuary bed. Sediment oxygenation was not recorded outside of fine scale sites in 2008 or 2012 so cannot be compared to the 2016 results.

4.4. OPPORTUNISTIC MACROALGAE

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

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

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 Catlins Estuary in Dec. 2016 was 0.62 (Table 6), a quality status of "GOOD". and indicates that the estuary overall is expressing limited symptoms of eutrophication. This is reflected by the "Good" Quality Status score for size of the Affected Area (AA) in relation to the overall AIH, and "High" Quality Status scores for low overall percentage cover and biomass in the AIH. This highlights that macroalgal growth is not particularly widespread and overall growth is relatively low. However where macroalgae has established, there are indications of excessive growth present with moderate biomass in some parts of the estuary (e.g. Figure 8), and a relatively high proportion of the macroalgae entrained in underlying sediments ("Poor" Quality Status).

The highest density growths were located on the poorly flushed upper intertidal flats of Catlins Lake, and the lower tidal channels of the Owaka River where sediment entrained growths of the red alga *Gracilaria chilensis* were dominant and are a concern as they commonly lead to significant sediment anoxia and enrichment.

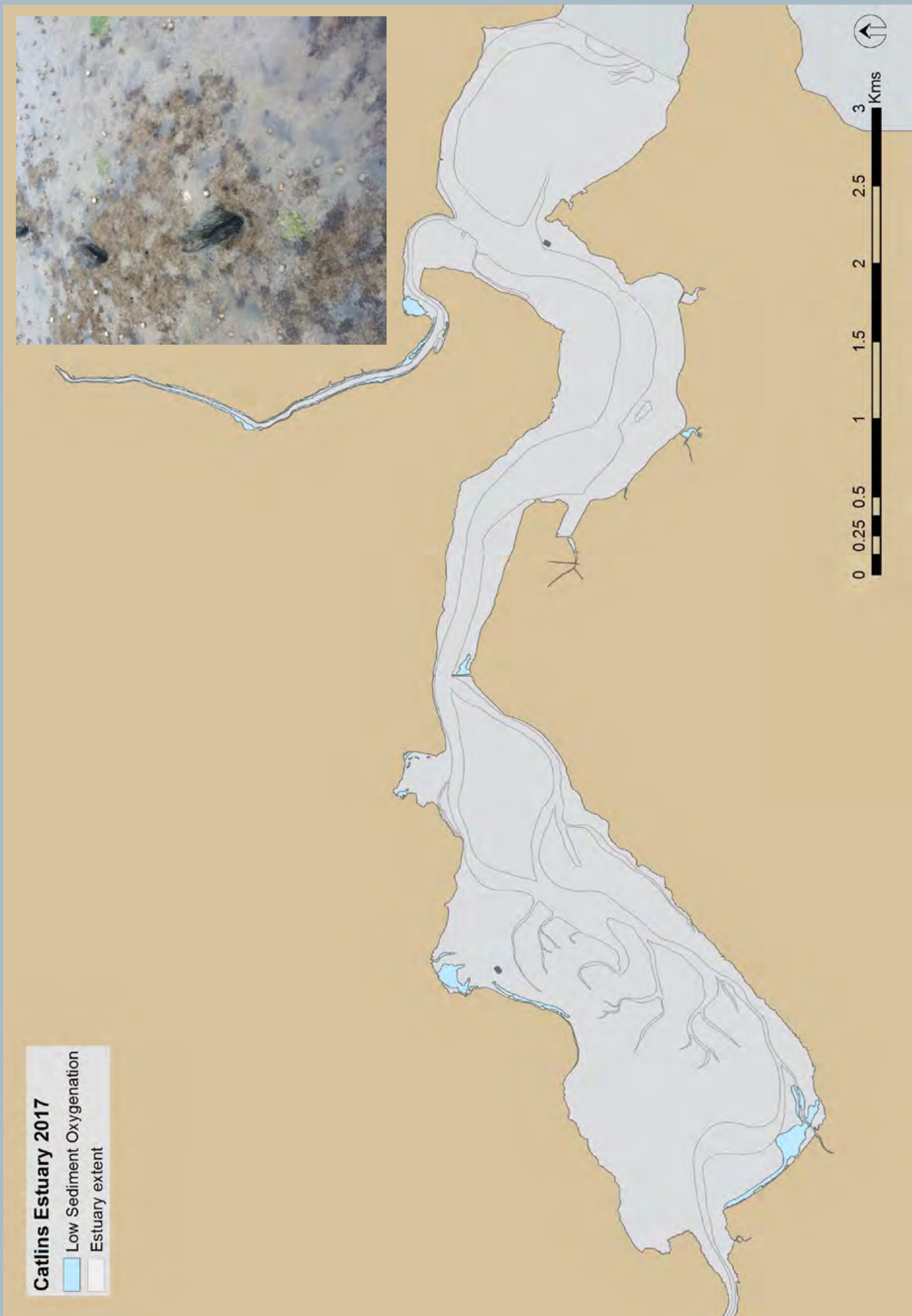


Figure 6. Map of areas with low sediment oxygenation - Catlins Estuary, Dec. 2016.

In the lower estuary the green alga *Ulva intestinalis* was commonly dominant to *Gracilaria* but nuisance macroalgae beds were uncommon, likely due to lower densities and cover combined with strong tidal flushing preventing the buildup of fine muds that often lead to sediment enrichment, and maintaining good sediment oxygenation which limits the release of sediment bound nutrients though anoxic processes.

Previous GIS mapping in 2008 and 2012 grouped nuisance macroalgae and high value seagrass together precluding comparisons or assessment of change over time. However, Stewart (2012) reported only two moderate patches of *Ulva* from the Owaka arm in 2012, and Stewart and Bywater (2009) reported no growths of *Gracilaria* in Catlins Lake in 2008 suggesting a significant deterioration in macroalgal condition has occurred over the past 4-8 years.

The 2016 risk indicator rating for macroalgae was LOW, although the likely increase in growth since 2008 was rated HIGH.

Table 6. Summary of intertidal opportunistic macroalgal cover, Catlins Estuary, Dec. 2016.

Metric	Face Value	Final Equidistant Score (FEDS)	Quality Status
AIH - Available Intertidal Habitat (ha)	625		
Percentage cover of AIH (%) = (Total % Cover / AIH} x 100 *where Total % cover = Sum of {(patch size) / 100} x average % cover for patch*	5.0	0.802	High
Biomass of AIH ($g.m^{-2}$) = Total biomass / AIH *where Total biomass = Sum of (patch size x average patch biomass)*	41.4	0.917	High
Biomass of Affected Area ($g.m^{-2}$) = Total biomass / AA *where Total biomass = Sum of (>5% cover patch size x average patch biomass)*	478.1	0.415	Moderate
Presence of Entrained Algae = (No. quadrats or area (ha) with entrained algae / total no. of quadrats or area (ha)) x 100	26.6	0.356	Poor
Affected Area (use the lowest of the following two metrics)		0.583	Moderate
Affected Area, AA (ha) = Sum of all patch sizes (with macroalgal cover >5%)	54.1	0.583	Moderate
Size of AA in relation to AIH (%) = (AA / AIH) x 100	8.7	0.727	Good
OVERALL MACROALGAL ECOLOGICAL QUALITY RATING - EQR (AVERAGE OF FEDS)		**0.62**	**GOOD**
Upper and Lower 90% Confidence Interval for EQR		0.597	0.648

Gross Eutrophic Zones (GEZ - the combined presence of high algal cover, soft mud and poor oxygenation) were present across 14.9ha (2.3%) of the intertidal area, a risk indicator rating of MODERATE. These areas were located predominantly in the Owaka arm and in the upper tidal reaches of Catlins Lake (Figure 7) and closely matched the location of high biomass growths (Figure 8).

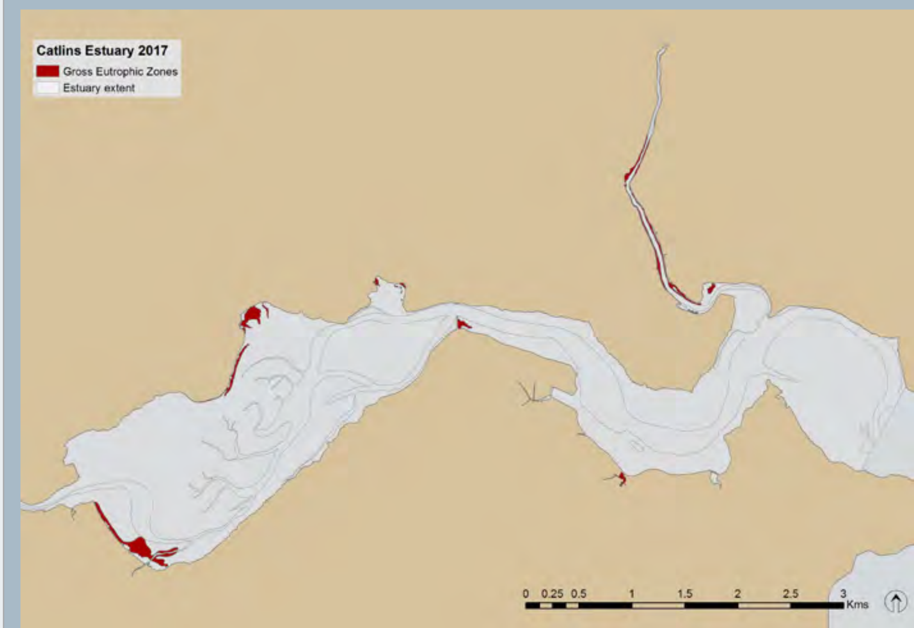


Figure 7. Map of Gross Eutrophic Zones - Catlins Estuary, Dec. 2016.

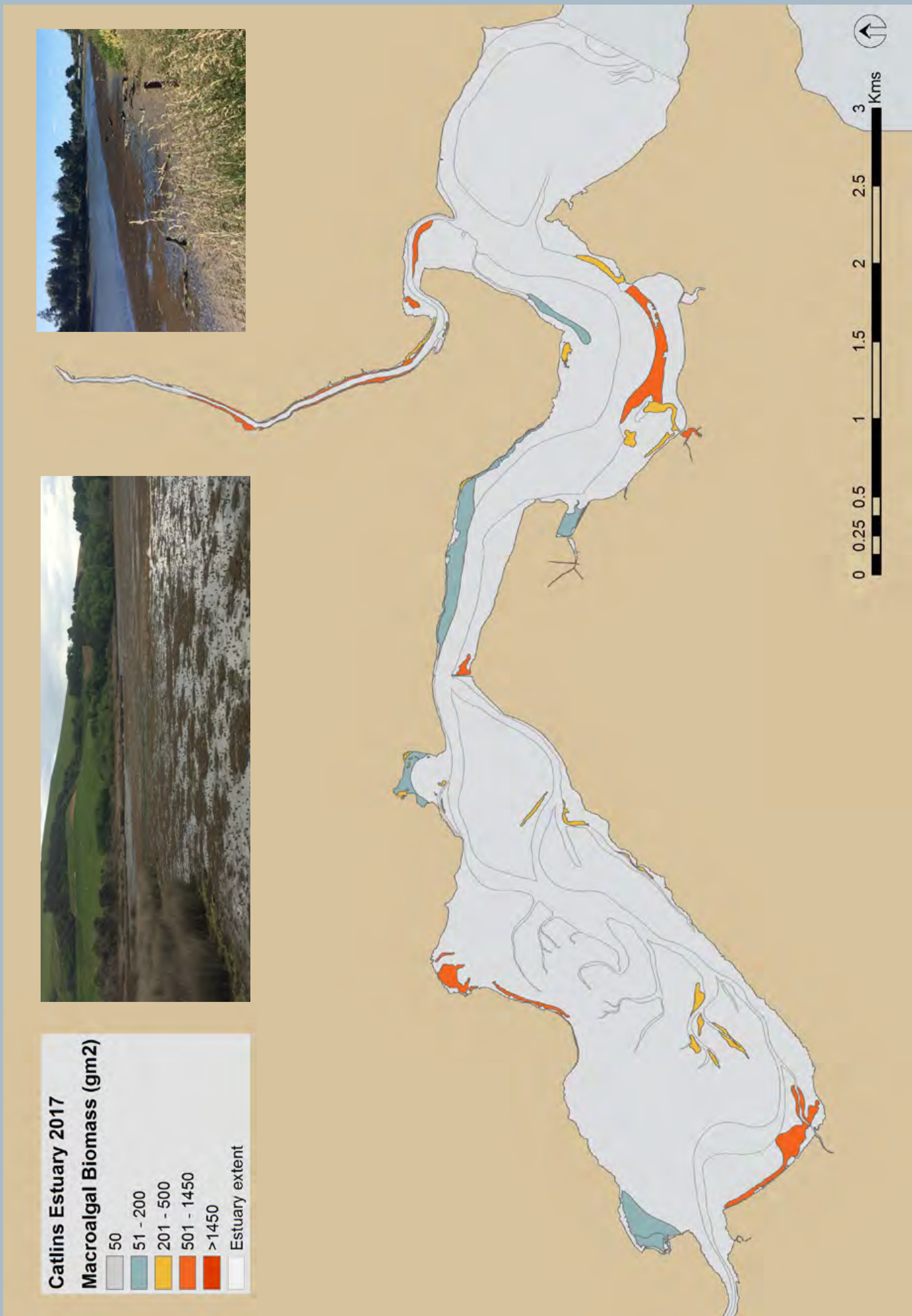
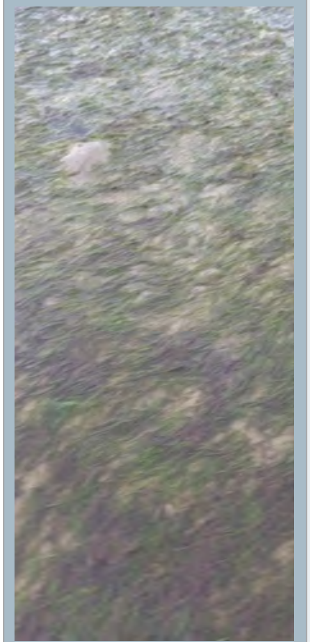
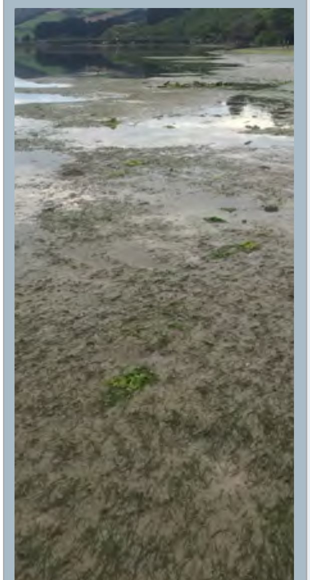


Figure 8. Map of intertidal opportunistic macroalgal biomass (g.m^{-2}) - Catlins Estuary, Dec. 2016.

4.5. SEAGRASS





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

Table 7 and Figure 9 summarise the results of the intertidal seagrass extent (the mapped intertidal estuary area minus saltmarsh). The results show:

- 4.9% of the intertidal estuary area (30.3ha) supported seagrass growth.
- Seagrass beds were located in firm muddy sand and firm sand substrate in the main basin of the lower estuary.
- Large contiguous beds were present near the entrance, and smaller more patchy beds were located further up the estuary near the channel margins.

The total area of intertidal seagrass in Catlins Estuary is relatively large but confined to lower estuary areas that have strong tidal flushing with relatively clear seawater. The seagrass beds appeared to be in good condition and not under any obvious stress from excessive sediment deposition or macroalgal smothering. Previous GIS mapping in 2008 and 2012 grouped nuisance macroalgae and high value seagrass together precluding comparisons or assessment of change over time.

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.

Table 7. Summary of seagrass *(Z. muelleri)* cover, Catlins Estuary, 2016.

Percentage Cover	Area (ha)	Percentage
No seagrass	594.0	95.1
50%	0.3	0.05
80%	27.4	4.4
100%	2.6	0.4
	624	**100**

Extensive seagrass beds in form sands near the estuary entrance.

4. RESULTS AND DISCUSSION (CONTINUED)

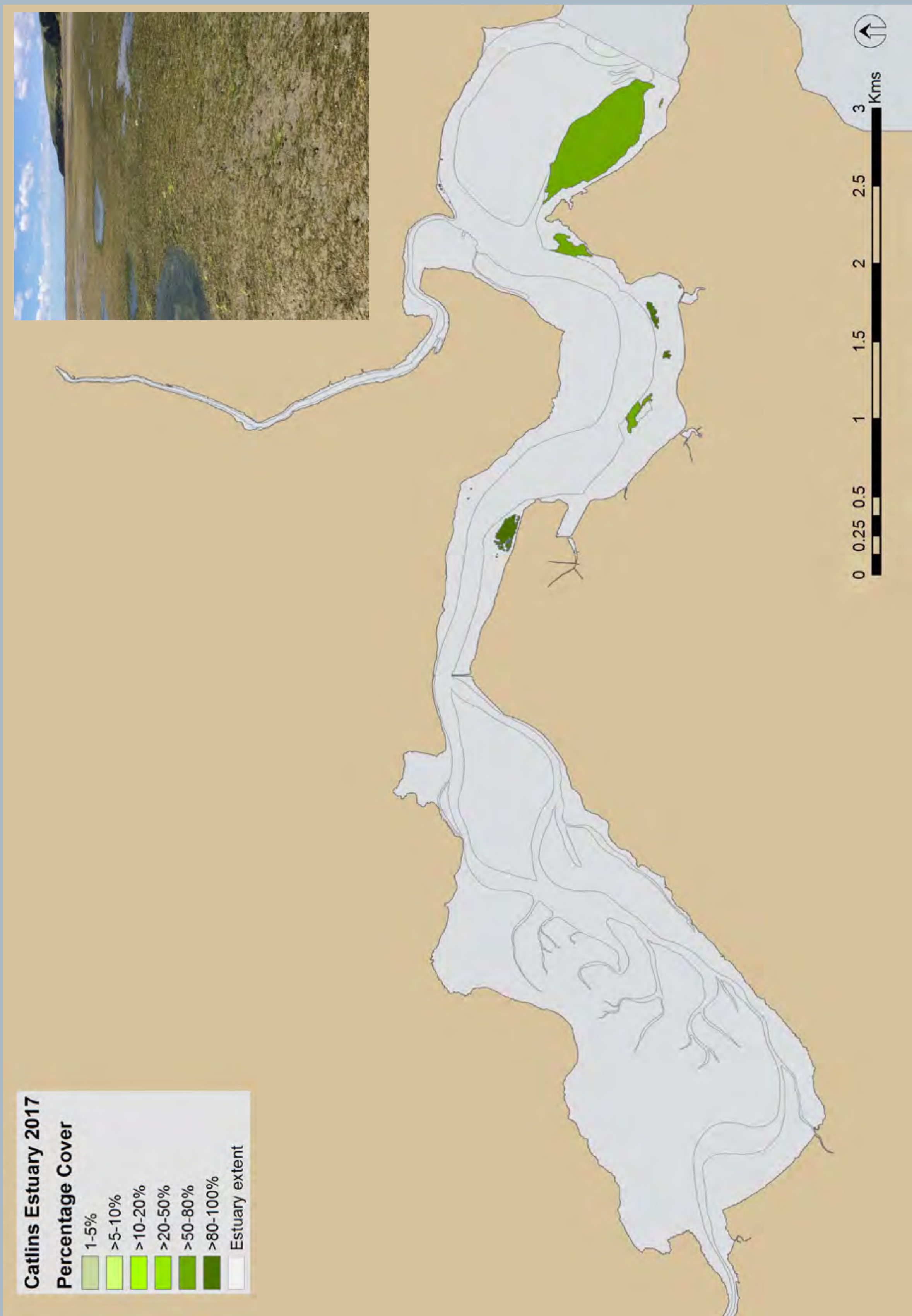
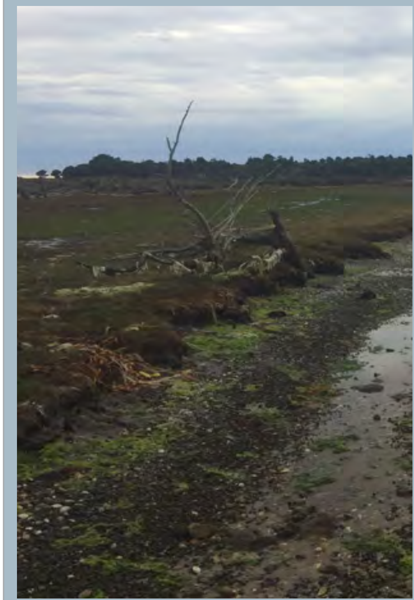
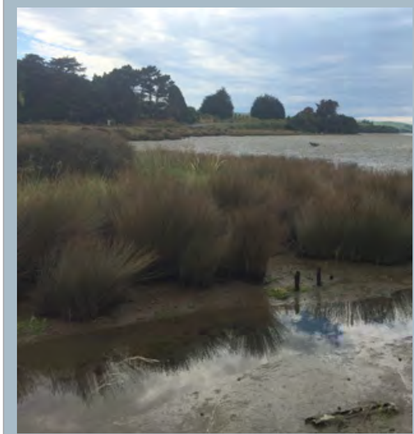


Figure 9. Map of intertidal seagrass percentage cover (*Zostera muelleri*) - Catlins Estuary, 2016.

4. RESULTS AND DISCUSSION (CONTINUED)

4.6. SALTMARSH





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

The primary measure to assess saltmarsh condition is the percent cover of the intertidal area. Table 8 and Figure 10 summarise the 2016 results and show saltmarsh was present across 12.1ha (1.9%) of the intertidal estuary area, a risk indicator rating of HIGH. Saltmarsh was dominated by rushland (57%) and herbfield (31%) located in relatively narrow strips along the estuary margins with the largest beds near Pounawea.

Rushland was dominated by jointed wirerush commonly mixed with saltmarsh ribbonwood and tall fescue at the upper tidal margins while primrose was the dominant herbfield cover, commonly present with remuremu and glasswort. A range of introduced weeds and grasses were common in the upper tidal range, particularly where margins have been modified.

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 >300ha (>90%) of saltmarsh has been lost from the estuary, a supporting risk rating of HIGH.

The combined overall risk rating was assessed as HIGH.

Table 8. Summary of dominant saltmarsh cover, Catlins Estuary, 2016.

Class	Dominant Species	Primary subdominant species	Area (ha)	Percentage
Estuarine shrub			1.3	11.0
	Plagianthus divaricatus (Saltmarsh ribbonwood)	*Plagianthus divaricatus (Saltmarsh ribbonwood)*	0.1	
		Apodasmia similis (Jointed wirerush)	1.2	
Sedgeland			0.1	1.0
	Schoenoplectus pungens (Three-square)		0.1	
Rushland			6.9	56.8
	Apodasmia similis (Jointed wirerush)	*Apodasmia similis (Jointed wirerush)*	3.8	
		Festuca arundinacea (Tall fescue)	0.8	
		Plagianthus divaricatus (Saltmarsh ribbonwood)	2.2	
Herbfield			3.8	31.2
	Sarcocornia quinqueflora (Glasswort)	*Sarcocornia quinqueflora (Glasswort)*	0.3	
		Samolus repens (Primrose)	3.5	
Total (Ha)			**12.1**	**100**

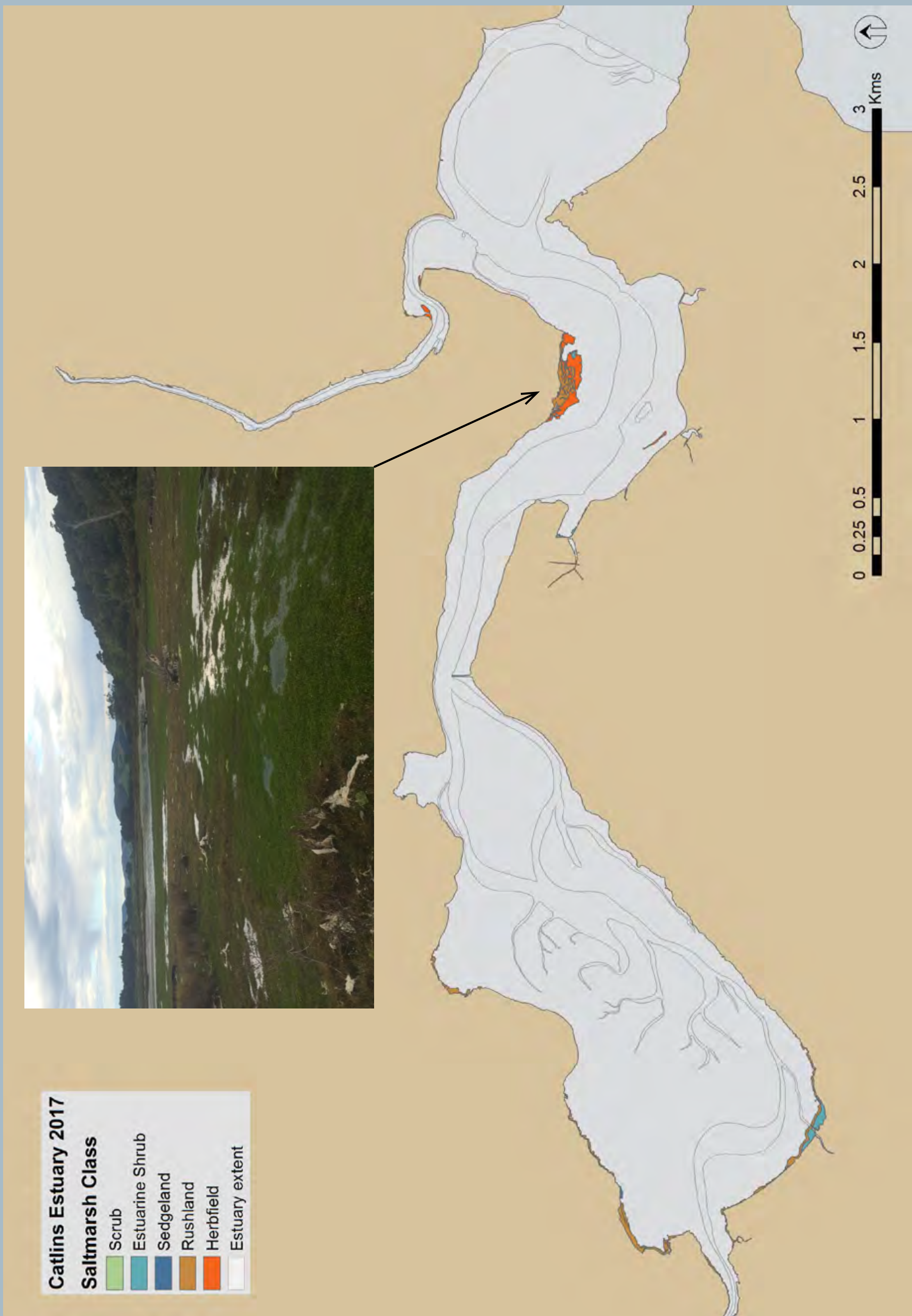
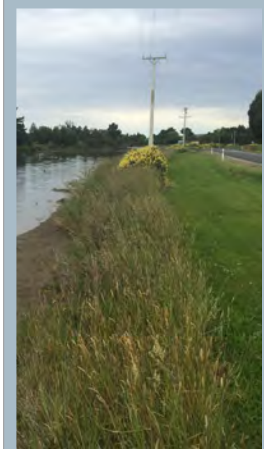


Figure 10. Map of dominant saltmarsh cover - Catlins Estuary, Dec. 2016.

4. RESULTS AND DISCUSSION (CONTINUED)

4.7. 200m TERRESTRIAL MARGIN



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 11) showed:

- 23% was densely vegetated (forest, scrub, tussock, dune, estuary shrub and rush).
- 71% was pasture or unmaintained grassland.
- 5% had been developed (residential, commercial, road etc).

A similar pattern was evident on a catchment wide scale with 36% of the catchment densely vegetated (predominantly in the upper catchment), and 61% high producing grassland in the lower catchment (Figure 12).

The 200m terrestrial margin estuary margin itself has been significantly modified historically, primarily through reclamation and drainage for conversion to pasture and, to a lesser extent road and residential development.

The small remaining extent of densely vegetated 200m terrestrial margin habitat means there is very limited buffering against adverse ecological degradation (e.g. localised sediment and nutrient inputs, introduced weeds), and poor natural ecological connectivity between the estuary and surrounding natural habitats. The 200m terrestrial margin risk indicator rating is therefore “HIGH”.

Table 9. Summary of 200m terrestrial margin land cover, Catlins Estuary, 2016.

Class	Dominant features	Percentage
Forest	Mixed native and exotic trees, predominantly remnant areas of native scrub and gorse in narrow margin strips near the estuary margin, and a stand of podocarp forest (rimu, totara, matai, kahikatea and miro) at Pounawea.	8.4
Scrub/Forest		1.5
Scrub		8.9
Tussockland	Flax dominated areas in the west	0.1
Duneland	Marram grass at the upper shore on both sides of the estuary entrance	0.4
Estuarine Shrub	Primarily saltmarsh areas historically drained and converted to pasture in the west and south of the estuary	2.4
Rushland		1.7
Pasture	Developed pasture present along much of the estuary edge	61.6
Grassland	Unmaintained grassland by road margins at the estuary edge	9.6
Residential	Pounawea	2.5
Commercial	Salmon hatchery (old)	0.1
Built feature	Road corridors, bridges, wharfs	2.9
Total		**100**

Developed pasture adjoining native scrub and forest along the northern estuary margin west of Pounawea.

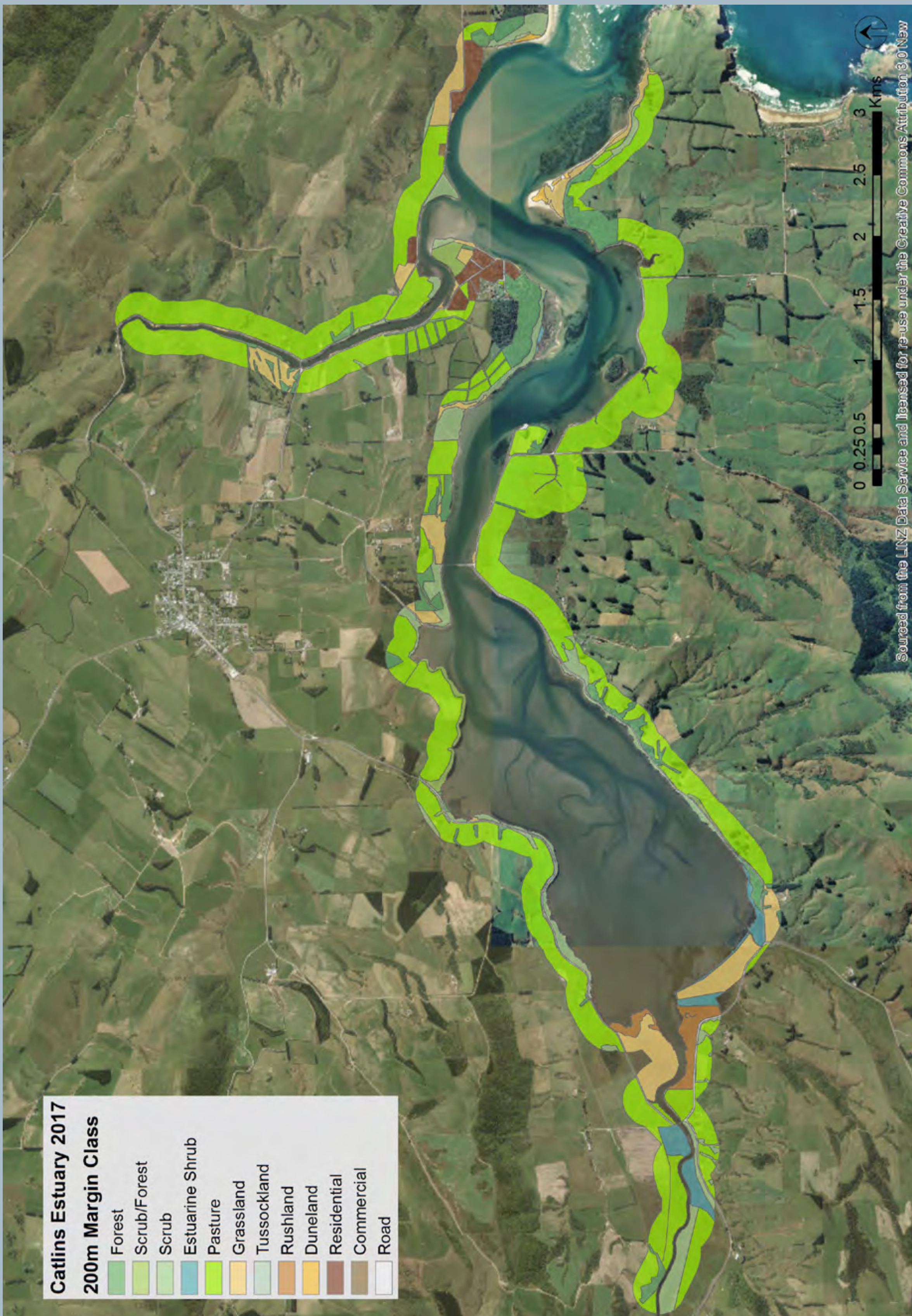
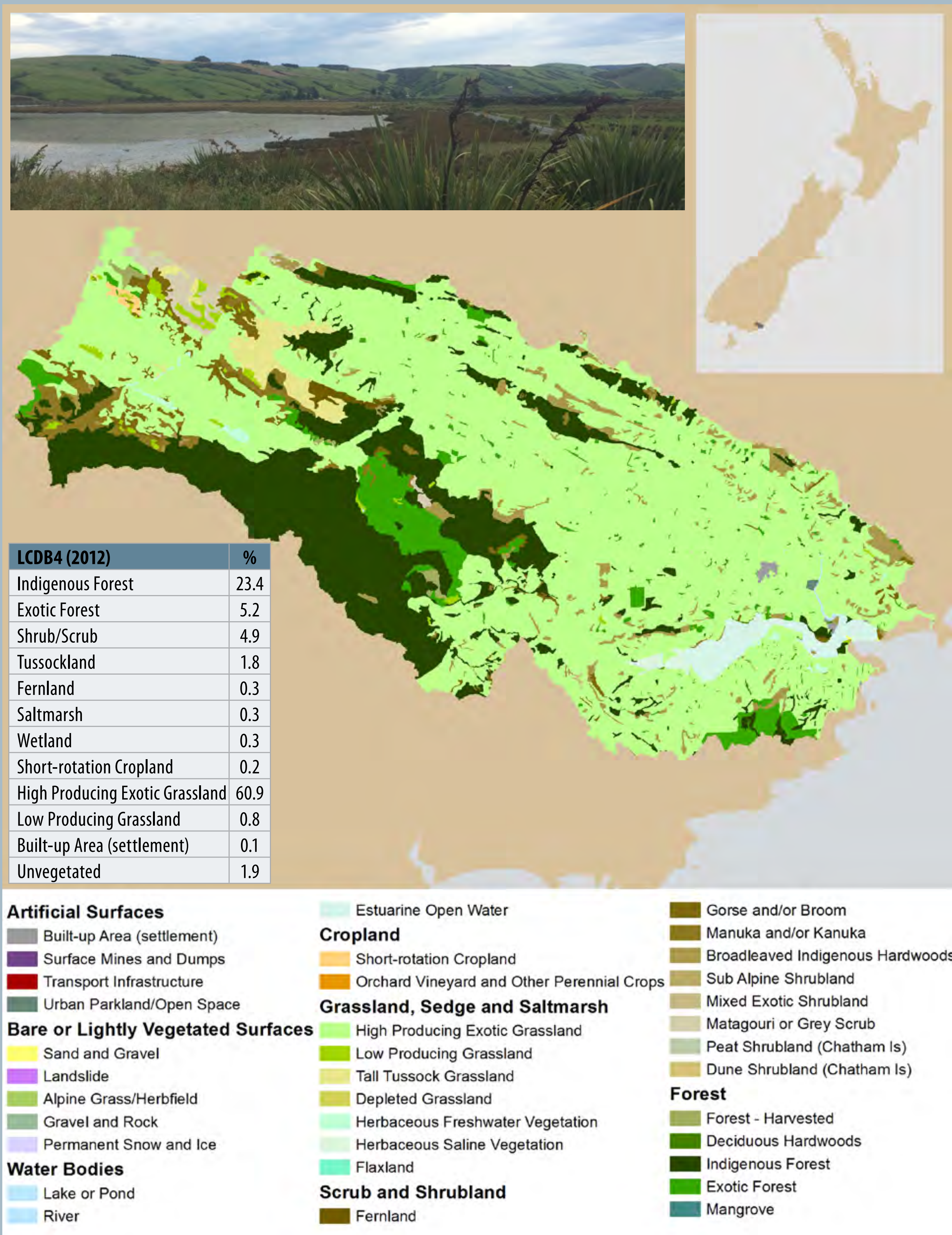


Figure 11. Map of 200m Terrestrial Margin - Dominant Land Cover, Catlins Estuary, Dec. 2016.



LCDB4 (2012)	%
Indigenous Forest	23.4
Exotic Forest	5.2
Shrub/Scrub	4.9
Tussockland	1.8
Fernland	0.3
Saltmarsh	0.3
Wetland	0.3
Short-rotation Cropland	0.2
High Producing Exotic Grassland	60.9
Low Producing Grassland	0.8
Built-up Area (settlement)	0.1
Unvegetated	1.9

Figure 12. Summary of Catchment Land Cover (LCDB4 2012), Catlins Estuary.

4.8. NZ ESTUARY TROPHIC INDEX

The recently developed 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. A key part of the ETI output has been the development of an integrated calculator that enables easy calculation of 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.

From the current broad scale monitoring (this report) and fine scale monitoring (Robertson et al. 2017), Table 10 presents the indicators used to derive an ETI score for the estuary.

The physical and nutrient load susceptibility of Catlins Estuary has been determined as "HIGH" based on catchment estimates of nutrient loads derived from NIWAs CLUES model, estuary characteristics sourced from the Coastal Explorer database, and ecological value. The overall ETI score for the estuary is 0.63, a risk rating of "MODERATE" for eutrophic symptoms.

Table 10. Primary and supporting indicator values used to calculate an ETI score for Catlins Estuary, December 2016.

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
	Macroalgal GEZ/Estuary Area	% Gross Eutrophic Zone (GEZ)		2.3
	Macroalgal GEZ	Ha Gross Eutrophic Zone (GEZ)		14.9
Optional	Phytoplankton biomass	Chl- a (summer 90 pctl, mg/m^3)	water column	-
	Cyanobacteria (if issue identified)			not yet developed
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	-241mV
		% of estuary with Redox Potential <-150mV at 3cm		2.7
		Ha of estuary with Redox Potential <-150mV at 3cm		17.1
		% of estuary with apparent Redox Potential Depth <1cm		2.7
	Sediment Total Organic Carbon	Mean TOC (%) measured at 0-2cm depth in most impacted sediments and representing at least 10% of estuary area		0.27
	Sediment Total Nitrogen	Mean TN (mg/kg) measured at 0-2cm depth in most impacted sediments and representing at least 10% of estuary area		600
	Macroinvertebrates	Mean AMBI score measured at 0-15cm depth in most impacted sediments and representing at least 10% of estuary area		4.4
		% of estuary with AMBI >4.3		not yet developed
		TBI (if toxicity an issue)		not yet developed
Optional Indicators	Dissolved oxygen	7 day mean, 7 day mean minimum, 1 day minimum (mg/m^3)	water column	not yet developed
	TN and TP concentration	mg/l - 7 day mean, 7 day mean minimum, 1 day minimum		not yet developed
	Water Clarity	Secchi or black disc (m)		not yet developed
	Sediment Sulphur	Requires development	shallow inter-tidal	not yet developed
	Soft mud	% estuary area with soft mud (>25% mud content)		21%
		% mud content (mean of whole estuary area)		not yet developed
	Sedimentation Rate	Ratio of current annual mean relative to Natural Sed. Rate (NSR)		2.3
		% Estuary Area with Sedimentation Rate >5xNSR		baseline estab.
	SAV (Seagrass)	Extent (% of ENSC)	all habitat	-
		% change from measured baseline		baseline estab.
NZ ETI Score				**0.63**

5. SUMMARY AND CONCLUSIONS

Broad scale habitat mapping undertaken in December 2016, 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 131ha (21%) of the intertidal area, a risk indicator rating of HIGH, and had a mud content measured in representative areas of 27-46%, a supporting risk indicator rating of HIGH. 17.1ha (2.7%) 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 MODERATE. Soft muds were concentrated in the upper tidal reaches of Catlins Lake and the Owaka arm where mud settlement is thought to predominantly reflect salinity driven flocculation, reduced flow velocities, and sheltered deposition zones. Within the dominant firm sandy mud substrate of the estuary, habitat appeared to be healthy with limited accumulation of muds and good sediment oxygenation.

Eutrophication

The NZ ETI combines a range of broad and fine scale indicators (see Robertson et al. 2017 for fine scale results) to provide an overall assessment of eutrophic expression in the estuary, including primary productivity through macroalgal growth and phytoplankton, and supporting indicators of sediment muddiness, oxygenation, organic content, nutrients, macroinvertebrates, and the presence of gross eutrophic zones (a combined presence of dense macroalgal growth, muds and poor sediment oxygenation). The overall ETI score for the estuary in December 2016 was 0.63, a risk rating of MODERATE for eutrophic symptoms.

Gracilaria dominated nuisance macroalgal growths had resulted in the establishment of gross eutrophic zones in the Owaka arm and the upper tidal reaches of Catlins Lake. Such findings highlight that nutrient inputs to the estuary, while relatively low (N areal load 51mg.m^2.d), are sufficient to facilitate nuisance growths in deposition zones where they increase trapping of fine sediment, which in turn increases sediment nutrient concentrations fuelling further macroalgal growth. When excessive growths lead to oxygen depletion, anoxic processes release sediment bound nutrients and inhibit atmospheric denitrification processes greatly increasing the available pool of nutrients.

Habitat modification

Relatively little saltmarsh remains in the estuary 12.1ha (1.9%) and represents only a small fraction of once very extensive historical cover (estimated at over 300ha). Saltmarsh was dominated by rushland (57%) and herbfield (31%) located in relatively narrow strips along the estuary margins with the largest beds near Pounawea. The 200m terrestrial margin had also been highly modified with 71% pasture or unmaintained grassland (predominantly historically drained saltmarsh), 5% developed (residential/road/commercial), although 23% supported a densely vegetated buffer including remnant podocarp forest at Pounawea contiguous with estuary saltmarsh. The estuary supported large beds of high value seagrass (30.3ha, 4.9%) confined to lower estuary areas that have strong tidal flushing with relatively clear seawater. The seagrass beds appeared to be in good condition and not under any obvious stress from excessive sediment deposition or macroalgal smothering.

Comparison with 2008 and 2012 results

Only limited comparisons are possible with the 2008 and 2012 results due to grouping of key features (e.g. high value seagrass and nuisance macroalgae), the lack of discrimination between terrestrial and estuarine vegetation, and the very coarse previous mapping resolution.

The results do show potential improvements in the estuary from a decrease in the area of soft mud (273ha in 2008/12 to 131ha in 2016), but declines in saltmarsh (~30ha to 12ha) and a likely significant increase in nuisance macroalgae. Seagrass changes could not be determined from the existing data. Future monitoring will determine if these results reflect ongoing trends in broad scale features of the estuary.

The combined results place the estuary in a "MODERATE" state overall in relation to ecological health with fine sediment and eutrophication issues evident in the relatively sheltered Catlins Lake and Owaka arm, and significant historical modification and loss of estuary saltmarsh.

6. MONITORING RECOMMENDATIONS

Catlins Estuary has been identified by ORC as a priority for monitoring because it is a large estuary with high ecological and human use values that is situated in a developed catchment, and therefore vulnerable to excessive sedimentation and eutrophication. As a consequence, it is a key part of ORC's coastal monitoring programme being undertaken throughout the Otago region. Broad scale habitat mapping and the first year of baseline fine scale sampling have now been undertaken (December 2016).

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

The present report addresses the broad scale component of the long term programme. The recommendation for ongoing monitoring to meet this requirement for the Catlins Estuary is as follows:

Broad Scale Habitat Mapping

To characterise any issues of change in habitat (e.g. saltmarsh or seagrass area, soft mud extent), it is recommended that broad scale habitat mapping be undertaken at 10 yearly intervals (next scheduled for 2026) unless obvious changes are observed in the interim.

Because nuisance opportunistic macroalgae and gross eutrophic conditions appear to have established in the estuary only relatively recently, it is recommended that a strong baseline be established by undertaking an annual macroalgal survey (January/February) over the next three years in conjunction with scheduled fine scale sampling.

Fine Scale Monitoring

To complete the fine scale baseline in Catlins Estuary it is recommended that the remaining 3 consecutive years of annual summer (i.e. December-February) fine scale monitoring of intertidal sites (including sedimentation rate measures), be undertaken in summer 2017/18, 2018/19 and 2019/20 (preferably during a summer low flow period).

To fully characterise the potential for upper estuary stratification and eutrophication, it is recommended that water column monitoring of the upper to mid estuary be undertaken during a prolonged summer, low flow period in 2018. It is envisaged that this should include sampling of surface and bottom water at 5-6 sites in the main channels of the estuary (i.e. Catlins and Owaka Rivers).

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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.

Opportunistic Macroalgae. The presence of opportunistic macroalgae is a primary indicator of estuary eutrophication, and when combined with gross eutrophic conditions (combined high algal cover, soft mud and poor oxygenation) can cause significant adverse ecological impacts that are very difficult to reverse. Thresholds used to assess this indicator are derived from the OMBT (see Section 3 and Appendix 2), with results combined with those of other indicators to determine overall condition.

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

As a baseline measure of seagrass presence, a continuous index (the seagrass coefficient - SC) has been developed to rate seagrass condition based on the percentage cover of seagrass in defined categories using the following equation: ***SC=((0 x %seagrass cover <1%)+(0.5 x %cover 1-5%)+(2 x %cover 6-10%)+(3.5 x %cover 11-20%)+(6 x %cover 21-50%)+(9 x %cover 51-80%)+(12 x %cover >80%))/100.*** Because estuaries are likely to support variable natural seagrass extents, the SC rating is intended to highlight estuaries with low seagrass cover for further evaluation (i.e. estimate natural seagrass cover to determine current state), and to provide an estuary specific metric against which future change can be assessed. It is not intended that the SC be used to directly compare different estuaries. The “early warning trigger” for initiating management action is a trend of decreasing SC.

Saltmarsh. Saltmarshes have high biodiversity, are amongst the most productive habitats on earth, and have strong aesthetic appeal. They are sensitive to a wide range of pressures including land reclamation, margin development, flow regulation, sea level rise, grazing, wastewater contaminants, and weed invasion. Most NZ estuarine saltmarsh grows in the upper estuary margins above mean high water neap (MHWN) tide where vegetation stabilises fine sediment transported by tidal flows. Saltmarsh zonation is commonly evident, resulting from the combined influence of factors including salinity, inundation period, elevation, wave exposure, and sediment type. Highest saltmarsh diversity is generally present above mean high water spring (MHWS) tide where a variety of salt tolerant species grow including scrub, sedge, tussock, grass, reed, rush and herb fields. Between MHWS and MHWN, saltmarsh is commonly dominated by relatively low diversity rushland and herbfields. Below this, the MHWN to MSL range is commonly unvegetated or limited to either mangroves or *Spartina*, the latter being able to grow to MLWN. Further work is required to develop a comprehensive saltmarsh metric for NZ. As an interim measure, the % of the intertidal area comprising saltmarsh is used to indicate saltmarsh condition. Two supporting metrics are also proposed: i. % loss from Estimated Natural State Cover. This assumes that a reduction in natural state saltmarsh cover corresponds to a reduction in ecological services and habitat values. ii. % of available habitat supporting saltmarsh. This assumes that saltmarsh should be growing throughout the majority of the available saltmarsh habitat (tidal area above MHWN), and that where this does not occur, ecological services and habitat values are reduced. The interim risk ratings proposed for these ratings are Very Low=>80-100%, Low=>60-80%, Moderate=>40-60%, and High=<40%. The “early warning trigger” for initiating management action/further investigation is a trend of a decreasing saltmarsh area or saltmarsh growing over <80% of the available habitat.

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

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

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 6. 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, 6 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 which can also be increased by applying fine scale approaches estuary-wide if a very high degree of accuracy is considered important.

For the OMBT, a methodology for calculating a measure of the confidence of class (CofC), has been developed (Davey, 2009) that defines the specific accuracy of the measures undertaken. Called CAPTAIN ('Confidence And Precision Tool Aids aNalysis') it calculates CofC at three levels: i. metric, ii. survey (single sampling event), and iii. water body over the reporting period (potentially several surveys). The upper and lower 90% Confidence Intervals for the SE of the EQR are presented in this report.

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 worse case scenario.

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

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

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

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

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

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

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

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

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

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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. >1kg.m^{-2} wet weight causes significant harmful effects on biota (DETR 2001, Lowthion et al. 1985, Hull 1987, Wither 2003).
- **Thresholds for Entrained Algae.** Empirical studies testing a number of scales were undertaken on a number of impacted waters. Seriously impacted waters have a very high percentage (>75%) of the beds showing entrainment (Poor / Bad boundary). Entrainment was felt to be an early warning sign of potential eutrophication problems so a tight High /Good standard of 1% was selected (this allows for the odd change in a quadrat or error to be taken into account). Consequently the Good / Moderate boundary was set at 5% where (assuming sufficient quadrats were taken) it would be clear that entrainment and potential over wintering of macroalgae had started.

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. CATLINS ESTUARY MACROALGAL DATA

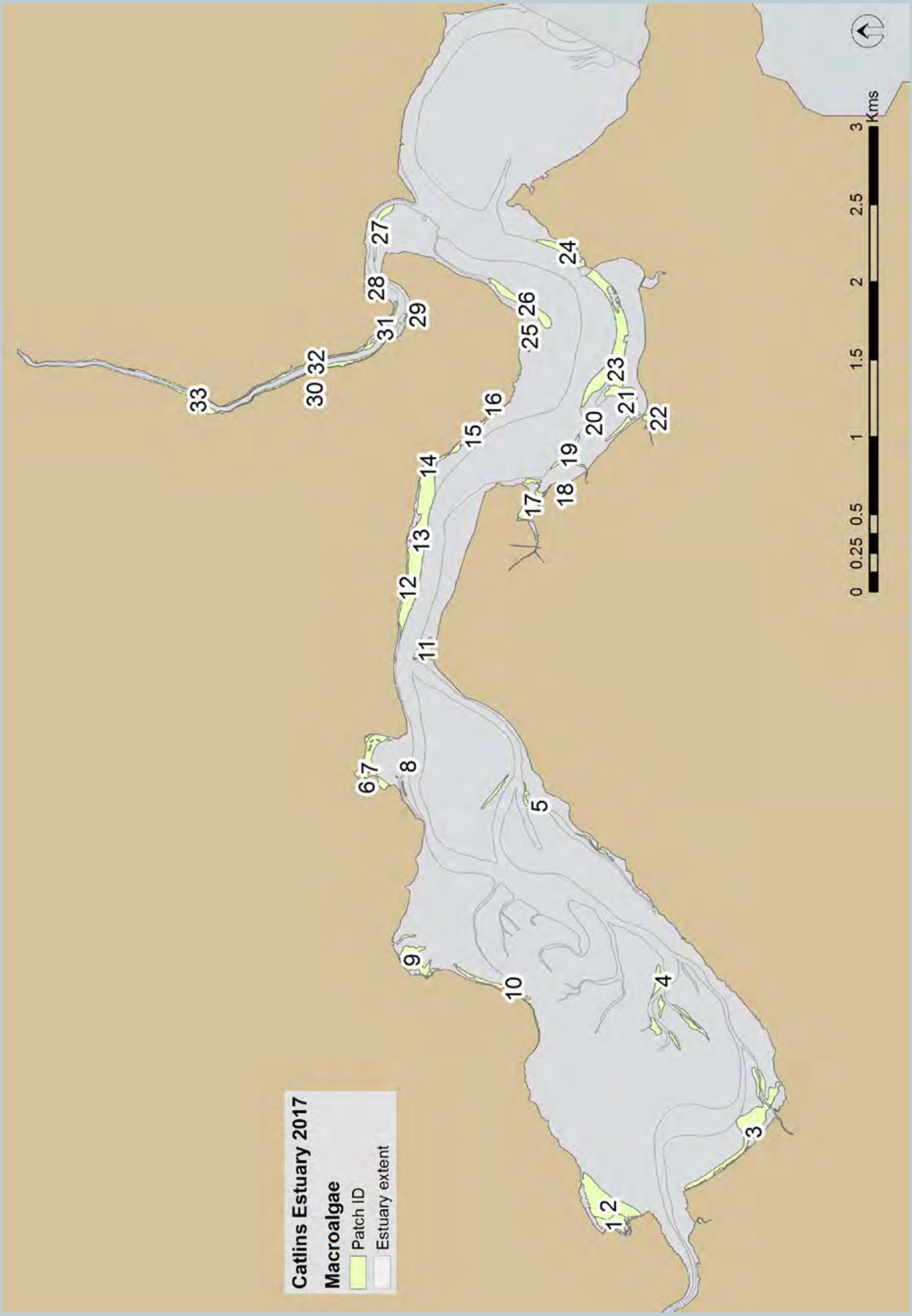

Figure A1. Location of macroalgal patches (>5% cover) used in assessing Catlins Estuary, Dec 2016.

APPENDIX 5. CATLINS ESTUARY MACROALGAL DATA

Macroalgal cover >15% used in calculating the OMBT EQR (see Figure A1 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	1.50	0	20	200	0	1	1	*Ulva lactucta Gracilaria chilensis*
2	4.73	0	10	100	0	1	1	*Ulva lactucta*
3	5.67	0	90	680	1	0	1	*Gracilaria chilensis*
4	2.41	0	80	400	0	1	0	*Gracilaria chilensis*
5	1.20	0	90	450	0	1	0	*Gracilaria chilensis*
6	0.39	0	90	450	1	0	1	*Gracilaria chilensis Ulva lactucta*
7	2.32	0	10	150	0	1	0	*Ulva lactucta Gracilaria chilensis*
8	0.16	0	90	250	0	1	0	*Gracilaria chilensis*
9	2.28	0	100	800	1	0	1	*Gracilaria chilensis*
10	1.23	0	100	950	1	0	1	*Gracilaria chilensis Ulva lactucta*
11	0.54	0	100	1200	0	0	0	*Gracilaria chilensis Ulva lactucta*
12	0.45	0	15	100	0	1	0	*Ulva lactucta*
13	8.61	0	15	100	0	1	0	*Ulva lactucta Gracilaria chilensis*
14	0.19	0	75	300	0	1	0	*Ulva lactucta Gracilaria chilensis*
15	0.91	0	15	200	0	1	0	*Ulva lactucta Gracilaria chilensis*
16	0.03	0	90	500	0	1	0	*Ulva lactucta Gracilaria chilensis*
17	1.57	0	15	200	0	1	0	*Ulva lactucta Gracilaria chilensis*
18	0.10	0	100	800	0	1	0	*Ulva lactucta Gracilaria chilensis*
19	0.92	0	100	950	0	1	0	*Ulva lactucta Gracilaria chilensis*
20	0.61	0	80	300	0	1	0	*Ulva lactucta*
21	1.79	0	90	500	0	1	0	*Ulva lactucta U. intestinalis G. chilensis*
22	0.44	0	70	700	1	0	1	*Gracilaria chilensis*
23	6.82	0	70	850	0	1	0	*Ulva lactucta U. intestinalis G. chilensis*
24	1.27	0	90	500	0	1	0	*Ulva lactucta U. intestinalis G. chilensis*
25	0.49	0	70	300	0	1	0	*Ulva lactucta*
26	2.07	0	20	200	0	1	0	*Ulva lactucta*
27	1.08	0	90	800	0	1	0	*Ulva lactucta Gracilaria chilensis*
28	0.36	0	100	1000	1	0	1	*Ulva lactucta Gracilaria chilensis*
29	0.08	0	100	300	1	0	1	*Gracilaria chilensis*
30	1.05	0	100	950	1	0	1	*Gracilaria chilensis*
31	0.53	0	100	500	1	0	0	*Gracilaria chilensis*
32	1.16	0	100	950	1	0	1	*Gracilaria chilensis*
33	1.19	0	100	950	1	0	1	*Gracilaria chilensis*

APPENDIX 6. DETAILS OF ANALYTICAL METHODS

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

Grain size results from representative sediments, Catlins Estuary, 2016.

Broad Scale Classification	Site #	% mud	% sand	% gravel	NZTM East	NZTM North
Firm Muddy Sand	6	3.1	96.9	< 0.1	1346637	4847618
Firm Muddy Sand	4	10.1	89.9	< 0.1	1342061	4847820
Soft Muddy Sand	2	18.4	81.6	< 0.1	1341988	4848007
Soft Muddy Sand	3	21.8	78.2	< 0.1	1342039	4847899
Very Soft Mud	5	27.2	69.9	2.9	1345752	4848880
Very Soft Mud	1	46.7	53.2	< 0.1	1341907	4848111