Macroalgae Monitoring of Catlins/Pounawea Estuary 2021/22

Prepared for

Otago Regional Council

June 2022

Salt Ecology
Report 089

Cover photo: Entrained nuisance macroalgae growing on mudflats, Catlins Lake/Kuramea, December 2021

RECOMMENDED CITATION

Stevens LM, Roberts KL. 2022. Macroalgae Monitoring of Catlins/Pounawea Estuary 2021/22. Salt Ecology Report 089, prepared for Otago Regional Council, June 2022. 28p.

For the People
Mō ngā tāngata

Macroalgae Monitoring of Catlins River/Pounawea Estuary 2021/22

Prepared by

Leigh Stevens and Keryn Roberts

for

Otago Regional Council

June 2022

leigh@saltecology.co.nz, +64 (0)21 417 936

www.saltecology.co.nz

For the environment
Mō te taiao

GLOSSARY

aRPD	Apparent Redox Potential Discontinuity
EQR	Ecological Quality Rating
ETI	Estuary Trophic Index
HEC	High Enrichment Condition
NEMP	National Estuary Monitoring Protocol
OMBT	Opportunistic Macroalgal Blooming Tool
ORC	Otago Regional Council
SIDE	Shallow, intertidally dominated estuary
SOE	State of Environment (monitoring)

ACKNOWLEDGEMENTS

Many thanks to Sam Thomas (ORC) for reviewing the draft report. We are also grateful to Thomas Scott-Simmonds, Barrie Forrest and Bryn Forrest for field assistance. The tools used to produce GIS summaries and maps were developed by Megan Southwick (Salt Ecology). ORC provided the aerial imagery used in the mapping.

TABLE OF CONTENTS

FIGURES

TABLES

SUMMARY

Catlins River/Pounawea Estuary is a medium sized (830ha) estuarine system located ~115km south of Dunedin on New Zealand's south coast. The estuary is a shallow, intertidally dominated, tidal lagoon type estuary (SIDE) monitored by Otago Regional Council (ORC) as part of its State of the Environment programme using methodologies described in New Zealand's National Estuary Monitoring Protocol (NEMP). This report describes a survey conducted in December 2021 which assessed macroalgal cover, biomass and entrainment.

KEY FINDINGS

- 80% of the 636ha intertidal area had <1% cover of macroalgae, indicating the majority of the estuary was not experiencing macroalgal problems.
- Opportunistic macroalgae (*Agarophyton* spp.) were present in dense beds (>50% cover) in the sheltered upper margins of Catlins Lake/Kuramea (see photo), the Ōwaka arm, and in several small embayments on the southern side of the lower estuary southeast of Hinahina. Nuisance macroalgae (>50%) covered 101ha (17.2%) of the intertidal area.
- The macroalgal Ecological Quality Rating (EQR), measuring the combined estuary-wide influence of macroalgal cover, biomass and entrainment, was 0.393, which equates to a condition rating of 'Poor'.
- 61.6ha (9.7% of the intertidal area) was classified as having High Enrichment Conditions (HECs), e.g. >50% macroalgal cover entrained in poorly oxygenated sediments with a high mud content and high organic enrichment. The largest areas of HEC were near Catlins River mouth, in the lower Ōwaka arm, and in small embayments with restricted tidal flushing near Hinahina.
- Localised areas of severe eutrophication (very soft anoxic mud with a strong rotten egg odour) were present in the lower Ōwaka arm and in the west of Catlins Lake/Kuramea.

Broad scale indicator	Unit	2016	2021
Macroalgae (OMBT)[1]	EQR	0.620	0.393
HEC[2]	Ha	14.9	61.6
HEC[2]	% of estuary	2.3	9.7

[1] OMBT = Opportunistic Macroalgal Blooming Tool
[2] High Enrichment Conditions
Condition rating colour key:

Very Good	Good	Fair	Poor

Overall, the December 2021 survey found eutrophication had increased significantly since December 2016 (see table), particularly along the western side of Catlins Lake/Kuramea where there was widespread sediment degradation. Localised areas of macroalgal dieback suggest sediment conditions have reached a state so poor that macroalgae can longer survive.

The expanded presence of entrained macroalgal growths since 2016, and the extensive presence of eutrophic symptoms including patches of extreme sediment anoxia, serve as clear indicators that the estuary's capacity to assimilate nutrients is being exceeded. These results are consistent with modelled nutrient loads to the estuary. Unless nutrient inputs to the estuary are reduced it is expected that the estuary will continue to express symptoms of eutrophication and potentially degrade further.

RECOMMENDATIONS

- Undertake annual monitoring during summer to track changes in nuisance macroalgae.
- Continue with planned work to determine limits on nutrient and sediment mass loads that would be expected to prevent further degradation and, where possible, mitigate current adverse impacts.
- Determine catchment nutrient and sediment sources as part of the mass load assessment and evaluate whether there are any effective and feasible management practices that could be undertaken to achieve ORC's desired condition for the estuary.

1. INTRODUCTION

1.1 BACKGROUND

Estuary monitoring is undertaken by most councils in New Zealand as part of their State of the Environment (SOE) programmes. Otago Regional Council (ORC) has undertaken monitoring of selected estuaries in the region since 2005 based on the methods outlined in New Zealand's National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002a-c), or variations of that approach.

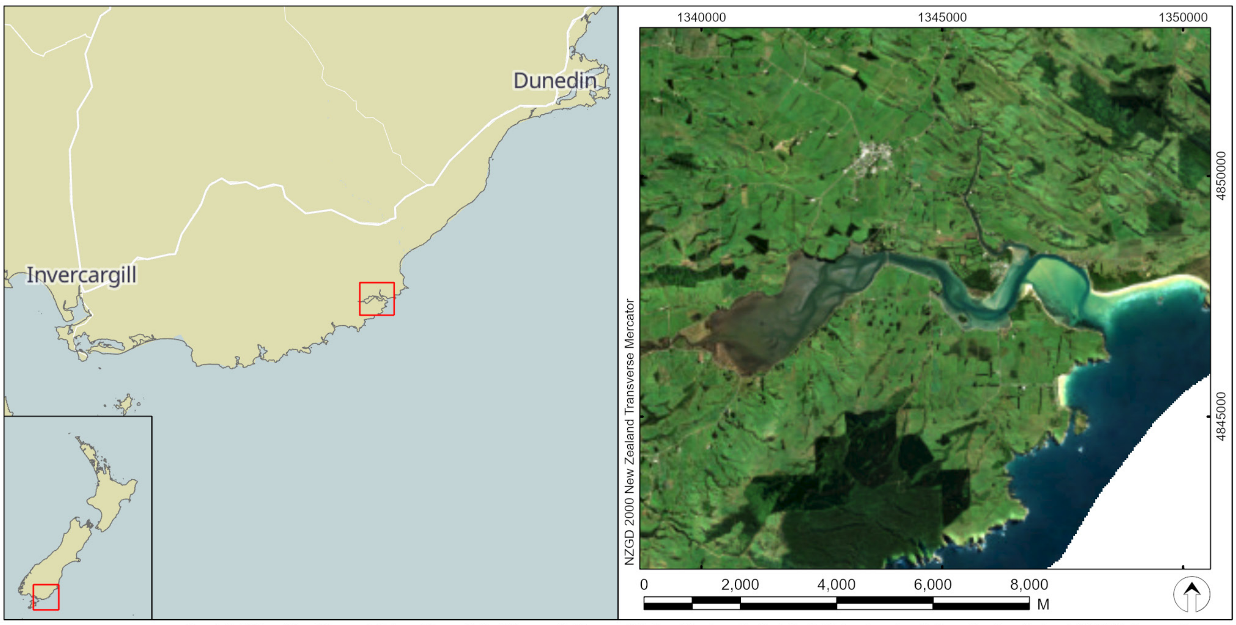
NEMP monitoring is primarily designed to detect and understand changes in estuaries over time and determine the effect of catchment influences, especially those contributing to the input of nutrients and muddy sediments. Excessive nutrient and fine sediment inputs are a primary driver of estuary eutrophication symptoms such as prolific macroalgal (seaweed) growth, and poor sediment condition.

Although macroalgae is an important feature of estuaries that contributes to their high productivity and biodiversity, when high nutrient inputs combine with suitable growing conditions, nuisance blooms of rapidly-growing species can occur (Table 1). These are typically referred to as 'opportunistic' species, of which the most significant in Otago are the red seaweed *Agarophyton* spp. (previously known as *Gracilaria* spp.) and the bright green *Ulva* spp. (commonly called 'sea lettuce').

At nuisance levels, muddy sediments and macroalgal growths can smother and deprive ecologically valuable seagrass (*Zostera muelleri*, see Table 1) of light, causing its eventual decline. Decaying macroalgae can also accumulate on shorelines causing localised depletion of sediment oxygen, and nuisance odours. When high macroalgal cover is associated with soft, muddy sediments, conditions for animal life in the sediments are generally very poor due to elevated organic matter, depleted oxygen and an accumulation of toxic sulphides.

Catlins/Pounawea Estuary (Fig. 1), the study site, is one of the key estuaries in Otago's SOE programme and has been previously surveyed in 2008, 2012 and 2016. No growths of the nuisance macroalgae *Agarophyton* spp. were recorded in 2008 (Stewart & Bywater 2009) and only two moderate patches of *Ulva* spp. were recorded in the Ōwaka arm in 2012 (Stewart 2012). In 2016, the estuary had significantly deteriorated with areas of entrained macroalgae recorded in Catlins Lake/Kuramea (upper estuary), the mid estuary and in the Ōwaka arm (Stevens & Robertson 2017). In 2016, 14.9ha or 2.3% of the intertidal area was classified as eutrophic (high macroalgae cover, poor sediment oxygenation and mud-dominated sediments; Stevens & Robertson 2017).

The current report describes the methods and results of the most recent macroalgal mapping undertaken in Catlins/Pounawea Estuary over two tides on 1 December 2021. The primary purpose of the current survey was to characterise the presence and extent of nuisance macroalgae. Results are discussed in terms of current state and trends in estuary health, and recommendations for future monitoring and assessment are made.



Map data © OpenStreetMap contributors, Microsoft, Esri Community Maps contributors, Map layer by Esri, Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors, Esri, HERE, Garmin, FAO, NOAA, USGS

Fig. 1. Location of Catlins/Pounawea Estuary, Otago.

1.2 OVERVIEW OF CATLINS/POUNAWEA ESTUARY

Background information on Catlins/Pounawea Estuary has been presented in previous reports (Stewart & Bywater 2009, Stewart 2012, Stevens & Robertson 2017). This information has been summarised and paraphrased here.

Catlins/Pounawea 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 (Fig. 1). The estuary is fed by two rivers, the Catlins River/ Pounawea River (mean flow ~3.7 m^3/s) and the slightly smaller Ōwaka River (mean flow 3.1m^3/s; source NIWA CLUES 10.3, 2016).

The estuary falls into two main areas, the eastern basin around Pounawea township 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 (Kuramea), which is relatively shallow with more restricted flushing.

The Catlins/Pounawea catchment is ~415km^2 with land cover dominated by high producing grassland (61%), indigenous forest (20%), and exotic forest (5%; Stevens & Robertson 2017). On high producing exotic grassland, sheep and beef grazing represents the majority of recorded land use and borders the majority of the estuary, with dairy, deer and forestry being less common.

A large barrier spit is present 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 township, a remnant and reminder that the main industry of the Catlins from 1870 to 1970 was logging.

A large wetland is located at the western head of the estuary (Catlins Lake/Kuramea) 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 (Otago Regional Plan: Coast).

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 salt marsh (1.5% of the estuary), and seagrass (3.5% of the estuary). Historically there has been a significant loss (>300ha) of salt marsh since c.1850 as a consequence of drainage and reclamation with much of the natural vegetated margin now developed for grazing.

Macroalgae in Catlins Lake/Kuramea (upper estuary)

Table 1. Overview of the ecological significance of seagrass and opportunistic macroalgae in estuaries.

Habitat	Description
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. Although tolerant of a wide range of conditions, seagrass is vulnerable to fine sediments in the water column (reducing light), sediment smothering (burial), excessive nutrients (primarily secondary impacts from macroalgal smothering), and sediment quality (e.g., low oxygen).
Opportunistic macroalgae	Opportunistic macroalgae are a primary symptom of estuary eutrophication (nutrient enrichment). 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 that adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and salt marsh.

2. METHODS

2.1 OVERVIEW OF MAPPING

Mapping was undertaken according to NEMP and New Zealand Estuary Trophic Index (ETI) methods, as used previously to delineate the spatial extent of macroalgae (Robertson et al. 2002a-c; Robertson et al. 2016a-b). This procedure combined aerial photography, detailed ground truthing, and digital mapping using Geographic Information System (GIS) technology.

In 2021, 1:3000 colour aerial imagery captured between 12 January and 5 February 2021 was supplied by ORC. During field ground-truthing, macroalgae areas were drawn onto laminated aerial imagery, and percent cover and biomass were measured or estimated (as described below). The macroalgae features were subsequently digitised into ArcMap 10.6 shapefiles using a Wacom Cintiq21UX drawing tablet and combined with field measurements and georeferenced photographs. From this information, maps were produced showing the spatial extent and density of macroalgae.

For mapping purposes, an estuary is defined as a partly enclosed body of water, where freshwater inputs (i.e. rivers, streams) mix with seawater. The estuary entrance (i.e seaward boundary) was defined as a straight line between the seaward-most points of land that enclose the estuary, and the upper estuary boundary (i.e. riverine boundary) was based on the estimated upper extent of saline intrusion (i.e. where ocean derived salts during average annual low flow are <0.5ppt). For further detail see FGDC (2012).

Complete cover of *Agarophyton* spp.

2.2 MACROALGAE ASSESSMENT

The United Kingdom Water Framework Directive (WFD-UKTAG 2014) Opportunistic Macroalgal Blooming Tool (OMBT) approach was a key part of the macroalgal assessment. The OMBT, described in detail in Appendix 1, is a five-part multi-metric index that provides a comprehensive measure of the combined influence of macroalgal growth and distribution in an estuary. It produces an overall Ecological Quality Rating (EQR) ranging from 0 (major disturbance) to 1 (minimally disturbed) and rates estuarine condition in relation to macroalgal status within five overall quality status bands (bad, poor, good, moderate, high). The individual metrics that are used to calculate the EQR include:

- *Percentage cover of opportunistic macroalgae*: The spatial extent and surface cover of algae present in intertidal soft sediment habitat in an estuary provides an early warning of potential eutrophication issues.
- *Macroalgal biomass:* Biomass provides a direct measure of macroalgal growth (wet weight biomass). Measurements and estimates of mean biomass are made within areas affected by macroalgal growth, as well as across the total estuary intertidal area.
- *Extent of algal entrainment into the sediment matrix*: Macroalgae is defined as entrained when growing in stable beds or with thalli or rhizoids ('roots') growing within the sediment matrix, which indicates that persistent macroalgal growths have established.

If an estuary supports <5% total opportunistic macroalgal cover within the Available Intertidal Habitat (AIH), then the overall quality status using the OMBT method is reported as 'high' with no further sampling required.

Using this approach in Catlins/Pounawea Estuary, opportunistic macroalgae patches were mapped during field ground truthing, using a 6-category rating scale (modified from FGDC 2012) as a guide to describe percentage cover (Fig. 2). Within these percent cover categories, representative patches of comparable macroalgal growth were identified and the biomass and the extent of macroalgal entrainment were measured.

Biomass was measured by collecting algae growing on the surface of the sediment from within a defined area (e.g. 25x25cm quadrat) and placing it in a sieve bag. The algal material was then rinsed to remove sediment. Any non-algal material including stones, shells and large invertebrate fauna (e.g. crabs, shellfish) were also removed. Remaining algae were then hand squeezed until water stopped running, and the wet weight was recorded to the nearest 10g using a 1kg Pesola light-line spring scale.

When sufficient representative patches had been measured to enable biomass to be reliably estimated, biomass estimates were made following the OMBT method.

Using the macroalgal cover and biomass data, macroalgal OMBT scores were calculated using the WFD-UKTAG Excel template. The scores were then categorised on a five-point scale, using the biomass thresholds described in Table A3 of Appendix 1. These thresholds reflect OMBT values revised for use in New Zealand (Plew et al. 2020).

In addition to macroalgal proliferation, a subjective indication of the trophic status (i.e. extent of excessive organic or nutrient enrichment) of soft sediment areas was provided by the depth of visible transition between oxygenated surface sediments (typically brown in colour) and deeper less oxygenated sediments (typically dark grey or black in colour). This transition is referred to as the apparent Redox Potential Discontinuity (aRPD) depth, and provides an easily measured, time-integrated, and relatively stable indicator of sediment enrichment and oxygenation conditions.

Hence, as a supporting indicator, aRPD was assessed in representative areas by digging into the underlying sediment with a hand trowel to determine whether there were any significant areas where sediment oxygenation was depleted close to the surface. Sediments were considered to have poor oxygenation if the aRPD was consistently <10mm deep and showed clear signs of organic enrichment indicated by a distinct colour change to grey or black in the sediments. Highly enriched sediments with a shallow aRPD also typically smell strongly of hydrogen sulphide (i.e. a rotten egg smell). As significant sampling effort is required to map sub-surface conditions accurately, the approach was intended as a preliminary screening tool to determine the need for additional sampling effort.

Sampling macroalgal biomass in Catlins/Pounawea Estuary

Weighing macroalgae in Catlins/Pounawea Estuary

2.3 DATA RECORDING AND QA/QC

Broad scale mapping provides a rapid overview of estuary macroalgae condition. The ability to correctly identify and map features is primarily determined by the resolution of available aerial imagery, the extent of ground-truthing undertaken to validate features visible on photographs, and the experience of those undertaking the mapping. In most instances features with readily defined edges can be mapped at a scale of

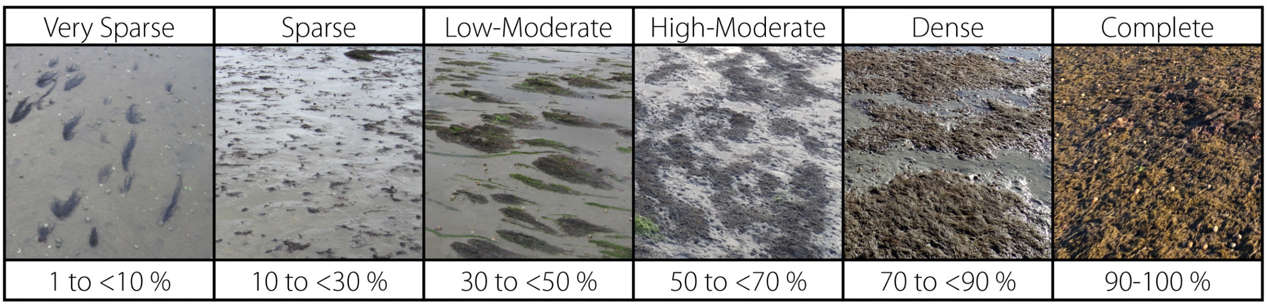


Fig. 2. Visual rating scale for percentage cover estimates. Modified from FGDC (2012).

~1:2000 to within 1-2m of their boundaries. The greatest scope for error occurs where boundaries are not readily visible on photographs, e.g. sparse macroalgal beds. Extensive mapping experience has shown that transitional boundaries can be mapped to within ±10m where they have been thoroughly ground-truthed, but when relying on photographs alone, accuracy is unlikely to be better than ±20-50m, and generally limited to vegetation features with a percent cover >50%.

As well as annotation of field information onto aerial photographs during the field ground truthing, point estimate macroalgae data (i.e. biomass, cover, entrainment), along with supporting measures of sediment aRPD, texture and sediment type were recorded in electronic templates custom-built using Fulcrum app software (www.fulcrumapp.com). Pre-specified constraints on data entry (e.g. with respect to data type, minimum or maximum values) ensured that the risk of erroneous data recording was minimised. Each sampling record created in Fulcrum generated a GPS position, which was exported to ArcMAP.

In December 2021, following digitising of habitat features, in-house scripting tools were used to check for duplicated or overlapping GIS polygons, validate typology (field codes) and calculate areas and percentages used in summary tables.

2.4 MACROALGAE CONDITION AND ASSESSMENT OF TEMPORAL CHANGE

In addition to the authors' interpretation of the data, results are assessed within the context of established or developing estuarine health metrics ('condition ratings'), drawing on approaches from New Zealand and overseas (Table 2). These metrics assign different indicators to one of four colour-coded 'health status' bands, as shown in Table 2. The condition ratings are primarily sourced from the ETI (Robertson et al. 2016b). Additional supporting information on the ratings is provided in Appendix 2. Note that the condition rating descriptors used in the four-point rating scale in the ETI (i.e. between 'very good' and 'poor') differ from the five-point scale for macroalgal OMBT EQR scores described above and in Appendix 1 (i.e. which range from 'high' to 'bad').

As an integrated measure of the combined presence of indicators which may result in adverse ecological outcomes, the occurrence of High Enrichment Conditions (HEC) was evaluated. For our purposes, HECs are defined as mud-dominated sediments (≥50% mud content, based on expert judgement) with >50% macroalgal cover and with macroalgae entrained and growing as stable beds within the sediment. These areas typically also have an aRPD depth shallower than 10mm due to sediment anoxia. Where areas become so enriched that macroalgae can no longer survive, e.g. areas of sulfidic and anoxic soft muds, they are included in the assessment of HECs despite not meeting the >50% macroalgal cover criterion because they represent severe levels of enrichment.

As many of the scoring categories in Table 2 are still provisional, they should be regarded only as a general guide to assist with interpretation of estuary health status. Accordingly, it is major spatio-temporal changes in the rating categories that are of most interest, rather than their subjective condition descriptors (e.g. 'poor' health status should be regarded more as a relative rather than absolute rating).

Seagrass in the well-flushed lower Catlins/Pounawea Estuary

Table 2. Indicators and condition rating criteria used to assess results in the current report.

Indicator[1]	Unit	Very Good	Good	Fair	Poor
Broad scale indicators					
Macroalgae (OMBT)	Ecological Quality Rating (EQR)	≥ 0.8 to 1.0	≥ 0.6 to < 0.8	≥ 0.4 to < 0.6	< 0.4
High Enrichment Conditions	ha	< 0.5ha	≥ 0.5 to 5ha	≥ 5 to 20ha	≥ 20ha
High Enrichment Conditions	% of estuary	< 1%	≥ 1 to 5%	≥ 5 to 10%	≥ 10%
Sediment quality					
aRPD depth	mm	≥ 50	20 to < 50	10 to < 20	< 10

[1] General indicator thresholds derived from a New Zealand Estuary Tropic Index (Robertson et al. 2016b), with adjustments for aRPD (FDGC 2012). See text and Appendix 2 for further explanation of the origin or derivation of the different metrics.

3. RESULTS

A summary of the December 2021 survey results is provided below, with raw data in Appendix 3. Supporting GIS files (supplied to ORC as a separate electronic output) provide a more detailed dataset designed for easy interrogation and to address specific monitoring and management questions.

3.1 OPPORTUNISTIC MACROALGAE

Table 3 summarises macroalgal percentage cover and biomass classes for Catlins/Pounawea Estuary in December 2021, with the mapped cover and biomass shown in Fig. 3 and Fig. 4, respectively. Macroalgal sampling stations and raw wet weights for biomass measurements are provided in Appendix 3.

Assessing macroalgal cover in Catlins Lake/Kuramea

Table 3. Summary of intertidal macroalgal cover (A) and biomass (B), Catlins/Pounawea Estuary December 2021.

A. Cover*

Percent cover category	Ha	%
Absent or trace	508.6	80.0
Very sparse (1 to <10%)	3.7	0.6
Sparse (10 to <30%)	13.6	2.1
Low-Moderate (30 to <50%)	9.1	1.4
High-Moderate (50 to <70%)	26.7	4.2
Dense (70 to >90%)	11.7	1.8
Complete (>90%)	62.5	9.8
Total	635.9	100

B. Biomass**

Biomass category (g/m^2)	Ha	%
Trace (<1)	508.6	80.0
Very low (1 - 100)	3.9	0.6
Low (101 - 200)	13.8	2.2
Moderate (201 - 500)	12.6	2.0
High (501 - 1450)	25.7	4.0
Very high (>1450)	71.4	11.2
Total	635.9	100

* Cover categories are shown in Fig. 2.

** Thresholds for biomass categories are based on Plew et al. (2020) as per Table A3 of Appendix 1.

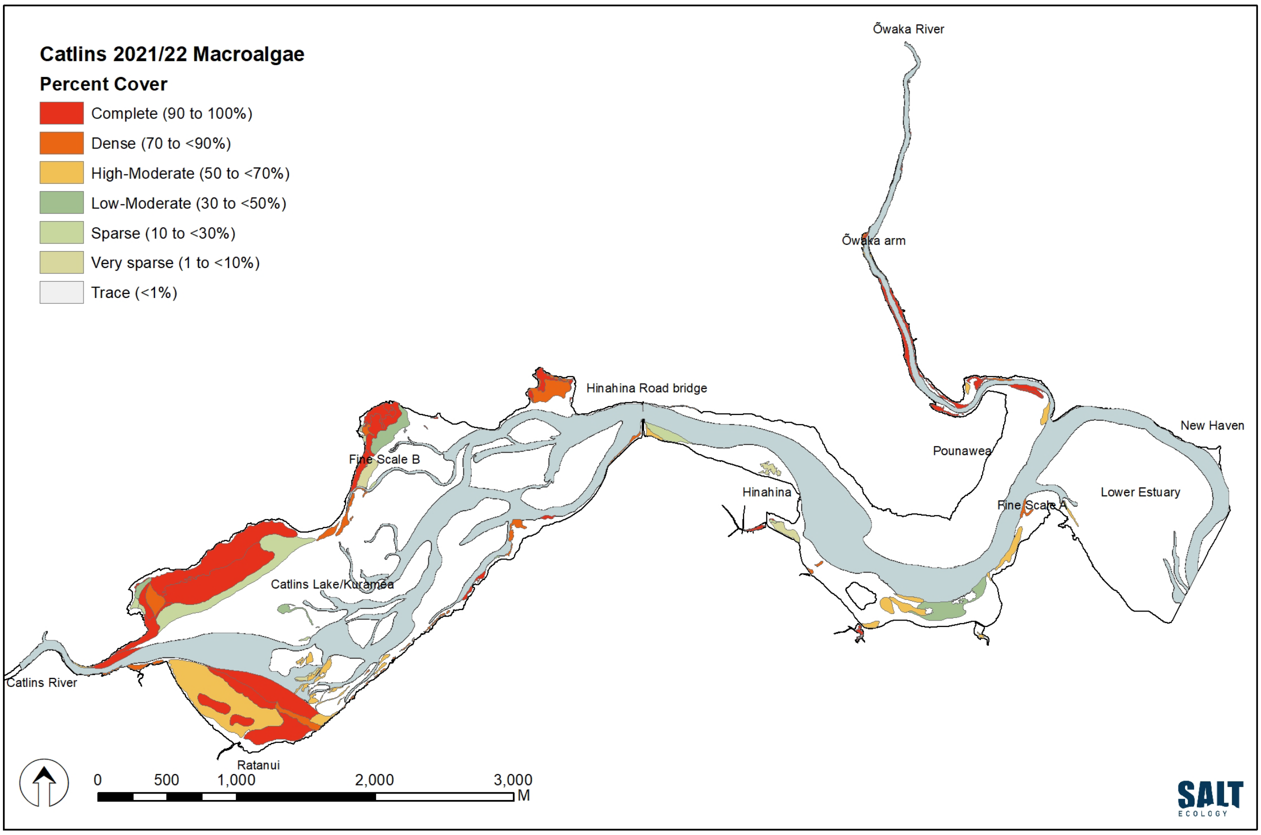


Fig. 3. Distribution and percentage cover classes of macroalgae, Catlins/Pounawea Estuary, December 2021.

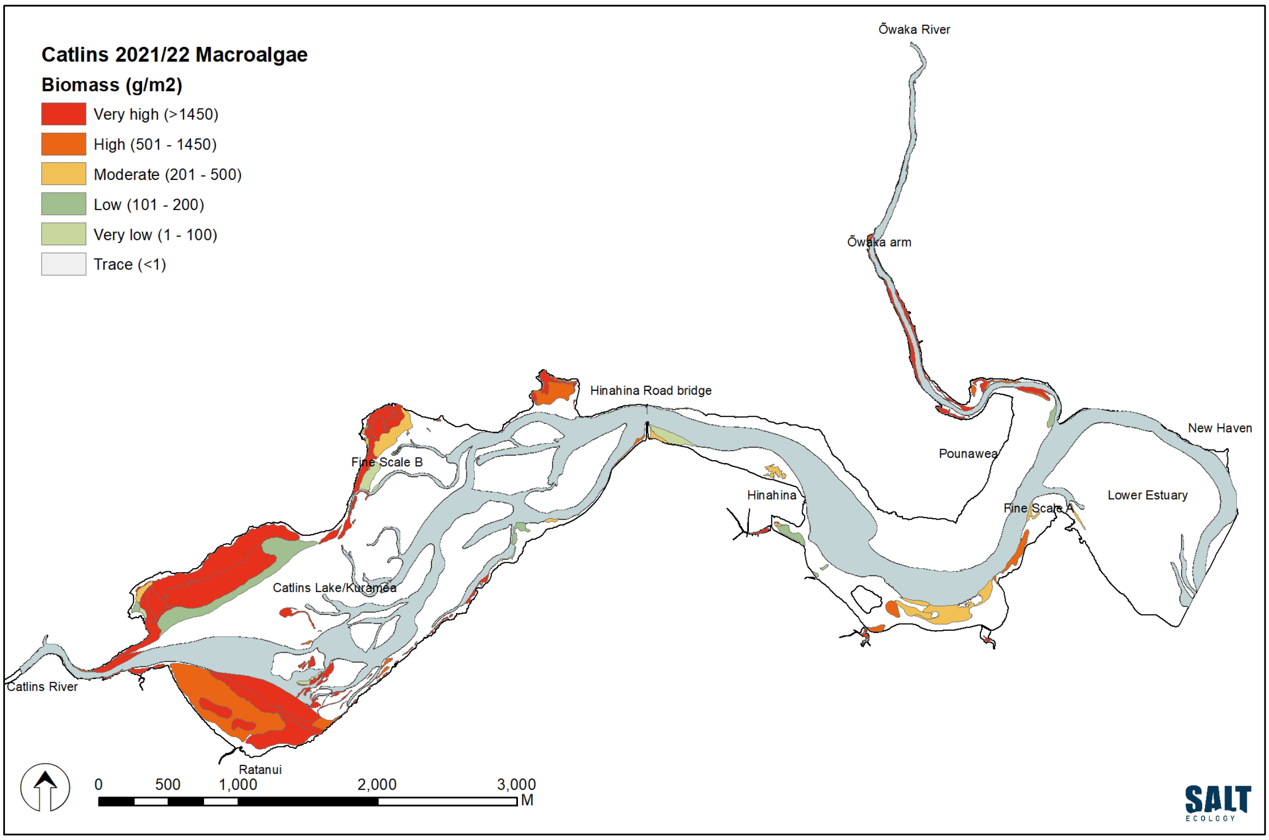


Fig. 4. Distribution and biomass (wet weight; g/m^2) classes of macroalgae, Catlins/Pounawea Estuary, December 2021.

Key results were as follows:

- Across 80% of the 636ha intertidal area, macroalgae cover was classified as absent or trace (i.e. <1% cover), indicating the majority of the estuary was not experiencing macroalgal issues (see photo; Fig. 3).
- In the sheltered upper margins of Catlins Lake/Kuramea, the Ōwaka arm, and in several small embayments on the southern side of the lower estuary (southeast of Hinahina), there were extensive dense beds (>50% cover) of *Agarophyton* spp. deeply entrained in muddy sediment (Fig. 3).
- Dense *Agarophyton* spp. beds (>50% cover) in Catlins Lake/Kuramea had wet weight biomass ranging from 0.8 to 9.97kg/m^2 (mean 4.17kg/m^2) and consisted of 5-10cm thick beds of *Agarophyton* spp. (Fig. 4). The maximum biomass recorded was ~6 times higher than the 'very high' threshold of 1.45 kg/m^2 (see photos on following page).
- Dense *Agarophyton* spp. beds (>50% cover) in the Ōwaka arm had wet weight biomass ranging from 0.8 to 6.0kg/m^2 (mean 2.6kg/m^2) and consisted of thick *Agarophyton* spp. beds (5-10cm high) deeply entrained in muddy sediment in the lower reaches of the river, and a dense cover of *Ulva* spp. (not entrained) in the upper reaches (Fig. 4). The maximum biomass recorded was ~4 times higher than the 'very high' threshold of 1.45 kg/m^2 (see photos on following page).
- Localised areas of severe eutrophication (very soft anoxic mud with a strong rotten egg odour) were present in the Ōwaka arm, but particularly in Catlins Lake/Kuramea. These included *Agarophyton* spp. beds that had died and were rotting, resulting in a reduction in surface macroalgal cover and biomass. Unfavourable sediment conditions appear to be causing a decrease in macroalgal cover in these eutrophic areas.
- The green seaweed *Ulva* spp. was present in the well flushed lower estuary, most notably between Hinihina and Fine Scale Site A, where it was generally growing on firm sands or hard substrates (e.g. cobbles or bedrock; Fig. 3).

The well-flushed central Catlins Lake/Kuramea

High biomass *Ulva* on *Agarophyton* spp. (top) and rotting beds of *Agarophyton* spp. (bottom) near Ratanui in Catlins Lake/Kuramea

High biomass *Ulva* spp. (top) and *Agarophyton* spp. (bottom) in the Ōwaka arm

High biomass *Agarophyton* spp. (top) and rotting beds of *Agarophyton* spp. (bottom) in near fine scale Site B

High cover of *Ulva* spp. on well flushed tidal flats (top) and *Agarophyton* spp. in an embayment in the lower estuary (bottom)

In December 2021, the EQR, calculated using the OMBT method, was 0.393, which equates to a condition rating of 'Poor' (Table 4). Although the percent cover in the Available Intertidal Habitat (AIH) was rated 'Good', reflecting the absence of macroalgae over ~80% of the estuary, when present macroalgae were resulting in degraded conditions over a large area (97ha with biomass rated as high or very high – Table 3).

Compared to macroalgal mapping undertaken in 2016 (Table 5, Appendix 5), the estuary has degraded significantly over the past 5 years. The Affected Area has increased from 54ha to 127ha, mean biomass has increased from 478g/m^2 to 1564g/m^2, and the EQR rating (Table 2) has shifted from 'Good' (0.620) to 'Poor' (0.393). Of particular concern was the large increase in macroalgal cover and biomass either side of the Catlins River mouth, and the widespread presence of degraded sediment conditions (shallow aRPD, high mud content, and high organic enrichment).

In places, sulphur oxidising bacteria were observed growing among macroalgae and on surface sediments, with localised areas of macroalgal dieback suggesting sediment conditions have reached a state so poor that macroalgae are no longer able to survive (see photos below).

Sulphur oxidising bacteria among macroalgae (left) and macroalgae dieback (right)

Table 4. Summary of 2021 OMBT input metrics and overall macroalgal Ecological Quality Rating (EQR), and corresponding OMBT Environmental Quality Class descriptors (see Appendix 1). The condition rating for the survey EQR score is based on Table 2.

December 2021 Metric	Face value	FEDS	Environmental Quality Class
%cover in AIH	14.6	0.608	Good
Average biomass (g/m^2) in AIH	318.8	0.521	Moderate
Average biomass (g/m^2) in AA	1564.3	0.198	Bad
%entrained in AA	38.9	0.274	Poor
Worst of AA (ha) and AA (% of AIH)		0.364	Poor
AA (ha)	127.4	0.364	Poor
AA (% of AIH)	20.4	0.569	Moderate
Survey EQR		**0.393**	'Poor'*

Notes: AA=Affected Area, AIH=Available Intertidal Habitat, FEDS=Final Equidistant Score, EQR=Ecological Quality Rating. *Table 2.

Table 5. Summary of 2016 OMBT input metrics and overall macroalgal Ecological Quality Rating (EQR), and corresponding OMBT Environmental Quality Class descriptors (see Appendix 1). The condition rating for the survey EQR score is based on Table 2. See Appendix 5 for maps of %cover and biomass.

December 2016 Metric	Face value	FEDS	Environmental Quality Class
%cover in AIH	5.0	0.802	High
Average biomass (g/m^2) in AIH	41.4	0.917	High
Average biomass (g/m^2) in AA	478.1	0.415	Moderate
%entrained in AA	26.6	0.356	Poor
Worst of AA (ha) and AA (% of AIH)		0.583	Moderate
AA (ha)	54.1	0.583	Moderate
AA (% of AIH)	8.7	0.726	Good
Survey EQR		**0.620**	'Good'*

Notes: AA=Affected Area, AIH=Available Intertidal Habitat, FEDS=Final Equidistant Score, EQR=Ecological Quality Rating. *Table 2.

Across the estuary, 61.6ha (9.7% of the intertidal area) was classified as having High Enrichment Conditions (HECs; Fig. 5). The largest areas were present near the upper tidal range on the intertidal flats by Catlins River mouth, in the lower Ōwaka arm, where they were a dominant feature, and in most of the small embayments near Hinahina that have restricted tidal flushing due to the presence of piped causeways. Compared to the 14.9ha (2.3%) of HEC area reported in December 2016 (Stevens & Robertson 2017), the December 2021 results show a large increase in HEC area.

High enrichment condition, high macroalgal cover growing in mud-dominated sediments with low sediment oxygen

Anoxic soft muds with decaying macroalgae, Catlins Lake/Kuramea

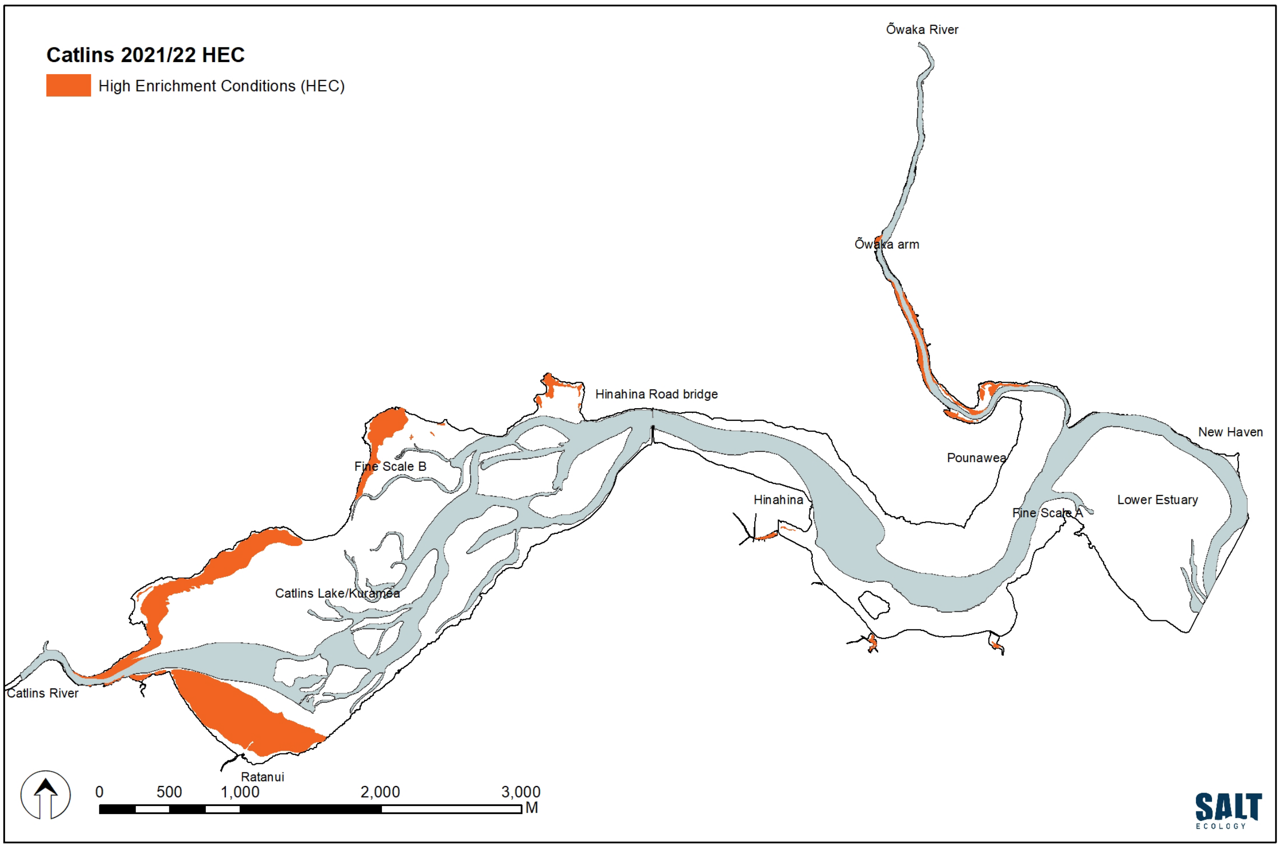


Fig. 5. Areas of High Enrichment Conditions (HEC), Catlins/Pounawea Estuary, December 2021.

4. SYNTHESIS OF KEY FINDINGS

Surveys of the estuary in 2008 (Stewart & Bywater 2009), and 2012 (Stewart 2012) did not report nuisance macroalgae as being either widespread or causing obvious eutrophication related issues. However, by 2016 nuisance macroalgae was well established with >50% cover over 32ha (5.1%) of the intertidal area and which was causing sediment condition to degrade (Stevens & Robertson 2017). Of this, 14.9ha (2.3%) of the intertidal area was classified as areas with high enrichment conditions, comprising high macroalgal cover and low oxygen, mud-dominated sediments (Stevens & Robertson 2017).

In December 2021 persistent eutrophic symptoms (nuisance macroalgae and the development of high enrichment conditions) have expanded (>50% cover over 101ha or 17.2% of the intertidal area) and become well established, particularly across the tidal flats along the western side of Catlins Lake/Kuramea. The areas of macroalgal proliferation in the Catlins/Pounewea Estuary represent sheltered deposition zones where fine sediments accrue creating the ideal environment for nuisance macroalgae to grow, particularly the red seaweed *Agarophyton* spp. In the area affected by macroalgae, there has been widespread degradation of sediment conditions including poor oxygenation, increased organic content and a build-up of mud-dominated sediments (Fig. 5; see photos). In localised areas macroalgal dieback suggests sediment conditions have reached a state so poor that macroalgae are no longer able to survive. While on a smaller scale here, these severe levels of enrichment have also been observed in New River Estuary, Southland (Roberts et al. 2021).

Between 2016 and 2021 there has been a rapid expansion of opportunistic macroalgae in Catlins/Pounawea Estuary accompanied by widespread sediment impacts, particularly in the Catlins Lake/Kuramea. These findings are reiterated when comparing the condition ratings for key macroalgal indicators between 2016 and 2021 (Table 6, see also Appendix 5). In December 2021 the extent and impact of macroalgae was rated 'Poor' whereas in December 2016 the condition ratings ranged from 'Fair' to 'Good'. This highlights conditions in the estuary are worsening and that catchment nutrient loads currently exceed the assimilative capacity of the estuary, with problems expected to persist in these areas unless there are significant reductions in nutrient inputs.

Table 6. Summary of condition rating scores for December 2016 and December 2021 based on the key indicators and criteria in Table 2.

Broad scale indicator	Unit	2016	2021
Macroalgae (OMBT)[1]	EQR	0.620	0.393
HEC[2]	Ha	14.9	61.6
HEC[2]	% of estuary	2.3	9.7

[1] OMBT = Opportunistic Macroalgal Blooming Tool
[2] High Enrichment Conditions
Condition rating colour key:

Very Good	Good	Fair	Poor

Area of HEC, sulphur oxidising bacteria visible on surface, decaying macroalgae and low oxygen mud-dominated sediments

Mix of entrained *Agarophyton* spp. and *Ulva* spp. growing on top

Blooms of opportunistic macroalgae in estuaries are directly linked to anthropogenically elevated nutrients, primarily nitrogen (Howarth 2008; Sutula et al. 2014; Woodland et al. 2015; Robertson et al. 2017; Zeldis et al. 2017). As such the management of nutrient loads to estuaries, as discussed, is essential to maintain or improve estuary health.

To help in this regard, total nitrogen (TN) thresholds (Plew et al. 2020) have been developed to indicate the point at which increasing nutrient availability is predicted to cause changes in macroalgal expression and subsequent ecological health of an estuary (Table 7). These TN thresholds have been used to both predict trophic state, and to guide estuary management by defining the likely nutrient reductions needed to meet desired states in the estuary.

Modelling of Catlins/Pounawea Estuary by Plew and Dudley (2018) estimated potential TN concentrations in Catlins Lake/Kuramea to be 260mg/m^3 ('Fair' - Band C), and in the lower estuary (downstream of Hinahina bridge) to be 99mg/m^3 ('Good' - Band B). Based on these estimates, which were largely consistent with the December 2016 macroalgal monitoring results, Plew and Dudley (2018) predicted that only a relatively small increase in the catchment TN load (from 93T/yr to 123T/yr) to Catlins Lake/Kuramea was needed to shift this area of the estuary into a 'Poor' (Band D) condition, reflecting the monitoring in December 2021. In contrast, a significant increase in TN load (from 142T/yr to 412T/yr) in the Ōwaka arm would be required to shift the lower estuary to a 'Poor' (Band D) state, largely because of extensive tidal flushing in the lower reaches.

The December 2021 macroalgal monitoring results and the findings of Plew and Dudley (2018), suggest that nutrient loads to the estuary have increased over the past 5 years. Without recent TN load data, it is not possible to determine the magnitude or source of any increased inputs. The disproportionately large increase in problems in the Catlins Lake/Kuramea arm suggests relatively large nutrient increases in the Catlins/Pounewea River catchment. However, because the Ōwaka arm was already substantially impacted in 2016, with limited areas available for further macroalgal growths to occur, changes in nutrient inputs in this part of the estuary are less easy to determine.

Entrained *Agarophyton* spp. and *Ulva* spp. in the Ōwaka arm

Table 7. Narrative ecological condition associated with macroalgal bandings in Plew and Dudley (2018) (adapted from Robertson et al. (2016b) and WFD-UKTAG (2014)).

Very Good	Good	Fair	Poor
Ecological communities (e.g., bird, fish, seagrass, and macroinvertebrates) are healthy and resilient. Algal cover <5% and low biomass (<50g/m^2 wet weight) of opportunistic macroalgal blooms and with no growth of algae in the underlying sediment. Sediment quality high	Ecological communities (e.g., bird, fish, seagrass, and macroinvertebrates) are slightly impacted by additional macroalgal growth arising from nutrients levels that are elevated. Limited macroalgal cover (5–20%) and low biomass (50–200g/m^2 wet weight) of opportunistic macroalgal blooms and with no growth of algae in the underlying sediment. Sediment quality transitional	Ecological communities (e.g., bird, fish, seagrass, and macroinvertebrates) are moderately to strongly impacted by macroalgae. Persistent, high % macroalgal cover (25–50%) and/or biomass (>200–1000g/m^2 wet weight), often with entrainment in sediment. Sediment quality degraded	Ecological communities (e.g., bird, fish, seagrass, and macroinvertebrates) are strongly impacted by macroalgae. Persistent very high % macroalgal cover (>75%) and/or biomass (>1000g/m^2 wet weight), with entrainment in sediment. Sediment quality degraded with sulphidic conditions near the sediment surface

Overall, the December 2021 monitoring results have highlighted a significant expansion of high biomass, entrained macroalgae since 2016, particularly in the Catlins Lake/Kuramea (Fig. 4; Table 6). Of concern, are the areas of severe eutrophication (i.e. HEC areas; Fig. 5) that have also expanded in extent with poor sediment condition leading to macroalgal dieback, extreme anoxia and the formation of white bacterial mats (i.e. sulphur oxidising bacteria). These results combined with the modelling of Plew and Dudley (2018) suggest that the capacity of the estuary to assimilate nutrients is being exceeded resulting in a relatively rapid decline in estuary condition. Unless nutrient inputs to the estuary are reduced it is expected that the estuary will continue to express widespread signs of eutrophication and potentially degrade further.

5. RECOMMENDATIONS

Based on the December 2021 survey findings and the rapid decline in estuary state since the previous survey in December 2016, it is recommended that ORC:

- Undertake annual monitoring during summer to track changes in nuisance macroalgae.
- Continue with planned work to determine limits on nutrient and sediment mass loads that would be expected to prevent further degradation and, where possible, mitigate current adverse impacts.
- Determine catchment nutrient and sediment sources as part of the mass load assessment and evaluate whether there are any effective and feasible management practices that could be undertaken to achieve ORC's desired condition for the estuary.

Macroalgal beds in the upper tidal reaches of Catlins Lake/Kuramea viewed towards Hinahina

6. REFERENCES

FGDC. 2012. Coastal and Marine Ecological Classification Standard Catalog of Units, Federal Geographic Data Committee FGDC-STD-018-2012. p343.

Howarth RW. 2008. Coastal nitrogen pollution: A review of sources and trends globally and regionally. Harmful Algae, 8: 14-20.

Hume T, Gerbeaux P, Hart D, Kettles H, Neale D 2016. A classification of New Zealand's coastal hydrosystems. NIWA Client Report HAM2016-062, prepared for Ministry of the Environment, October 2016. 120p.

Plew D, Dudley B. 2018. Eutrophication susceptibility assessment of Pounawea (Catlins) Estuary. NIWA Client Report No: 2018232CH, prepared for Otago Regional Council, May 2018. Updated August 2018. 30p.

Plew D, Zeldis J, Dudley B, Whitehead A, Stevens L, Robertson BM, Robertson BP. 2020. Assessing the Eutrophic Susceptibility of New Zealand Estuaries. Estuaries and Coasts (2020) 43:2015–2033, https://doi.org/10.1007/s12237-020-00729-w

Roberts KL, Stevens LM, Forrest BM. 2021. Macroalgae and Seagrass Monitoring of New River Estuary. Salt Ecology Report 080, prepared for Environment Southland, September 2021. 34p.

Robertson BM, Gillespie P, Asher R, Frisk S, Keeley N, Hopkins G, Thompson S, Tuckey B. 2002a. Estuarine environmental assessment and monitoring: A national protocol part A. Development of the monitoring protocol for New Zealand estuaries. Introduction, rationale and methodology. Sustainable Management Fund Contract No. 5096, Cawthron Institute, Nelson, New Zealand. 93p.

Robertson BM, Gillespie P, Asher R, Frisk S, Keeley N, Hopkins G, Thompson S, Tuckey B. 2002b. Estuarine environmental assessment and monitoring: a national protocol part B: development of the monitoring protocol for New Zealand Estuaries. Appendices to the introduction, rationale and methodology. Sustainable Management Fund Contract No. 5096, Cawthron Institute, Nelson, New Zealand. 159p.

Robertson BM, Gillespie P, Asher R, Frisk S, Keeley N, Hopkins G, Thompson S, Tuckey B. 2002c. Estuarine environmental assessment and monitoring: a national protocol part C: application of the estuarine monitoring protocol. Sustainable Management Fund Contract No. 5096, Cawthron Institute, Nelson, New Zealand. 40p.

Robertson BM, Stevens L, Robertson BP, Zeldis J, Green M, Madarasz-Smith A, Plew D, Storey R, Hume T, Oliver M. 2016a. NZ Estuary Trophic Index. Screening Tool 1. Determining eutrophication susceptibility using physical and nutrient load data. Prepared for Envirolink Tools Project: Estuarine Trophic Index MBIE/NIWA Contract No: C01X1420. 47p.

Robertson BM, Stevens L, Robertson BP, Zeldis J, Green M, Madarasz-Smith A, Plew D, Storey R, Hume T, Oliver M. 2016b. NZ Estuary Trophic Index. Screening Tool 2. Screening Tool 2. Determining Monitoring Indicators and Assessing Estuary Trophic State. Prepared for Envirolink Tools Project: Estuarine Trophic Index MBIE/NIWA Contract No: C01X1420. 68p.

Robertson BM, Stevens LM, Ward N, Robertson BP 2017. Condition of Southland's Shallow, Intertidal Dominated Estuaries in Relation to Eutrophication and Sedimentation: Output 1: Data Analysis and Technical Assessment - Habitat Mapping Vulnerability Assessment and Monitoring Recommendations Related to Issues of Eutrophication and Sedimentation. Report prepared by Wriggle Coastal Management for Environment Southland. 172p.

Stevens LM, Robertson BM. 2017. Catlins Estuary: Broad Scale Habitat Mapping 2016/17. Report prepared by Wriggle Coastal Management for Otago Regional Council. 38p.

Stewart B. 2012. Habitat Mapping of the Ōwaka Estuary. Otago Regional Council State of the Environment Report. Prepared for Otago Regional Council by Ryder Consulting Ltd. 36p.

Stewart B, Bywater C. 2009. Habitat Mapping of the Catlins Estuary. Otago Regional Council State of the Environment Report. Prepared for Otago Regional Council by Ryder Consulting Ltd. 36p.

Sutula M, Green L, Cicchetti G, Detenbeck N, Fong P. 2014. Thresholds of adverse effects of macroalgal abundance and sediment organic matter on benthic habitat quality in estuarine intertidal flats. Estuaries and Coasts, doi:10.1007/s12237-014-9796-3.

WFD-UKTAG 2014. UKTAG Transitional and Coastal Water Assessment Method Macroalgae Opportunistic Macroalgal Blooming Tool. Water Framework Directive – United Kingdom Technical Advisory Group. https://www.wfduk.org/sites/default/files/Media/Characterisation%20of%20the%20water%20environment/Biological%20Method%20Statements/TraC%20Macroalgae%20OMBT%20UKTAG%20Method%20Statement.PDF.

Woodland RJ, Thomson JR, Mac Nally R, Reich P, Evrard V, Wary FY, Walker JP, Cook PLM. 2015. Nitrogen loads explain primary productivity in estuaries at the ecosystem scale. Limnology and Oceanography, 60, 1751-1762.

Zeldis J, Whitehead A, Plew D, Madarasz-Smith, A, Oliver M, Stevens L, Robertson B, Storey R, Burge O, Dudley B. 2017. The New Zealand Estuary Trophic Index (ETI) Tools: Tool 2 - Assessing Estuary Trophic State using Measured Trophic Indicators. Ministry of Business, Innovation and Employment Envirolink Tools: C01X1420.

APPENDIX 1. OPPORTUNISTIC MACROALGAL BLOOMING TOOL

The UK-WFD (Water Framework Directive) Opportunistic Macroalgal Blooming Tool (OMBT) (WFD-UKTAG 2014) is a comprehensive 5-part multi-metric index approach suitable for characterising the different types of estuaries and related macroalgal issues found in NZ. The tool allows 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 multi-metric OMBT, modified for NZ estuary types, is presented in the WFD-UKTAG (2014) with additions described in Plew et al. (2020), and is paraphrased below. It is based on macroalgal growth within the Available Intertidal Habitat (AIH) - the estuary area between high and low water spring tide able to support opportunistic macroalgal growth. Suitable areas are considered to consist of *mud*, *muddy sand*, *sandy mud*, *sand*, *stony mud and mussel beds*. Areas which are judged unsuitable for algal blooms, e.g. channels and channel edges subject to constant scouring, need to be excluded from the AIH. The following measures are then taken:

1. PERCENTAGE COVER OF THE AVAILABLE INTERTIDAL HABITAT (AIH).

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

2. TOTAL EXTENT OF AREA COVERED BY ALGAL MATS (AFFECTED AREA (AA)) OR AFFECTED AREA AS A PERCENTAGE OF THE AIH (AA/AIH, %).

The affected area represents the total area of macroalgal cover in hectares. In large water bodies, small patches of macroalgal coverage relative to the estuary size would result in the total percent cover across the AIH remaining within the 'high' or 'good' status. While the affected area may be relatively small when compared to estuary size the total area covered could actually be quite substantial and could still affect the surrounding and underlying communities (WFD-UKTAG 2014). In order to account for this, the OMBT included an additional metric; the affected area as a percentage of the AIH (i.e. (AA/AIH)*100). This helps to scale the area of impact to the size of the waterbody. In the final assessment the lower of the two metrics (the AA or percentage AA/AIH) is used, i.e. whichever reflects the worse-case scenario.

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. 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 (% 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 multi-metric, in order to best describe the changes in the nature and degree of opportunistic macroalgae growth on sedimentary shores due to nutrient pressure.

TIMING

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

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 intermittently closed and open estuaries (ICOEs) 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 A1).

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 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.

Table A1. The final face value thresholds and metrics for levels of the ecological quality status. These thresholds have been recently revised for New Zealand (see Table A3).

ECOLOGICAL QUALITY RATING (EQR)	High[1]	Good	Moderate	Poor	Bad
	≥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)[2]	≥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[3]	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
Average biomass (g.m^{-2}) of AA[3]	≥0 - 100	≥100 - 500	≥500 - 1000	≥1000 - 3000	≥3000
% algae entrained >3cm deep	≥0 - 1	≥1 - 5	≥5 - 20	≥20 - 50	≥50 - 100

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

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 <500g.m^{-2} wet weight was an acceptable level above the reference level of <100g.m^{-2} wet weight. In Good status only slight deviation from High status is permitted so 500g.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 >500gm^{-2} but less than 1,000g.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 applied in the current study are described and presented in Table A3.**

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.

EQR CALCULATION

Each metric in the OMBT has equal weighting and is combined to produce the **Ecological Quality Rating** score (EQR).

The face value metrics work on a sliding scale to enable an accurate metric EQR value to be calculated; an average of these values is then used to establish the final water body level EQR and classification status. The EQR determining the final water body classification ranges between a value of zero to one and is converted to a Quality Status by using the categories in Table A1. The EQR calculation process is as follows:

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

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

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

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

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

Table A2 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'.

Table A2. 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

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

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.

CHANGES TO BIOMASS THRESHOLDS IN NEW ZEALAND

Biomass thresholds included in the OMBT were lowered for use in NZ by Plew et al. (2020) based on unpublished data from >25 shallow well-flushed intertidal NZ estuaries (Robertson et al. 2016b) and the results from similar estuaries in California. Sutula et al. (2014) reported that in eight Californian estuaries, macroalgal biomass of 1450g.m^{-2} wet weight, total organic carbon of 1.1% and sediment total nitrogen of 0.1% were thresholds associated with anoxic conditions near the surface (aRPD < 10 mm). Green et al. (2014) reported significant and rapid negative effects on benthic invertebrate abundance and species richness at macroalgal abundances as low as 840–930g.m^{-2} wet weight in two Californian estuaries. McLaughlin et al. (2014) reviewed Californian biomass thresholds and found the elimination of surface deposit feeders in the range of 700–800g.m^{-2}. As the Californian results were consistent with NZ findings, the latter thresholds were used to lower the OMBT good/moderate threshold from ≤500 to ≤200g.m^{-2}, the moderate/poor threshold from ≤1000 to ≤500gm^{-2} and the poor/bad threshold from >3000 to >1450g.m^{-2}. These thresholds are considered to provide an early warning of nutrient related impacts in NZ prior to the establishment of adverse enrichment conditions that are likely difficult to reverse.

REFERENCES

DETR 2001. Development of ecological quality objectives with regard to eutrophication. Final report, unpublished.

Foden J, Wells E, Scanlan C, Best MA. 2010. Water Framework Directive development of classification tools for ecological assessment: Opportunistic Macroalgae Blooming. UK TAG Report for Marine Plants Task Team, January 2010, Publ. UK TAG.

Green L, Sutula M, and Fong P. 2014. How much is too much? Identifying benchmarks of adverse effects of macroalgae on the macrofauna in intertidal flats. Ecological Applications 24: 300–314.

Hull SC. 1987. Macroalgal mats and species abundance: a field experiment. Estuaries and Coastal Shelf Science 25, 519-532.

Lowthion D, Soulsby PG, Houston MCM. 1985. Investigation of a eutrophic tidal basin: 1. Factors affecting the distribution and biomass of macroalgae. Marine Environmental Research 15: 263–284.

McLaughlin K, Sutula M, Busse L, Anderson S, Crooks J, Dagit R, Gibson D, Johnston K, Stratton L. 2014. A regional survey of the extent and magnitude of eutrophication in Mediterranean Estuaries of Southern California, USA. Estuaries and Coasts 37: 259–278.

Plew D, Zeldis J, Dudley B, Whitehead A, Stevens L, Robertson BM, Robertson BP. 2020a. Assessing the Eutrophic Susceptibility of New Zealand Estuaries. Estuaries and Coasts (2020) 43:2015–2033, https://doi.org/10.1007/s12237-020-00729-w

Raffaelli D, Hull S, Milne H, 1989. Long-term changes in nutrients, weedmats and shore birds in an estuarine system. Cahiers de Biologie Marine. 30, 259–270.

Robertson BM, Stevens L, Robertson B, Zeldis J, Green M, Madarasz-Smith A, Plew D, Storey R, Oliver M. 2016b. NZ estuary trophic index screen tool 2. Determining monitoring indicators and assessing estuary trophic

Table A3. Revised final face value thresholds and metrics for levels of the ecological quality status used in the current assessment.

ECOLOGICAL QUALITY RATING (EQR)	High[1]	Good	Moderate	Poor	Bad
	≥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)[2]	≥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[3]	≥0 - 100	≥100 - 200	≥200 - 500	≥500 - 1450	≥1450
Average biomass (g.m^{-2}) of AA[3]	≥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 should be used in the final EQR calculation.

state. Prepared for Environlink tools project: estuarine trophic index, 68: MBIE/NIWA Contract No: COX1420.

Sutula M, Green L, Cicchetti G, Detenbeck N, Fong P. 2014. Thresholds of adverse effects of macroalgal abundance and sediment organic matter on benthic habitat quality in estuarine intertidal flats. Estuaries and Coasts 37: 1532–1548.

WFD-UKTAG (Water Framework Directive – United Kingdom Technical Advisory Group) 2014. UKTAG Transitional and Coastal Water Assessment Method Macroalgae Opportunistic Macroalgal Blooming Tool. Retrieved from http://www.wfduk.org/sites/default/files/Media/Characterisation of the water environment/Biological Method Statements/TraC Macroalgae OMBT UKTAG Method Statement.PDF.

Wither A, 2003. Guidance for sites potentially impacted by algal mats (green seaweed). EC Habitats Directive Technical Advisory Group report WQTAG07c.

APPENDIX 2. INFORMATION SUPPORTING RATINGS IN THE REPORT

SEDIMENT MUD CONTENT

Sediments with mud contents of <25% are generally relatively firm to walk on. When mud contents increase above ~25%, sediments start to become softer, more 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, and sediment-bound nutrients and heavy metals whose concentrations typically increase with increasing mud content. Consequently, muddy sediments are often poorly oxygenated, nutrient rich, can have elevated heavy metal concentrations 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 re-suspension of fine muds, impacting on seagrass, birds, fish and aesthetic values. Such conditions indicate changes in land management may be needed.

APPARENT REDOX POTENTIAL DISCONTINUITY (ARPD)

aRPD depth, the visually apparent transition between oxygenated sediments near the surface and deeper more anoxic sediments, is a useful estuary condition indicator as it is a direct measure of time integrated sediment oxygenation. Knowing if the aRPD is close to the surface is important for three main reasons:

i) The closer to the surface anoxic sediments are, the less habitat there is available for most sensitive macroinvertebrate species; ii) the tendency for sediments to become anoxic is much greater if the sediments are muddy; iii) anoxic sediments contain toxic sulphides and support very little aquatic life.

As sediments transition from oxic to anoxic, a "tipping point" is reached where nutrients bound to sediment under oxic conditions, become released under anoxic conditions to potentially fuel algal blooms that can degrade estuary quality.

In sandy porous sediments, the aRPD layer is usually relatively deep (i.e. >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 & Revsbech 1985) unless bioturbation by infauna oxygenates the sediments.

OPPORTUNISTIC MACROALGAE

The presence of opportunistic macroalgae is a primary indicator of estuary eutrophication and, when combined with high mud and low oxygen conditions (see previous), can cause significant adverse ecological impacts that are very difficult to reverse. Thresholds used to assess this indicator are derived from the OMBT (see WFD-UKTAG (Water Framework Directive – United Kingdom Technical Advisory Group), 2014; Robertson et al 2016; Zeldis et al. 2017), with results combined with those of other indicators to determine overall condition.

REFERENCES

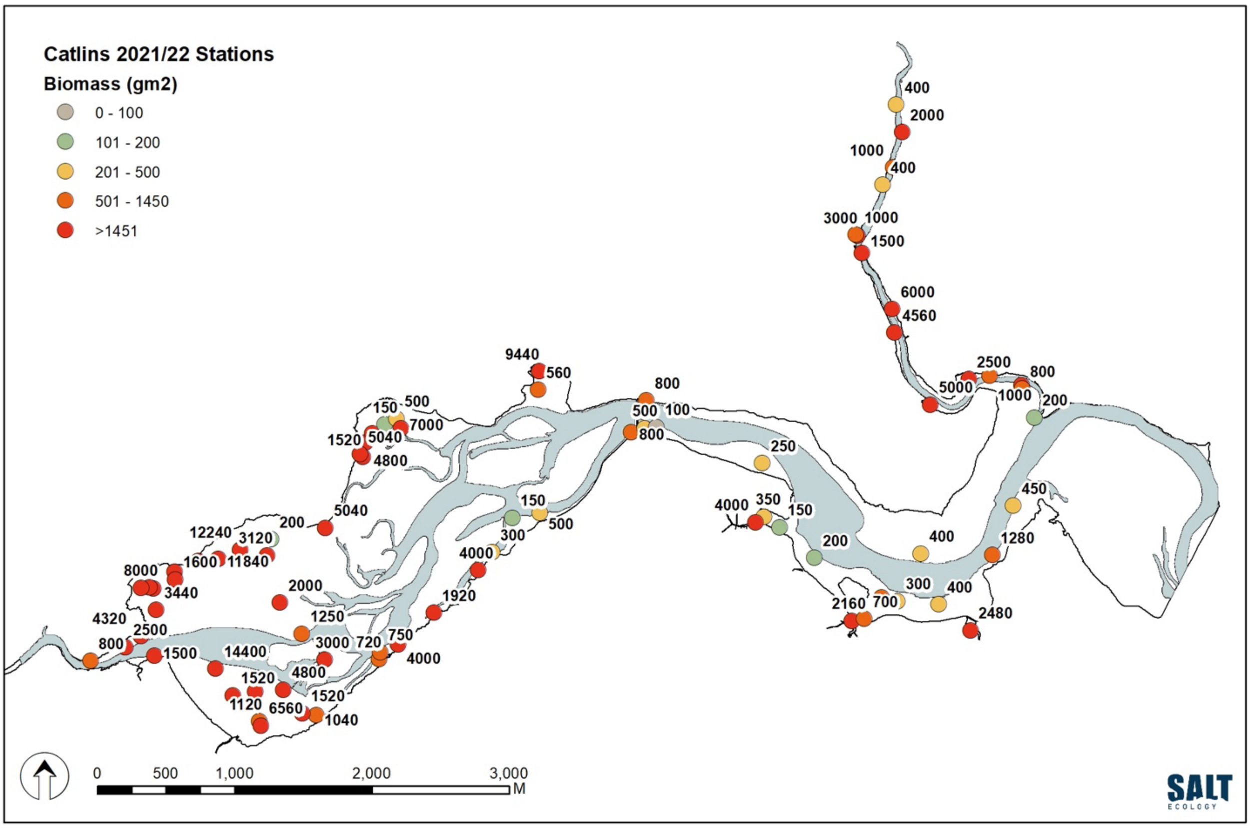
Jørgensen N, Revsbech NP. 1985. Diffusive boundary layers and the oxygen uptake of sediments and detritus. Limnology and Oceanography 30:111-122.

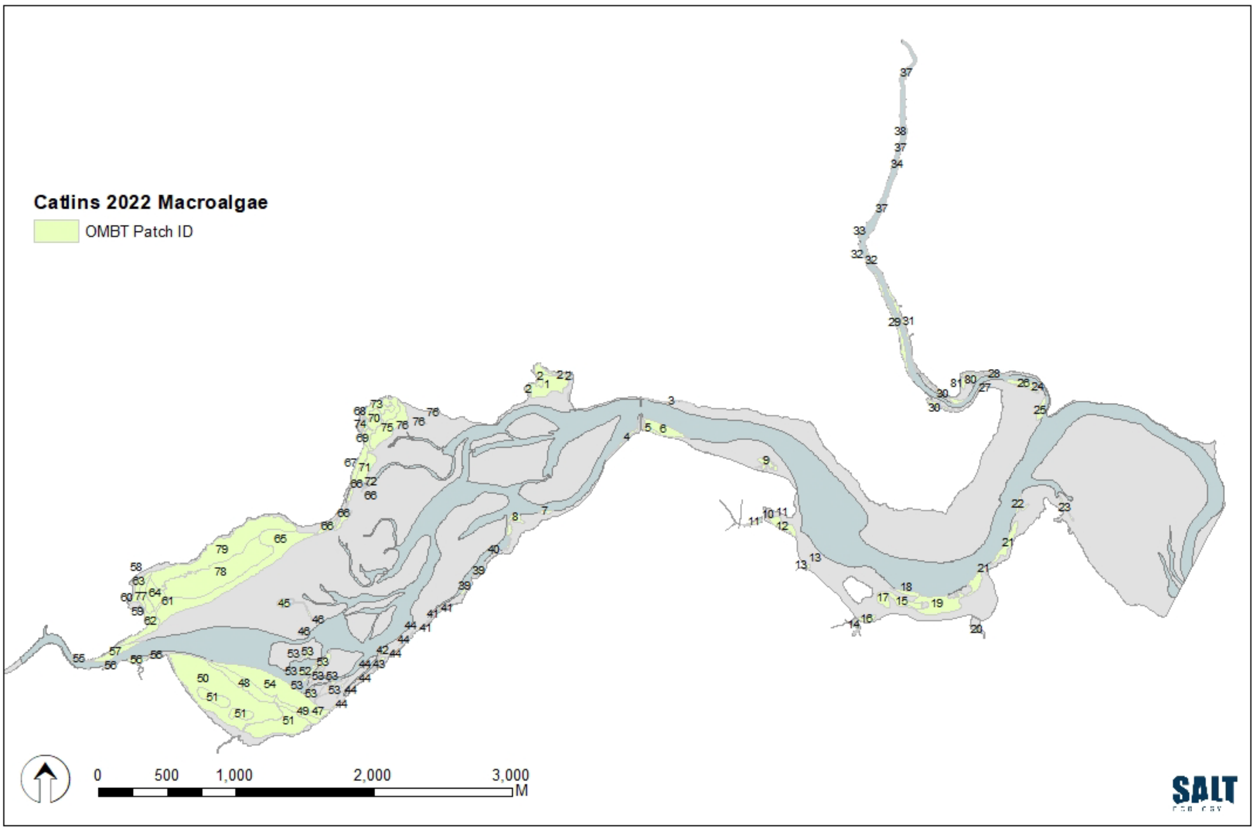
Robertson BM, Stevens LM, Robertson BP, Zeldis J, Green M, Madarasz-Smith A, Plew D, Storey R, Oliver, M. 2016. NZ Estuary Trophic Index. Screening Tool 2. Determining Monitoring Indicators and Assessing Estuary Trophic State. Prepared for Envirolink Tools Project: Estuarine Trophic Index MBIE/NIWA Contract No: C01X1420. 68p.

WFD-UKTAG (Water Framework Directive – United Kingdom Technical Advisory Group). 2014. UKTAG Transitional and Coastal Water Assessment Method Macroalgae Opportunistic Macroalgal Blooming Tool.http://www.wfduk.org/sites/default/files/Media/Characterisation of the water environment/Biological Method Statements/TraC Macroalgae OMBT UKTAG Method Statement.PDF.

Zeldis J, Whitehead A, Plew D, Madarasz-Smith, A, Oliver M, Stevens L, Robertson B, Storey R, Burge O, Dudley B. 2017. The New Zealand Estuary Trophic Index (ETI) Tools: Tool 2 - Assessing Estuary Trophic State using Measured Trophic Indicators. Ministry of Business, Innovation and Employment Envirolink Tools C01X1420.

APPENDIX 3. MACROALGAL BIOMASS STATIONS, OMBT PATCH ID AND RAW DATA, DECEMBER 2021





Patch ID Table

Estuary	Year	PatchID	Code	Pct_Cover	TotPctCov	PctCover Category	Biomass (gm^2)	Biomass Category	Entrained*	Dominant Species	SubDom Sp.1	SubDom Sp.2	Area_ha
Catlins	2021	1	Ulva Other Grch	70 4 1	75	Dense (70 to <90%)	560	High (501 - 1450)	0	Ulva (Sea lettuce)	Unspecified Macroalgae	Gracilaria chilensis	3.24
Catlins	2021	2	Grch Ulva	99 1	100	Complete (>90%)	9440	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		1.32
Catlins	2021	3	Ulva Grch	70 10	80	Dense (70 to <90%)	800	High (501 - 1450)	0	Ulva (Sea lettuce)	Gracilaria chilensis		0.12
Catlins	2021	4	Grch Ulva	70 10	80	Dense (70 to <90%)	800	High (501 - 1450)	0	Gracilaria chilensis	Ulva (Sea lettuce)		0.28
Catlins	2021	5	Ulva Grch	40 10	50	High-Moderate (50 to <70%)	500	Moderate (201 - 500)	0	Ulva (Sea lettuce)	Gracilaria chilensis		0.36
Catlins	2021	6	Grch Ulva	10 1	11	Sparse (10 to <30%)	100	Very low (1 - 100)	0	Gracilaria chilensis	Ulva (Sea lettuce)		1.72
Catlins	2021	7	Ulva Grch	80 20	100	Complete (>90%)	500	Moderate (201 - 500)	0	Ulva (Sea lettuce)	Gracilaria chilensis		0.20
Catlins	2021	8	Grch Ulva	60 20	80	Dense (70 to <90%)	150	Low (101 - 200)	0	Gracilaria chilensis	Ulva (Sea lettuce)		0.82
Catlins	2021	9	Grch Ulva	4 1	5	Very sparse (1 to <10%)	250	Moderate (201 - 500)	0	Gracilaria chilensis	Ulva (Sea lettuce)		0.70
Catlins	2021	10	Grch	10	10	Sparse (10 to <30%)	350	Moderate (201 - 500)	1	Gracilaria chilensis			0.08
Catlins	2021	11	Grch	90	90	Complete (>90%)	4000	Very high (>1450)	1	Gracilaria chilensis			0.28
Catlins	2021	12	Ulva	5	5	Very sparse (1 to <10%)	150	Low (101 - 200)	0	Ulva (Sea lettuce)			1.10
Catlins	2021	13	Ulva	80	80	Dense (70 to <90%)	200	Low (101 - 200)	0	Ulva (Sea lettuce)			0.18
Catlins	2021	14	Grch Ulva	95 1	96	Complete (>90%)	2160	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.19
Catlins	2021	15	Ulva Other	30 20	50	High-Moderate (50 to <70%)	300	Moderate (201 - 500)	0	Ulva (Sea lettuce)	Unspecified Macroalgae		1.17
Catlins	2021	16	Ulva	50	50	High-Moderate (50 to <70%)	700	High (501 - 1450)	0	Ulva (Sea lettuce)			0.40
Catlins	2021	17	Ulva Other	50 5	55	High-Moderate (50 to <70%)	880	High (501 - 1450)	0	Ulva (Sea lettuce)	Unspecified Macroalgae		0.81
Catlins	2021	18	Ulsp Grch Other	40 5 5	50	High-Moderate (50 to <70%)	400	Moderate (201 - 500)	0	Ulva sp (Sea lettuce)	Gracilaria chilensis	Unspecified Macroalgae	0.49
Catlins	2021	19	Ulva Other Grch	40 5 2	47	Low-Moderate (30 to <50%)	400	Moderate (201 - 500)	0	Ulva (Sea lettuce)	Unspecified Macroalgae	Gracilaria chilensis	4.63
Catlins	2021	20	Grch Ulva	50 1	51	High-Moderate (50 to <70%)	2480	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.10
Catlins	2021	21	Ulva Other Grch	59 5 1	65	High-Moderate (50 to <70%)	1280	High (501 - 1450)	0	Ulva (Sea lettuce)	Unspecified Macroalgae	Gracilaria chilensis	1.41
Catlins	2021	22	Ulva Other	60 10	70	Dense (70 to <90%)	450	Moderate (201 - 500)	0	Ulva (Sea lettuce)	Unspecified Macroalgae		0.36
Catlins	2021	23	Ulsp Other	50 5	55	High-Moderate (50 to <70%)	450	Moderate (201 - 500)	0	Ulva sp (Sea lettuce)	Unspecified Macroalgae		0.25
Catlins	2021	24	Ulva Grch	60 30	90	Complete (>90%)	800	High (501 - 1450)	1	Ulva (Sea lettuce)	Gracilaria chilensis		0.23
Catlins	2021	25	Ulva Other	50 5	55	High-Moderate (50 to <70%)	200	Low (101 - 200)	0	Ulva (Sea lettuce)	Unspecified Macroalgae		0.56
Catlins	2021	26	Grch Ulva	80 10	90	Complete (>90%)	2400	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.76
Catlins	2021	27	Ulsp Grch	70 20	90	Complete (>90%)	1100	High (501 - 1450)	1	Ulva sp (Sea lettuce)	Gracilaria chilensis		0.10
Catlins	2021	28	Ulva Grch	60 10	70	Dense (70 to <90%)	1000	High (501 - 1450)	1	Ulva (Sea lettuce)	Gracilaria chilensis		0.20
Catlins	2021	29	Grch	100	100	Complete (>90%)	4560	Very high (>1450)	1	Gracilaria chilensis			1.27
Catlins	2021	30	Grch Ulva	90 5	95	Complete (>90%)	5000	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.91
Catlins	2021	31	Grch Ulva	99 1	100	Complete (>90%)	6000	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.81
Catlins	2021	32	Ulva	50	50	High-Moderate (50 to <70%)	1500	Very high (>1450)	0	Ulva (Sea lettuce)			0.21
Catlins	2021	33	Grch	80	80	Dense (70 to <90%)	1000	High (501 - 1450)	1	Gracilaria chilensis			0.09
Catlins	2021	34	Ulva	100	100	Complete (>90%)	1000	High (501 - 1450)	0	Ulva (Sea lettuce)			0.04
Catlins	2021	35	Ulva	90	90	Complete (>90%)	2000	Very high (>1450)	0	Ulva (Sea lettuce)			0.01
Catlins	2021	36	Grch Ulva	99 1	100	Complete (>90%)	3000	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.07
Catlins	2021	37	Ulsp	80	80	Dense (70 to <90%)	400	Moderate (201 - 500)	0	Ulva sp (Sea lettuce)			0.17
Catlins	2021	38	Ulva	80	80	Dense (70 to <90%)	400	Moderate (201 - 500)	0	Ulva (Sea lettuce)			0.15
Catlins	2021	39	Ulva Other Grch	80 10 10	100	Complete (>90%)	4000	Very high (>1450)	1	Ulva (Sea lettuce)	Unspecified Macroalgae	Gracilaria chilensis	0.43
Catlins	2021	40	Grch Ulva Other	20 10 10	40	Low-Moderate (30 to <50%)	300	Moderate (201 - 500)	0	Gracilaria chilensis	Ulva (Sea lettuce)	Unspecified Macroalgae	0.04

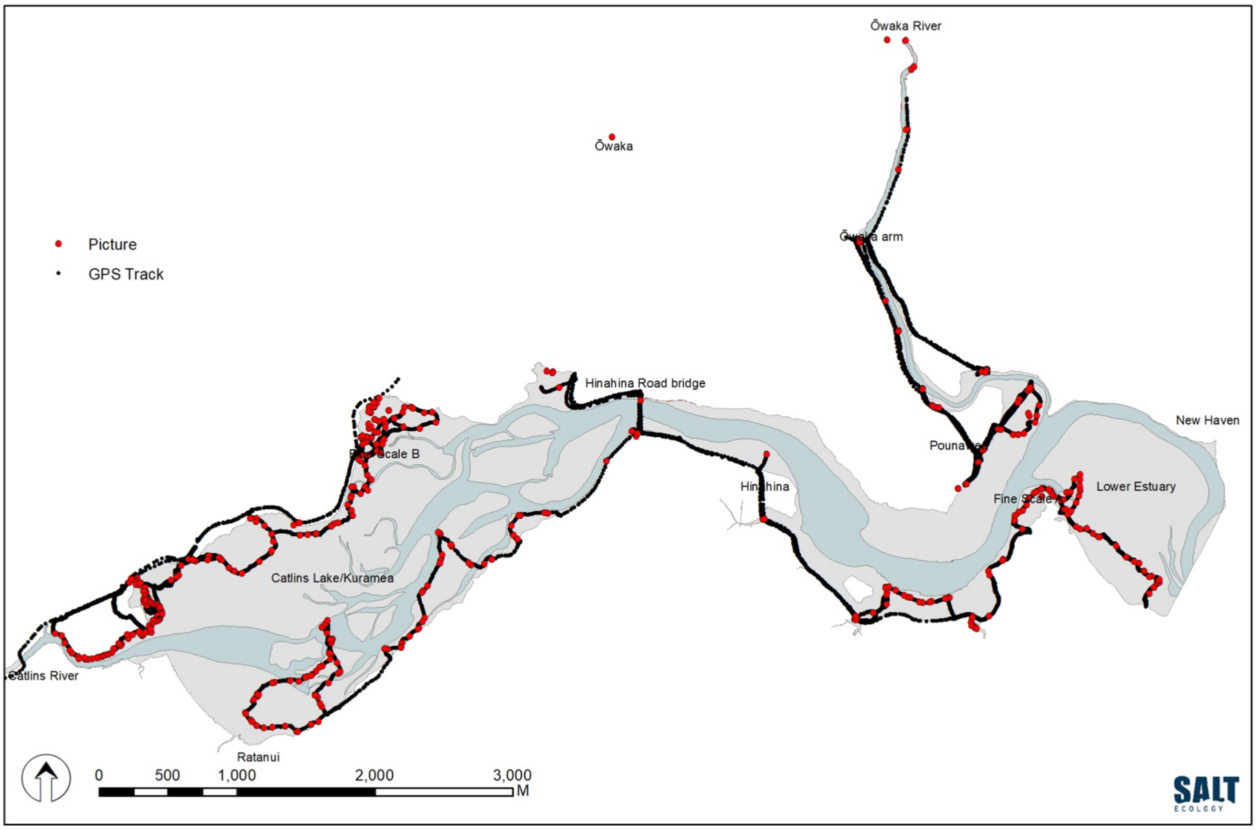
* 0=not entrained, 1=entrained

Patch ID Table continued...

Estuary	Year	PatchID	Code	Pct_Cover	TotPctCov	PctCover Category	Biomass (gm^2)	Biomass Category	Entrained*	Dominant Species	SubDom Sp.1	SubDom Sp.2	Area_ha
Catlins	2021	41	Ulva Grch	50 20	70	Dense (70 to <90%)	1920	Very high (>1450)	0	Ulva (Sea lettuce)	Gracilaria chilensis		0.19
Catlins	2021	42	Grch Ulva Other	30 10 10	50	High-Moderate (50 to <70%)	750	High (501 - 1450)	0	Gracilaria chilensis	Ulva (Sea lettuce)	Unspecified Macroalgae	0.19
Catlins	2021	43	Grch Ulva Other	30 10 10	50	High-Moderate (50 to <70%)	720	High (501 - 1450)	0	Gracilaria chilensis	Ulva (Sea lettuce)	Unspecified Macroalgae	0.17
Catlins	2021	44	Ulva Grch	60 20	80	Dense (70 to <90%)	4000	Very high (>1450)	0	Ulva (Sea lettuce)	Gracilaria chilensis		0.27
Catlins	2021	45	Grch Ulva	30 10	40	Low-Moderate (30 to <50%)	2000	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.72
Catlins	2021	46	Grch Ulva	20 5	25	Sparse (10 to <30%)	1250	High (501 - 1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.11
Catlins	2021	47	Grch Ulva	50 10	60	High-Moderate (50 to <70%)	1040	High (501 - 1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.83
Catlins	2021	48	Grch Ulva	99 1	100	Complete (>90%)	9360	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		3.08
Catlins	2021	49	Grch Ulva	80 1	81	Dense (70 to <90%)	1520	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		1.40
Catlins	2021	50	Grch Ulva	50 10	60	High-Moderate (50 to <70%)	1320	High (501 - 1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		17.10
Catlins	2021	51	Grch Ulva	95 5	100	Complete (>90%)	6560	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		8.02
Catlins	2021	52	Grch	1	1	Very sparse (1 to <10%)	100	Very low (1 - 100)	1	Gracilaria chilensis			0.38
Catlins	2021	53	Grch Ulva	60 5	65	High-Moderate (50 to <70%)	3000	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		2.33
Catlins	2021	54	Grch Ulva	80 10	90	Complete (>90%)	4800	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		7.88
Catlins	2021	55	Ulva Grch Other	40 15 1	56	High-Moderate (50 to <70%)	800	High (501 - 1450)	1	Ulva (Sea lettuce)	Gracilaria chilensis	Unspecified Macroalgae	0.14
Catlins	2021	56	Ulva Grch	75 10	85	Dense (70 to <90%)	1500	Very high (>1450)	1	Ulva (Sea lettuce)	Gracilaria chilensis		0.65
Catlins	2021	57	Ulva Grch Other	75 20 1	96	Complete (>90%)	2500	Very high (>1450)	1	Ulva (Sea lettuce)	Gracilaria chilensis	Unspecified Macroalgae	1.45
Catlins	2021	58	Grch Ulva	80 20	100	Complete (>90%)	2000	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.12
Catlins	2021	59	Grch Ulva	5 5	10	Sparse (10 to <30%)	100	Very low (1 - 100)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.20
Catlins	2021	60	Grch Ulva	10 5	15	Sparse (10 to <30%)	200	Low (101 - 200)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.32
Catlins	2021	61	Ulva Grch	45 45	90	Complete (>90%)	3440	Very high (>1450)	1	Ulva (Sea lettuce)	Gracilaria chilensis		0.29
Catlins	2021	62	Grch Ulva Other	80 10 5	95	Complete (>90%)	4320	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)	Unspecified Macroalgae	2.03
Catlins	2021	63	Grch Ulva	20 10	30	Low-Moderate (30 to <50%)	500	Moderate (201 - 500)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.63
Catlins	2021	64	Grch Ulva	47 42	89	Dense (70 to <90%)	6160	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		1.70
Catlins	2021	65	Grch Ulva	15 5	20	Sparse (10 to <30%)	200	Low (101 - 200)	0	Gracilaria chilensis	Ulva (Sea lettuce)		10.81
Catlins	2021	66	Grch Ulva	80 5	85	Dense (70 to <90%)	5040	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		1.56
Catlins	2021	67	Grch Ulva	90 2	92	Complete (>90%)	3280	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		1.22
Catlins	2021	68	Ulva Grch	60 40	100	Complete (>90%)	3000	Very high (>1450)	1	Ulva (Sea lettuce)	Gracilaria chilensis		0.03
Catlins	2021	69	Grch Ulsp	15 2	17	Sparse (10 to <30%)	500	Moderate (201 - 500)	1	Gracilaria chilensis	Ulva sp (Sea lettuce)		0.20
Catlins	2021	70	Grch Ulva	97 1	98	Complete (>90%)	6280	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		3.22
Catlins	2021	71	Grch Ulva	5 1	6	Very sparse (1 to <10%)	50	Very low (1 - 100)	1	Gracilaria chilensis	Ulva (Sea lettuce)		1.52
Catlins	2021	72	Ulsp	15	15	Sparse (10 to <30%)	100	Very low (1 - 100)	0	Ulva sp (Sea lettuce)			0.11
Catlins	2021	73	Grch Ulsp	80 10	90	Complete (>90%)	3500	Very high (>1450)	1	Gracilaria chilensis	Ulva sp (Sea lettuce)		1.45
Catlins	2021	74	Grch	85	85	Dense (70 to <90%)	3500	Very high (>1450)	1	Gracilaria chilensis			0.34
Catlins	2021	75	Grch Ulva	27 10	37	Low-Moderate (30 to <50%)	325	Moderate (201 - 500)	0	Gracilaria chilensis	Ulva (Sea lettuce)		3.13
Catlins	2021	76	Grch Ulva	95 5	100	Complete (>90%)	7000	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.08
Catlins	2021	77	Grch Ulva	60 35	95	Complete (>90%)	8000	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		1.16
Catlins	2021	78	Ulva Grch Other	52 37 2	91	Complete (>90%)	2360	Very high (>1450)	1	Ulva (Sea lettuce)	Gracilaria chilensis	Unspecified Macroalgae	12.96
Catlins	2021	79	Grch Ulva	95 3	98	Complete (>90%)	9770	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		12.48
Catlins	2021	80	Grch Ulva	80 15	95	Complete (>90%)	2500	Very high (>1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.42
Catlins	2021	81	Grch Ulva	40 10	50	High-Moderate (50 to <70%)	1125	High (501 - 1450)	1	Gracilaria chilensis	Ulva (Sea lettuce)		0.20

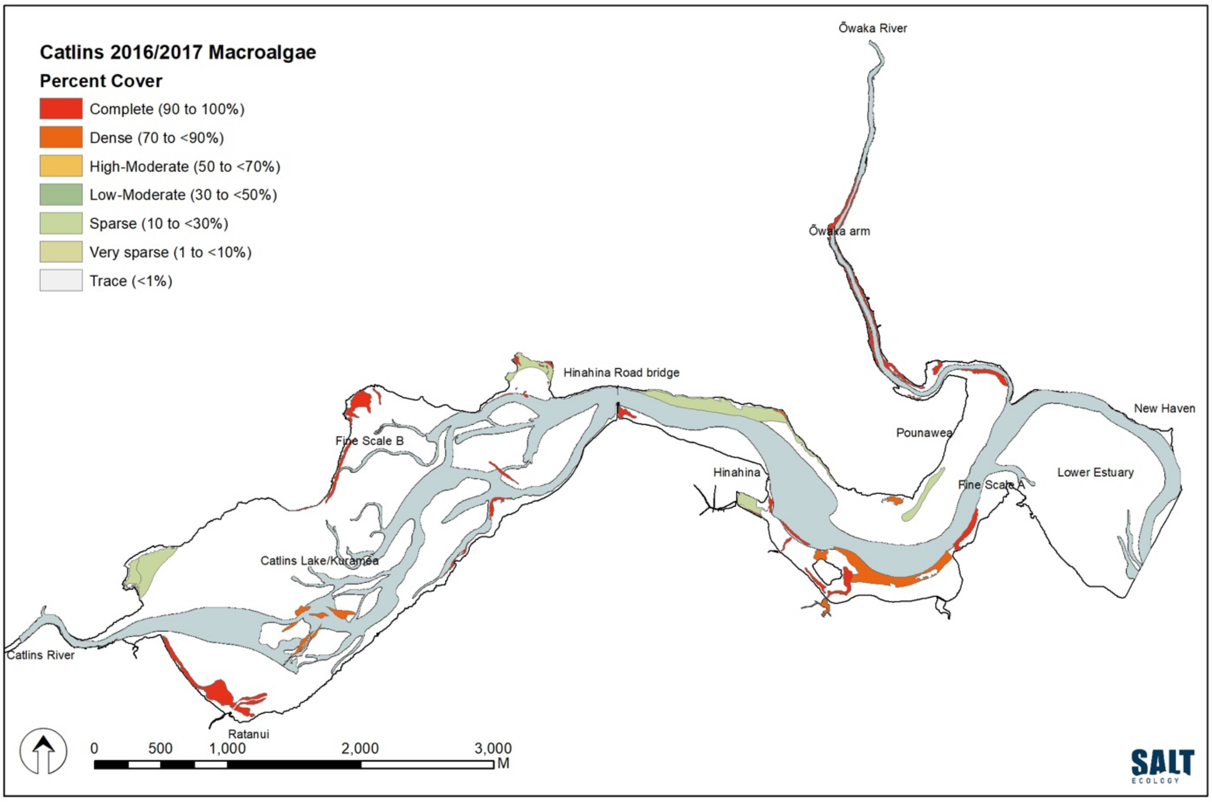
* 0=not entrained, 1=entrained

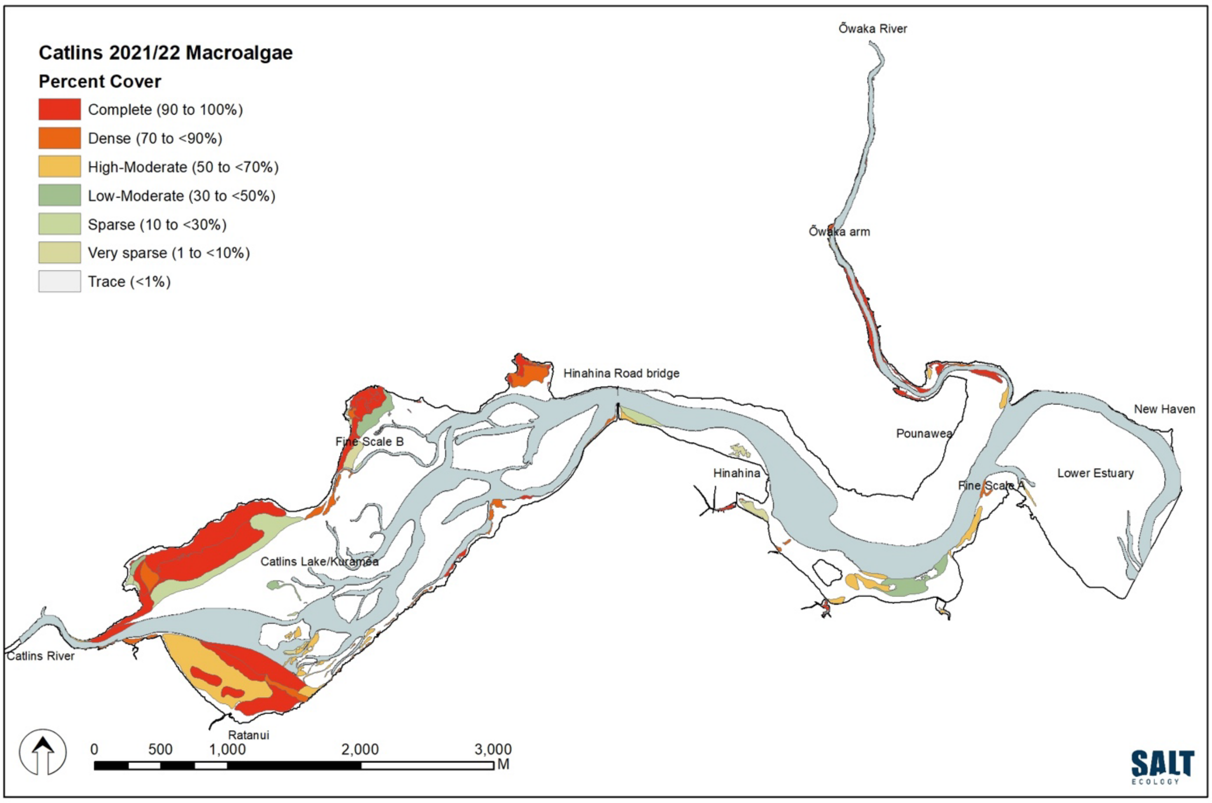
APPENDIX 4. GROUND TRUTHING IN CATLINS/POUNAWEA ESTUARY, DECEMBER 2021



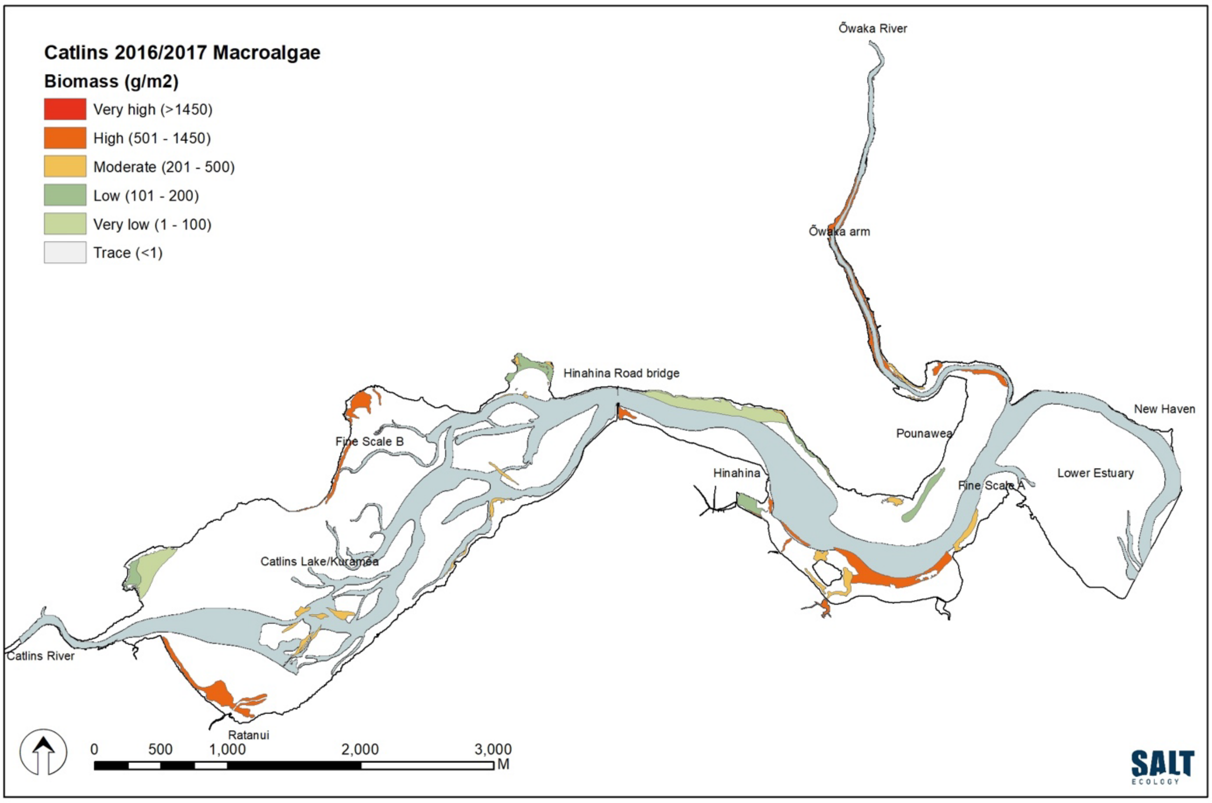
APPENDIX 5. MAPS OF (A) %COVER, (B) BIOMASS AND (C) HEC, CATLINS/POUNAWEA ESTUARY

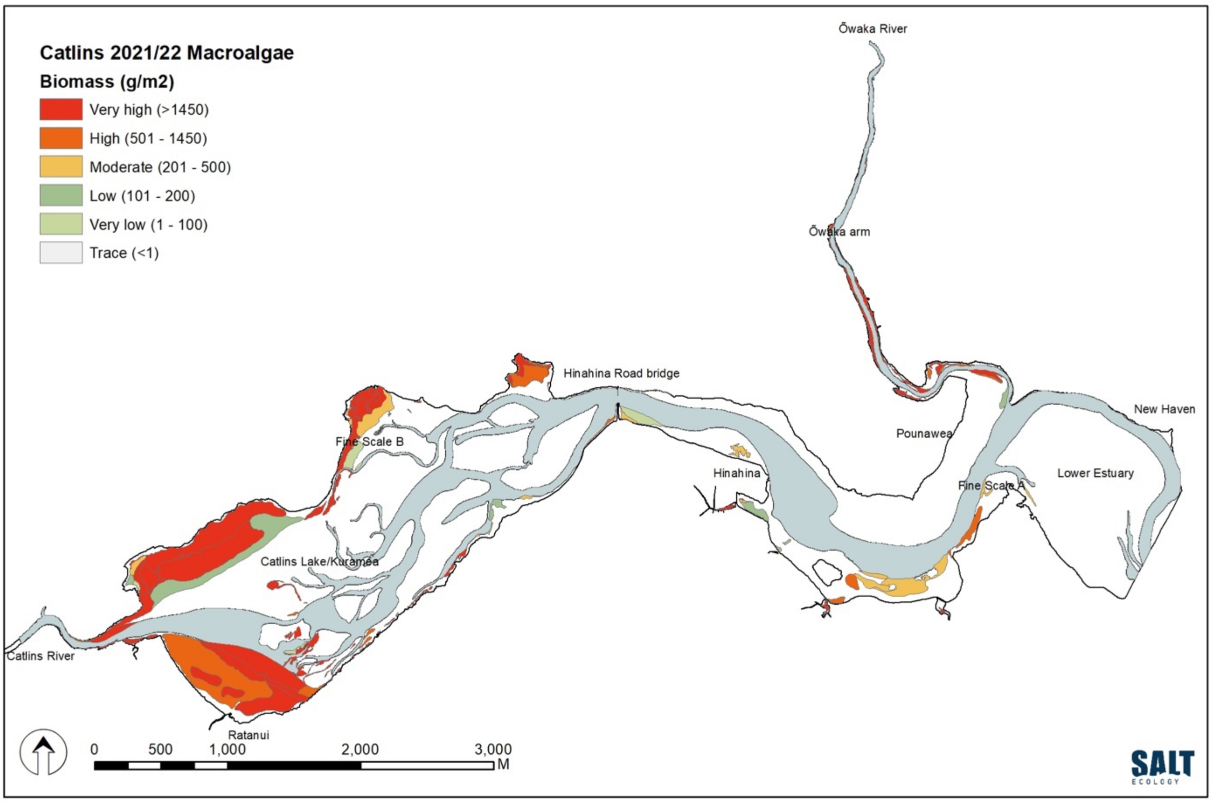
(a)



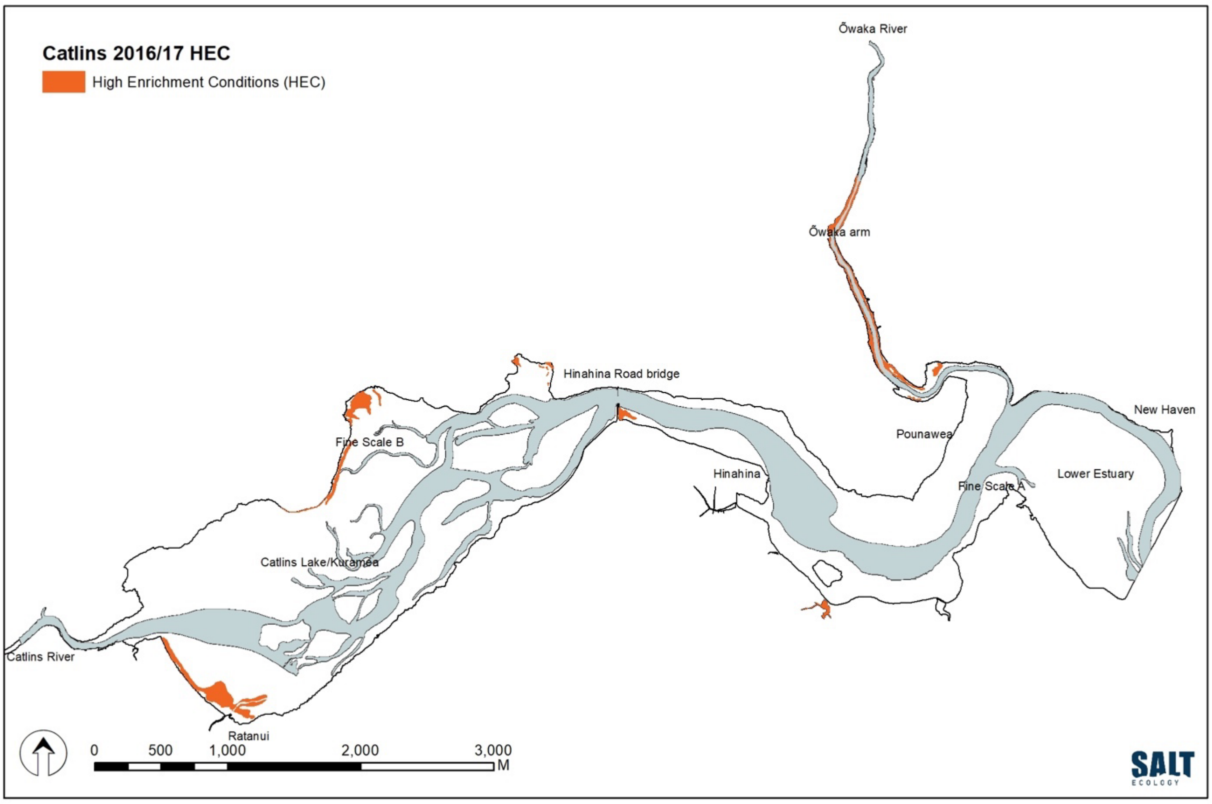


(b)

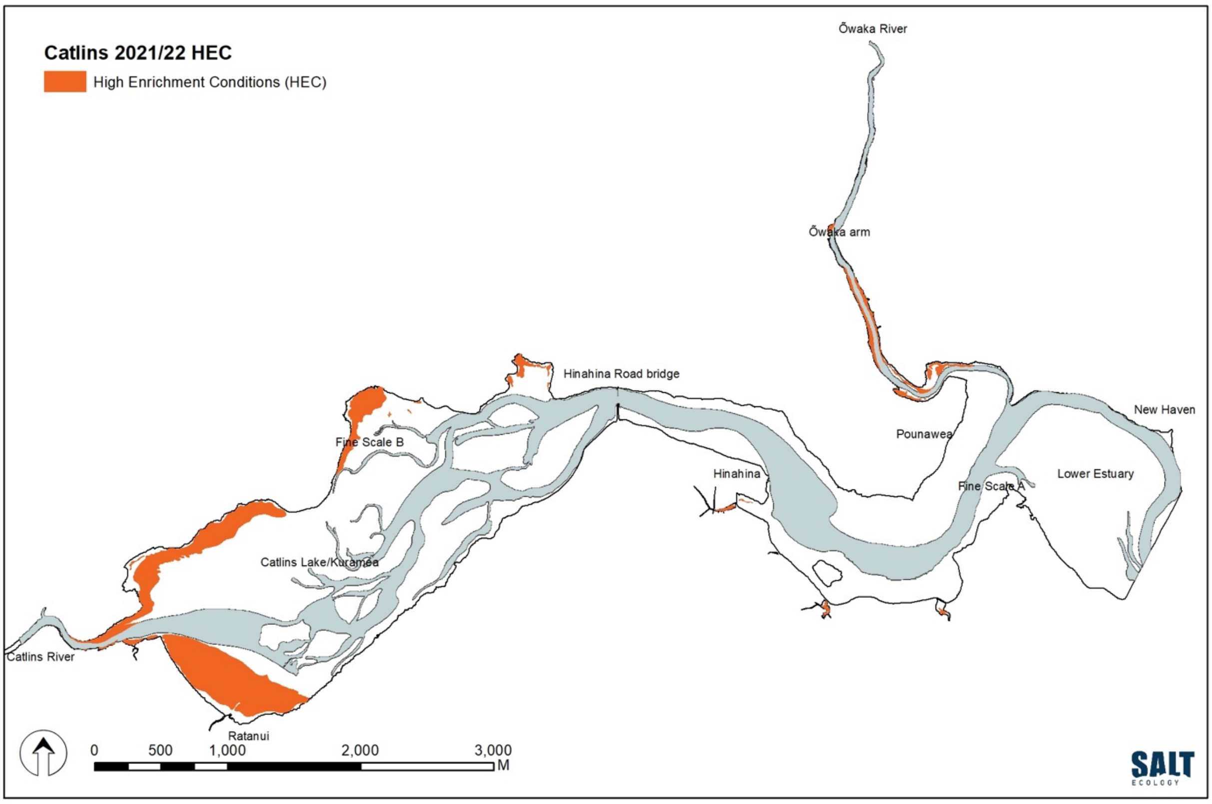

Catlins 2016/2017 Macroalgae
Biomass (g/m2)
Very high (>1450)
High (501 - 1450)
Moderate (201 - 500)
Low (101 - 200)
Very low (1 - 100)
Trace (<1)
Ōwaka River
Ōwaka arm
Hinahina Road bridge
New Haven
Pounawea
Hinahina
Fine Scale A
Lower Estuary
Fine Scale B
Catlins Lake/Kuramea
Catlins River
Ratanui
0
500
1,000
2,000
3,000
M
SALT ECOLOGY


Catlins 2021/22 Macroalgae
Biomass (g/m2)
Very high (>1450)
High (501 - 1450)
Moderate (201 - 500)
Low (101 - 200)
Very low (1 - 100)
Trace (<1)
Ōwaka River
Ōwaka arm
Hinahina Road bridge
New Haven
Pounawea
Hinahina
Fine Scale A
Lower Estuary
Fine Scale B
Catlins Lake/Kuramea
Catlins River
Ratanui
0
500
1,000
2,000
3,000
M
SALT ECOLOGY

(c)



Catlins 2016/17 HEC
High Enrichment Conditions (HEC)
Ōwaka River
Ōwaka arm
Hinahina Road bridge
New Haven
Pounawea
Fine Scale B
Hinahina
Lower Estuary
Fine Scale A
Catlins Lake/Kuramea
Catlins River
Ratanui
0 500 1,000 2,000 3,000 M
SALT ECOLOGY



Catlins 2021/22 HEC
High Enrichment Conditions (HEC)
Ōwaka River
Ōwaka arm
Hinahina Road bridge
New Haven
Pounawea
Fine Scale B
Hinahina
Lower Estuary
Fine Scale A
Catlins Lake/Kuramea
Catlins River
Ratanui
0 500 1,000 2,000 3,000 M
SALT ECOLOGY


SALT
ECOLOGY