SALT ECOLOGY

Synoptic Broad Scale Ecological Assessment of Catlins (Pounawea) Estuary

Prepared for

Otago Regional Council

August 2024

Salt Ecology
Report 144

Cover and back photo: Catlins (Pounawea) Estuary highlighting growths of *Gracilaria* spp. and *Pylaiella* sp. over very soft muds within the upper estuary (Catlins Lake), December 2023.

RECOMMENDED CITATION

Roberts KL, Scott-Simmonds T, Forrest BM, Stevens LM. 2024. Synoptic Broad Scale Ecological Assessment of Catlins (Pounawea) Estuary. Salt Ecology Report 144, prepared for Otago Regional Council, August 2024. 74p.

For the environment
Mō te taiao

Synoptic Broad Scale Ecological Assessment of Catlins (Pounawea) Estuary

Prepared by

Keryn Roberts,

Thomas Scott-Simmonds, Barrie Forrest,

and Leigh Stevens

for

Otago Regional Council

August 2024

keryn@saltecology.co.nz, +64 (0)21 0294 8546

www.saltecology.co.nz

For the environment
Mō te taiao

SALT
ECOLOGY

GLOSSARY

AA	Affected Area (OMBT metric)
AIH	Available Intertidal Habitat (OMBT metric)
AMBI	AZTI Marine Biotic Index
ANZG	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018)
aRPD	Apparent Redox Potential Discontinuity
CSR	Current Sedimentation Rate
As	Arsenic
Cd	Cadmium
Cr	Chromium
Cu	Copper
DGV	Default Guideline Value (ANZG 2018)
EQR	Ecological Quality Rating (OMBT metric)
ETI	Estuary Trophic Index
HEC	High Enrichment Conditions
Hg	Mercury
LCDB	Land Cover Data Base
NEMP	National Estuary Monitoring Protocol
Ni	Nickel
NSR	Natural Sedimentation Rate
OMBT	Opportunistic Macroalgal Blooming Tool
ORC	Otago Regional Council
Pb	Lead
QA/QC	Quality Assurance/Quality Control
SACFOR	Epibiota categories of Super abundant, Abundant, Common, Frequent, Occasional, Rare
SLR	Sea level rise
SIDE	Shallow, intertidally dominated estuary
SOE	State of Environment (monitoring)
TN	Total Nitrogen
TOC	Total Organic Carbon
TRP	Total Recoverable Phosphorus
TS	Total Sulphur
Zn	Zinc

ACKNOWLEDGEMENTS

Many thanks to Sam Thomas (ORC) for reviewing the draft report. We are also grateful to Hayden Rabel, Bryn Forrest and Sorrel O'Connell-Milne of Salt Ecology for field assistance and Hayden Rabel for support in the analysis and preparation of sediment quality and macrofauna data. The tools used to QA/QC the GIS data and produce summaries and maps were developed by Megan Southwick of Salt Ecology.

TABLE OF CONTENTS

FIGURES

TABLES

SUMMARY

In December 2023, a synoptic broad scale ecological assessment was conducted in Catlins (Pounawea) Estuary (hereafter Catlins), one of several estuaries in Otago Regional Council's (ORC) long-term State of the Environment (SOE) monitoring programme. This report describes dominant intertidal substrate and vegetation, an assessment of sediment quality (and associated biota) at discrete sites, and compares findings with previous surveys in 2008, 2012, 2016 and 2021. Historical data on seagrass and salt marsh extent were also derived from 1948, 1985 and 2006 imagery.

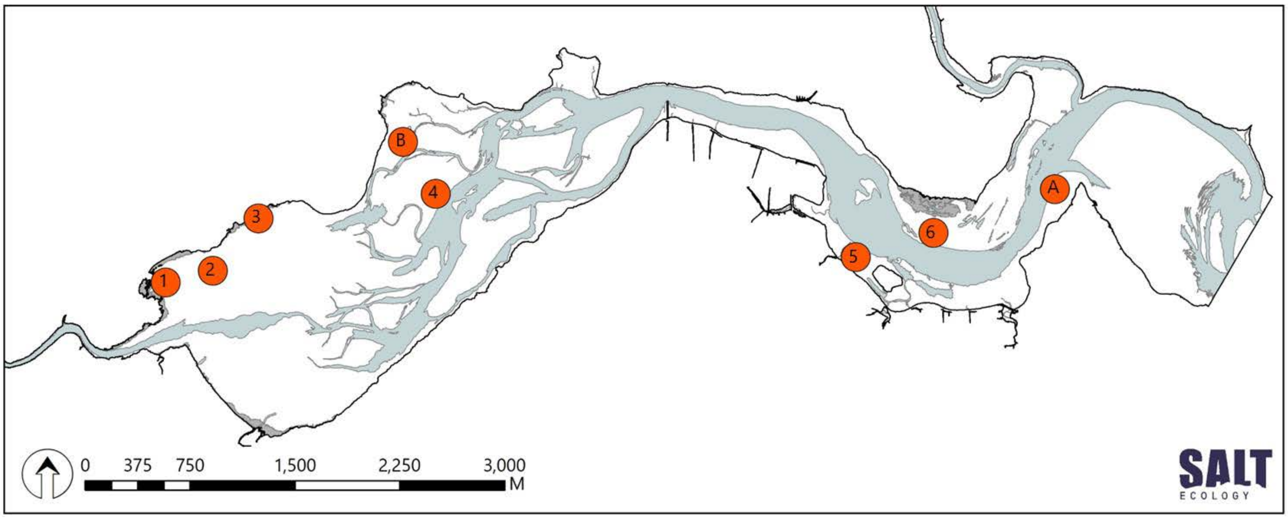
Key monitoring results are summarised below in order of importance, and assessed against preliminary condition rating criteria in the tables below and on the following page.

- Nuisance macroalgae beds first appeared in 2010 imagery and had expanded to Catlins Lake, the Ōwaka Arm, and southern embayments by 2016 (rated 'Fair'). By 2021, macroalgae had expanded further and the biomass increased in existing areas resulting in a condition rating of 'Poor'. In 2023, severe levels of enrichment and macroalgal decay were present with an increase in the extent of High Enrichment Conditions (HEC) (79ha, rated 'Poor'). Algal decay led to a decrease in biomass and contributed to the macroalgae index changing from 'Poor' to 'Fair'. However, this reflects worsening conditions rather than an improvement.
- In 2023, mud-elevated (≥25-100% mud) substrate covered 149ha or 26% of the available intertidal habitat, a condition rating of 'Poor'. These areas were located near the mouths of Catlins River, the Ōwaka River and smaller freshwater inputs and these areas have been muddy since at least 2008. Discrete sampling at mud-elevated sites showed a macrofaunal community dominated by hardy taxa that are resilient to elevated mud and disturbance.
- In 2023, an estimated 21% of historic salt marsh remains (rated 'Poor'), with present day salt marsh comprising only 2.3% of the intertidal area (rated 'Poor'). Losses are attributed to drainage for pasture and/or limited tidal exchange owing to roading infrastructure. Most losses occurred prior to 1948, with further losses occurring in the upper Catlins Lake between 1967 and 1975.
- In 2023, the well-flushed lower estuary supported healthy seagrass beds with a species-rich sediment biota community. Since 2006, there has been a 47% loss in high (≥50%) cover seagrass, a condition rating of 'Poor'. However, overall seagrass presence (1-100% cover) only decreased by ~10%, losses primarily from bed erosion and fragmentation south of Pounawea, and natural variability near river channels and at the estuary entrance.
- The lower catchment, including within the 200m terrestrial margin, was cleared in the early 1900's and is now dominated by pasture (72%). In 2023, dense vegetation covered 20% of the 200m terrestrial margin, rated 'Poor'.
- Sediment sampling in 2023 indicated low concentrations of trace metal contaminants. Sand-dominated substrates were generally well-oxygenated with moderate to low nutrient concentrations. Mud-dominated sediments in the upper Catlins Lake were poorly oxygenated, organically enriched and had high nutrient concentrations.

Broad Scale Indicators	Unit	2006#	2016	2021^	2023
200m terrestrial margin	% densely vegetated	nd	23.2	nd	20.0
Mud-elevated substrate	% AIH[1] area (≥25% mud)	nd	23.6	nd	25.9
Macroalgae (OMBT-EQR[2])	Ecological Quality Rating (EQR)	>0.8*	0.615	0.386	0.533
Seagrass (≥50% cover)	% decrease from baseline	baseline	8.7	11.5	47.6
Salt marsh extent (current)	% of intertidal area	2.3	1.9	nd	2.3
Historical salt marsh extent[3]	% of historical remaining	21.6	18.9	nd	20.8
High Enrichment Conditions	ha	nd	14.9	74.6	79.4
High Enrichment Conditions	% of estuary	nd	2.9	12.5	13.8

[1]Available Intertidal Habitat excludes salt marsh area; [2]Opportunistic Macroalgal Blooming Tool (OMBT) scores have been updated following Stevens et al. (2022); [3]Estimated natural extent see Appendix 5; nd= no data. *Estimated. #2006 represents a desktop appraisal of seagrass, macroalgae and salt marsh. ^Seagrass and macroalgae survey only.

Very Good	Good	Fair	Poor



Fine Scale Indicators	Unit	1	2	3	B	4	5	6	A
		Site							
Mud	%	79.5	70.9	76.1	28.1	6.0	3.6	21.3	3.5
aRPD	mm	3	2	1	40	50	20	5	25
TN	mg/kg	2000	5900	7900	600	300	300	500	300
TP	mg/kg	580	920	1190	360	200	260	360	240
TOC	%	2.2	5.8	7.0	0.5	0.2	0.3	0.4	0.1
TS	%	0.5	0.8	1.3	0.09	0.07	0.05	0.1	0.03
As	mg/kg	3.7	6.2	5.6	3.7	2.9	4.4	4.6	5.5
Cd	mg/kg	0.08	0.09	0.16	0.02	0.01	0.01	0.04	0.02
Cr	mg/kg	10.4	14.8	17.7	8.5	6.0	6.9	9.6	6.0
Cu	mg/kg	7.9	12.2	15.4	4.7	3.0	3.2	5.3	2.2
Hg	mg/kg	0.03	0.05	0.06	<0.02	<0.02	<0.02	<0.02	<0.02
Ni	mg/kg	7.2	9.7	10.8	5.8	4.1	4.4	6.7	3.5
Pb	mg/kg	5.1	8.9	10.7	2.7	1.5	1.9	2.8	1.3
Zn	mg/kg	47.0	56.0	65.0	27.0	17.9	16.6	25.0	12.0
AMBI	na	5.3	3.3	4.8	4.3	3.4	3.4	1.7	1.7

See Glossary for abbreviations. < Values below lab detection limit.

Overall, Catlins has extensive areas of mud-elevated sediments and is expressing symptoms of eutrophication in the form of nuisance macroalgae, poor sediment quality (e.g., high nutrients and poor sediment oxygenation) and enrichment tolerant species. The worsening condition of Catlins, particularly over the last decade, highlights the urgent need to manage nutrient and sediment loads.

RECOMMENDATIONS

Monitoring

- Undertake targeted macroalgae and seagrass monitoring every 3-years with a full broad scale survey every ~6-years to track changes in the dominant features of the estuary.
- Review the SOE programme, and assess monitoring needs in Catlins alongside priorities for other estuaries.

Management

- Maintain records of major catchment land use changes (e.g., forest clearance, road development, pastoral conversion, exotic afforestation), and any significant flood events that may impact the estuary.
- Improve characterisation of estuary sediment and nutrient loads, evaluate potential catchment nutrient and sediment sources, and investigate options for a reduction of inputs where loads exceed guidance thresholds.
- Continue with the ORC objective setting programme that aims to maintain or improve current estuary state by reducing sediment and nutrient loads to levels that prevent significant ecological degradation.
- Develop a strategy for ecological restoration and protection that builds on previous work by Stevens (2023).

1. INTRODUCTION

Estuary monitoring is undertaken by most councils in New Zealand as part of their State of the Environment (SOE) programmes. The most widely-used monitoring framework is that outlined in New Zealand's National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002). The NEMP is intended to provide resource managers nationally with a scientifically defensible, cost-effective and standardised approach for monitoring the ecological status of estuaries in their region. The results establish a benchmark of estuarine health in order to better understand human influences, and against which future comparisons can be made. The NEMP approach involves two main types of survey:

- Broad scale mapping of estuarine intertidal habitats. This type of monitoring is typically undertaken every 5 to 10 years.
- Fine scale monitoring of estuary biota and sediment quality. This type of detailed monitoring is typically conducted at 2-3 fixed sites in the dominant habitat of the estuary and is repeated at intervals of ~5 years after initially establishing a multi-year baseline.

The approaches are intended to detect and understand changes in estuaries over time, with a particular focus on changes in habitat type (e.g., salt marsh or seagrass), as well as changes within habitats from the input of nutrients, fine (muddy) sediments and contaminants, which are key drivers of degraded estuary sediment condition as well as of eutrophication symptoms such as prolific macroalgal (seaweed) growth.

Otago Regional Council (ORC) has undertaken monitoring of selected estuaries in the region since 2005 using NEMP methods (or variations of that approach) with key locations being (from north to south) Kakanui, Shag, Pleasant River, Waikouaiti, Blueskin Bay, Pūrākaunui, Papanui, Hoopers Inlet, Kaikorai, Tokomairiro, Akatore, Catlins, Tahakopa (Papatowai), Tautuku and Waipati (Chaslands) estuaries. The current report describes the methods and results of a synoptic broad scale ecological assessment undertaken on 5-9 December 2023 in Catlins (Pounawea) Estuary (hereafter Catlins; Fig. 1).

The purpose of the work was to characterise substrate, salt marsh, and the presence and extent of any seagrass or macroalgae using NEMP broad scale mapping approaches, and to compare findings to previous broad-scale surveys undertaken in 2008, 2012, 2016 and 2022 (Stewart & Bywater 2009; Stewart 2012; Stevens & Robertson 2017; Stevens & Roberts 2022). In addition, a synoptic assessment of sediment quality and biota was undertaken at representative sites throughout the estuary, using some of the same indicators typically used for NEMP fine scale monitoring. The purpose of this additional work was to provide information on the ecological condition of unvegetated habitats to support the broad scale assessment.

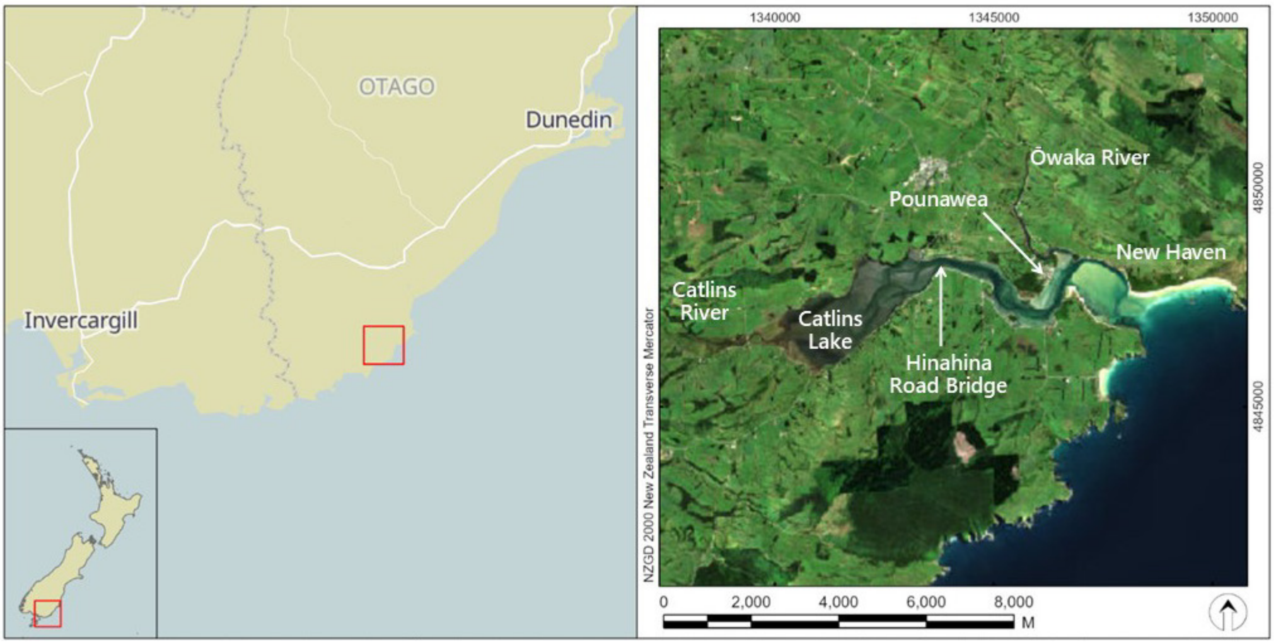


Fig. 1. Location of Catlins Estuary, Otago.

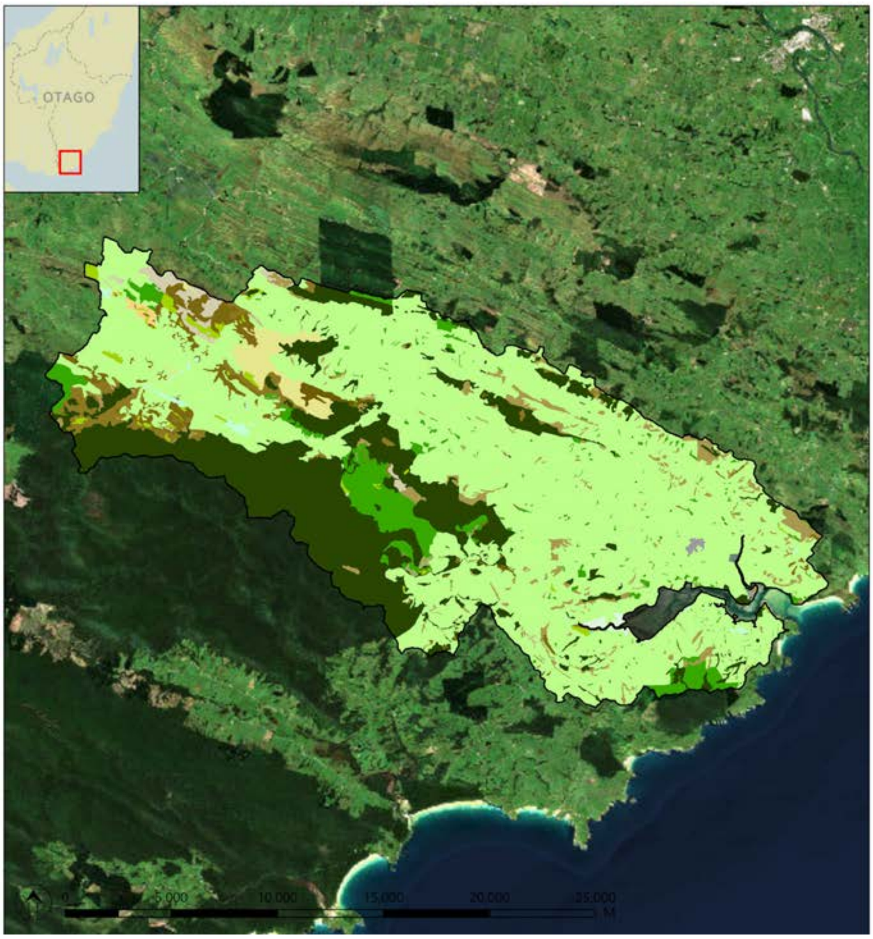
2. OVERVIEW OF CATLINS

Background information on Catlins has been presented in previous reports (Stewart & Bywater 2009; Stewart 2012; Stevens & Robertson 2017; Stevens & Roberts 2022). This information is summarised below.

Catlins is a large (~830ha), shallow, intertidally dominated estuary (SIDE). It discharges into the Pacific Ocean through a permanently open tidal mouth located east of the small settlement of Pounawea (Fig. 1). The estuary is fed by two main rivers: the Catlins (Pounawea) River, with a mean flow of 3.7m^3/s and a TN load of ~24mg/m^2/day, and the Ōwaka River, with a mean flow of 2.6m^3/s and a TN load of 31mg/m^2/day (NIWA CLUES 10.3). The Ōwaka River flows north of Pounawea into the eastern basin near the entrance, which has strong tidal flushing (<0.5 days; Plew & Dudley 2018) and is dominated by sands. The Catlins (Pounawea) River flows from the west into the upper estuary, known as Catlins/Kuramea Lake (hereafter Catlins Lake). Compared to the eastern basin, this area is muddier, relatively shallow and more susceptible to nutrient problems due to its restricted flushing (~5 days; Plew & Dudley 2018), likely exacerbated by the narrowing of estuary for the Hinahina Road bridge.

Catlins' permanently open tidal mouth, east of Pounaewa.

Both rivers drain a combined catchment area of approximately 410km^2 with the dominant land cover high-producing grassland (62%) primarily used for sheep and beef grazing, with smaller areas of dairy present, particularly in the Ōwaka catchment (Yang 2022). Exotic plantation forestry accounts for 5% of the total catchment area, with the largest area within the Catlins (Pounawea) River catchment. While the Catlins (Pounawea) River has a higher flow, the modelled nutrient loads are higher in the Ōwaka River, likely because a larger portion of the Catlins River catchment comprises native forest or scrub (i.e., 41% compared to 15% in the Ōwaka River catchment; Fig. 2).



Catchment Land Use in 2018	ha	%
Artificial Surfaces		
Built-up Area (settlement)	59.0	0.1
Surface Mines and Dumps	0	0
Transport Infrastructure	0	0
Urban Parkland/Open Space	15.3	0.0
Bare or Lightly Vegetated Surfaces		
Sand and Gravel	1.6	0.0
Landslide	0	0
Alpine Grass/Herbfield	0	0
Gravel and Rock	0	0
Water Bodies		
River, Lake or Pond	5.4	0.0
Cropland		
Short-rotation Cropland	66.4	0.2
Orchard Vineyard and Other Perennial Crops	0	0
Grassland, Sedge and Saltmarsh		
High Producing Exotic Grassland	25,360.7	61.8
Low Producing Grassland	345.6	0.8
Tall Tussock Grassland	687.8	1.7
Depleted Grassland	0	0
Herbaceous Freshwater Vegetation	144.2	0.4
Herbaceous Saline Vegetation	98.7	0.2
Flaxland	1.9	0.0
Scrub and Shrubland		
Fernland	129.9	0.3
Gorse and/or Broom	897.8	2.2
Manuka and/or Kanuka	822.1	2.0
Broadleaved Indigenous Hardwoods	1,338.7	3.3
Sub Alpine Shrubland	0	0
Mixed Exotic Shrubland	19.6	0.0
Matagouri or Grey Scrub	406.7	1.0
Forest		
Forest Harvested	65.8	0.2
Deciduous Hardwoods	25.7	0.1
Indigenous Forest	8,359.4	20.4
Exotic Forest	2,168.3	5.3
	41,020.4	100.0

Fig. 2. Catlins Estuary catchment land use classifications from the Land Cover Database (LCDB5 2017/2018).

Between 1865 and 1970, the main industry in the Catlins was the harvest and milling of native timber, such as rimu, matai, and miro. In the late 1800s, timber was transported by rivers and shipped from the coast. However, the expansion of roads and advent of rail in 1896 in Ōwaka township ~3km north of the estuary, and improved harvest and milling technology, increased the timber industry's output. Today, only small areas of remnant virgin podocarp forest (rimu, totara, matai, kahikatea and miro) remain around the estuary margin and in the upper Catlins (Pounawea) River catchment.

Drainage channels cut through historic areas of salt marsh at the head of Catlins Lake.

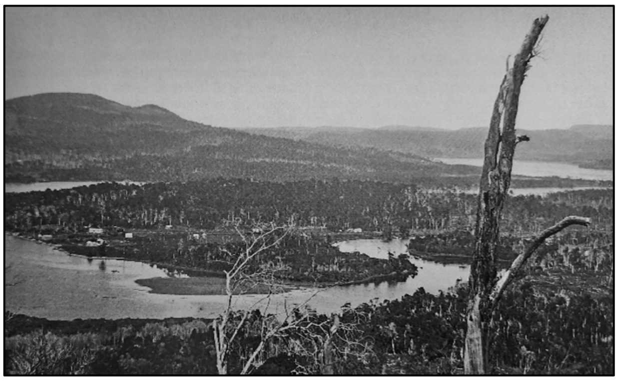


Photo taken in 1906 from Jacobs Hill looking over the town of Pounawea and Ōwaka River with Catlins Lake in the background. Dense native forest surrounds most of the estuary (source: Patrick Collection in Tyrrell 1989).

Large scale historic modification of the estuary, combined with contemporary nutrient inputs, has resulted in the significant expansion of high biomass, entrained macroalgae since 2010, particularly in Catlins Lake. The affected area now has widespread sediment degradation including poor oxygenation, increased organic content and a build-up of mud-dominated sediments. In 2022, localised areas of macroalgal dieback indicated that sediment conditions were so poor that macroalgae were no longer able to survive. Stevens & Roberts (2022) highlighted that in 2021 conditions in the estuary were worsening and catchment nutrient loads exceeded the assimilative capacity of the estuary, with problems expected to persist without significant reductions in nutrient inputs, particularly in the Catlins River (Plew & Dudley 2018).

Hinahina Road bridge (1926) looking south, with native vegetation cover on the estuary margin (source: Alexander Turnball Library, Wellington, New Zealand).

Entrained beds of *Gracilaria* spp. in Catlins Lake, December 2023.

In addition to forest clearance for timber, historically large areas of salt marsh and wetland bordering the estuary were drained and reclaimed for farming. The relatively small area of wetland remaining is located at the head of Catlins Lake and is classified as a regionally significant wetland and is an important habitat for waterfowl and nationally threatened fish species including the giant kokopu (*Galaxias argenteus*; Otago Regional Plan: Water 2004). The estuary itself is also an important habitat for marine and freshwater fish, and as a coastal recreation area for boating, swimming, fishing and walking. It is listed as a coastal protection area with Kai Tahu cultural and spiritual values (Otago Regional Plan: Water 2004).

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, and seagrass. In the last decade persistent blooms of macroalgae, a symptom of eutrophication, have established, indicating estuary condition is deteriorating.

3. METHODS

3.1 OVERVIEW

The survey of Catlins was carried out on 5-9 December 2023. It consisted of broad scale habitat mapping of substrates and vegetation, and targeted sampling of sediment quality and macrofauna in representative areas. Fig. 3 shows the estuary area surveyed and indicates where sampling was undertaken. The survey approach is summarised below and in Table 1 and 2, with further detail of sampling methods and analyses provided in Appendix 1.

Broad-scale habitat mapping at the head of Catlins Lake.

3.2 BROAD SCALE HABITAT MAPPING

Broad scale mapping characterised the dominant intertidal substrates and vegetation types, with the spatial extent and location of different habitat types, and temporal changes in features, providing valuable indicators of estuary condition. Mapping was based on NEMP methods (Robertson et al. 2002), and included refinements by Salt Ecology that improve the utility and accuracy of the NEMP approach as summarised in Table 1, and detailed in Appendix 1.

The approach combined the use of satellite and aerial imagery, detailed field ground-truthing (e.g., annotation of aerial images, spot data on macroalgae and substrate type, and field photos), and post-field digital mapping using Geographic Information System (GIS) technology. Imagery for Catlins was sourced from Apollo Mapping (Colorado) and consisted of 30cm/pixel colour satellite imagery captured 29 October 2023 and 30cm/pixel aerial imagery captured 5 February 2021. QA/QC procedures, applied through the phases of field data collection, digitising, and GIS data collation and processing, are described in Appendix 1.

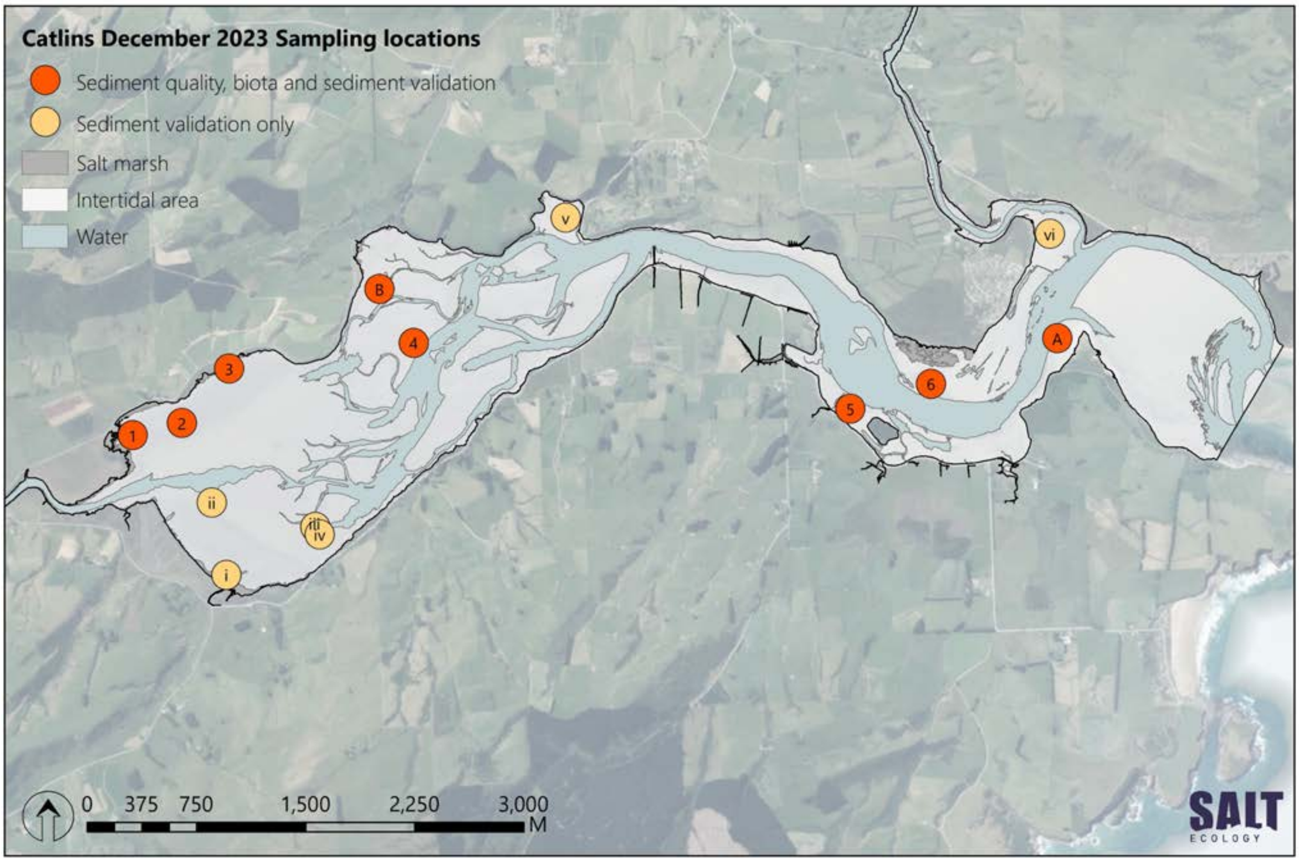


Fig. 3. Sediment quality, biota (Sites 1-6 & A-B) and sediment validation (Sites i-vi) samples, Catlins Estuary, December 2023.

GIS layers for 2008, 2012, 2016 and 2022 were also QA/QC checked. Surveys from 2008 and 2012 were found to contain many digitising errors, and incomplete or missing data, which prevented its use in any temporal comparisons.

The main broad scale survey elements were as follows:

- Substrate mapping subjectively classified sediments (e.g., mud, sand, gravel, cobble, bedrock) according to the scheme described in Table A2 of Appendix 1. As mud is a key stressor on estuary habitats, an important focus was to map the spatial extent of soft-sediment (mud and sand) habitats, with laboratory analyses of grain size collected from 14 representative locations (Fig. 2) used to validate field classifications.
- Vegetation mapping characterised high-value features, namely salt marsh (e.g., rushland, herbfield, estuarine scrub) and seagrass (*Zostera muelleri*), and also described the occurrence and extent of algae species that can be symptomatic of estuary degradation. Particularly important among the latter were nuisance 'opportunistic' macroalgae that can 'bloom' in response to conditions such as excess nutrient inputs.

To assist with percent cover estimates of seagrass and opportunistic macroalgae, a visual rating scale was used as shown in Fig. 4. For macroalgae, field data collection also included wet-weighing of macroalgae biomass, to enable calculation of Opportunistic Macroalgal Blooming Tool (OMBT) scores. The OMBT is a multi-metric index that combines different measures of opportunistic macroalgal proliferation to inform ecological condition (see Table 1; Appendix 1; WFD-UKTAG 2014; Stevens et al. 2022). OMBT scores from previous monitoring years have been recalculated using the method in Stevens et al. (2022).

Very soft muds in the upper Catlins Lake (top) and mobile sands in the lower estuary (bottom).

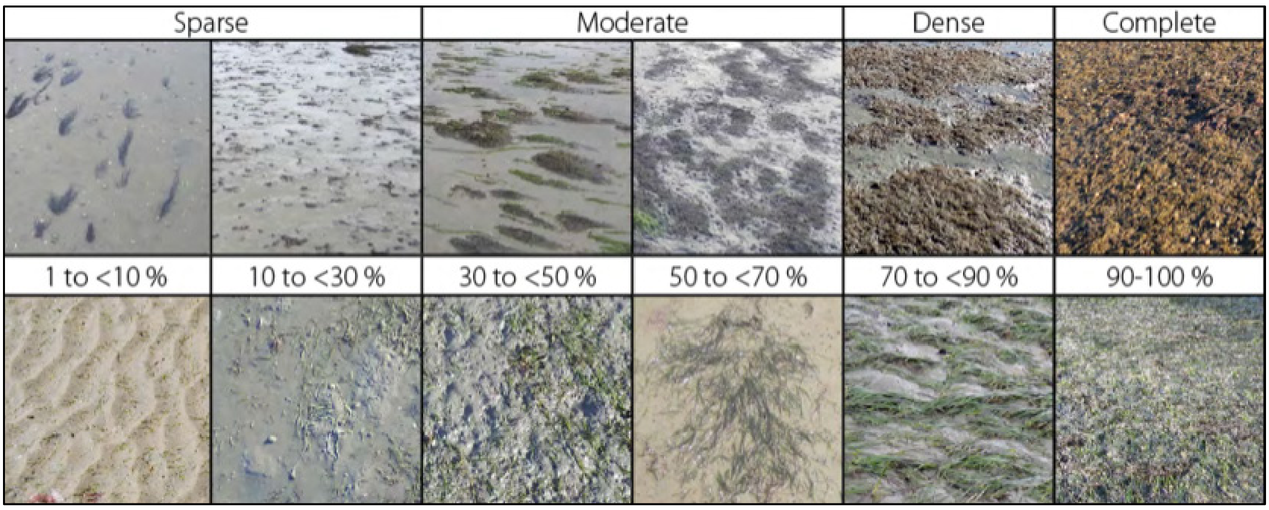


Fig. 4. Visual rating scale for % cover estimates of macroalgae and seagrass. Modified from FGDC (2012).

Table 1. Broad scale indicators of estuary condition that are assessed by field mapping and related methods.

Indicator	General rationale	Method description
Terrestrial margin vegetation	A densely vegetated terrestrial margin filters and assimilates sediment and nutrients, is a buffer to introduced grasses and weeds, is an important food source and habitat for a variety of species and, in waterway riparian zones, provides shade that moderates stream temperature fluctuations, and improves estuary biodiversity.	Mapped based on aerial extent and classified using the LCDB5 classes, dominant species are also recorded as meta data where known.
Substrate type	High substrate heterogeneity generally supports high estuary biodiversity. Increases in fine sediment (i.e., mud <63µm) can reduce heterogeneity, concentrate contaminants, nutrients and organic matter, and lead to degradation of benthic communities by displacing sensitive species including shellfish. Enrichment of muddy sediments (i.e., high TOC and nutrients; Table 2) can additionally fuel algal growth and deplete sediment oxygen.	Mapped based on aerial extent and classified using a modified version of the NEMP system (see Table A2, Appendix 1). The improved classification framework, developed by Salt Ecology, characterises substrate type based on mud content and is supported by grain size validation samples. Substrate type is also recorded beneath vegetation.
Salt marsh	Salt marsh (vegetation able to tolerate saline conditions where terrestrial plants are unable to survive) is important in estuaries as it is highly productive, naturally filters and assimilates sediment and nutrients, mitigates shoreline erosion, and provides an important habitat for a variety of species including insects, fish and birds.	Mapped based on aerial extent. Dominant salt marsh species are recorded and categorised into sub-classes (e.g., rushland, herbfield). Pressures on salt marsh (e.g., drainage, grazing, erosion) are also recorded.
Seagrass	Seagrass (*Zostera muelleri*) beds enhance primary production and nutrient cycling, stabilise sediments, elevate biodiversity, and provide nursery and feeding grounds for invertebrates and fish. Seagrass is vulnerable to muddy sediments in the water column (reducing light), sediment smothering (burial), excessive nutrients (primarily secondary impacts from macroalgal smothering), and sediment quality (e.g., low oxygenation).	Mapped based on aerial extent, and percent cover recorded within each seagrass patch. Pressures on seagrass beds (e.g., sediment or macroalgae smothering, leaf discolouration) are also recorded.
Opportunistic macroalgae	Opportunistic macroalgae (species of *Gracilaria* and *Ulva*) are a symptom of estuary eutrophication (nutrient enrichment). At nuisance levels, these algae can form mats on the estuary surface that can adversely impact underlying sediments and fauna, other algae, fish, birds, seagrass, and salt marsh. The Opportunistic Macroalgal Blooming Tool (OMBT) is a multi-metric index that combines different measures of macroalgae (see text) and is calculated as an indicator of ecological condition.	Mapped based on aerial extent. Species, percent cover, biomass and level of entrainment are recorded in each macroalgae patch to apply the OMBT (WFD-UKTAG 2014). The application of the OMBT incorporates New Zealand-based improvements described in Stevens et al. (2022).
High Enrichment Conditions	HECs characterise substrates with extreme levels of organic or nutrient enrichment (i.e., eutrophication). HECs are sediments depleted in (or devoid of) oxygen, which have a very shallow aRPD (e.g., <10mm), an intense black colour in the sediment profile, and typically have a strong hydrogen sulfide (i.e., rotten egg) smell. Sediment samples are likely to have a quantitatively high nutrient or organic content (e.g., TOC >2%). In a broad scale context, the HEC metric is intended as an initial guide to highlight areas of enrichment that may require further investigation.	Mapped based on aerial extent where there are obvious low sediment oxygen conditions (e.g., black sediments with rotten egg smell), conspicuous surface growths of sulfur-oxidising bacteria, stable, entrained, dense (>50% cover) beds of opportunistic macroalgae, or the extensive presence of surface micro-algae or filamentous-algae.

3.3 SEDIMENT QUALITY AND BIOTA

Sampling of sediment quality and associated biota was undertaken in representative soft-sediment habitats at eight discrete sites (Fig. 3). Table 2 summarises sediment and biota indicators, field sampling methods, and the rationale for their use. These indicators, and the associated sampling methods, largely adhered to the NEMP protocol for 'fine scale' surveys of estuaries (except as noted in Table 2). However, whereas NEMP fine scale surveys involve intensive (high replication) sampling of 1-3 sites (typically) in the most common estuary habitat, the current survey had a less intensive, estuary-wide focus to provide a synoptic picture of ecological health across the range of soft-sediment habitat types present in the estuary. The key sampling elements can be summarised as follows:

Sediment quality: Indicators included sediment mud content, oxygenation status (measured as the apparent Redox Potential Discontinuity depth; aRPD), nutrients, organic content, and chemical contaminants (selected trace elements). Sediment aRPD was measured in the field. For the other variables a single sample for sediment quality analyses at each site was composited from three sub-samples, and sent to Hill Labs for analysis.

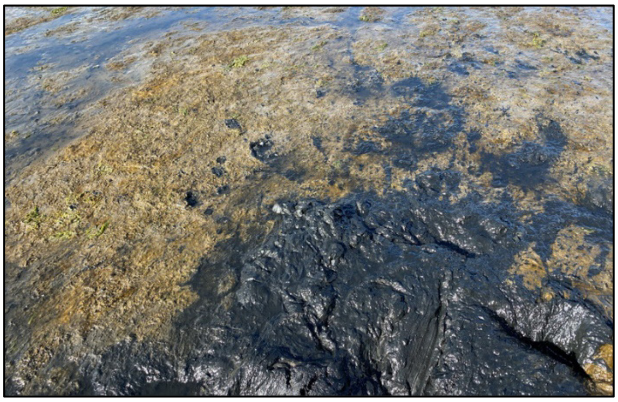
Biota: Macrofauna, which are small organisms that live within or on the sediment matrix and are retained on a 0.5mm sieve, were sampled quantitatively using sediment cores (130mm diameter, 150mm deep). The composition of the core samples in terms of macrofauna species (or higher taxa) and their abundance, was determined by taxonomic experts at NIWA. We also used qualitative field methods to estimate the abundance or percent cover of conspicuous surface-dwelling estuary snails, macroalgae and microalgae.

In addition to the raw indicator data, three measures of macrofauna health were derived. Two of these (richness and abundance) are simple measures that describe the number of different species present in a sample (i.e., richness), and total organism abundance. A third derived variable ('AMBI') was also calculated. The AMBI is an international biotic health index (Borja et al. 2000) whose calculation is based on the proportion of macrofauna species falling into one of five eco-groups (EG) that reflect sensitivity to pollution, ranging from relatively sensitive (EG-I) to relatively resilient (EG-V).

The QA/QC procedures applied through the phases of field data collection, lab dispatch of samples, data transfer, macrofauna naming, EG standardisation, and other QA procedures, are described in Appendix 1.

Sediment core sampling for macrofauna at Site 4 in the lower Catlins Lake.

Visual assessment of the depth of sediment oxygenation, as defined by the aRPD depth at Site A in the lower estuary.



Sediment devoid of oxygen, as evidenced by the black colouring, at Site 3 in the upper Catlins Lake.

Table 2. NEMP sediment quality and biota indicators, rationale for their use, and sampling method. Any significant departures from the NEMP are described in footnotes.

Indicator	General rationale	Sampling method
Physical and chemical		
Sediment grain size	Indicates the relative proportion of fine-grained sediments that have accumulated.	Composited surface scrape to 20mm sediment depth.
Nutrients (nitrogen and phosphorus), organic matter & total sulfur	Reflects the enrichment status of the estuary and potential for algal blooms and other symptoms of enrichment.	Surface scrape to 20mm sediment depth. Organic matter measured as Total Organic Carbon (TOC)[1].
Trace elements (arsenic copper, chromium, cadmium, lead, mercury, nickel, zinc)	Common toxic contaminants generally associated with human activities. High concentrations may indicate a need to investigate other anthropogenic inputs, e.g., pesticides, hydrocarbons.	Surface scrape to 20mm sediment depth[2].
Substrate oxygenation (apparent Redox Potential Discontinuity depth; aRPD)	Measures the enrichment/trophic state of sediments according to the depth of the aRPD. This is the visual transition between brown oxygenated surface sediments and deeper less oxygenated black sediments. The aRPD can occur closer to the sediment surface as organic matter loading or sediment mud content increase.	Sediment core, split vertically, with average depth of aRPD recorded in the field where visible.
Biological		
Macrofauna	Abundance, composition and diversity of infauna living with the sediment are commonly-used indicators of estuarine health.	130mm diameter sediment core to 150mm depth (0.013m^2 sample area, 2L core volume), sieved to 0.5mm to retain macrofauna.
Epibiota (epifauna)	Abundance, composition and diversity of epifauna are commonly-used indicators of estuarine health.	Abundance based on SACFOR in Appendix 1, Table B3[3].
Epibiota (macroalgae)	The composition and prevalence of macroalgae are indicators of nutrient enrichment.	Percent cover based on SACFOR in Appendix 1, Table B3[3].
Epibiota (microalgae)	The prevalence of microalgae is an indicator of nutrient enrichment.	Visual assessment of conspicuous growths based on SACFOR in Appendix 1, Table B3[3, 4].

[1] Since the NEMP was published, Total Organic Carbon (TOC) has become available as a routine low-cost analysis which provides a more direct and reliable measure than the NEMP recommendation of converting Ash Free Dry Weight (AFDW) to TOC.

[2] Arsenic and mercury are not specified in the NEMP, but can be included in the trace element suite by the analytical laboratory.

[3] Assessment of epifauna, macroalgae and microalgae uses SACFOR instead of quadrat sampling outlined in the NEMP. Quadrat sampling is subject to considerable within-site variation for epibiota that have clumped or patchy distributions.

[4] NEMP recommends taxonomic composition assessment for microalgae but this is not typically undertaken due to clumped or patchy distributions and the lack of demonstrated utility of microalgae as a routine indicator.

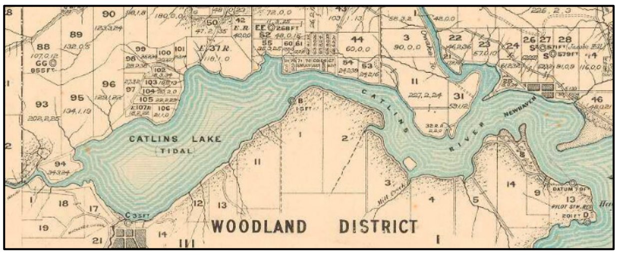
Catlins Lake, looking upstream, on the southern margin.

3.4 ASSESSMENT OF ESTUARY CONDITION

In addition to the authors' expert interpretation of the data and summaries, results are assessed against established or developing estuarine health metrics ('condition ratings'), drawing on approaches from New Zealand and overseas (Table 3). These metrics assign different indicators to one of four colour-coded 'health status' bands, as shown in Table 3.

In previous reports for ORC, scores have been calculated for the New Zealand Estuary Trophic Index (ETI; Robertson et al. 2016). The ETI is a multi-metric index developed in New Zealand to provide a single score for estuary health. However, as the ETI documentation provides no clear guidance on the estuary area (and associated data) that should be used for the calculation, ETI scores can vary according to the data choices made; for example, whether scores are calculated from the most degraded sections of an estuary, or for the estuary overall. As such, we have deferred the further application of the ETI approach until the methodology issues are resolved.

Salt marsh and seagrass rely on assessment of differences between current state and historical or baseline state. To determine historical state, we assessed aerial imagery captured from 1948, 1975, 1985, 1995 (source: retrolens.co.nz), 2006 (source: data.linz.govt.nz) and 2010 (Google Earth Imagery). Where required, imagery was merged and georectified. To estimate natural salt marsh extent, imagery, LiDAR contours (Stevens 2023) and hand-drawn survey maps from the late 1890's and early 1900's were also used. Where imagery was of suitable resolution and tide height (1948, 1985, 2006), historical salt marsh and/or seagrass was digitised following the same principles described in Section 3.2 and Appendix 1 for each of the imagery years. As it is difficult to reliably map seagrass areas with <50% cover solely from aerial imagery (i.e., no ground-truthing), comparisons between historical extents and recent surveys were limited to categories with ≥50% seagrass cover.



Survey map of Catlins Estuary from 1892 (sourced: LINZ; Crown Copyright reserved).


Seagrass at the estuary entrance, December 2023.


Aerial image from 1985 showing areas of salt marsh, and small patches of seagrass in Catlins Lake and toward the entrance.

Table 3. Indicators and condition ratings used to assess results in the current report. See Glossary for definitions.

a. Broad scale

Indicator	Unit	Very good	Good	Fair	Poor
Mapped indicators					
200m terrestrial margin[1]	% densely vegetated	≥80 to 100	≥50 to 80	≥25 to 50	<25
Mud-elevated substrate[2, 3]	% intertidal area >25% mud	<1	1 to 5	>5 to 15	>15
Macroalgae (OMBT)[2,4]	Ecological Quality Rating	≥0.8 to 1.0	≥0.6 to <0.8	≥0.4 to <0.6	0.0 to <0.4
Seagrass (≥50% cover)[1]	% decrease from baseline	<5	≥5 to 10	≥10 to 20	≥20
Salt marsh extent (current)[1]	% of intertidal area	>20	>10 to 20	>5 to 10	0 to 5
Historical salt marsh extent[1,5]	% historical remaining	≥80 to 100	≥60 to 80	≥40 to 60	<40
High Enrichment Conditions[1,6]	ha	<0.5	≥0.5 to 5	≥5 to 20	≥20
High Enrichment Conditions[1,6]	% AIH	<1	≥1 to 5	≥5 to 10	≥10
Estuary-wide sedimentation indicators					
Mean sedimentation ratio[2,7]	CSR:NSR ratio	1 to 1.1 x NSR	>1.1 to 2	>2 to 5	>5
Sedimentation rate[8]	mm/yr	<0.5	≥0.5 to <1	≥1 to <2	≥2

1. General guidance as used in SOE reports for council(s) since 2007.
2. Ratings derived from Robertson et al. (2016).
3. Mud-elevated substrate modified from Robertson et al. (2016) to apply to the intertidal area excluding salt marsh, not the whole estuary area.
4. OMBT = Opportunistic Macroalgal Blooming Tool (WFD-UKTAG 2014).
5. Estimated from historic aerial imagery.
6. The final condition rating is based on the worst of the two High Enrichment Condition (HEC) scores.
7. Current Sedimentation Rate (CSR) to Natural Sedimentation Rate (NSR) ratio derived from catchment models (Hicks et al. 2019).
8. Condition rating adapted from Townsend and Lohrer (2015). Sedimentation rate derived from catchment models (Hicks et al. 2019).

b. Sediment quality and macrofauna

Indicator	Unit	Very good	Good	Fair	Poor
Sediment quality and macrofauna					
Mud content[1]	%	<5	5 to <10	10 to <25	≥25
aRPD depth[2]	mm	≥50	20 to <50	10 to <20	<10
TN[1]	mg/kg	<250	250 to <1000	1000 to <2000	≥2000
TP	mg/kg	Requires development			
TOC[1]	%	<0.5	0.5 to <1	1 to <2	≥2
TS	%	Requires development			
Macrofauna AMBI[1]	na	0 to 1.2	>1.2 to 3.3	>3.3 to 4.3	≥4.3
Sediment trace contaminants[3]					
As	mg/kg	<10	10 to <20	20 to <70	≥70
Cd	mg/kg	<0.75	0.75 to <1.5	1.5 to <10	≥10
Cr	mg/kg	<40	40 to <80	80 to <370	≥370
Cu	mg/kg	<32.5	32.5 to <65	65 to <270	≥270
Hg	mg/kg	<0.075	0.075 to <0.15	0.15 to <1	≥1
Ni	mg/kg	<10.5	10.5 to <21	21 to <52	≥52
Pb	mg/kg	<25	25 to <50	50 to <220	≥220
Zn	mg/kg	<100	100 to <200	200 to <410	≥410

1. Ratings from Robertson et al. (2016).
2. aRPD based on FGDC (2012).
3. Trace element thresholds scaled in relation to ANZG (2018) as follows: Very good <0.5 x DGV; Good 0.5 x DGV to <DGV; Fair DGV to <GV-high; Poor >GV-high. DGV = Default Guideline Value, GV-high = Guideline Value-high.

4. BROAD SCALE MAPPING

A summary of the December 2023 mapping survey undertaken in Catlins is provided below, with ground-truthing tracks shown in Appendix 2. Supporting GIS files have been supplied separately to ORC.

4.1 TERRESTRIAL MARGIN

Table 4 and Fig. 5 summarise the land cover of the 200m terrestrial margin, which is primarily high producing grassland (38%) and low producing grassland (34%). Like the wider catchment, most of the pasture supports sheep and beef grazing with a small area of dairying west of Pounawea (Yang 2022; Fig. 2). In some areas (e.g., Catlins Lake; Fig. 1), pasture within the margin would have historically been wetland or salt marsh habitat with drainage channels observed during the field survey (see Section 4.2).

Sheep grazing adjacent to the Catlins River in the upper estuary.

High producing grassland used for grazing, with historic drainage channel containing salt marsh still connected to the estuary.

Drainage channels through historic wetland at the head of Catlins Lake, an area now designated low producing grassland.

Table 4. Summary of 200m terrestrial margin land cover, Catlins Estuary, December 2023.

LCDB5 Class		ha	% Margin
1	Built-up Area (settlement)	27.8	3.6
2	Urban Parkland/Open Space	11.2	1.5
5	Transport Infrastructure	19.8	2.6
16	Gravel and Rock	0.0	0.0
20	Lake or Pond	0.9	0.1
40	High Producing Exotic Grassland	291.0	38.2
41	Low Producing Grassland	255.9	33.6
410	Duneland	3.3	0.4
46	Herbaceous Saline Vegetation	10.9	1.4
47	Flaxland	0.6	0.1
50	Fernland	0.5	0.1
51	Gorse and/or Broom	9.8	1.3
52	Mānuka and/or Kānuka	4.0	0.5
54	Broadleaved Indigenous Hardwoods	61.4	8.1
56	Mixed Exotic Shrubland	1.8	0.2
69	Indigenous Forest	32.9	4.3
71	Exotic Forest	30.5	4.0
Grand Total		762.2	100.0
Total dense vegetated margin (LCDB5 classes 45-71)		152.3	20.0

[1]Duneland is an additional category to the LCDB classes to help differentiate between "Low Producing Grassland" and "Duneland".

Transport infrastructure (2.6%) and two small settlements (3.6%) of Pounawea and New Haven border the estuary (see Fig. 1). Margin hardening to protect infrastructure is common, particularly on the southern margin, along the Ōwaka River and around the settlements (see photo).

Road bordering the southern margin of the estuary.

Most herbaceous saline vegetation (1.4%) was recorded at the head of Catlins Lake where areas of historic salt marsh have either been disconnected from the estuary, drained or are naturally elevated. In these areas salt marsh species persist including *Apodasmia similis* (Jointed wirerush) and *Plagianthus divaricatus* (Salt marsh ribbonwood).

Area of herbaceous saline vegetation at the head of Catlins Lake, comprising *Apodasmia similis*, *Plagianthus divaricatus* and *Coprosma* sp. (mingi mingi).

Duneland comprised only 0.4% of the margin and was located toward the estuary entrance (Fig. 5). The dominant species recorded were introduced marram grass (*Ammophila arenaria*) and tree lupin (*Lupinus arboreus*). Broad scale mapping only records the dominant terrestrial cover, as such these results do not represent a comprehensive survey of dune vegetation.

Dense vegetation comprised only 20% of the 200m terrestrial margin, a condition rating of 'Poor'. Of this, native vegetation consisted of broad-leaved indigenous hardwoods (8.1%), indigenous forest (4.3%) and smaller areas (<1%) of fernland, flaxland and mānuka and/or kānuka. Exotic forest (4.0%) and gorse and/or broom (1.3%) were also present.

The small change in the area of densely vegetated margin between 2016 and 2023 (from 23% to 20%) is attributed primarily to the reclassification of some features. For example, some areas on the true right bank of the Catlins River classified as herbaceous saline vegetation in 2016 were re-classified as low producing grassland in 2023 following more extensive ground-truthing and access to higher resolution aerial photographs.

Native forest in the lower estuary.

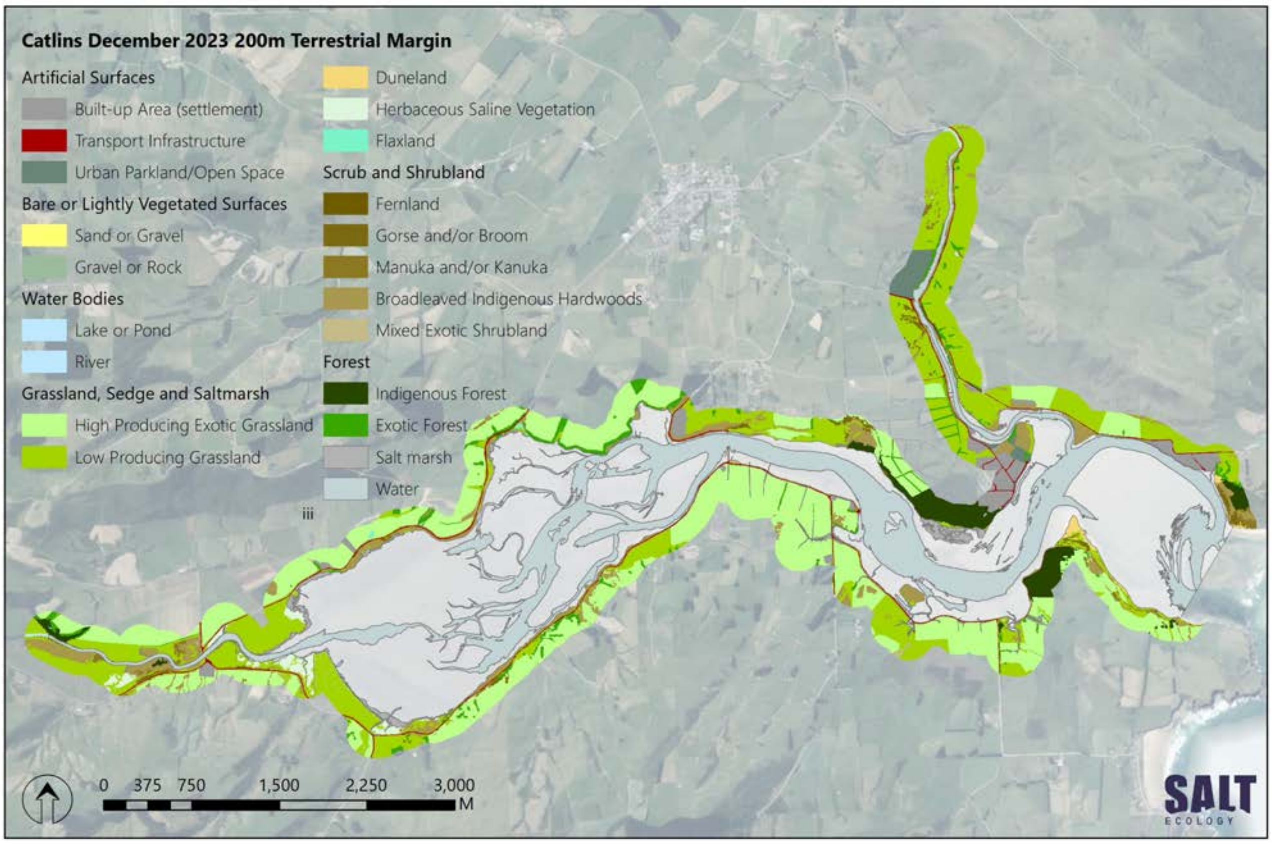


Fig. 5. Map of 200m terrestrial margin land cover, Catlins Estuary, December 2023.

4.2 SALT MARSH

In December 2023, Catlins had 13ha of salt marsh, comprising 2.3% of the mapped intertidal area (589ha; Table 5, Fig. 6), a condition rating of 'Poor'. Dominant species are noted in Table 5, with sub-dominant species detailed in Appendix 3 and accompanying GIS files.

Salt marsh was predominantly located at the head of Catlins Lake and on the true left bank near Pounawea (Fig. 6). Salt marsh was dominated (65%) by rushland (8.6ha), and primarily comprised jointed wirerush (*Apodasmia similis*). Herbfield (4.0ha) was also prominent in the lower estuary, and comprised primrose (*Samolus repens*), remuremu (*Selliera radicans*) and glasswort (*Sarcocornia quinqueflora*). The estuary also supported small areas of estuarine shrub, tussockland and sedgeland (Table 5).

South of Pounawea salt marsh transitions through to remnant native bush. However, in the same area vehicle damage and erosion on the seaward edge of herbfields were observed (see photos). A small area of *Spartina anglica*, the invasive cord grass, was recorded in an embayment near Jacks Bay Road on the southern side of the lower estuary (see photo opposite).

Salt marsh habitat naturally retains fine sediments and as such most (97.4%) of the substrate within salt marsh had an elevated mud content (≥25% mud; Appendix 4). Therefore, when assessing substrate metrics in Section 4.3, areas of salt marsh habitat are excluded.

Table 5. Summary of salt marsh area (ha) and percent of intertidal area, Catlins Estuary, December 2023.

Class	Dominant species*	ha	%
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	0.6	0.1
Tussockland	*Puccinella stricta* (Salt grass)	0.08	0.01
Sedgeland	*Schoenoplectus pungens* (Three square)	0.04	0.01
Reedland	*Spartina anglica* (Cord grass)	0.003	0.001
Rushland	*Apodasmia similis* (Jointed wirerush)	8.6	1.5
Herbfield	*Samolus repens* (Primrose) *Selliera radicans* (Remuremu) *Sarcocornia quinqueflora* (Glasswort)	4.0	0.7
Total		13.3	2.3

* See Appendix 3 for additional sub-dominant species.

Salt marsh transitioning to remnant native bush, south of Pounawea.

The invasive cord grass *Spartina anglica* in a small embayment near Jacks Bay Road in the lower estuary.

Vehicle damage (top) and erosion on the seaward edge (bottom) of herbfields, south of Pounawea.

Primrose (*Samolus repens*) and glasswort (*Sarcocornia quinqueflora*) transitioning to native forest.

Jointed wirerush (*Apodasmia similis*) at the head of Catlins Lake.

Salt marsh extent is limited in many areas by naturally steep banks, hardened margins, historic drainage and reduced flushing in areas restricted by road culverts. However, salt marsh extent has not significantly changed between 2006 and 2023 (Appendix 5). A small discrepancy (1.2ha) between 2016 and 2023 is associated with salt marsh features at the Catlins River mouth being classified as terrestrial in 2016. True losses have occurred due to erosion on the seaward edge of herbfield, particularly near Pounawea.

The natural extent of salt marsh was estimated to be 64ha or 11% of the intertidal area (Fig. 7). A cursory assessment of historic imagery dating back to 1948 indicates substantial losses near the Catlins River mouth had already occurred by this time, due to drainage, roading infrastructure and conversion to pasture. Further losses have occurred near Cabbage Point (across the channel from Pounawea) in the lower estuary where a large sand-spit containing small pockets of salt marsh eroded in the 1990's (Fig. 8). Current salt marsh extent represents only 21% of the estimated natural extent, a condition rating of 'Poor' (Fig. 7; Appendix 5).

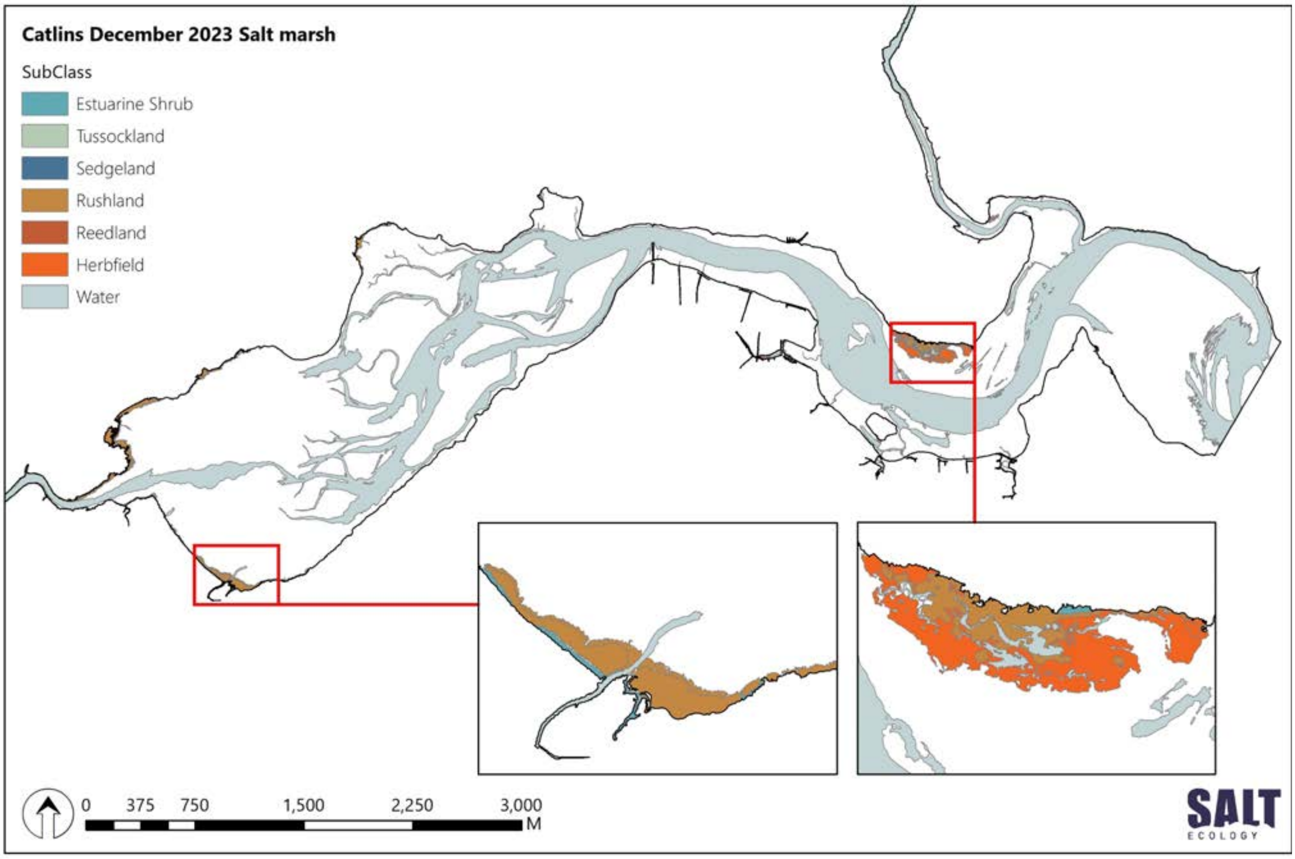


Fig. 6. Salt marsh sub-classes and their distribution, Catlins Estuary, December 2023.

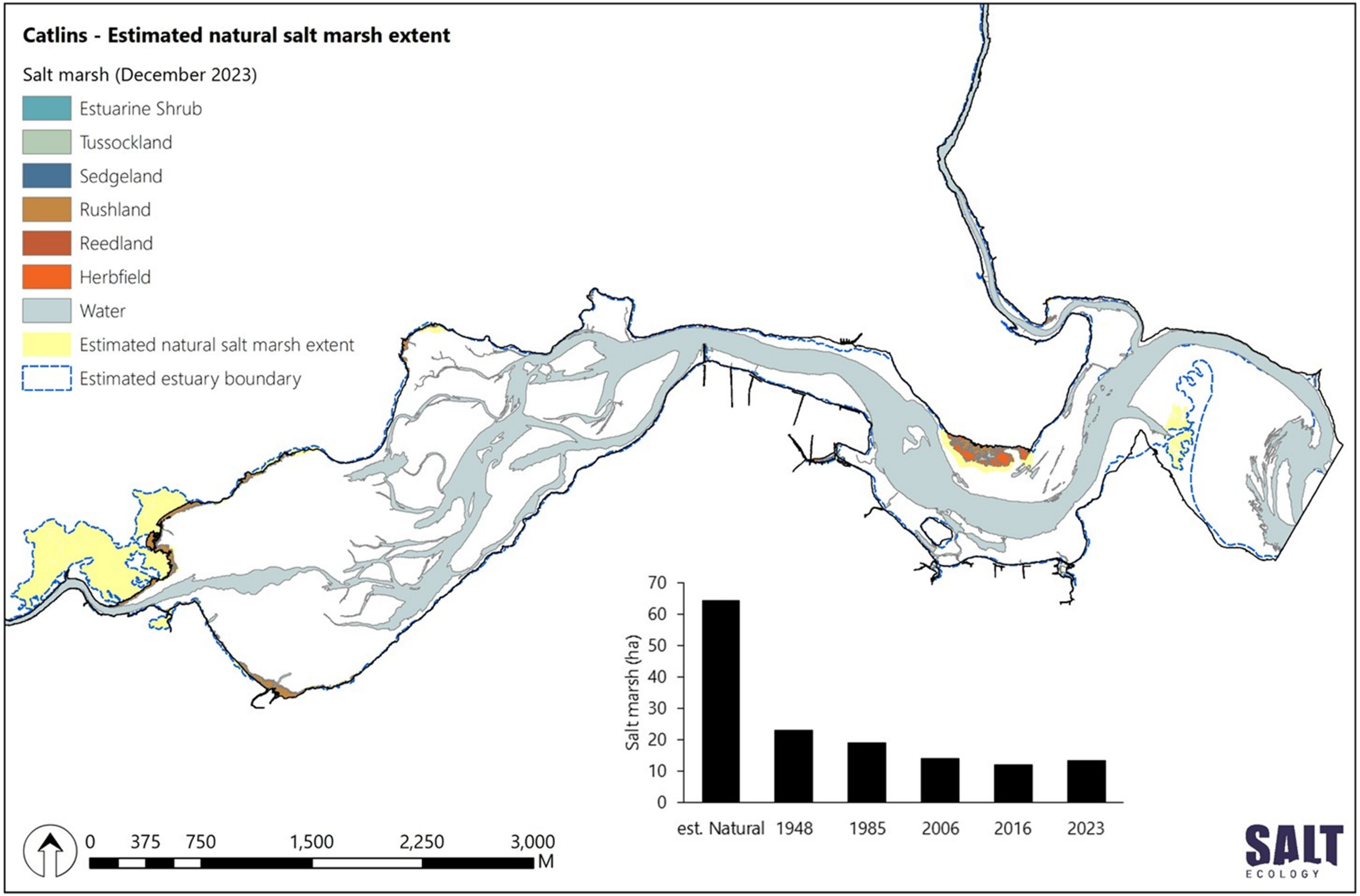


Fig. 7. The historic salt marsh extent (yellow) and historic estuary boundary (dashed line) overlaid with the current mapped salt marsh extent.

4.3 SUBSTRATE

Outside of salt marsh, ~576ha of intertidal substrate was mapped (Table 6, Fig. 8). There was good agreement between the subjective sediment classifications applied during mapping and the sediment grain size validation measures (Appendix 6).

Sand (<10% mud) was the dominant substrate type. Mobile sands were prominent in the lower estuary, while firm sands were the dominant substrate type west of the Hinahina Road bridge in the lower Catlins Lake. Firm muddy sand (10-25% mud) was also common on the north and northwest flats of Catlins Lake.

Mud-elevated (>25%) sediments comprised 26% of the available intertidal habitat, a condition rating of 'Poor'. These areas were located near the mouths of Catlins River, the Ōwaka River and smaller freshwater inputs. This is expected, as these areas are depositional zones where the mixing of fresh and saline waters promote the settling of fine sediments. Many of these areas comprised very soft sandy muds (50-90% mud), often associated with poor oxygenation and algal growth (see Section 4.5).

Table 6. Summary of dominant substrate in available intertidal habitat (AIH) outside areas of salt marsh, Catlins Estuary, December 2023.

Substrate Class	Features	ha	% AIH
Bedrock	Rock field	8.9	1.5
Artificial substrate	Artificial boulder field	2.9	0.5
	Artificial cobble field	0.2	0.04
Coarse substrate (>2mm)	Boulder field	0.03	0.01
	Cobble field	1.7	0.3
	Gravel field	4.2	0.7
	Shell bank	2.6	0.4
Sand (0-10% mud)	Mobile sand	199.2	34.6
	Firm shell/sand	35.6	6.2
	Firm sand	90.9	15.8
	Soft sand	1.0	0.2
Muddy Sand (≥10-25% mud)	Firm muddy sand	56.3	9.8
	Soft muddy sand	22.7	3.9
Muddy Sand (≥25-50% mud)	Firm muddy sand	1.7	0.3
	Soft muddy sand	38.4	6.7
Sandy Mud (≥50-90% mud)	Firm sandy mud	0.1	0.0
	Soft sandy mud	75.7	13.2
	Very soft sandy mud	30.4	5.3
Mud (>90% mud)	Very soft mud	2.9	0.5
Zoogenic	Cockle bed	0.3	0.0
Total		575.6	100.0

While hard substrates were a minor feature of the overall intertidal area, artificial boulder field was common on the estuary margin to protect transport infrastructure (as discussed in Section 4.1).

Mobile sands near the entrance of Catlins Estuary.

Firm muddy sand (10-25% mud) - northern flats of Catlins Lake.

Very soft sandy muds (50-90% mud) near the Catlins River mouth.

Artificial boulder field on the estuary margin.

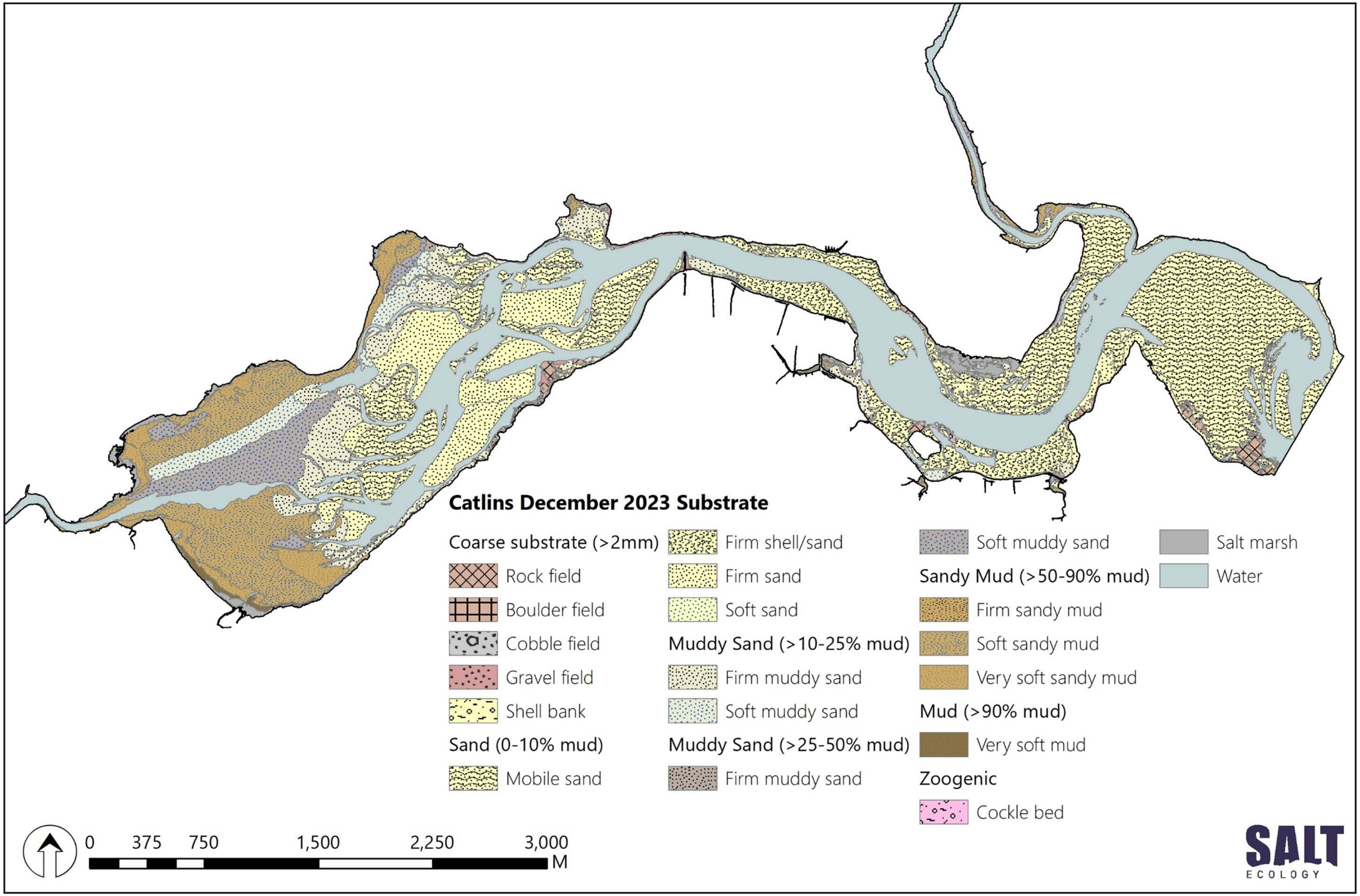


Fig. 8. Dominant intertidal substrate in the AIH (excluding salt marsh), Catlins Estuary, December 2023.

4.4 SEAGRASS

Table 7 and Fig. 9 summarise seagrass (*Zostera muelleri*) cover. Catlins had a total of 33.8ha of seagrass (1-100% cover), comprising ~6% of the available intertidal habitat (576ha; Table 7, Fig. 9).

Seagrass was observed on the main tidal flats below Hinahina Road bridge in the central part of the eastern basin, and toward the estuary entrance. While seagrass has been present in the central part of the eastern basin since 2006 (see Appendix 5), there was a small decline in extent between 2006 and 2016. Seagrass beds directly in front of Pounawea township were absent in 2016, possibly caused by scouring during high river flows. These beds had begun to re-establish by 2021.

In December 2023, seagrass with ≥50% cover was recorded across 3.5% of the available intertidal habitat, representing a steady decrease in patches with ≥50% cover since 2006 (Fig. 9). Losses can be attributed to; (1) erosion and fragmentation of beds south of Pounawea and on the true right bank below Hinahina Road bridge, (2) natural variability of beds near the river channel in front of the Pounawea township, and (3) natural variability of seagrass beds growing in mobile sands at the estuary entrance. Minor losses may also be attributed to leaf discolouration and some macroalgae smothering that was observed in December 2023.

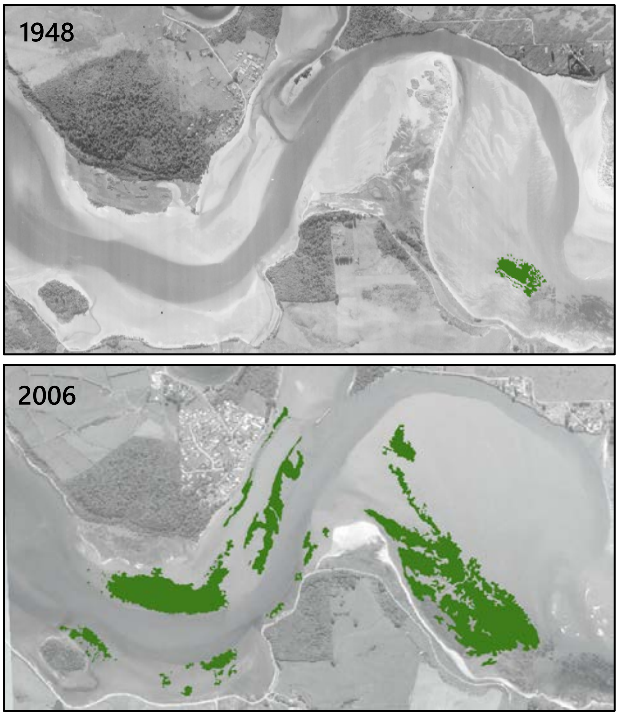
Leaf discolouration and macroalgae smothering, near Pounawea (top). Seagrass growing in mobile sands at the entrance (bottom).

A review of historic imagery showed that historically seagrass was scarce in the lower estuary and more extensive in Catlins Lake, with beds expanding in this area between 1948 and 1985 (see Appendix 5). No high (≥50%) cover seagrass has been evident in Catlins Lake since 1995 based on a review of available imagery. Physical changes in the lower estuary (i.e., erosion of a large sandspit, see photos below) and reduced water quality in the Catlins Lake have likely led to these changes in seagrass distribution. The complete erosion of the sandspit by 2006, and likely improved flushing, was coincident with expansion of seagrass in this area (see photos). Because the physical characteristics of the estuary differ significantly between 1948 and present day, the seagrass condition rating was determined from a baseline of like physical conditions (i.e., 2006). Since 2006, there has been a 47% loss in seagrass (≥50% cover), a condition rating of 'Poor'. However, it should be acknowledged that the overall spatial extent (1-100% cover) has only decreased by ~10% (see Appendix 5).

Table 7. Summary of intertidal seagrass in the AIH, Catlins Estuary, December 2023.

Percent cover category	ha	% AIH*
Absent or trace (<1%)	541.8	94.1
Very sparse (1 to <10%)	0.0	0.0
Sparse (10 to <30%)	11.7	2.0
Low-Moderate (30 to <50%)	2.1	0.4
Moderate-High (50 to <70%)	6.9	1.2
Dense (70 to <90%)	9.9	1.7
Complete (≥90%)	3.2	0.6
Total Seagrass (1-100% cover)	**33.8**	**5.9**
Total Seagrass (≥50% cover)	**20.1**	**3.5**

*Available intertidal habitat



Seagrass change in the lower estuary between 1948 (top) and 2006 (bottom), where a large sand spit at Cabbage Point eroded.

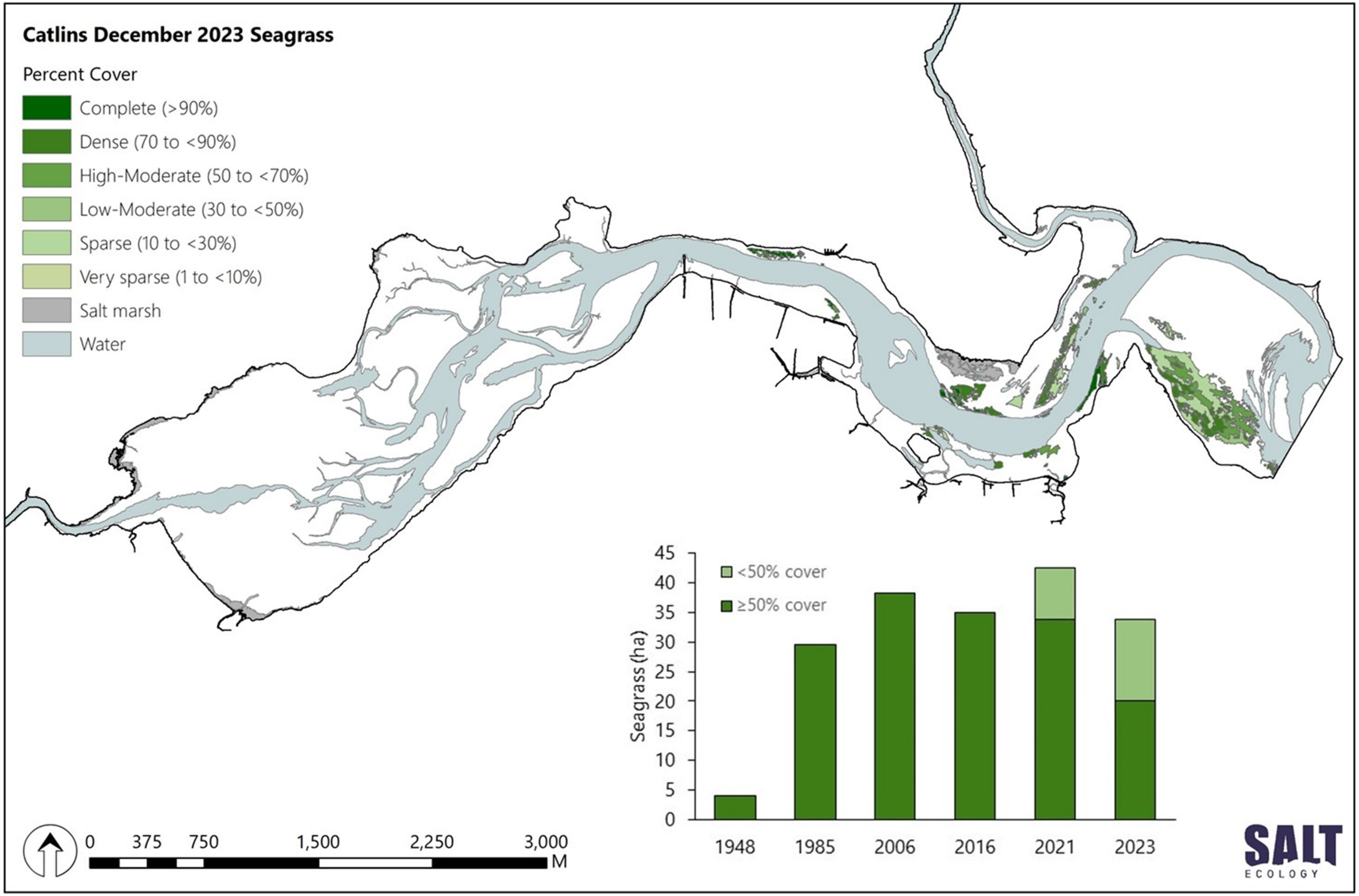


Fig. 9. Distribution and percent cover classes of seagrass, Catlins Estuary, December 2023. Inset graph represents estimated seagrass cover from historic imagery in 1948, 1985 and 2006 and ground-truthed seagrass mapped seagrass in 2016 and 2021.

4.5 MACROALGAE

4.5.1 Opportunistic macroalgae

Opportunistic macroalgae species and biomass information is included in Appendix 6, with key results summarised in Table 8 and Fig. 9, and temporal changes in Table 9. Macroalgae comprised the green algae *Ulva* spp., the red algae *Gracilaria* spp. (previously known as *Agarophyton* spp.), unidentified green filamentous algae, and brown filamentous algae preliminarily identified as *Pylaiella littoralis*.

Macroalgae was mapped as absent or trace (<1% cover) across ~73% of the AIH, indicating most of the estuary was not experiencing macroalgal issues. *Ulva* spp. was primarily found in the well-flushed lower estuary, generally as patches of sparse (10-30%) or low-moderate (30-50%) cover. As discussed in Section 4.4, some *Ulva* spp. was recorded growing on and around seagrass beds. While not mapped, high cover subtidal growths of *Ulva* spp., and filamentous green and brown algae were also common in the lower estuary.

Sparse cover of *Ulva* spp. in the lower estuary.

Dense, entrained beds of *Gracilaria* spp. were recorded in the upper sheltered margins of Catlins Lake, on the channel edges of the Ōwaka River, and in small embayments on the southern side of the estuary. In general, these areas were associated with poorly oxygenated, mud-elevated (>25% mud) sediments.

Areas of previously high cover on the seaward edge of salt marsh in the upper Catlins Lake had reduced to <50% cover in December 2023. While this might seem like an improvement, the decrease was due to severe sediment degradation (i.e., anoxic, sulphide-rich sediments) caused by macroalgal decay. The initial stages of this decay cycle were also observed on the true left bank of the upper Catlins Lake (see photos on following page). In these areas microalgae and/or bacterial mats were visible on the sediment surface.

Concerningly, in December 2023 there was a widespread bloom of a brown filamentous algae recorded as a thin, but complete, surface cover on established *Gracilaria* spp. beds in Catlins Lake. This alga was also found growing in smothering growths on sand and rock substrates in the mid to lower estuary.

Table 8. Summary of intertidal macroalgal cover (A) and biomass (B), Catlins Estuary, November 2023.

A. Percent cover

Percent cover category	ha	% AIH
Absent or trace (<1%)	418.4	72.7
Very sparse (1 to <10%)	9.2	1.6
Sparse (10 to <30%)	32.7	5.7
Low-Moderate (30 to <50%)	8.0	1.4
Moderate-High (50 to <70%)	14.0	2.4
Dense (70 to <90%)	33.9	5.9
Complete (≥90%)	59.5	10.3
Total	575.6	100.0

B. Biomass

Biomass category (g/m^2)	ha	% AIH
Absent or trace (<1)	418.4	72.7
Very low (1 - 100)	38.1	6.6
Low (101 - 200)	6.3	1.1
Moderate (201 - 500)	14.8	2.6
High (501 - 1450)	14.3	2.5
Very high (>1450)	83.6	14.5
Total	575.6	100.0

Prior to 2006, no persistent *Gracilaria* spp. were observed in Catlins Lake, corresponding to an estimated OMBT-EQR score of >0.8 and a condition rating of 'Very good'. Based on a review of imagery, the first signs of persistent *Gracilaria* blooms were evident in 2010, in two small embayments northwest of the Hinahina Road Bridge. Monitoring in 2016 recorded the expansion of these beds into the upper Catlins Lake. Because these areas comprised only a small portion of the estuary in 2016, the macroalgae condition rating remained 'Good' (Table 9). By 2019, *Gracilaria* spp. had become more widespread in the upper Catlins Lake, with biomass peaking in 2021, resulting in a condition rating of 'Poor' (Table 9). Although the OMBT-EQR score for Catlins has improved to 'Fair' in 2023, this improvement is likely due to a reduction in cover and biomass caused by macroalgal dieback rather than a true improvement in estuary condition.

Table 9. Opportunistic Macroalgal Blooming Tool (OMBT) Ecological Quality Rating (Appendix 6).

Year	OMBT-EQR	Rating
2006*	>0.8	Very Good
2016	0.615	Good
2021	0.386	Poor
2023	0.533	Fair

*Estimated, no areas of persistent macroalgae were visible in 2006.

A persistent dense bed of *Gracilaria* spp. on the sheltered northern margin of Catlins Lake (top) and on the margin of Ōwaka River (bottom).

Sparse cover of filamentous brown algae growing on firm muddy sand (10-25% mud; top) and dense cover west of Hinahina Road bridge (bottom).

High cover and biomass *Gracilaria* spp. in the small embayment south of Hinahina Road and closest to Hinahina Island.

Areas of previously high macroalgal cover in 2021 comprised of very soft sandy muds with sparse cover and sediment anoxia in 2023.

Complete cover of filamentous brown algae growing on rock substrate in the mid estuary (top) and thin, but complete cover over *Gracilaria* spp. in the upper Catlins Lake (bottom).

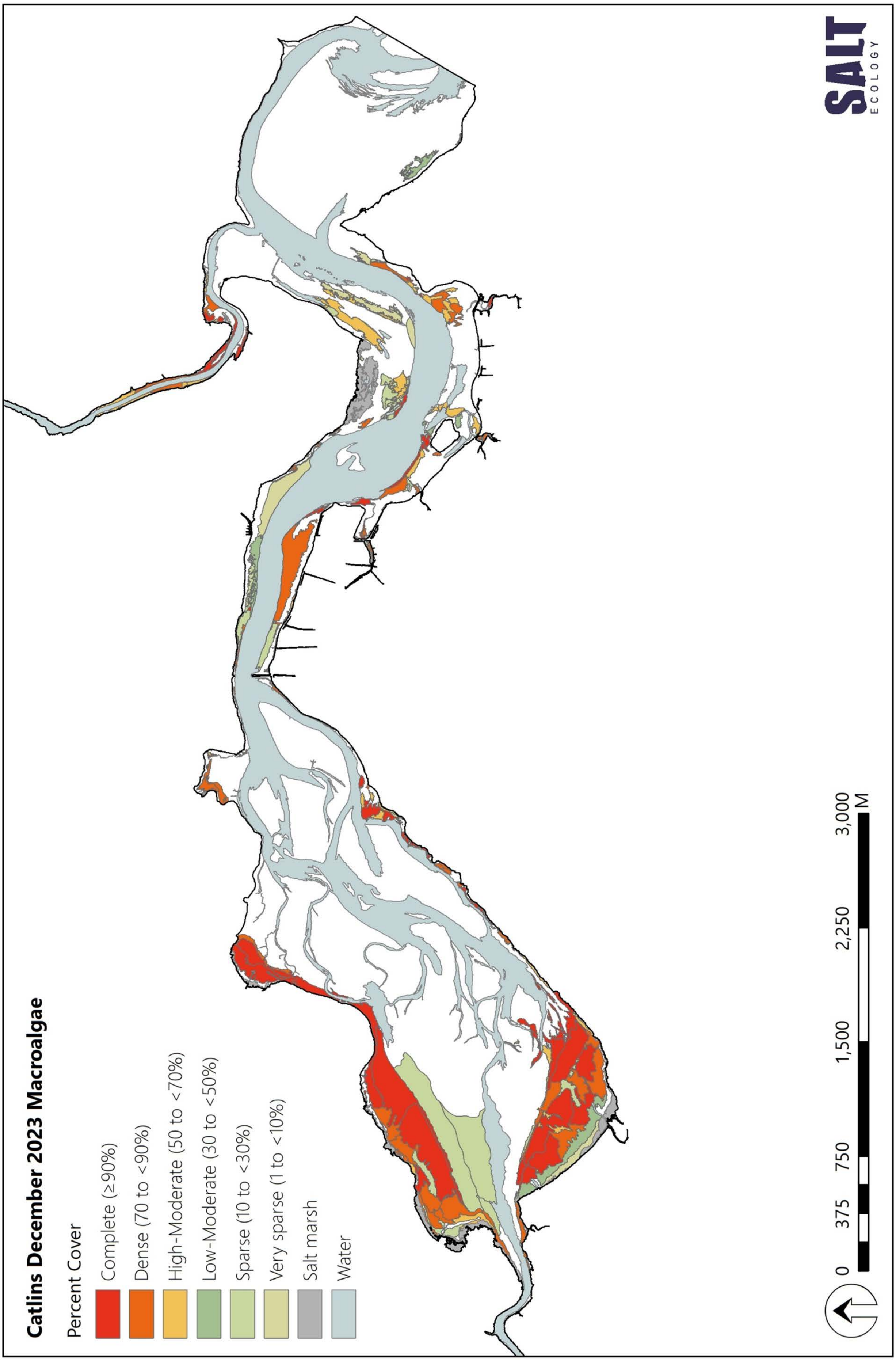


Fig. 10. Distribution and percent cover classes of macroalgae, Catlins Estuary, December 2023.

4.5.2 High Enrichment Conditions

High Enrichment Conditions (HEC) within the AIH are defined in relation to the proliferation of opportunistic macroalgae (i.e., *Gracilaria* spp., *Ulva* spp., and filamentous species) in areas of ≥50% mud and which are characterised by anoxic sediments with a strong sulphur smell and black colouration. However, the definition was broadened in the current report to include areas of severe sediment degradation (i.e., anoxia, surface bacteria, microalgae) caused by macroalgal decay. HEC areas covered a total of 79.4ha, 13.8% of the AIH (Table 10; Fig. 11). This represents a severe decline in estuary health, with areas of HEC increasing 5-fold since 2016.

Table 10. Summary of High Enrichment Conditions (HEC) in available intertidal habitat (AIH).

Year	ha	% AIH	Rating
2016	14.9	2.9	Fair
2021	74.6	12.5	Poor
2023	79.4	13.8	Poor

Photos from the upper Catlins Lake showing high cover, high biomass macroalgae decay that has led to oxygen depletion and bacterial mats on the sediment surface.

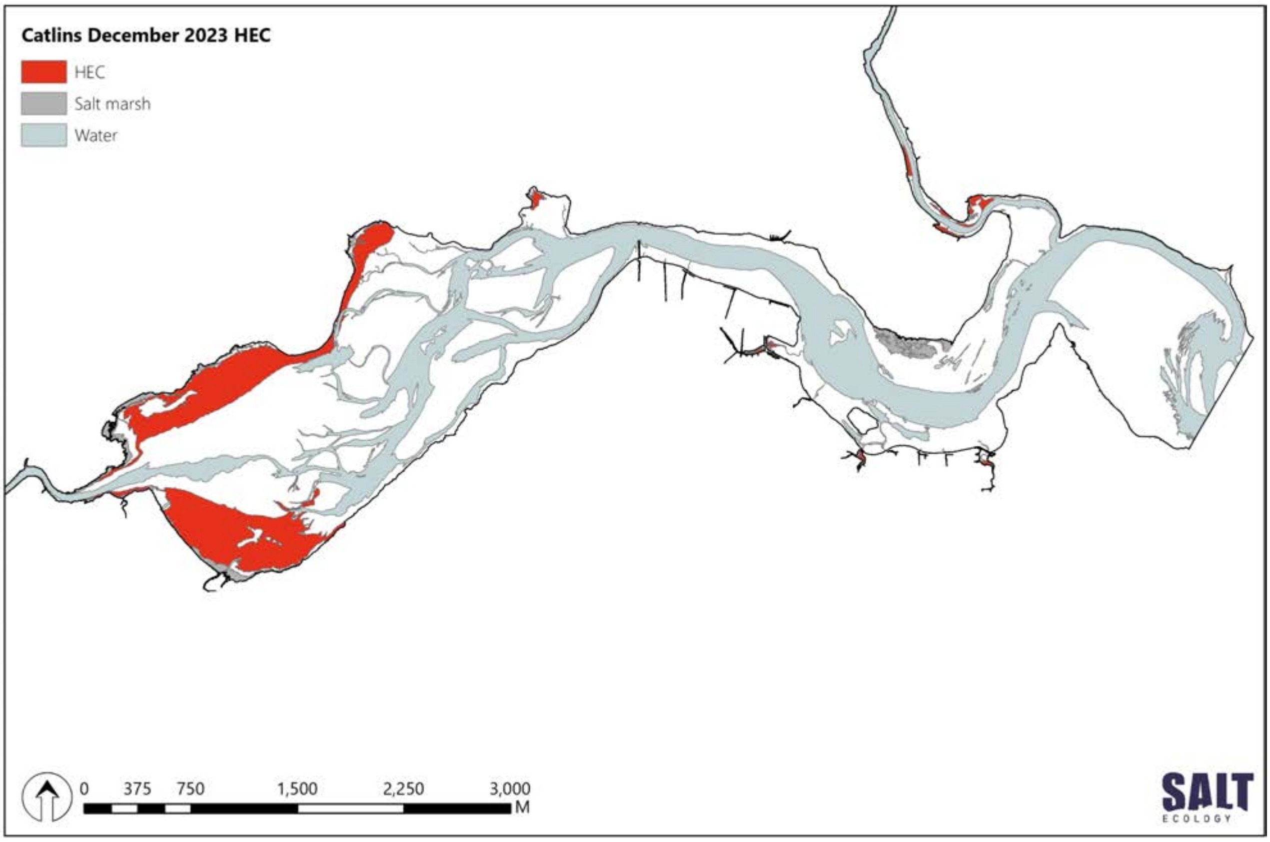


Fig. 11. Areas of High Enrichment Conditions (HEC), Catlins Estuary, December 2023.

5. SEDIMENT QUALITY AND BIOTA

Illustrative photos of the sites where sediment quality and biota sampling were undertaken are provided in Fig. 12 and Appendices 4 & 8. Sediment quality and biota sampling aimed to capture a broad range of representative habitat and substrate types, including upper estuary (i.e., Catlins Lake) sites strongly influenced by sediment deposition and lower salinities, and lower estuary sites strongly influenced by tidal flushing. Site 2, in upper Catlins Lake, was covered in dense macroalgae and Site 3 was expressing extreme anoxia associated with the decomposition of macroalgae (Fig. 12). Site 6, in the lower estuary, comprised dense seagrass habitat (Fig. 12). All other sites were comparatively unvegetated.

5.1 SEDIMENT QUALITY INDICATORS

Sediment sampling confirmed the general broad-scale mapping pattern of decreasing mud content toward the estuary entrance, with sites in the upper Catlins Lake (~70-80% mud) having a higher mud content than lower estuary sites (3-21% mud; Figures 12 & 13).

As discussed in Section 4.3, sediment deposition in the upper Catlins Lake (Sites 1 to 3) is promoted by the mixing of fresh and saline waters. Macroalgal growth in these areas (i.e., Sites 2 and 3) also promotes sediment trapping. At these same sites, concentrations of sediment total nitrogen (TN) and total organic carbon (TOC) were very high and rated 'Poor' (Fig. 13). Site 3 was also high in Total Sulphur (TS), signifying a high level of enrichment (Appendix 4). Additionally, these sites had low levels of sediment oxygenation, with aRPD also rated 'Poor.'

Poor sediment oxygenation at Site 3, upper Catlins Lake, due to decomposing macroalgae.

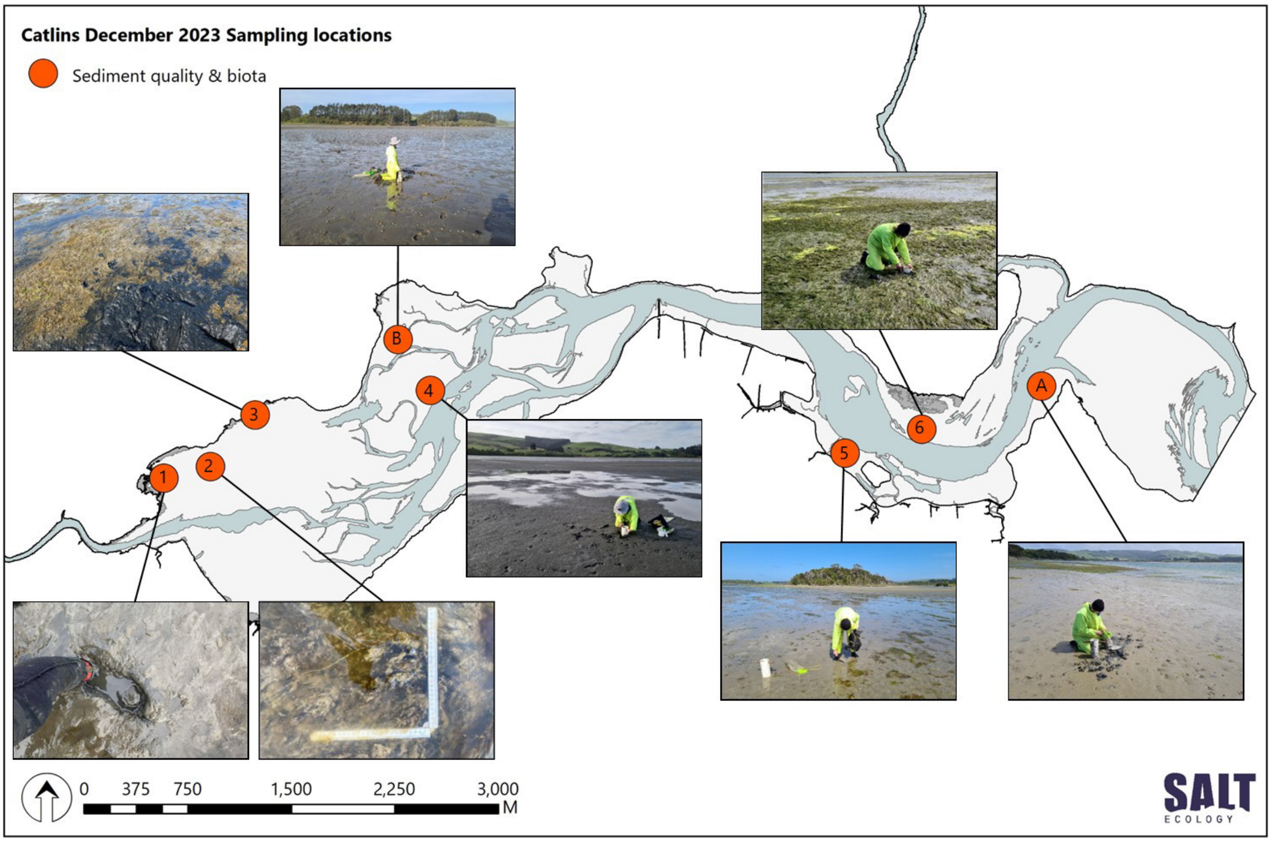


Fig. 12. Sediment quality and biota locations including site photos, Catlins Estuary, December 2023. Sites A and B are locations where intensive fine-scale monitoring has been previously undertaken (Morrisey & Forrest 2023).

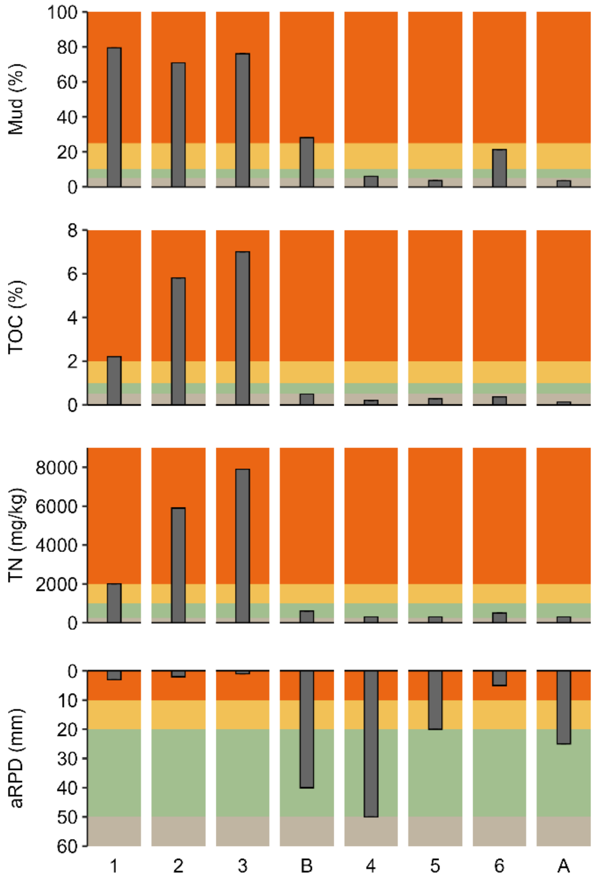


Fig. 13. Sediment %mud, total organic carbon (TOC), total nitrogen (TN) and aRPD at sediment quality and biota sites, relative to condition ratings.

Condition rating key:

Very Good	Good	Fair	Poor

TN and TOC at unvegetated sites in the mid-estuary (Sites B & 4) were rated 'Good' and 'Very good', respectively (Fig. 14). Despite Site B having elevated mud (28.1%), corresponding to a condition rating of 'Poor', sediments were well oxygenated with an aRPD of 40mm. The deeper oxygenation at this site is likely attributed to extensive burrowing in the sediment (see photo below).

Sediment aRPD at Site B, rated as 'Good' (aRPD ~40mm).

The unvegetated lower estuary sites (Sites 5 & A) comprised firm sands with a low mud content that corresponded to a condition rating of 'Very good'. These sites also consisted of low TN, TOC and 'Good' sediment oxygenation. Seagrass habitat (Site 6) in the lower estuary was low in TN and TOC (both rated 'Good'). Consistent with the ability of dense seagrass beds to promote sediment trapping by slowing water movement at the sediment surface, the mud content at Site 6 was 21.3%, which was rated 'Fair'. Sediment oxygenation within the seagrass bed was rated 'Poor', likely owing to oxygen consumption (i.e., respiration) during decomposition of seagrass detritus within the root system.

Low sediment oxygenation within seagrass, Site 6.

Trace metal concentrations were very low (well below the DGV) in all samples and rated 'Very good', except for nickel at Site 3 which was rated 'Good' (Table 11). These results indicate there are no significant metal contaminant sources in the catchment and that there is a low risk of unacceptable effects (to biota) occurring (ANZG 2018). The results are consistent with previous fine scale monitoring within the estuary (Morrisey & Forrest 2023, and references therein).

Table 11. Trace metal concentrations (mg/kg) relative to ANZG (2018) Default Guideline Values (DGV).

Site	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
1	3.7	0.084	10.4	7.9	0.03	7.2	5.1	47.0
2	6.2	0.091	14.8	12.2	0.05	9.7	8.9	56.0
3	5.6	0.161	17.7	15.4	0.06	10.8	10.7	65.0
B	3.7	0.017	8.5	4.7	<0.02	5.8	2.7	27.0
4	2.9	0.010	6.0	3.0	<0.02	4.1	1.5	17.9
5	4.4	0.013	6.9	3.2	<0.02	4.4	1.9	16.6
6	4.6	0.038	9.6	5.3	<0.02	6.7	2.8	25.0
A	5.5	0.015	6.0	2.2	<0.02	3.5	1.3	12.0
DGV	20	1.5	80	65	0.15	21	50	200

Beige and green shading corresponds to 'Very good' (<0.5 x DGV) and 'Good' (0.5 x DGV to <DGV) condition ratings, respectively.

5.2 BIOTA

Conspicuous surface-dwelling epibiota were only recorded from Site B and Site 4 in the lower section of Catlins Lake, where mud snails (*Amphibola crenata*) were categorised as common (10-99/m^2) and occasional (0.1-1/m^2), respectively. Epibiota were absent at other sites, although at Site A, closest to the estuary entrance, there were obvious faunal signs on the sediment surface (e.g., burrows and imprints).

Vegetation cover was variable across sites (see photos in Fig. 12 and Appendix 6). Upper Catlins Lake Site 1 was unvegetated, as were Site B and Site 4 in the lower section of Catlins Lake, and Site A in the lower estuary near the entrance.

In the upper Catlins Lake, Site 2 had >90% macroalgae cover dominated by *Gracilaria* spp. with a thin surface cover of filamentous brown algae, and Site 3 comprised a 100% cover of decaying macroalgae species.

In the lower estuary, Site 5 had 5-9% cover of macroalgae, and Site 6 was ~90% seagrass with a sparse (1-4%) cover of drift *Ulva* spp.

Mud snails (*Amphibola crenata*) at Site B in the mid-estuary.

In contrast to the typically sparse surface epibiota, all sites had a broad suite of sediment-dwelling macrofauna in the core samples. A total of 45 species or higher taxa were recorded, representing 13 main organism groups (Appendix 8). Fig. 14 shows the average species richness per site was low-to-moderate in the upper Catlins Lake and mid-estuary, but organism abundances were generally high. The exception was Site 3, where both richness and abundance were low likely owing to the severe sediment enrichment at this site. Both vegetated (i.e., seagrass) and unvegetated sites in the lower estuary had high species richness, however abundances were lower than upper estuary sites (Fig. 14).

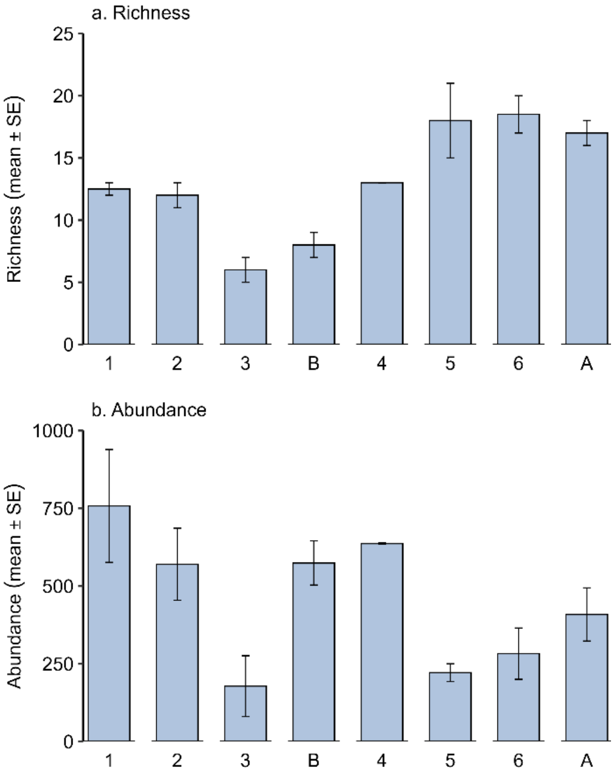


Fig. 14. Mean (±SE) taxon richness and abundance in duplicate core samples.

Species tolerant to disturbance, high mud contents and low salinities were recorded at the upper Catlins Lake sites (Sites 1-3), including Oligochaeta, Chironomidae, *Josephosella awa*, Mysida, *Paracorophium excavatum* and *Paracalliope novizealandiae* (Table 12). At the mid-estuary sites (Site B & Site 4) *P. excavatum* was most abundant (Table 12), possibly explained by the higher mud content (28.1%) at Site B and lower salinities at Site 4 due to its proximity to the river channel.

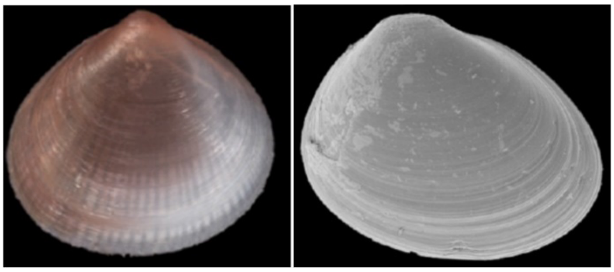
At the mid and upper estuary sites, most species were in eco-groups (EG) III-V, representing a relatively hardy suite of species, resulting in elevated AMBI scores (Fig. 15) that suggest 'Fair' to 'Poor' ecological conditions. The exception was Site 2, which was rated 'Good' and is discussed further below.

The tube-building amphipod *Paracorophium excavatum* drove much of the abundance captured at mid-estuary Sites B & 4 (Photo courtesy of NIWA).

Table 12. Dominant macrofauna at the eight sites. Numbers are total abundances summed across duplicate cores. Grey shading represents fine-scale sites.

Main group	Taxa	EG	1	2	3	B	4	5	6	A	Description
Oligochaeta	Oligochaeta	V	1101	442	257	46	8	178	50	4	Segmented worms in the same group as earthworms. Deposit feeders that are generally considered pollution or disturbance tolerant.
Amphipoda	*Paracorophium excavatum*	IV	223	60	10	985	846		1	79	Corophioid amphipod that is an opportunistic tube-dweller, tolerant of excess organic enrichment, elevated mud content (i.e., >40%) and low salinities.
Amphipoda	*Josephosella awa*	II	68	149	2	1			2		Amphipods are shrimp-like crustaceans. This species is found in freshwater to estuarine/brackish environments and has a laterally compressed body.
Chironomidae	Chironomidae	III	64	143	44	1					Non-biting midge larvae. Larvae are important as food items for fish and other aquatic organisms. They are also important as indicator organisms because they are generally pollution tolerant.
Amphipoda	*Paracalliope novizealandiae*	I	24	280	1	60	6	41	268	29	Amphipods are shrimp-like crustaceans. This species is common in New Zealand estuaries. It is indifferent to sedimentation and can tolerate muddy habitats despite its EG I classification.
Mysida	Mysida	II	4	22	40						Small shrimp-like crustaceans that are omnivorous filter feeders. Probably prey items for fish and crustaceans.
Polychaeta	*Microspio maori*	I				10	276			1	A small, common, intertidal spionid that are often prey items for fish and birds. Can handle moderately enriched sediment but sensitive to chronic sediment deposition.
Bivalvia	*Legrandina turneri*						2	1		100	A small bivalve that appears to be an endemic southern New Zealand species. Sensitive to chronic sediment deposition and elevated nutrients.
Polychaeta	*Macroclymenella stewartensis*	II						45	3	3	A sub-surface, deposit-feeding bamboo worm that is usually found in tubes of fine sand or mud. This species may have a key role in turn-over of sediment. Tolerant of mud, but optimum range 10-15%. Intolerant of anoxic conditions.
Polychaeta	*Prionospio aucklandica*	III						25	159	88	A surface deposit-feeding spionid common in harbours and estuaries. Indifferent to sedimentation and prefers muddy sands, but occurs across a range of mud contents (12-50 % optimum). Considered tolerant to organic enrichment despite EG II classification.
Bivalvia	*Lasaea parengaensis*	II						5		337	Small and little-known bivalve. Probably a prey item in the diet of birds and fish.

Lower estuary sites had a more diverse range of both species and main taxa groups, including small bivalves and cockles (*Austrovenus stutchburyi*), and various polychaetes and amphipods (Table 12). Several species recorded at the lower estuary sites were not recorded elsewhere and species ranged across all eco-groups (EG) I-V, with AMBI scores (Fig. 15) rated 'Fair' to 'Good'. The slightly elevated AMBI score at Site 5 was driven by high abundances of the tolerant Oligochaeta (EG-V).



Small bivalves recorded at the unvegetated habitats in the lower estuary. *Legrandina turneri* (left) and *Lasaea parengaensis* (right); Photo source: Dr. Jean-Claude Stahl, Museum of New Zealand.

Interestingly, the seagrass habitat (Site 6) had comparable abundances (>250 individuals) of the amphipod *Paracalliope novizealandiae* to the macroalgae covered site in the upper Catlins Lake (Site 2) indicating this species may flourish in vegetated habitats and may not necessarily be reflective of sediment condition. For AMBI calculation, *P. novizealandiae* was assigned an EG-I (i.e., sensitive) rating based on the international EG for *Paracalliope* sp. However, as the New Zealand species was recorded at all sites across a broad range of mud contents (i.e., ~3 to 80%) it appears far more resilient than EG-I suggests. High abundances of *P. novizealandiae* at Site 2 and Site 6 therefore disproportionately decrease AMBI scores indicating relatively undisturbed conditions (Fig. 15). In the case of Site 2, inclusion of this species with an EG-I means the AMBI score does not accurately reflect the degraded nature of the sediment observed at that site.

Paracalliope novizealandiae shrimp-like crustacean recorded at all sites (Photo courtesy of NIWA).

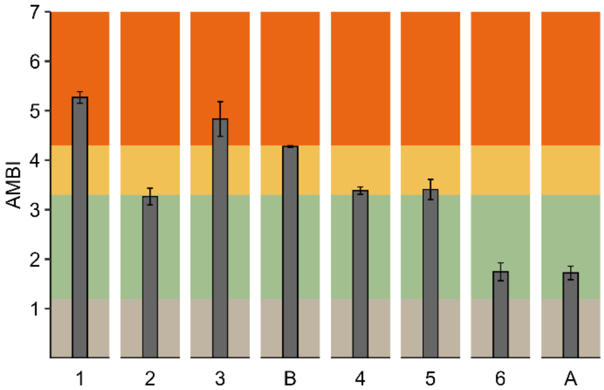


Fig. 15. Mean (±SE) macrofauna AMBI scores (in duplicate cores at Sites 1 to 6 & A to B) relative to condition ratings. Sites ordered from upper to lower estuary.

Condition rating key: Very Good | Good | Fair | Poor

Overall, there was a general trend of high abundances of more tolerant species in the upper and mid-estuary when compared to the lower estuary (Fig. 16), with sediment mud content likely the most significant driver of both richness and abundance (Fig. 16). This hypothesis is supported by the multivariate analysis of macrofauna community composition, summarised in Fig. 17. The figure illustrates the magnitude of difference among sites in terms of their macrofauna taxa and abundances, with the bubble size of each site indicating the relative mud content present. The analysis determined that macrofauna community composition differences were best described by changes in mud content and, to a lesser extent, aRPD (Spearman rank correlation coefficient ρ=0.598 for %mud alone, ρ=0.692 for sediment %mud and aRPD together).

Species composition differences between upper (Sites 1-3) and lower (Sites 5-6 & A) estuary sites were driven by presence or absence of species (i.e., left-to-right in the Fig. 17 plot). For example, *Macroclymenella stewartensis* and *Prionospio aucklandica*, that are more accustomed to lower mud contents, were recorded at sandier estuary sites in the lower estuary and not at muddier upper estuary sites, while the more tolerant Chironomidae and Mysida showed the reverse pattern (Table 12; Fig. 17). Differences between mid-estuary sites (especially Sites 4 & B) and other parts of the estuary were primarily driven by high abundances of the *P. excavatum* (i.e., up-down in the Fig. 17 plot) and a few other species shown on Fig. 17. Sites 4 and B also exhibited high levels of sediment oxygenation (i.e., aRPD>40mm; see Fig. 14) relative to other sites.

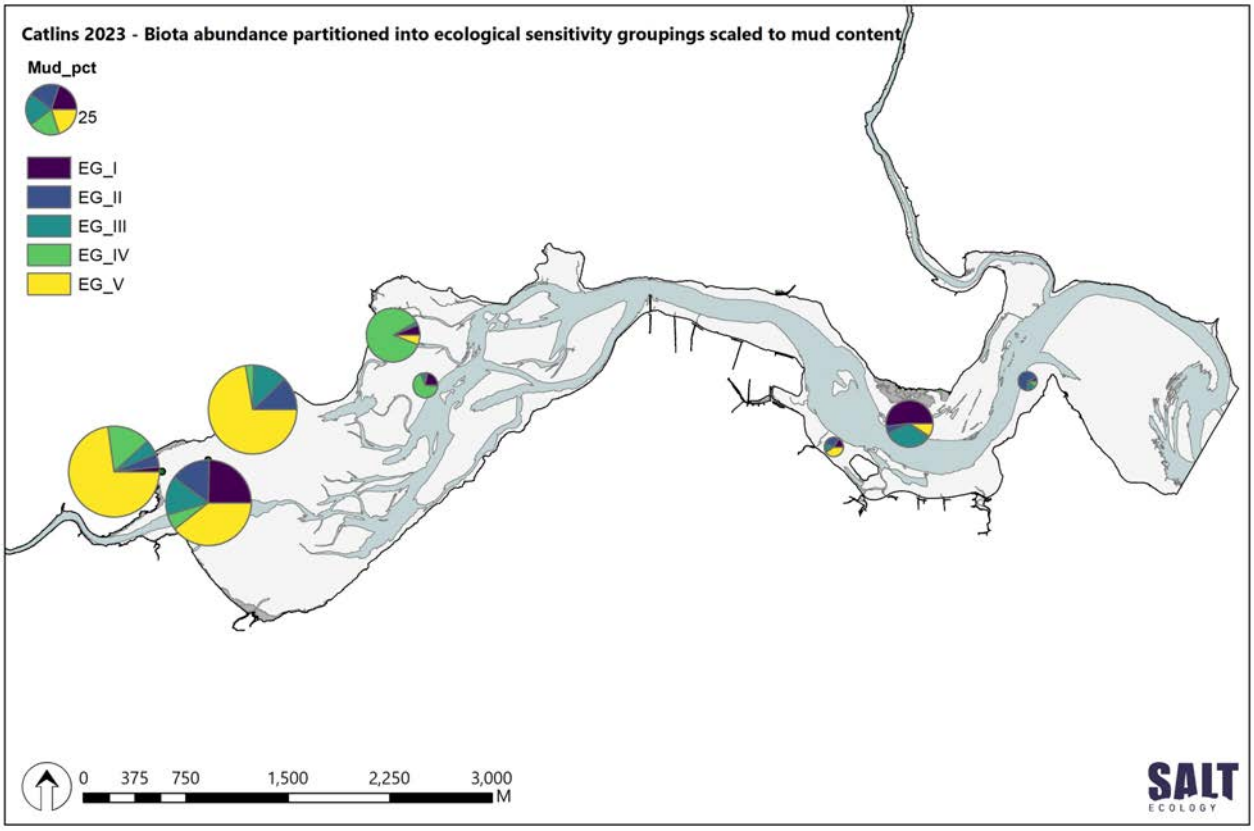


Fig. 16. Biota abundance partitioned into Ecological sensitivity Groupings (EGs), Catlins Estuary, December 2023. Circles are scaled to sediment mud content, the variable most strongly correlated with community composition. EGs range from relatively sensitive (EG-I) to relatively resilient (EG-V).

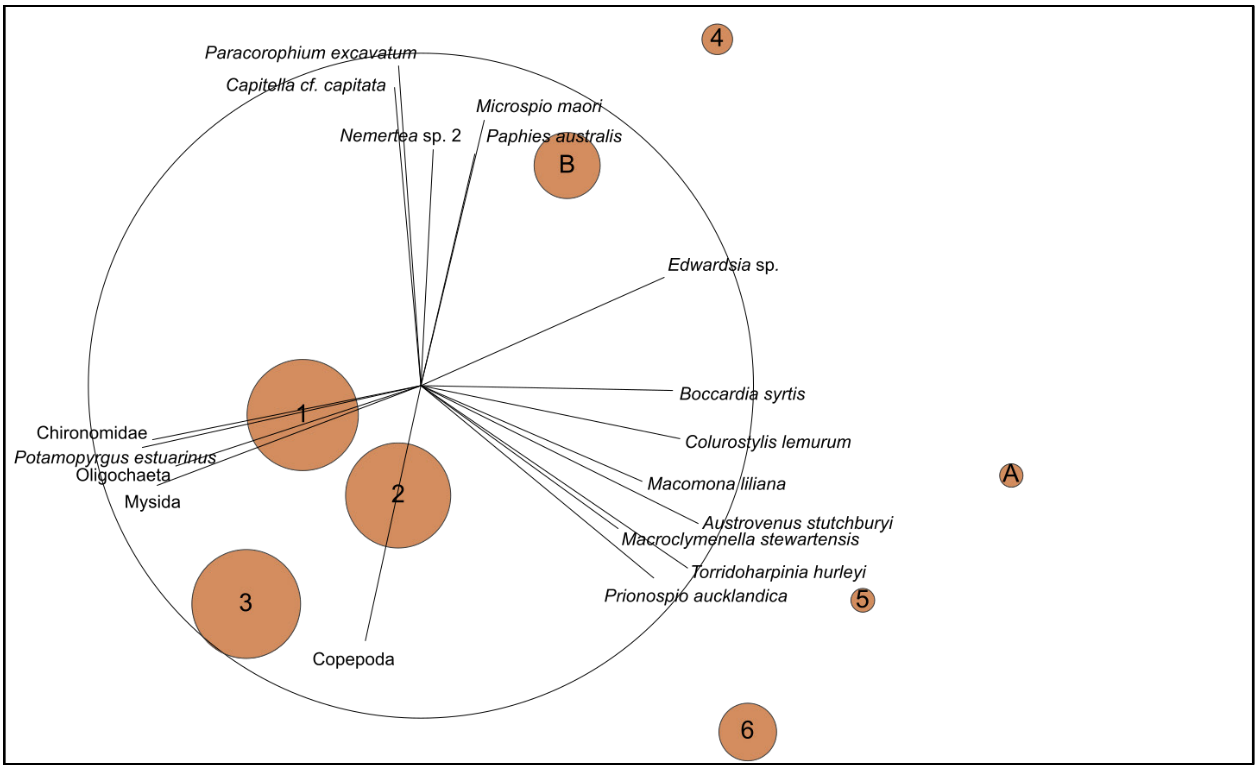


Fig. 17. Non-metric MDS ordination of macrofaunal core samples from each site.

Sites closer to each other have more similar community composition than distant ones. This plot has a 2D stress value of 0.05, meaning that a 2-dimensional plot provides a reliable representation of site differences. The vectors show the direction and strength of association (length of lines relative to the circle) of grouping patterns for macrofauna species most correlated (>0.7) with site differences. Brown circles are scaled to sediment mud content, the variable most strongly correlated with macrofauna composition.

6. SYNTHESIS

A summary of key 2023 results is provided in Table 13 and results relative to condition ratings are summarised in Tables 14 and 15, including temporal changes in broad scale indicators. Table 16 presents additional supporting indicators derived from catchment-scale nutrient and sediment models (e.g., CLUES; Hicks et al. 2019).

Table 13. Summary of key broad scale features, Catlins Estuary, December 2023.

a. Area summary	ha	% Estuary
Intertidal Area	589.0	69.9
Subtidal Area	254.2	30.1
Estuary Area	843.2	100
AIH Area	575.6	68.3
b. Key substrate features	**ha**	**% AIH**
Mud-enriched (25 to <50% mud)	40.1	7.0
Mud-dominated (≥50% mud)	109.0	18.9
c. Key habitat features	**ha**	**% Intertidal**
Salt marsh	13.3	2.3
		% AIH
Seagrass (≥50% cover)	20.1	3.5
Macroalgae (≥50% cover)	107.4	18.7
Microalgae (1-100% cover)	1.8	0.3
High Enrichment Conditions	79.4	13.8
d. Terrestrial margin (200m)	**ha**	**% Margin**
200m densely vegetated margin	152.3	20.0

6.1 KEY FINDINGS

Prior to settlement, native forest surrounded Catlins, with wetland and salt marsh prominent in the upper reaches of Catlins Lake and on the southern side of the lower estuary. Extensive logging of native forest in the early 1900's culminated in most of the estuary margin being cleared by 1948. Today, 62% of the catchment is in pastoral grazing with only 20% in native forest. Examples from a nearby estuary (i.e., New River Estuary) show that land use changes of this type have led to increased catchment nutrient and sediment loads ((Hale et al. 2024).

Large areas of natural wetland and salt marsh have also been drained for pasture and/or partially disconnected from the estuary due to roading infrastructure. Most losses occurred prior to 1948, with further drainage of adjacent wetland and salt marsh occurring in the upper Catlins Lake between 1967 and 1975 (see photos). It is estimated that ~80% of the historic salt marsh cover has been lost, with present day salt marsh comprising only 13ha, 2.3% of the intertidal area.

Upper Catlins Lake in February 1967 (top) and February 1975 (bottom) showing extensive drainage of wetland and salt marsh on the estuary margin.

Salt marsh (and adjacent wetland) habitat are important features in estuaries due to their ability to assimilate catchment-derived nutrients, and trap fine sediments. Additionally, salt marsh provides a wide range of other benefits, such as enhanced biodiversity, erosion control, carbon sequestration, flood and storm surge buffering, and cultural and recreational services. When salt marsh is lost, the effects of habitat loss are immediate for biodiversity outcomes, but the subtle effects of reduced sediment trapping efficiency and nutrient assimilation capacity generally become increasingly evident over longer (i.e., decadal) timescales. Salt marsh loss means sediments and nutrients that would have previously been trapped are dispersed across the wider estuary, accumulating in new areas (e.g., embayments or sediment deposition zones).

The small amount of remaining salt marsh in Catlins is unable to assimilate current catchment sediment and nutrient loads, resulting in the eutrophication and sediment impacts evident in many parts of the estuary. Without reductions to sediment and nutrient loads, ongoing degradation is expected, particularly where land development or naturally steep margins limit the potential for salt marsh to recover or migrate inland in response to changes in sea level rise leading to loss through displacement. Some losses could potentially be mitigated by reinstatement of salt marsh in suitable areas.

Table 14. Summary of broad scale indicator ratings for Catlins Estuary, 2006, 2016, 2021 and 2023.

Broad Scale Indicators	Unit	2006#	2016	2021^	2023
200m terrestrial margin	% densely vegetated	nd	23.2	nd	20.0
Mud-elevated substrate	% AIH[1] area (≥25% mud)	nd	23.6	nd	25.9
Macroalgae (OMBT-EQR[2])	Ecological Quality Rating (EQR)	>0.8*	0.615	0.388	0.533
Seagrass (≥50% cover)	% decrease from baseline	baseline	8.7	11.5	47.6
Salt marsh extent (current)	% of intertidal area	2.3	1.9	nd	2.3
Historical salt marsh extent[3]	% of historical remaining	21.6	18.9	nd	20.8
High Enrichment Conditions	ha	nd	14.9	74.6	79.4
High Enrichment Conditions	% of estuary	nd	2.9	12.5	13.8
Estuary wide indicators					
Sedimentation rate	CSR:NSR[4] ratio	nd	nd	nd	1.8
Sedimentation rate	mm/yr	nd	nd	nd	1.1

[1]Available Intertidal Habitat excludes salt marsh area; [2]Opportunistic Macroalgal Blooming Tool (OMBT) scores have been updated following Stevens et al. (2022); [3]Estimated natural extent see Appendix 5; [4]CSR=Current Sedimentation Rate, NSR=Natural Sedimentation Rate (predicted from catchment modelling). nd=no data. *Estimated. #2006 represents a desktop appraisal of seagrass, macroalgae and salt marsh. Although a broad-scale survey was undertaken in 2008, a high number of errors prevented its use in numeric temporal comparisons. ^Seagrass and macroalgae survey only.

Very Good	Good	Fair	Poor

Table 15. Summary of fine scale indicator condition ratings for sediment quality and macrofauna AMBI, Catlins Estuary, December 2023.

Fine Scale Indicators	Unit	Site 1	2	3	B	4	5	6	A
Mud	%	79.5	70.9	76.1	28.1	6.0	3.6	21.3	3.5
aRPD	mm	3	2	1	40	50	20	5	25
TN	mg/kg	2000	5900	7900	600	300	300	500	300
TP	mg/kg	580	920	1190	360	200	260	360	240
TOC	%	2.2	5.8	7.0	0.5	0.2	0.3	0.4	0.1
TS	%	0.5	0.8	1.3	0.09	0.07	0.05	0.1	0.03
As	mg/kg	3.7	6.2	5.6	3.7	2.9	4.4	4.6	5.5
Cd	mg/kg	0.08	0.09	0.16	0.02	0.01	0.01	0.04	0.02
Cr	mg/kg	10.4	14.8	17.7	8.5	6.0	6.9	9.6	6.0
Cu	mg/kg	7.9	12.2	15.4	4.7	3.0	3.2	5.3	2.2
Hg	mg/kg	0.03	0.05	0.06	<0.02	<0.02	<0.02	<0.02	<0.02
Ni	mg/kg	7.2	9.7	10.8	5.8	4.1	4.4	6.7	3.5
Pb	mg/kg	5.1	8.9	10.7	2.7	1.5	1.9	2.8	1.3
Zn	mg/kg	47.0	56.0	65.0	27.0	17.9	16.6	25.0	12.0
AMBI	na	5.3	3.3	4.8	4.3	3.4	3.4	1.7	1.7

See Glossary for abbreviations. < Values below lab detection limit.

Very Good	Good	Fair	Poor

An initial broad scale survey of Catlins in 2008 (Stewart & Bywater 2009) identified extensive areas of fine sediments, with moderate levels of nutrient enrichment. Follow up surveys in 2012, 2016, 2021, and the current survey, all indicate that fine sediment deposition and nutrient enrichment remain issues in Catlins, particularly in Catlins Lake. The expression of sediment and nutrient problems in Catlins Lake are consistent with a hydrodynamic model which showed the Catlins Lake flushing time was 10 times (5.1 days) longer than the lower estuary (<0.5 days; Plew & Dudley 2018). The extended flushing time, combined with lower tidal flows in Catlins Lake, likely promote fine sediment and nutrient accumulation. This is supported by both mapped broad-scale mud extents (Fig. 8; Table 13) and concurrent sediment plate monitoring at Site B in the mid Catlins Lake where, since 2016, there has been an average annual sedimentation rate of 6.2mm/y (Rabel 2024), three times the 2mm/yr guideline value for New Zealand estuaries (Townsend & Lohrer 2015).

Drainage channel through low-lying land on the southern margin.

Tidal drainage channels with salt marsh species on the landward side of the road edge.

Salt marsh southwest of Pounawea.

These measured data are in contrast to high-level catchment modelling estimates which provide some indication of the likelihood of sediment issues, but generally do not account well for the physical characteristics that often govern an estuary's susceptibility to sediment. For example, the predicted Current to Natural Sedimentation Rate (CSR:NSR) ratio is relatively low at 1.8 and, combined with an estimated 88% trapping efficiency (Hicks et al. 2019), results in a relatively low modelled estuary-wide sediment deposition rate of 1.1mm/yr. This discrepancy from the measured data is most likely due to present-day loads being underestimated (see O'Connell-Milne et al. 2024), noting that deposition measured from a small number of sites annually over a short time period is also likely to return variable results.

Table 16. Supporting data to assess estuary ecological condition in Catlins Estuary, December 2023.

Supporting Condition Measure	Catlins
Mean freshwater flow (m^3/s)[1]	6.3
Catchment Area (Ha)[1]	41,020
Catchment nitrogen load (TN-t/yr)[2]	171.6
Catchment phosphorus load (TP-t/yr)[2]	23.9
Catchment sediment load (KT/yr)[1]	15.3
Estimated N areal load in estuary ($mg/m^2/d$)[2]	55.7
Estimated P areal load in estuary ($mg/m^2/d$)[2]	7.8
CSR:NSR ratio[1]	1.8
Trap efficiency (sediment retained in estuary)[1]	88%
Estimated rate of sedimentation (mm/yr)[1]	1.1

[1] Hicks et al. (2019) & Oldham (2022).
[2] CLUES version 10.8 (LCBD5); Run date: April 2024.

Sediment plate monitoring Site B in the mid Catlins Lake.

As well as elevated sediment deposition within Catlins Lake, sediment samples collected in deposition areas (i.e., Sites 1-3) comprised very high mud contents (71-80% mud), accompanied by high levels of enrichment, including elevated levels of TN, TOC, TS and poor sediment oxygenation (Table 15). Elevated mud contents can exacerbate nutrient enrichment problems (discussed below), and their combined effect is reflected in biota at these sites which comprise primarily mud- and disturbance-tolerant species.

Macroalgal blooms have also become a significant issue causing adverse impacts on the estuary. An assessment of imagery from 2006 did not identify any significant growths of macroalgae. While not recorded in the 2008 broad-scale survey (Stewart & Bywater 2009), imagery from 2010 shows persistent blooms of the nuisance macroalgae *Gracilaria* spp. had appeared in two small embayments northwest of the Hinahina Road Bridge, before expanding more widely into the upper Catlins Lake, the Ōwaka Arm and within small embayments on the southern margin of the lower estuary (Stewart 2012; Stevens & Robertson 2017). By 2021, both macroalgal extent and biomass in these areas had significantly increased (Stevens & Roberts 2022). Relatively rapid expansion is a characteristic of *Gracilaria* which can grow from fragments or thalli (like roots) that can break off and be transported around the estuary (Luxton 1981; Guillemin et al. 2008). An established 'seed' source of macroalgae, combined with high nutrient loads and poorer flushing in the Catlins Lake, make this part of the estuary highly susceptible to eutrophication problems.

In December 2023, sediment eutrophic symptoms (e.g., sediment anoxia, sulfur oxidising bacteria, microalgae) had become so severe in some areas that macroalgae were no longer able to survive, leading to a decrease in macroalgal biomass and, consequently, an improvement in the OMBT-EQR score (Table 14). These worsening eutrophic symptoms are reflected in the increased extent of High Enrichment Conditions (HEC) areas (Table 14; see photos).

Area of decaying macroalgae and HEC evident with surface anoxia and white patches of sulphide-reducing bacteria, upper Catlins Lake.

The observed symptoms of nutrient enrichment, in the form of nuisance macroalgal blooms, are consistent with deteriorating water quality in the main river inputs over the same period. Between 2000 and 2020, water quality monitoring undertaken by ORC showed that both nutrients and sediment increased in the Catlins and Ōwaka Rivers (Ozanne 2020). The Catlins River remains within the worst 50% of all New Zealand sites (lawa.org.co.nz).

Catlins Lake in November 2008 (top; Stewart & Bywater 2009) and December 2023 (bottom).

In addition to persistent macroalgae species, a widespread bloom of brown filamentous algae (likely *Pylaiella littoralis*) was recorded in the estuary in December 2023. It was growing epiphytically on existing *Gracilaria* beds in Catlins Lake, and in other areas it was growing attached to hard substrates (i.e., rock or cockle). Subtidal growths of both brown and green filamentous macroalgae were also extensive.

It is uncertain, what triggered the filamentous algae bloom observed in 2023. Air and sea surface temperatures were within expected ranges (harbourconditions.otago.ac.nz). A large flood flow, that exceeded the mean annual flood flow, was recorded in September 2023 which may have led to a pulse of nutrients into the estuary (envdata.orc.govt.nz). Nelson et al. (2015), and references therein, suggested the proliferation of *Pylaiella littoralis* can be sustained by *in situ* nutrient generation, indicating a potential link between available nutrient concentrations and blooming conditions.

Brown filamentous algae growing epiphytically on *Gracilaria* beds (top), attached to a cockle (middle) and extensive sub-tidally upstream of Hinahina Road bridge (bottom).

While nutrient loads in the Catlins River and Ōwaka River are below the ~100mgTN/m^2/d threshold at which nuisance macroalgae problems are predicted to occur in intertidally dominated estuaries (Robertson et al. 2017), macroalgal problems are still occurring. A detailed study of Catlins by Plew & Dudley (2018) also highlighted that Catlins Lake had a high physical susceptibility due to limited flushing and dilution which, combined with high present day nutrient loads in the Catlins River, resulted in high eutrophication susceptibility to macroalgal blooms. Furthermore, macroalgal species can sustain growth from both internal nutrient stores as well as sediments (Robertson & Savage 2018; Dudley et al. 2022). The concentration of nutrients within the sediments in areas of macroalgal proliferation (i.e., Sites 1-3) were high (rated 'Poor') suggesting algal growth may be fuelled by both catchment nutrient inputs and *in situ* nutrient sources.

In contrast to the significant eutrophic symptoms in the Catlins Lake and upper Ōwaka Arm, the lower estuary is relatively well-flushed with clean sands and several extensive areas of healthy seagrass. Sediment biota, both in seagrass areas and the unvegetated tidal flats, were species-rich, with a diverse range of sensitive species, indicating the lower estuary is in a healthy state. Since 2006, there has been a 47% loss in high (≥50%) cover seagrass, but relatively little change of the overall footprint in which seagrass is growing. Losses can be attributed to; (1) erosion and fragmentation of beds south of Pounawea and on the true right bank below Hinahina Road bridge, (2) natural variability of beds near the river channel in front of the Pounawea township, and (3) natural variability of seagrass beds growing in mobile sands at the estuary entrance. Large beds remain near Pounawea and at the estuary entrance, but no seagrass has been evident in Catlins Lake since ~1995.

In conclusion, Catlins is in a 'Fair' to 'Poor' state (Table 14 & 15). While the lower estuary retains high value seagrass beds and is dominated by firm, sandy substrates, the Catlins Lake, Ōwaka Arm and many small embayments are of concern because of their eutrophication symptoms (e.g., macroalgae, poor sediment quality, enrichment tolerant species, bacterial mats), and a trend of declining health since the last survey. Ongoing pressures to salt marsh from drainage, grazing, and displacement due to sea level rise are all likely to become increasingly significant if they are not appropriately managed or planned for.

Sampling for biota in the seagrass beds near Pounawea.

6.2 MONITORING AND MANAGEMENT CONSIDERATIONS

Monitoring

SOE monitoring data are available for several estuaries in Otago, and planning processes are underway for setting environmental limits for estuaries, e.g., the National Policy Statement for Freshwater Management (NPS-FM) objective setting process. It would therefore be timely to assess the available SOE monitoring data in a holistic manner to determine monitoring priorities for Catlins, alongside other estuaries regionally. A programme review should consider the regional planning context in addition to estuary susceptibility, condition, and current and predicted future pressures.

Management

Monitoring of Catlins has highlighted the following management priorities:

- **Reduce catchment nutrients loads**, particularly in the Catlins River catchment given the higher susceptibility of Catlins Lake. Although macroalgal issues are also evident in Ōwaka Arm. Reducing nutrient inputs is essential to limit the further expansion of macroalgae and other eutrophic symptoms (e.g., poor sediment oxygenation, enrichment tolerant biota) causing current estuary degradation.
- **Reduce catchment sediment loads**, in both the Catlins River and Ōwaka River. Mud-dominated sediments were common in both the Catlins Lake and Ōwaka Arm, with measured sediment deposition three times the guideline value in the central Catlins Lake. Reducing sediment inputs will improve water clarity for seagrass habitat, likely improve species richness, and reduce sediment (and associated nutrient) trapping within macroalgal beds.
- **Protect and enhance salt marsh and adjacent wetland habitat**, including vehicle exclusion, pest control (i.e., removal of the invasive pest species *Spartina*), and stock exclusion.
- **Incorporate salt marsh migration in response to sea level rise into planning decisions** and, where appropriate, remove barriers such as tidal flap gates to reinstate tidal flushing of low-lying areas containing residual or past salt marsh habitat.

7. RECOMMENDATIONS

Based on the monitoring undertaken in Catlins it is recommended ORC consider the following:

Monitoring

- Undertake targeted macroalgae and seagrass monitoring every 3-years with a full broad scale survey every ~6-years to track changes in the dominant features of the estuary. Substrate mapping should be supported by measurements of sediment grain size and sediment oxygenation to complement routine fine-scale and sediment plate monitoring.
- Monitor sedimentation annually (see recommendations in Rabel 2024).
- Utilise estuary monitoring data to review the SOE programme and assess monitoring needs in Catlins alongside priorities for other estuaries regionally.

Management

- Maintain records of major catchment landuse changes (e.g., forest clearance, road development, pastoral conversion, exotic afforestation), and any significant flood events that may impact the estuary.
- Improve characterisation of estuary sediment and nutrient loads, evaluate potential catchment nutrient and sediment sources, and investigate options for a reduction of inputs where loads exceed guidance thresholds. It is noted that this is currently underway through development of the CREST model by DHI for Catlins.
- Continue with the ORC objective-setting programme that aims to maintain or improve current estuary state by reducing sediment and nutrient loads to levels that prevent significant ecological degradation.
- Develop a strategy for ecological restoration and protection (e.g., vehicle exclusion and pest control within salt marsh, replanting salt marsh, improving tidal flushing, re-contouring shorelines (in preference to hardening, removing barriers to salt marsh expansion) that builds on previous work by Stevens (2023).

8. REFERENCES

ANZG 2018. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian State and Territory Governments, Canberra ACT, Australia. Available at https://www.waterquality.gov.au/anz-guidelines/guideline-values/default/sediment-quality-toxicants.

Dudley BD, Barr NG, Plew DR, Scheuer K 2022. Experiments to parametrise a growth and nutrient storage model for Agarophyton spp. Estuarine, Coastal and Shelf Science. 264: 107660.

Guillemin ML, Faugeron S, Destombe C, Viard F, Correa JA, Valero M 2008. Genetic variation in wild and cultivated populations of the haploid-diploid red alga *Gracilaria chilensis*: how farming practices favor asexual reproduction and heterozygosity. Evolution 62(6): 1500-1519.

Hale R, Zeldis J, Dudley BD, Haddadchi A, Plew D, Shankar U, Swales A, Roberts KL, O'Connell-Milne S, Verburg P 2024. Hindcasting estuary ecological states using sediment cores, modelled historic nutrient loads, and a Bayesian network. Frontiers in Marine Science 11.

Hicks M, Semadeni-Davies A, Haddadchi A, Shankar U, Plew D 2019. Updated sediment load estimator for New Zealand. NIWA Client Report No: 2018341CH, prepared for Ministry for the Environment, March 2019. 190p.

Luxton DM 1981. Experimental harvesting of *Gracilaria* in New Zealand. In: Proceedings 10th International Seaweed Symposium. Berlin, Walter de Gruyter and Co. p.693–698.

Morrisey D, Forrest BM 2023. Catlins/Pounawea Estuary Intertidal Fine-Scale Monitoring Data Summary. Salt Ecology Report 130, prepared for Otago Regional Council, February 2024. 13p.

Nelson WA, Neill KF, D'Archino R 2015. When seaweeds go bad: an overview of outbreaks of nuisance quantities of marine macroalgae in New Zealand. New Zealand Journal of Marine and Freshwater Research 49(4): 472-491.

O'Connell-Milne S, Roberts KL, Forrest BM, Stevens L 2024. Synoptic Broad Scale Ecological Assessment of Shag Estuary. Salt Ecology Report 134, prepared for Otago Regional Council, May 2024. 70p.

Ozanne R 2020. State and Trends of River and Lake Water Quality in the Otago Region 2000-2020. Prepared by Otago Regional Council. 135p.

Plew DR, Dudley BD 2018. Eutrophication susceptibility assessment of Pounawea (Catlins) Estuary. Prepared for Otago Regional Council. NIWA Client Report No. 2018232CH, 32 p.

Rabel H 2024. Catlins River (Pounawea) Estuary: 2023/2024 intertidal sediment monitoring summary. Salt Ecology short report 041. Prepared for Otago Regional Council. 2p.

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

Robertson BM, Stevens LM, Robertson BP, Zeldis J, Green M, Madarasz-Smith A, Plew D, Storey R, Hume T, 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.

Robertson BP, Savage C 2018. Mud-entrained macroalgae utilise porewater and overlying water column nutrients to grow in a eutrophic intertidal estuary. Biogeochemistry, 139(1), 53–68.

Stevens L 2023. Method note for GIS based inundation modelling to predict changes in salt marsh extent in response to sea level rise. Salt Ecology Short Report 035, prepared for Otago Regional Council, October 2023.

Stevens LM, Robertson BM 2017. Catlins Estuary broad scale habitat mapping 2016/17. Prepared for Otago Regional Council, May 2017. 38p.

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.

Stevens LM, Forrest BM, Dudley BD, Plew DR, Zeldis JR, Shankar U, Haddadchi A, Roberts KL 2022. Use of a multi-metric macroalgal index to document severe eutrophication in a New Zealand estuary. New Zealand Journal of Marine and Freshwater Research: 1-20.

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 Envrionment Report. Prepared by Ryder Consulting for Otago Regional Council. 36p.

Townsend M, Lohrer D 2015. ANZECC Guidance for Estuary Sedimentation. NIWA client report number HAM2015-096, prepared for Ministry for the Environment. 45p.

Tyrrell AR 1989. Catlins Pioneering. Published by Catlins Historic Society, Owaka, New Zealand. 164p.

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.

Yang Y 2022. Catlins Freshwater Management Unit Economic Snapshot. Prepared by Otago Regional Council for the Otago Regional Council Economic Work Programme, Dunedin. 14p. .

APPENDIX 1. SAMPLING METHODS, CATLINS, DECEMBER 2023

This Appendix details the synoptic ecological assessment approach used by Salt Ecology for assessing intertidal estuary condition. It comprises estuary-wide broad-scale habitat mapping, and an assessment of sediment quality including associated biota. In relation to these components, note that:

- The broad-scale habitat mapping methods largely follow the National Estuary Monitoring Protocol (NEMP; Robertson et al. 2002), with improvements to some of the assessment, analysis and QA/QC elements as described in Section A.
- Broad scale mapping seeks to characterise the spatial extent of dominant substrate types (with a particular focus on muddy sediments as a key indicator of catchment sediment inputs), opportunistic macroalgae (as an indicator of nutrient enrichment status), and ecologically important vegetated habitats vulnerable to human disturbance. The latter consist of intertidal seagrass (*Zostera muelleri*) and salt marsh, as well as vegetation of the 200m terrestrial margin bordering the estuary.
- The synoptic assessments of sediment quality and biota largely use the NEMP fine scale indicators and analytical methods described in Section B, but vary from the NEMP by incorporating more sites with reduced within-site replication to provide a synoptic picture of ecological health across a range of soft-sediment habitat types throughout the estuary. In contrast, NEMP fine-scale surveys are typically based on intensive (high replication) sampling of 1-3 sites in the dominant habitat type.

A. BROAD SCALE METHODS

A1. MAPPING

A1.1 Overview

For broad scale mapping purposes, the estuary was defined as a partly enclosed body of water where freshwater inputs (i.e., rivers, streams) mix with seawater. The seaward boundary (estuary entrance) was defined as a straight line between the seaward-most points of land that enclose the estuary, with the upper estuary (i.e., riverine) boundary at the estimated upper extent of saline intrusion. For further discussion on estuary boundary definitions see FGDC (2012) and Hume et al. (2016).

Broad scale NEMP surveys involve mapping the intertidal zone of estuaries, according to dominant surface habitat (substrate and vegetation) features. The type, presence and extent of estuary substrate, salt marsh, macroalgae or seagrass reflects multiple factors, for example the combined influence of sediment deposition, nutrient availability, salinity, water quality, clarity and hydrology or direct human disturbance. As such, broad scale mapping provides time-integrated measures of prevailing environmental conditions that are generally less prone to the small scale spatial or temporal variation commonly associated with instantaneous measures of water quality or, to a lesser extent, sediment quality. Once a baseline map has been constructed, changes in the position and/or size or type of dominant features can be monitored by repeating the mapping exercise, and temporal changes due to the effects of anthropogenic inputs of sediment or nutrients, or activities such as vegetation clearance, margin hardening (e.g., rock walls), reclamation, or drainage of salt marsh, can be elucidated.

The mapping procedure follows NEMP methods and combines aerial photography or satellite imagery, detailed ground-truthing, and digital mapping using Geographic Information System (GIS) technology. Field surveys are typically carried out during September to May, when most plants are still visible and seasonal vegetation has not died back, with experienced scientists ground-truthing the estuary and margin on foot to directly map or validate the dominant vegetation and substrate visible on aerial imagery. Field maps are ideally <50cm/per pixel resolution at a scale of between 1:2000 and 1:5000, as at a coarser scale it becomes difficult to map features with sufficient resolution to reliably characterise features. The drawn or validated features, combined with field notes and georeferenced photographs, are later digitised into ArcMap (currently v10.8) shapefiles at a scale of at least 1:2000 using a drawing tablet to produce maps of the dominant estuary features.

A summary of the broad scale indicators and the rationale for their use is provided in the main body of the report, with methods for mapping and assessing each indicator also described.

A1.2 Catchment description and terrestrial margin mapping

Catchment land use maps are constructed from the most recent Landcare Research Land Cover Data Base (currently LCDB5 2017/2018) where dominant land cover has been classified based on the codes described in Table A1. Using the broad scale NEMP methods described in section A1.1, these same LCDB5 classes are used to categorise features within the 200m terrestrial margin of an estuary. The one exception is the addition by Salt Ecology of a new sub-class (410 – Duneland) to delineate coastal duneland from low producing grassland, due to the high value of duneland habitat type.

Table A1. Landcare Land Cover Database (LCDB5) classes used in the mapping of terrestrial features.

Artificial Surfaces		Grassland, Sedge and Saltmarsh	
1	Built-up Area (settlement)	40	High Producing Exotic Grassland
2	Urban Parkland/Open Space	41	Low Producing Grassland
5	Transport Infrastructure	410*	Duneland
6	Surface Mines and Dumps	43	Tussockland
Bare or Lightly Vegetated Surfaces		45	Herbaceous Freshwater Vegetation
10	Sand and Gravel	46	Herbaceous Saline Vegetation
12	Landslide	Scrub and Shrubland	
14	Permanent Snow and Ice	47	Flaxland
15	Alpine Grass/Herbfield	50	Fernland
16	Gravel and Rock	51	Gorse and/or Broom
Water Bodies		52	Manuka and/or Kanuka
20	Lake or Pond	54	Broadleaved Indigenous Hardwoods
21	River	55	Sub Alpine Shrubland
22	Estuarine water	56	Mixed Exotic Shrubland
Cropland		58	Matagouri or Grey Scrub Forest
30	Short-rotation Cropland	Forest	
33	Orchard Vineyard & Other Perennial Crops	64	Forest - Harvested
		68	Deciduous Hardwoods
		69	Indigenous Forest
		71	Exotic Forest

*Duneland is an additional category to the LCDB classes to differentiate between "Low Producing Grassland" and "Duneland".

A1.3 Estuary substrate classification and mapping

NEMP substrate classification is based on the dominant surface features present, e.g., rock, boulder, cobble, gravel, sand, mud. However, many of the defined NEMP sediment classifications are inconsistent with commonly accepted geological criteria (e.g., the Wentworth scale), aggregate mud/sand mixtures into categories that can range in mud content from 10-100%, and use a subjective and variable measure of sediment 'firmness' (how much a person sinks) as a proxy for mud content. To address such issues, Salt Ecology has revised the NEMP classifications (summarised in Table A2) using terms consistent with commonly accepted geological criteria (e.g., Folk 1954) and, for fine unconsolidated substrate (<2mm), divided classes based on estimates of mud content where biologically meaningful changes in sediment macrofaunal communities commonly occur (e.g., Norkko et al. 2002, Thrush et al. 2003, Gibbs & Hewitt 2004, Hailes & Hewitt 2012, Rodil et al. 2013, Robertson et al. 2016c). Sediment 'firmness' is used as a descriptor independent of mud content. Salt Ecology also maps substrate beneath vegetation to create a continuous substrate layer for an estuary.

The Salt Ecology revisions (Table A2) use upper-case abbreviations to designate four fine unconsolidated substrate classes based on sediment mud content (S=Sand: 0-10%; MS=Muddy Sand: ≥10-50%; SM=Sandy Mud: ≥50-90%; M=Mud: ≥90%), with muddy sand further divided into two sub-classes of ≥10-25% or ≥25-50% mud content. These reflect categories that can be subjectively assessed in the field by experienced scientists, and validated by the laboratory analysis of particle grain size samples (wet sieving) collected from representative sites (typically ~10 per estuary) based on the methods described in Section B.

Lower-case abbreviations are used to designate sediment 'firmness' based on how much a person sinks (f=firm: 0-<2cm; s=soft: 2-5cm; vs=very soft: ≥5cm). Because this measure is highly variable between observers, it is only used as a supporting narrative descriptor of substrate type. Mobile substrate (m) is classified separately and, based on the NEMP, is considered to only apply to firm substrate.

Table A2 presents the revised classifications alongside the original NEMP equivalent classifications to facilitate consistent comparisons with previous work (by aggregating overlapping classes). The area (horizontal extent) of mud-elevated sediment (>25% mud content) is used as a primary indicator of sediment mud impacts, and in assessing susceptibility to nutrient enrichment impacts (trophic state).

Examples of substrate types: Top row (L to R); mobile sand (mS; 0-10%), firm shell/sand (fShS; 0-10%), firm sand (fS; 0-10%).
Bottom row (L to R); firm muddy sand (fMS10; ≥10-25%), soft muddy sand (sMS25; ≥25-50%), very soft sandy mud (vsSM; ≥50-90%).

Table A2. Modified NEMP substrate classes and field codes.

Consolidated substrate			Code	NEMP equivalent (depth of sinking)	
Bedrock		Rock field "solid bedrock"	RF	RF	Rockland
Coarse Unconsolidated Substrate (>2mm)					
Boulder	>256mm	Boulder field "bigger than your head"	BF	BF	Boulder field
Cobble	64 to <256mm	Cobble field "hand to head sized"	CF	CF	Cobble field
Gravel	2 to <64mm	Gravel field "smaller than palm of hand"	GF	GF	Gravel field
Shell	2 to <64mm	Shell "smaller than palm of hand"	Shel	Shell	Shell bank
Fine Unconsolidated Substrate (<2mm) – see footnotes					
Sand (S)	Low mud (0-10%)	Mobile sand	mS	MS	Mobile sand (<1cm)
		Firm shell/sand	fShS	FSS	Firm shell/sand (<1cm)
		Firm sand	fS	FS	Firm sand (<1cm)
		Soft sand	sS	SS	Soft sand (>2cm)
		Very soft sand	vsS	SS	Soft sand (>2cm)
Muddy Sand (MS)	Moderate mud (≥10-25%)	Mobile muddy sand	mMS10	MS	Mobile sand (<1cm)
		Firm muddy shell/sand	fMShS10	FSS	Firm shell/sand (<1cm)
		Firm muddy sand	fMS10	FMS	Firm mud/sand (<2cm)
		Soft muddy sand	sMS10	SM	Soft mud/sand (2-5cm)
		Very soft muddy sand	vsMS10	VSM	Very soft mud/sand (>5cm)
	High mud (≥25-50%)	Mobile muddy sand	mMS25	MS	Mobile sand (<1cm)
		Firm muddy shell/sand	fMShS25	FSS	Firm shell/sand (<1cm)
		Firm muddy sand	fMS25	FMS	Firm mud/sand (<2cm)
		Soft muddy sand	sMS25	SM	Soft mud/sand (2-5cm)
		Very soft muddy sand	vsMS25	VSM	Very soft mud/sand (>5cm)
Sandy Mud (SM)	Very high mud (≥50-90%)	Firm sandy mud	fSM	FMS	Firm mud/sand (<2cm)
		Soft sandy mud	sSM	SM	Soft mud/sand (2-5cm)
		Very soft sandy mud	vsSM	VSM	Very soft mud/sand (>5cm)
Mud (M)	Mud (≥90%)	Firm mud	fM90	FMS	Firm mud/sand (<2cm)
		Soft mud	sM90	SM	Soft mud/sand (2-5cm)
		Very soft mud	vsM90	VSM	Very soft mud/sand (>5cm)
Zoogenic (living)					
Area dominated by both live cockle, mussel, oyster, shellfish or tubeworm species respectively.		Cocklebed	CKLE		Cockle
		Mussel reef	MUSS		Mussel
		Oyster reef	OYST		Oyster
		Shellfish bed	SHFI		
		Tubeworm reef	TUBE		Sabellid
Artificial Substrate					
Introduced natural or human-made materials that modify the environment. Includes rip-rap, rock walls, wharf piles, bridge supports, walkways, boat ramps, groynes, flood control banks, stop gates.		Substrate (bund, ramp, wall, whf)	aS		
		Boulder field	aBF		Boulder field
		Cobble field	aCF		Cobble field
		Gravel field	aGF		Gravel field
		Sand field	aSF		Firm/Soft sand

Sediment firmness: Subjectively classified as firm if you sink 0-<2cm, soft if you sink 2-5cm, or very soft if you sink >5cm.
Mobile: Sediment is firm but routinely moved by tidal currents or waves. Commonly characterised by having a rippled surface layer.
Sand: Sandy sediment that is granular when rubbed between the fingers and releases no conspicuous fines when sediment is disturbed.
Shell/Sand: Mixed sand and shell hash. See muddy sand sub-classes below for field guidance on estimating mud content.
Muddy Sand: Sand-dominated sediment that is mostly granular when rubbed between the fingers but has a smoother consistency than sand. Subdivided into two sub-classes based on estimated mud content (commonly validated by laboratory analysis of representative substrate);

i. Moderate mud (≥10-25%) content: Muddy fines evident when sediment is disturbed. Sediments generally firm to walk on.
ii. High mud (≥25-50%) content): Muddy fines conspicuous when sediment is disturbed. Sediments generally soft to walk on.

Sandy Mud (≥50-90% mud content): Mud-dominated sediment primarily smooth/silken when rubbed between the fingers, but retains a granular component. Sediments generally soft or very soft and only firm if dried out, or another component (e.g., gravel) prevents sinking.
Mud (≥90% mud content): Mud-dominated sediment with no obvious sand component. Smooth/silken when rubbed between the fingers. Sediments generally only firm if dried out, or another component (e.g., gravel underneath mud) prevents sinking.

A1.4 Estuary salt marsh

Salt marsh grows in the upper tidal extent of estuaries, usually bordering the terrestrial margin. NEMP methods are used to map and categorise salt marsh, with dominant estuarine plant species used to define broad structural classes (e.g., rush, sedge, herb, grass, reed, tussock; see Robertson et al. 2002). The following changes have been made to the original NEMP vegetation classifications:

- <u>Forest</u> (woody plants >10 cm density at breast height - dbh) and <u>scrub</u> (woody plants <10cm dbh) are considered terrestrial and mapped using LCDB codes as outlined in Table A1.
- <u>Introduced weeds:</u> Weeds are a common margin feature occasionally extending into upper intertidal areas and have been added to broad salt marsh structural classes.
- <u>Estuarine shrubland:</u> Woody plants <10 cm dbh growing in intertidal areas (e.g., mangroves, saltmarsh ribbonwood) have been added to broad salt marsh structural classes.

Two measures are used to assess salt marsh condition: i) intertidal extent (percent cover of total intertidal area) and ii) current extent compared to estimated historical extent.

LiDAR (where available) and historic aerial imagery are used to estimate historic salt marsh extent. All LiDAR geoprocessing is performed using ArcGIS Pro (currently v2.9.3). The terrain dataset is converted to raster using the Terrain to Raster (3D Analyst) tool. Contour lines are created using the Contour List (Spatial Analyst) tool. An elevation contour that represents the upper estuary boundary elevation is selected based on a comparison with existing estuary mapping and a visual assessment of aerial imagery. To estimate historic salt marsh extent, both the upper estuary boundary and historic aerial imagery (e.g., sourced from retrolens.co.nz or council archives) are used to approximate the margin of salt marsh which is digitised to determine areal extent.

In addition to mapping of the salt marsh itself, the substrate in which the salt marsh is growing is also mapped, based on the methods described in Section A1.3. As salt marsh can naturally trap and accrete muddy sediment, substrate mapping within salt marsh can provide an insight into ongoing or historic muddy sediment inputs.

A1.5 Estuary seagrass assessment

The NEMP provides no guidance on the assessment of seagrass beyond recording its presence when it is a dominant surface feature. To improve on the NEMP, the mean percent cover of discrete seagrass patches is visually estimated through ground-truthing, based on the 6-category percent cover scale in Fig. A1.

The state of seagrass is assessed by the change in spatial cover as a percentage of the measured 'baseline' which generally represents the earliest available ground-truthed broad scale survey. In the absence of ground-truthed

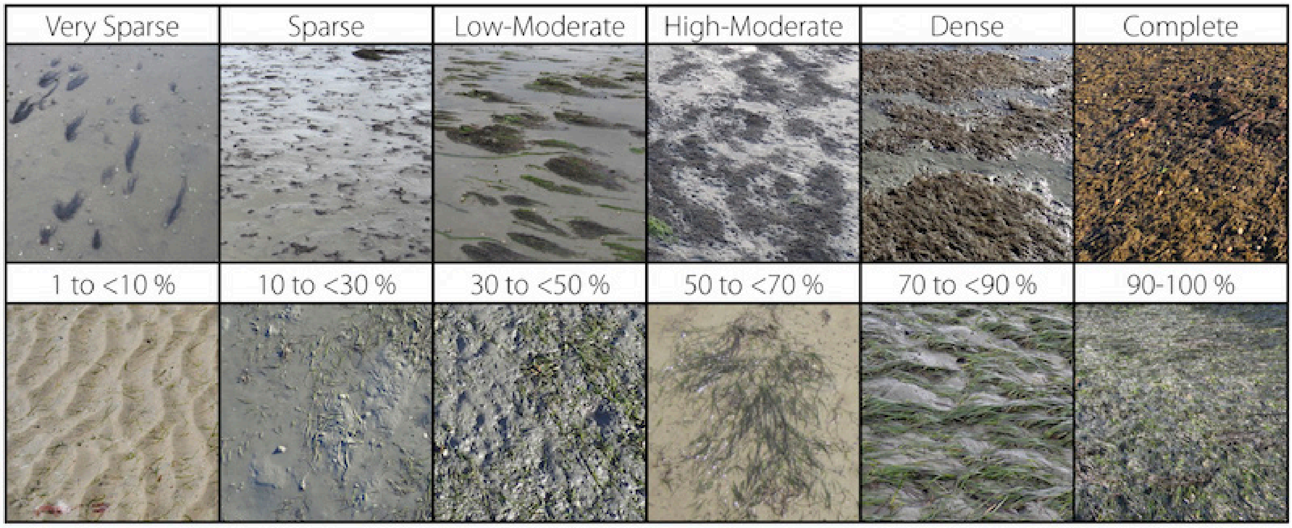


Fig. A1. Visual rating scale for percentage cover estimates. Macroalgae (top), seagrass (bottom). Modified from FGDC (2012).

broad scale surveys, historic imagery, supported by anecdotal reports of seagrass presence, can be georeferenced in ArcGIS and visible seagrass digitised. It is difficult to reliably map seagrass areas of <50% cover, and to distinguish boundaries between subtidal and intertidal areas, solely from historic imagery (i.e., no ground-truthing). Therefore, comparisons of broad scale data captured from aerial imagery alone can generally only be reliably made for percent cover categories ≥50%, with the estuary-wide area of seagrass ≥50% cover typically compared across years. Notwithstanding that seagrass extent derived from historic imagery may be less reliable than that derived from ground-truthed surveys, it remains a useful metric to understanding the narrative of seagrass change, including its natural variability.

A1.6 Estuary macroalgae assessment

The NEMP provides no guidance on the assessment of macroalgae beyond recording its presence when it is a dominant surface feature, hence, improved methods are used by Salt Ecology. These are based on the New Zealand Estuary Trophic Index (Robertson et al. 2016a), which adopts the United Kingdom Water Framework Directive (WFD-UKTAG 2014) Opportunistic Macroalgal Blooming Tool (OMBT). The OMBT, described in detail in previous reports (e.g., Stevens et al. 2022; Roberts et al. 2022), 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 threshold bands (bad, poor, moderate, good, 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 roots deep (e.g., >30mm) within the sediments, which indicates that persistent macroalgal growths have established.

If an estuary supports <5% opportunistic macroalgal cover within the Available Intertidal Habitat (AIH), then the overall quality status using the OMBT method is reported as 'high' (EQR score ≥ 0.8 to 1.0) with no further sampling required. In this situation a numeric EQR score, which is based directly on the measured opportunistic macroalgal percent cover in the AIH, is calculated for the 'high' band using the approach described in Stevens et al. (2022).

Using the OMBT, opportunistic macroalgae patches are mapped during field ground-truthing using a 6-category rating scale (modified from FGDC 2012) as a percentage cover guide (Fig. A1). Within these percent cover categories, representative patches of comparable macroalgal growth are identified and the biomass and the extent of macroalgal entrainment in sediment is measured. Biomass is 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 is then rinsed to remove sediment. Any non-algal material including stones, shells and large invertebrate fauna (e.g., crabs, shellfish) are also removed. Remaining algae are then hand squeezed or spun until water stops running, and the wet weight is recorded to the nearest 10g using 1kg Pesola light-line spring scales. When sufficient representative patches have been measured to enable biomass to be reliably estimated, biomass estimates are then made following the OMBT method.

Macroalgae patches are digitised in ArcGIS as described in Section 1.1 with each patch containing data on the species present, percent cover, biomass and entrainment status. Each macroalgal patch is given a unique 'Patch ID' up to a maximum of 100 patches per estuary (i.e., the maximum the OMBT Microsoft Excel calculator can calculate). If more than 100 patches are present, comparable patches are grouped (i.e., patches with the same species, percent cover, biomass and entrainment). The raw data is exported from ArcGIS into Excel using a scripting tool. The OMBT Microsoft Excel template (i.e., WFD-UKTAG Excel template) is used to calculate an OMBT EQR, with OMBT biomass thresholds (Table A3) updated to reflect conditions in New Zealand estuaries as described in Plew et al. (2020). The scores are then categorised on the five-point scale adopted by the method as outlined in Table A3.

Table A3. Thresholds used to calculate the OMBT-EQR in the current report.

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

[1] Where ≤5%,cover AIH EQR was calculated as described in Section A1.6.
[2] Only the lower EQR of the 2 metrics, AA or AA/AIH, should be used in the final EQR calculation (WFD-UKTAG (2014).
[3] Updated thresholds for New Zealand estuaries described in Plew et al. (2020).

A1.7 Broad scale data recording, QA/QC and analysis

Broad scale mapping provides a rapid overview of estuary substrate, macroalgae, seagrass and salt marsh 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 ~1:2000 to within 1-2m of their boundaries. The greatest scope for error occurs where boundaries are not readily visible on imagery, e.g., sparse seagrass or 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 imagery alone (i.e., no ground-truthing), accuracy is unlikely to be better than ±20-50m, and generally limited to vegetation features with a percent cover >50%.

There are many potential sources of error that can occur during the digitising and GIS data collation process that may affect the accuracy of the metrics derived from broad scale mapping, and undermine the assessment of temporal change. To minimise this risk, Salt Ecology has developed in-house scripting tools in Phyton to create a customised GIS toolbox for broad scale mapping outputs. The scripting tools sequentially run through a QA/QC checklist to check for duplicated or overlapping GIS polygons and to identify gaps or slivers and validate typology (field codes). Following rectification of any errors, the customised toolbox is used to create maps with consistent symbology, generate standardised summary tables for reporting, and to add metadata to final GIS packages.

Additional to the annotation of field information onto aerial imagery during ground-truthing, electronic templates (custom-built using Fulcrum app software - www.fulcrumapp.com) are used to record substrate validation locations and measurements of sediment aRPD, texture and sediment type, as well as macroalgal data (i.e., biomass and cover measurements, entrainment). Each sampling record created in Fulcrum generates a GPS position, which is exported to ArcGIS, with pre-specified data entry constraints (e.g., with minimum or maximum values for each data type) minimising the risk of erroneous data recording. Scripting tools are then used within ArcGIS to upload data.

B. SEDIMENT QUALITY AND BIOTA METHODS

B1.1 Overview

Mapping the main habitats in an estuary using the NEMP broad scale approach provides a basis for identifying representative areas to sample sediment quality and associated biota. Samples are typically collected from sufficient sites to characterise the range of conditions in estuary soft sediments, from the seaward extent to upper estuary areas, including areas in the vicinity of any potentially strong catchment influences (e.g., river mouths, stormwater point sources). A summary of sediment and biota indicators, the rationale for their use, and field sampling methods, is provided in the main body of the report (i.e., Table 2). The sampling methods generally adhere to the NEMP 'fine scale' sampling protocol, except where noted.

B1.2 Sediment quality sampling and laboratory analyses

At each site, a composite sediment sample (~500g) is pooled from three sub-samples (to 20mm depth). Samples are stored on ice and sent to Hill Labs for analysis of: particle grain size in three categories (%mud <63µm, sand <2mm to ≥63µm, gravel ≥2mm); organic matter (total organic carbon, TOC); nutrients (total nitrogen, TN; total phosphorus, TP; total sulphur, TS); and trace contaminants (arsenic, As; cadmium, Cd; chromium, Cr; copper, Cu; mercury, Hg; lead, Pb; nickel, Ni; zinc, Zn). Details of laboratory methods and detection limits are provided in Table B1.

Table B1. Hill Labs methods and detection limits.

Sample Type: Sediment		
Test	**Method Description**	**Default Detection Limit**
Individual Tests		
Environmental Solids Sample Drying*	Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%.	-
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation May contain a residual moisture content of 2-5%.	-
Dry Matter for Grainsize samples (sieved as received)*	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd
Total Recoverable digestion	Nitric / hydrochloric acid digestion. US EPA 200.2.	-
Total Recoverable Phosphorus	Dried sample, sieved as specified (if required). Nitric/Hydrochloric acid digestion, ICP-MS, screen level. US EPA 200.2.	40 mg/kg dry wt
Total Sulphur*	LECO S144 Sulphur Determinator, high temperature furnace, infra-red detector. Subcontracted to SGS, Waihi. ASTM 4239.	0.010 g/100g dry wt
Total Nitrogen*	Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt
Total Organic Carbon*	Acid pretreatment to remove carbonates present followed by Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt
Heavy metals, trace As,Cd,Cr,Cu,Ni,Pb,Zn,Hg	Dried sample, <2mm fraction. Nitric/Hydrochloric acid digestion, ICP-MS, trace level.	0.010 - 0.8 mg/kg dry wt
3 Grain Sizes Profile as received		
Fraction >/= 2 mm*	Wet sieving with dispersant, as received, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt
Fraction < 2 mm, >/= 63 µm*	Wet sieving using dispersant, as received, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt
Fraction < 63 µm*	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt

B1.3 Field sediment oxygenation assessment

The apparent Redox Potential Discontinuity (aRPD) depth is used to assess the trophic status (i.e., extent of excessive organic or nutrient enrichment) of soft sediment. The aRPD depth is the visible transition between oxygenated surface sediments (typically brown in colour) and deeper less oxygenated sediments (typically dark grey or black in colour). The aRPD provides an easily measured, time-integrated, and relatively stable indicator of sediment enrichment and oxygenation conditions (Rosenberg et al. 2001; Gerwing et al. 2013). Sediments are considered to have poor oxygenation if the aRPD is consistently <10mm deep and shows clear signs of organic enrichment, indicated by a distinct colour change to grey or black in the sediments.

Example of distinct aRPD colour change with brown oxygenated sediments from the surface down to ~40mm

B1.4 Biological sampling: sediment-dwelling macrofauna

To sample sediment-dwelling macrofauna, duplicate large (130mm diameter) sediment cores (see Table 2 in main body of the report) are collected and placed in separate 0.5mm mesh sieve bags, which are gently washed in seawater to remove fine sediment. The retained animals are preserved in a mixture of ~75% isopropyl alcohol and 25% seawater for later sorting and taxonomic identification by a skilled taxonomic laboratory (e.g., NIWA). The types of animals present in each sample, as well as the range of different species (i.e., richness) and their abundance, are well-established indicators of ecological health in estuarine and marine soft sediments.

B1.5 Biological sampling: surface-dwelling epibiota

In addition to macrofaunal core sampling, epibiota (macroalgae and conspicuous surface-dwelling animals nominally >5mm body size) visible on the sediment surface at each site are semi-quantitatively categorised using 'SACFOR' abundance (animals) or percentage cover (macroalgae) ratings shown in Table B2. These ratings represent a scoring scheme simplified from established monitoring methods (MNCR 1990; Blyth-Skyrme et al. 2008).

The SACFOR method is ideally suited to characterise intertidal epibiota with patchy or clumped distributions. It was conducted as an alternative to the quantitative quadrat sampling specified in the NEMP, which is known to poorly characterise scarce or clumped species. Note that our epibiota assessment does not include infaunal species that may be visible on the sediment surface, but whose abundance cannot be reliably determined from surface observation (e.g., cockles). Nor does it include very small organisms such as the estuarine snail *Potamopyrgus* spp.

Table B2. SACFOR ratings for site-scale abundance, and percent cover of epibiota and algae, respectively.

SACFOR category	Code	Density per m^2	Percent cover
Super abundant	S	> 1000	> 50
Abundant	A	100 - 999	20 - 50
Common	C	10 - 99	10 - 19
Frequent	F	2 - 9	5 - 9
Occasional	O	0.1 - 1	1 - 4
Rare	R	< 0.1	< 1

B1.6 Sediment quality and biota data recording, QA/QC and analysis

All sediment and macrofaunal samples sent to analytical laboratories were tracked using standard Chain of Custody forms, and results were transferred electronically from the laboratory to avoid transcription errors. Field measurements (e.g., aRPD) and site metadata were recorded electronically in templates (custom-built using Fulcrum app software - www.fulcrumapp.com), with pre-specified data entry constraints (e.g. with minimum or maximum values for each data type) minimising the risk of erroneous data recording.

Excel sheets were imported into the software R 4.2.3 (R Core Team 2023) and assigned sample identification codes. All summaries of univariate responses (e.g., sediment analyte concentrations, macrofauna abundances) were produced in R, including tabulated or graphical representations of the data. Where results for sediment quality parameters were below analytical detection limits, half of the detection limit value was used, according to convention.

Before sediment-dwelling macrofaunal analyses, the data were screened to remove species that were not regarded as a true part of the macrofaunal assemblage; these were planktonic life-stages and non-marine organisms (e.g., freshwater drift). To facilitate comparisons with any future surveys, and other estuaries, cross-checks were made to ensure consistent naming of species and higher taxa. For this purpose, the adopted name was that accepted by the World Register of Marine Species (WoRMS, www.marinespecies.org/).

Macrofaunal response variables included richness and abundance by species and higher taxonomic groupings. In addition, scores for the biotic health index AMBI (Borja et al. 2000; Borja et al. 2019) were derived. AMBI scores reflect the proportion of taxa falling into one of five eco-groups (EG) that reflect sensitivity to pollution, ranging from relatively sensitive (EG-I) to relatively resilient (EG-V).

To meet the criteria for AMBI calculation, macrofauna data were reduced to a subset that included only adult ‘infauna’ (those organisms living within the sediment matrix), which involved removing surface dwelling epibiota and any juvenile organisms. AMBI scores were calculated based on standard international eco-group classifications where possible (http://ambi.azti.es). However, to reduce the number of taxa with unassigned eco-groups, international data were supplemented with more recent eco-group classifications for New Zealand (Keeley et al. 2012; Robertson et al. 2015; Robertson et al. 2016c; Robertson 2018). Note that AMBI scores were not calculated for macrofaunal cores that did not meet operational limits defined by Borja et al. (2012), in terms of the percentage of unassigned taxa (>20%), or low sample richness (<3 taxa) or abundances (<6 individuals).

Where helpful in understanding estuary health, multivariate analyses of macrofaunal community data are undertaken, mainly using the software package Primer v7.0.13 (Clarke et al. 2014). Patterns in site similarity as a function of macrofaunal composition and abundance are assessed using an ‘unconstrained’ non-metric multidimensional scaling (nMDS) ordination plot, based on pairwise Bray-Curtis similarity index scores among samples.

Prior to the multivariate analysis, macrofaunal abundance data are transformed (e.g., square root) to down-weight the influence on the ordination pattern of the dominant species or higher taxa. The procedure PERMANOVA may be used to test for compositional differences among samples. Overlay vectors and bubble plots on the nMDS are used to visualise relationships between multivariate biological patterns and sediment quality data (the latter may need to be transformed (e.g., log x+1) and normalised to a standard scale. The Primer procedure Bio-Env is typically used to evaluate the suite of sediment quality variables that best explain the macrofauna ordination pattern.

C. METHODS REFERENCES

Atkinson IAE 1985. Derivation of vegetation mapping units for an ecological survey of Tongariro National North Island, New Zealand. New Zealand Journal of Botany 23(3): 361-378.

Borja A, Franco J, Pérez V 2000. A Marine Biotic Index to Establish the Ecological Quality of Soft-Bottom Benthos Within European Estuarine and Coastal Environments. Marine Pollution Bulletin 40(12): 1100-1114.

Borja A, Chust G, Muxika I 2019. Forever young: The successful story of a marine biotic index. Advances in marine biology 82: 93-127.

Borja Á, Mader J, Muxika I 2012. Instructions for the use of the AMBI index software (Version 5.0). Revista de Investigación Marina, AZTI-Tecnalia 19(3): 71-82.

Clarke KR, Gorley RN, Somerfield PJ, Warwick RM 2014. Change in marine communities: an approach to statistical analysis and interpretation, 3rd edition. PRIMER-E, Plymouth, UK. 260p.

FGDC 2012. Coastal and Marine Ecological Classification Standard. Standard FGDC-STD-018-2012, Marine and Coastal Spatial Data Subcommittee, Federal Geographic Data Committee, June, 2012. 343p. Available at: https://www.fgdc.gov/standards/projects/cmecs-folder/CMECS_Version_06-2012_FINAL.pdf.

Folk RL 1954. The distinction between grain size and mineral composition in sedimentary rock nomenclature. Journal of Geology 62 (4), 344-359.

Gerwing TG, Gerwing AMA, Drolet D, Hamilton DJ, Barbeau MA 2013. Comparison of two methods of measuring the depth of the redox potential discontinuity in intertidal mudflat sediments. Marine Ecology Progress Series 487: 7-13.

Gibbs M, Hewitt JE 2004. Effects of sedimentation on macrofaunal communities: a synthesis of research studies for ARC. Auckland Regional Council, Auckland.

Hailes SF, Hewitt JE 2012. Manukau Harbour Ecological Programme: Report on data collected up until February 2011. Prepared by The National Institute of Water and Atmospheric Research for Auckland Council. Auckland Council Technical Report 2012/004.

Keeley NB, Macleod CK, Forrest BM 2012. Combining best professional judgement and quantile regression splines to improve characterisation of macrofaunal responses to enrichment. Ecological Indicators 12: 154-166.

Norkko A, Talman S, Ellis J, Nicholls P, Thrush S 2002. Macrofaunal Sensitivity to Fine Sediments in the Whitford Embayment. Auckland Regional Council, Technical Publication, 158: 1-30.

NPSFM 2020. National Policy Statement for Freshwater Management 2020. Minstry for the Environment, August 2020. 70p.

Plew DR, Zeldis JR, Dudley BD, Whitehead AL, Stevens LM, Robertson BM, Robertson BP 2020. Assessing the Eutrophic Susceptibility of New Zealand Estuaries. Estuaries and Coasts 43(8): 2015-2033.

R Core Team 2023. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

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

Roberts KL, Stevens LM, Forrest BM 2022. Broadscale Intertidal Habitat Mapping of Pleasant River (Te Hakapupu) Estuary. Salt Ecology Report 086, prepared for Otago Regional Council, July 2022. 56p.

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

Robertson BM, Stevens LM, Robertson BP, Zeldis J, Green M, Madarasz-Smith A, Plew D, Storey R, Hume T, Oliver M 2016a. 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.

Robertson BM, Stevens LM, Robertson BP, Zeldis J, Green M, Madarasz-Smith A, Plew D, Storey R, Hume T, Oliver M 2016b. 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 BP 2018. Optimising indicators of ecological condition in shallow tidal estuaries as function of nitrogen loading. A thesis submitted for the degree of Doctor of Philosophy at the University of Otago, Dunedin, New Zealand. 125p.

Robertson BP, Gardner JPA, Savage C 2015. Macrobenthic–mud relations strengthen the foundation for benthic index development: A case study from shallow, temperate New Zealand estuaries. Ecological Indicators 58: 161-174.

Robertson BP, Savage C, Gardner JPA, Robertson BM, Stevens LM 2016c. Optimising a widely-used coastal health index through quantitative ecological group classifications and associated thresholds. Ecological Indicators 69: 595-605.

Rodil IF, Lohrer AM, Hewitt JE, Townsend M, Thrush SF, Carbines M 2013. Tracking environmental stress gradients using three biotic integrity indices: Advantages of a locally-developed traits-based approach. Ecological Indicators34, 560-570.

Rosenberg R, Nilsson HC, Diaz RJ 2001. Response of Benthic Fauna and Changing Sediment Redox Profiles over a Hypoxic Gradient. Estuarine, Coastal and Shelf Science 53(3): 343-350.

Skilton J, Thompson N 2017. Mahakipawa Estuary fine-scale monitoring and broad-scale habitat mapping 2017. Report prepared by SLR Consulting for Marlborough District Council. SLR Report Number 740.10043. 58p.

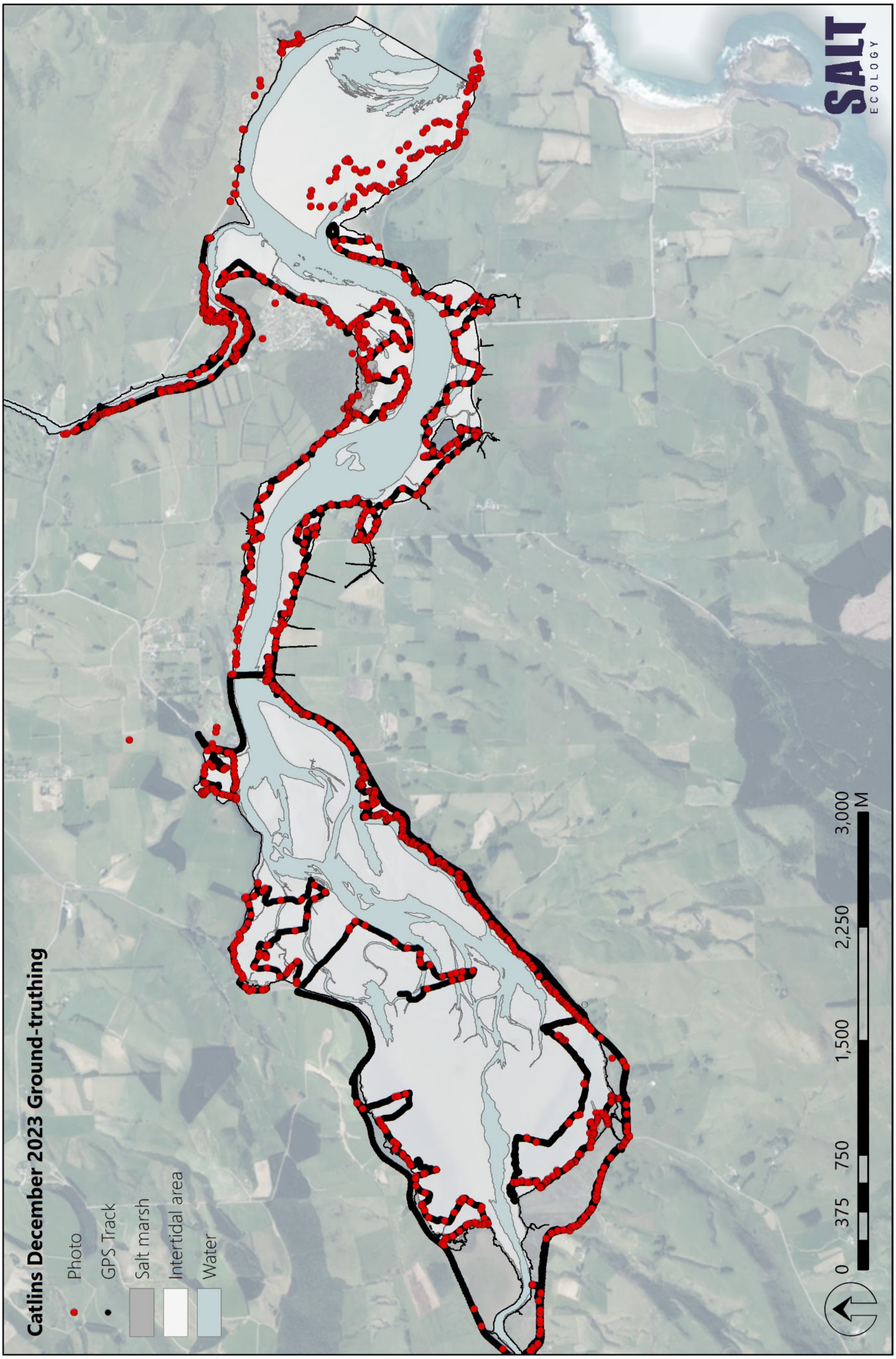
Stevens LM, Robertson BM 2014. Havelock Estuary 2014: Broad scale habitat mapping. Report prepared by Wriggle Coastal Management for Marlborough District Council. 43p.

Stevens LM, Forrest BM, Dudley BD, Plew DR, Zeldis JR, Shankar U, Haddadchi A, Roberts KL 2022. Use of a multi-metric macroalgal index to document severe eutrophication in a New Zealand estuary. New Zealand Journal of Marine and Freshwater Research: 1-20.

Thrush S, Hewitt, J, Norkko A, Nicholls P, Funnell G, Ellis J 2003. Habitat change in estuaries: predicting broad-scale responses of intertidal macrofauna to sediment mud content. Marine Ecology Progress Series, 263: 101-112.

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

APPENDIX 2. GROUND-TRUTHING



APPENDIX 3. RAW DATA ON DOMINANT SALT MARSH SPECIES

Sub-class	Dominant Species	Sub-dominant species	Sub-dominant species 2	Area (ha)	% Salt marsh
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)			0.24	1.78
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)		0.11	0.81
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)	*Festuca arundinacea* (Tall fescue)	0.04	0.33
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Apodasmia similis* (Jointed wirerush)	*Samolus repens* (Primrose)	0.11	0.79
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Festuca arundinacea* (Tall fescue)	*Apodasmia similis* (Jointed wirerush)	0.07	0.49
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Puccinella stricta* (Salt grass)		0.02	0.12
Estuarine Shrub	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Selliera radicans* (Remuremu)	*Samolus repens* (Primrose)	0.05	0.39
Tussockland	*Puccinella stricta* (Salt grass)	*Samolus repens* (Primrose)	*Selliera radicans* (Remuremu)	0.08	0.63
Sedgeland	*Schoenoplectus pungens* (Three square)			0.04	0.27
Reedland	*Spartina anglica* (Cord grass)			0.003	0.02
Rushland	*Apodasmia similis* (Jointed wirerush)			1.78	13.3
Rushland	*Apodasmia similis* (Jointed wirerush)	*Carex litorosa* (Sea sedge)	*Festuca arundinacea* (Tall fescue)	0.02	0.11
Rushland	*Apodasmia similis* (Jointed wirerush)	*Festuca arundinacea* (Tall fescue)		0.13	0.95
Rushland	*Apodasmia similis* (Jointed wirerush)	*Festuca arundinacea* (Tall fescue)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	0.57	4.29
Rushland	*Apodasmia similis* (Jointed wirerush)	*Isolepis cernua* (Slender clubrush)		0.02	0.14
Rushland	*Apodasmia similis* (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)		2.52	18.9
Rushland	*Apodasmia similis* (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Coprosma propinqua* (Mingimingi)	0.22	1.64
Rushland	*Apodasmia similis* (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Coprosma propinqua* (Mingimingi)	0.81	6.04
Rushland	*Apodasmia similis* (Jointed wirerush)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	*Festuca arundinacea* (Tall fescue)	0.95	7.13
Rushland	*Apodasmia similis* (Jointed wirerush)	*Schoenoplectus pungens* (Three square)		0.02	0.14
Rushland	*Apodasmia similis* (Jointed wirerush)	*Selliera radicans* (Remuremu)	*Carex litorosa* (Sea sedge)	1.52	11.4
Herbfield	*Disphyma australe* (NZ Ice Plant, Horokaka)			0.001	0.01
Herbfield	*Samolus repens* (Primrose)			0.06	0.46
Herbfield	*Samolus repens* (Primrose)	*Isolepis cernua* (Slender clubrush)		0.04	0.30
Herbfield	*Samolus repens* (Primrose)	*Puccinella stricta* (Salt grass)		0.07	0.53
Herbfield	*Samolus repens* (Primrose)	*Puccinella stricta* (Salt grass)	*Selliera radicans* (Remuremu)	0.02	0.16
Herbfield	*Samolus repens* (Primrose)	*Puccinella stricta* (Salt grass)	*Selliera radicans* (Remuremu)	0.06	0.47
Herbfield	*Samolus repens* (Primrose)	*Sarcocornia quinqueflora* (Glasswort)		0.04	0.34
Herbfield	*Samolus repens* (Primrose)	*Sarcocornia quinqueflora* (Glasswort)	*Isolepis cernua* (Slender clubrush)	0.08	0.56
Herbfield	*Samolus repens* (Primrose)	*Selliera radicans* (Remuremu)		0.11	0.84
Herbfield	*Samolus repens* (Primrose)	*Selliera radicans* (Remuremu)	*Cotula coronopifolia* (Bachelor's button)	0.05	0.34
Herbfield	*Samolus repens* (Primrose)	*Selliera radicans* (Remuremu)	*Sarcocornia quinqueflora* (Glasswort)	1.89	14.2
Herbfield	*Samolus repens* (Primrose)	*Selliera radicans* (Remuremu)	*Schoenoplectus pungens* (Three square)	0.04	0.31
Herbfield	*Sarcocornia quinqueflora* (Glasswort)			0.02	0.11
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Puccinella stricta* (Salt grass)		0.01	0.09
Herbfield	*Sarcocornia quinqueflora* (Glasswort)	*Selliera radicans* (Remuremu)	*Samolus repens* (Primrose)	0.23	1.71
Herbfield	*Selliera radicans* (Remuremu)	*Festuca arundinacea* (Tall fescue)	*Plagianthus divaricatus* (Salt marsh ribbonwood)	0.01	0.10
Herbfield	*Selliera radicans* (Remuremu)	*Samolus repens* (Primrose)		0.03	0.25
Herbfield	*Selliera radicans* (Remuremu)	*Samolus repens* (Primrose)	*Carex litorosa* (Sea sedge)	0.06	0.43
Herbfield	*Selliera radicans* (Remuremu)	*Samolus repens* (Primrose)	*Sarcocornia quinqueflora* (Glasswort)	0.01	0.10
Herbfield	*Selliera radicans* (Remuremu)	*Samolus repens* (Primrose)	*Sarcocornia quinqueflora* (Glasswort)	1.21	9.04
Total				13.3	100.0

APPENDIX 4. RAW DATA ON SUBSTRATE

Total estuary substrate, substrate within salt marsh, and substrate within other vegetated habitats.

		Intertidal Area		Available Intertidal Habitat		Salt marsh		Seagrass		Macroalgae		Microalgae	
Sub-class	Feature	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
Barrier	Seawall	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bedrock	Rock field	8.9	1.5	8.9	1.5	0.0	0.0	1.1	3.4	4.2	2.7	0.0	0.0
Coarse substrate (>2mm)	Artificial boulder field	2.9	0.5	2.9	0.5	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
	Artificial cobble field	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Boulder field	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Cobble field	1.7	0.3	1.7	0.3	0.0	0.1	0.0	0.0	0.5	0.3	0.0	0.0
	Gravel field	4.2	0.7	4.2	0.7	0.0	0.1	0.0	0.0	1.2	0.8	0.0	0.0
	Shell bank	2.6	0.4	2.6	0.4	0.0	0.0	0.0	0.0	0.4	0.3	0.0	0.0
Sand (0-10% mud)	Firm shell/sand	35.6	6.0	35.6	6.2	0.0	0.0	2.6	7.6	15.8	10.1	0.0	0.0
	Mobile sand	199.2	33.8	199.2	34.6	0.0	0.0	25.2	74.4	11.9	7.5	0.0	0.0
	Firm sand	91.0	15.5	90.9	15.8	0.2	1.3	4.9	14.5	4.9	3.1	0.0	0.0
	Soft sand	1.0	0.2	1.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Muddy Sand (>10-25% mud)	Firm muddy sand	56.4	9.6	56.3	9.8	0.1	0.9	0.1	0.1	3.5	2.2	0.0	0.0
	Soft muddy sand	22.7	3.9	22.7	3.9	0.0	0.0	0.0	0.0	13.5	8.6	0.0	0.0
Muddy Sand (>25-50% mud)	Firm muddy sand	1.9	0.3	1.7	0.3	0.3	2.1	0.0	0.0	0.2	0.1	0.0	0.0
	Soft muddy sand	38.4	6.5	38.4	6.7	0.0	0.0	0.0	0.0	17.4	11.1	0.0	0.0
Sandy Mud (>50-90% mud)	Firm sandy mud	10.5	1.8	0.1	0.0	10.4	77.7	0.0	0.0	0.0	0.0	0.0	0.0
	Soft sandy mud	77.0	13.1	75.7	13.2	1.3	9.7	0.0	0.0	56.0	35.6	0.0	0.0
	Very soft sandy mud	31.2	5.3	30.4	5.3	0.8	6.3	0.0	0.0	25.8	16.4	0.1	7.4
Mud (>90% mud)	Very soft mud	3.1	0.5	2.9	0.5	0.2	1.6	0.0	0.0	1.8	1.2	1.8	92.6
Zoogenic	Cockle bed	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0
Total		589.0	100.0	575.6	100.0	13.3	100.0	33.8	100.0	157.3	100.0	2.0	100.0

Hills Laboratories sediment analytical results from Sites 1-6 and fine-scale Sites A-B.

	Sample Name:	Site 1	Site 2	Sites 3	Site 4	Site 5	Site 6	Site A	Site B
Total Nitrogen	mg/kg dry wt	2000	5900	7900	300	300	500	300	600
Total Recoverable Phosphorus	mg/kg dry wt	580	920	1190	200	260	360	240	360
Total Organic Carbon	g/100g dry wt	2.2	5.8	7.0	0.2	0.28	0.36	0.13	0.49
Total Sulphur	g/100g dry wt	0.45	0.76	1.33	0.07	0.05	0.12	0.03	0.09
Metals									
Total Recoverable Arsenic	mg/kg dry wt	3.7	6.2	5.6	2.9	4.4	4.6	5.5	3.7
Total Recoverable Cadmium	mg/kg dry wt	0.084	0.091	0.161	0.01	0.013	0.038	0.015	0.017
Total Recoverable Chromium	mg/kg dry wt	10.4	14.8	17.7	6.0	6.9	9.6	6.0	8.5
Total Recoverable Copper	mg/kg dry wt	7.9	12.2	15.4	3.0	3.2	5.3	2.2	4.7
Total Recoverable Lead	mg/kg dry wt	5.1	8.9	10.7	1.52	1.92	2.8	1.34	2.7
Total Recoverable Mercury*	mg/kg dry wt	0.03	0.05	0.06	<0.02	<0.02	<0.02	<0.02	<0.02
Total Recoverable Nickel	mg/kg dry wt	7.2	9.7	10.8	4.1	4.4	6.7	3.5	5.8
Total Recoverable Zinc	mg/kg dry wt	47	56	65	17.9	16.6	25	12	27

*< refers to below the limit of detection.

APPENDIX 5. ESTIMATED HISTORIC SALT MARSH AND SEAGRASS EXTENT

To estimate historic salt marsh extent, we assessed current mapped layers, LiDAR contours, and historic aerial imagery captured in 1948, 1985 (source: retrolens.co.nz), and 2006 (data.linz.govt.nz). Where required, imagery was merged and georectified to digitise the salt marsh area and inform historic extent. The salt marsh was digitised from low-resolution imagery with no ground-truthing. As such, summaries and maps of historic salt marsh extent represent best estimates only. The estimated natural salt marsh extent is presented in Fig. 8.

Table of historic salt marsh extent (ha).

Year	Estuary (ha)	Intertidal (ha)	Subtidal (ha)	Salt marsh (ha)	% Intertidal
Estimated natural	840.0	601.9	238.0	64.2	10.7
1948	798.7	561.4	237.4	23.1	4.1
1985	816.7	581.9	234.8	19.1	3.3
2006	825.3	613.0	212.2	13.9	2.3
2016	829.1	636.4	192.6	12.1	1.9
2023	843.2	589.0	254.2	13.3	2.3

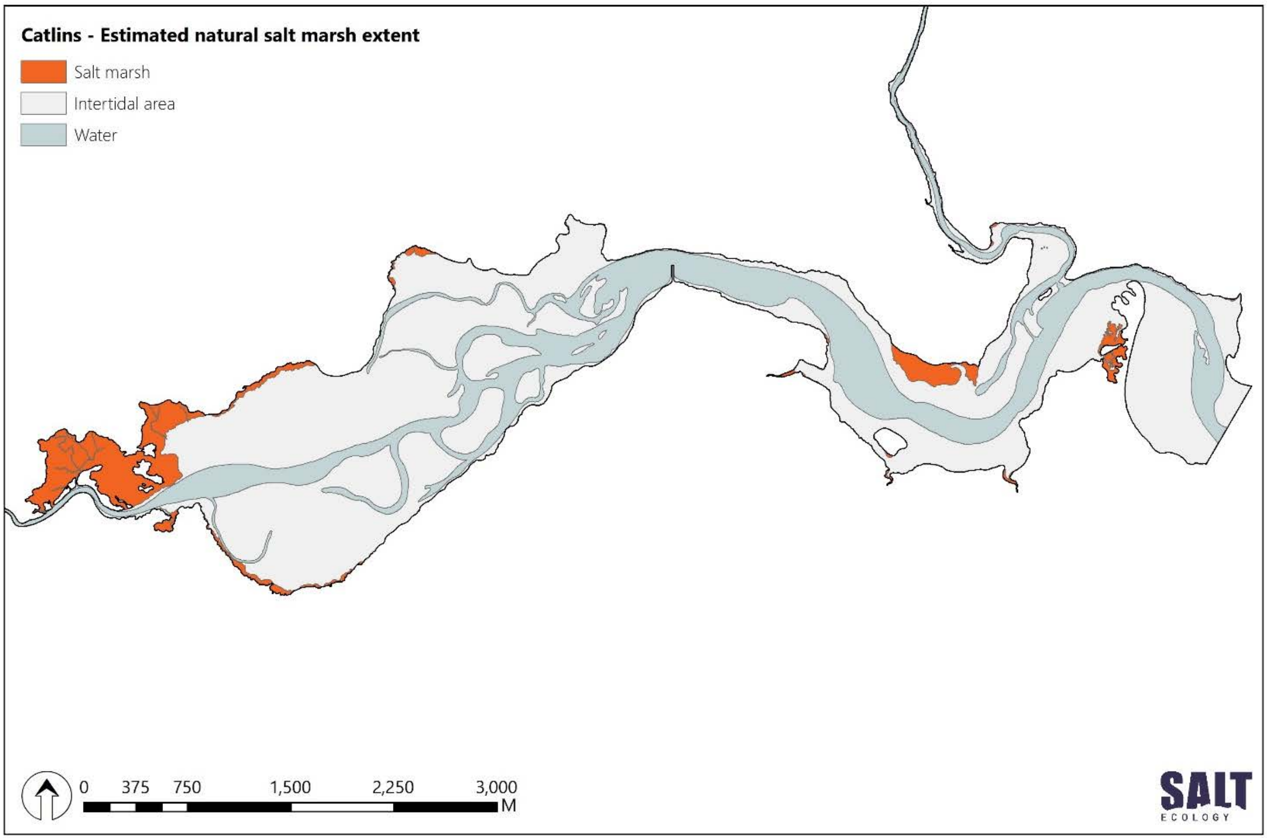
To estimate historic seagrass extent, we assessed current mapped layers and historic aerial imagery captured in 1948, 1985 (source: retrolens.co.nz), and 2006 (data.linz.govt.nz). Where required, imagery was merged and georectified to digitise the seagrass area and inform historic extent. Historic seagrass was digitised following the same principles described in Section 3.2 and Appendix 1 for each of the imagery years. For seagrass, it is difficult to reliably map seagrass areas of <50% cover solely from aerial imagery (i.e., no ground-truthing), therefore any comparisons between historic extent and recent surveys were made with the percent cover categories ≥50% cover.

Table of historic seagrass (≥50% cover) extent (ha).

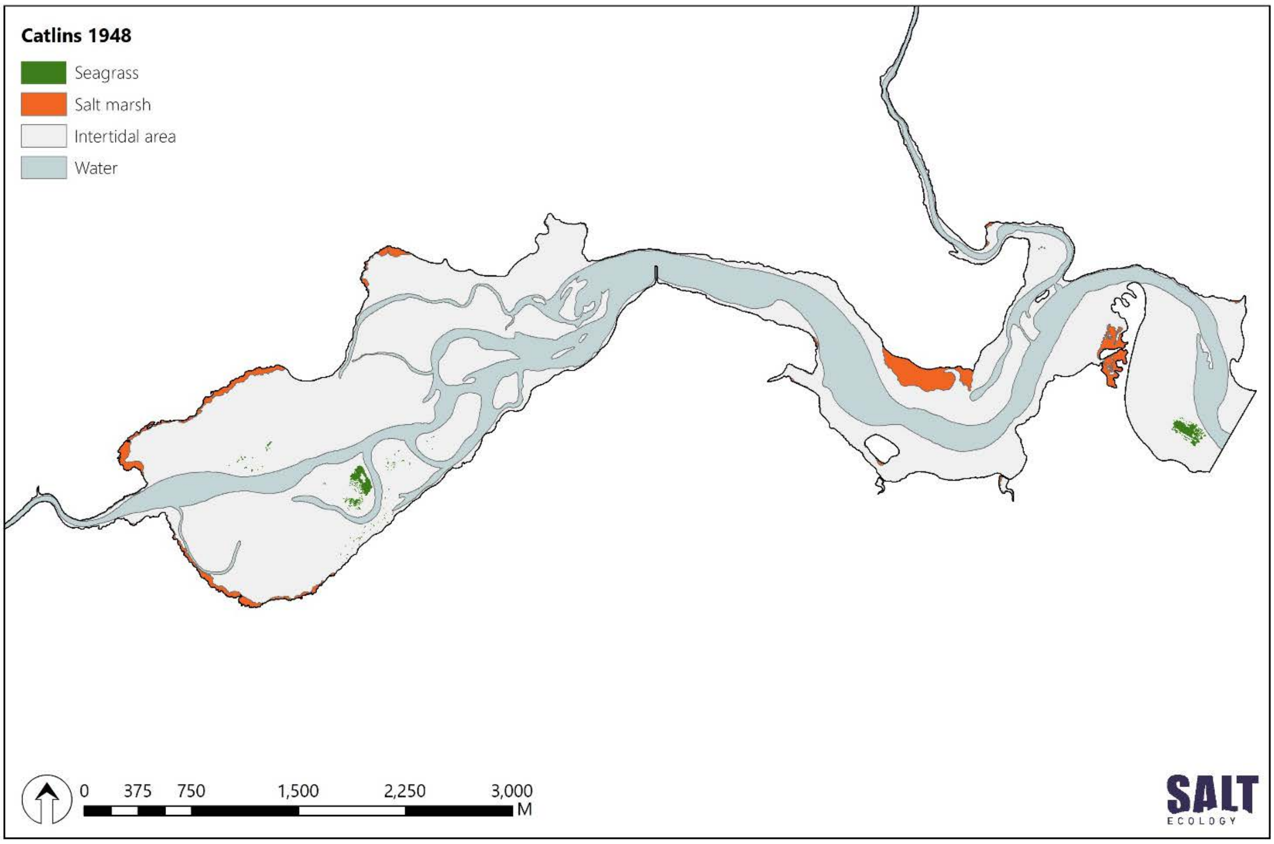
Year	Estuary (ha)	Intertidal (ha)	Subtidal (ha)	AIH* (ha)	Seagrass (ha) (>1-100% cover)	Seagrass (ha) (≥50% cover)	% AIH (≥50% cover)
1948	798.7	561.4	237.4	538.3	4.0	4.0	0.7
1985	816.7	581.9	234.8	562.8	29.6	29.6	5.3
2006	825.3	613.0	212.2	599.2	38.3	38.3	6.4
2016	829.1	636.4	192.6	624.3	35.0	35.0	5.6
2021	844.2	611.1	233.1	598.0	42.5	33.9	5.7
2023	843.2	589.0	254.2	575.6	33.8	20.1	3.5

*Available intertidal habitat

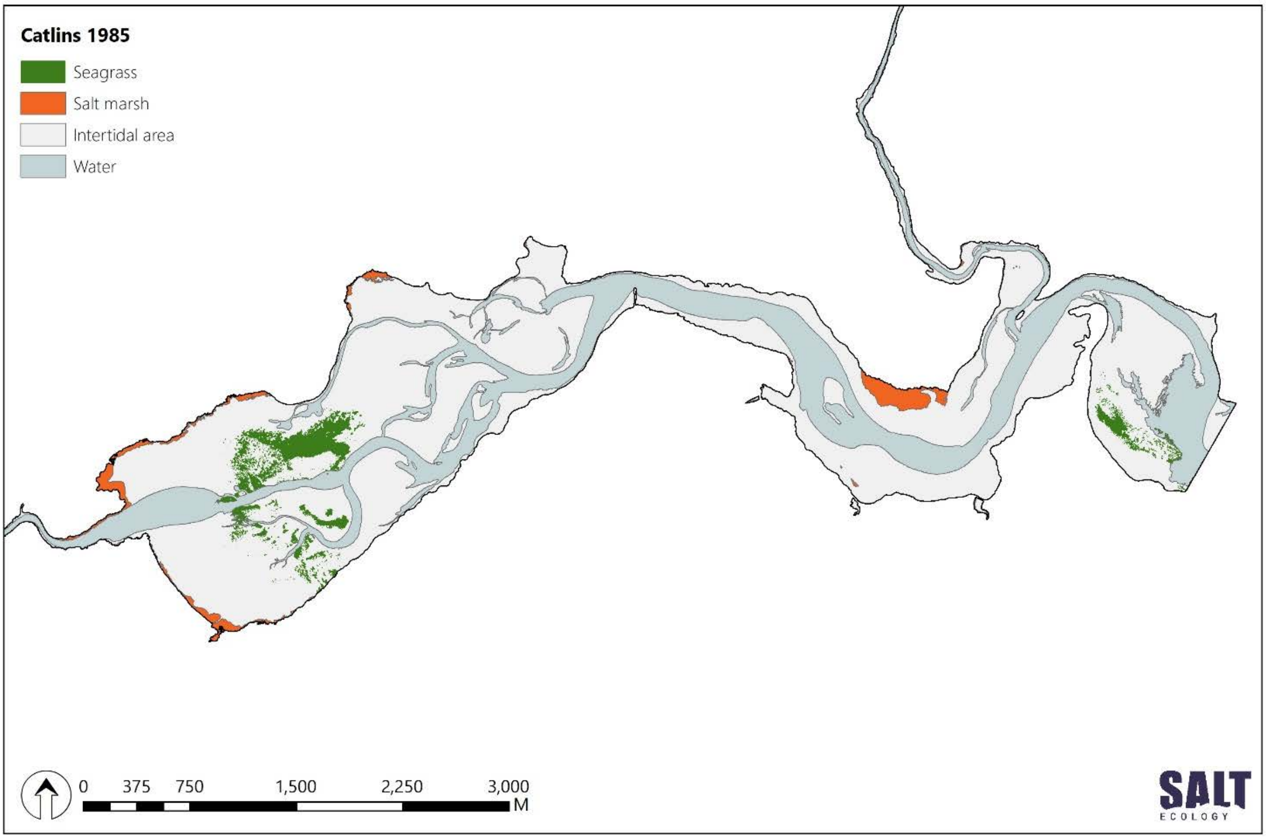
Estimated natural salt marsh extent. *Note natural seagrass extent could not be determined.*



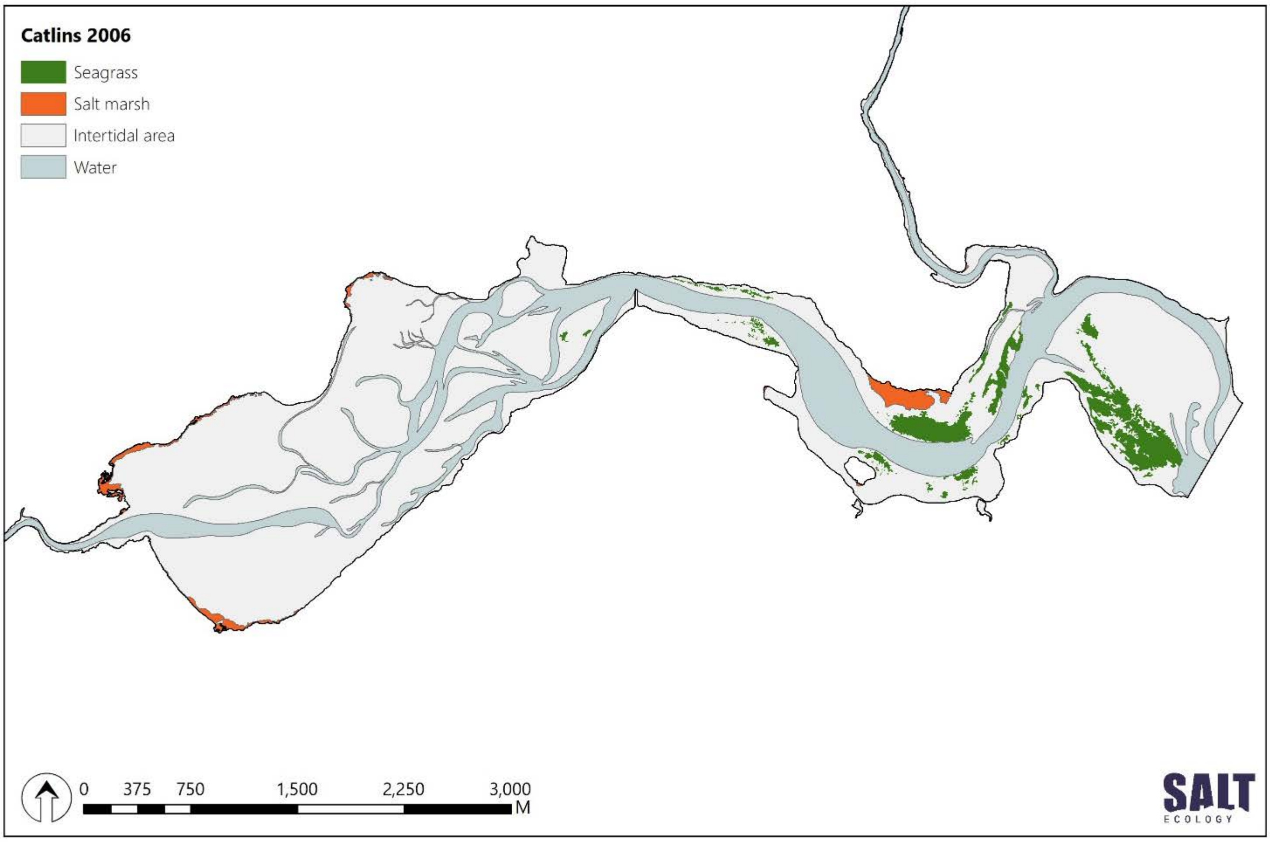
Salt marsh and seagrass extent in 1948.



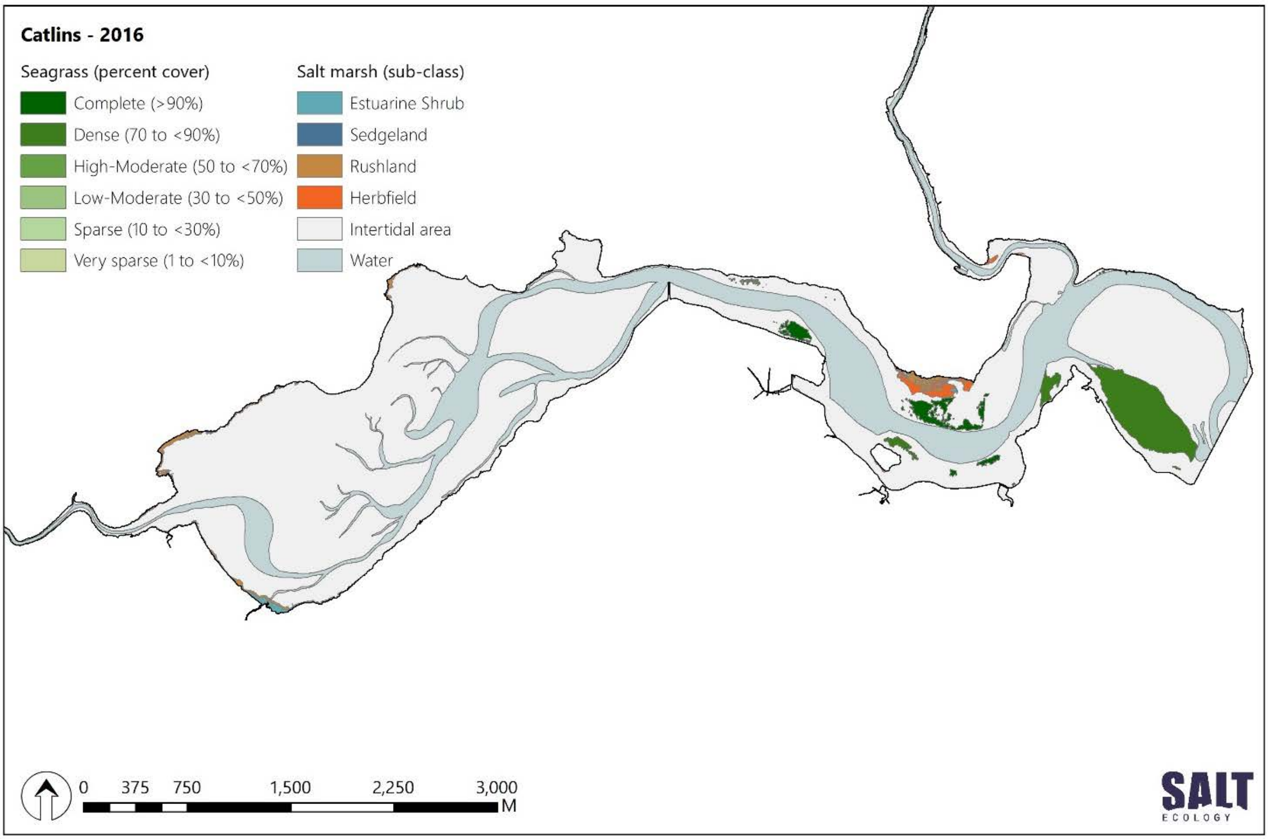
Salt marsh and seagrass extent in 1985.



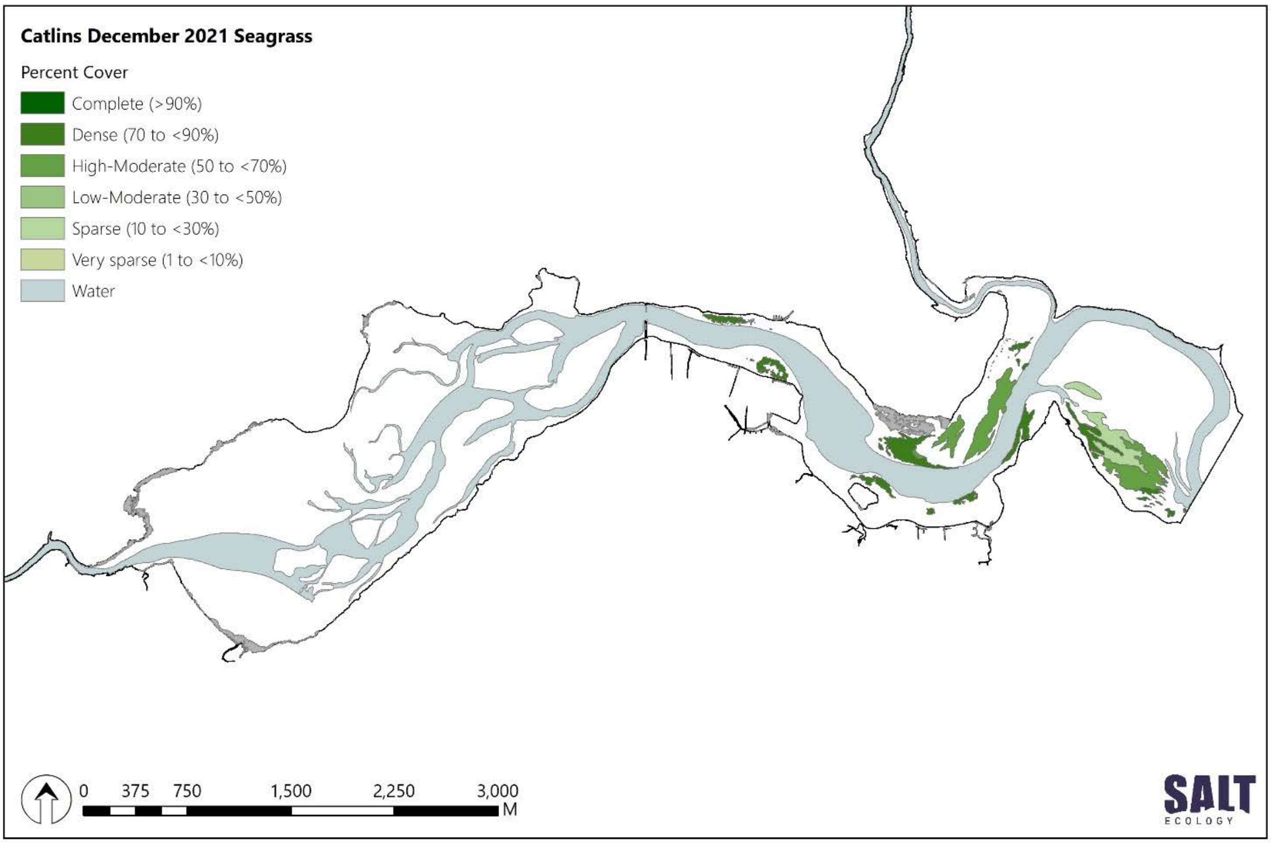
Salt marsh and seagrass extent in 2006.



Salt marsh and seagrass extent in 2016.



Seagrass extent in 2021 (salt marsh not mapped)



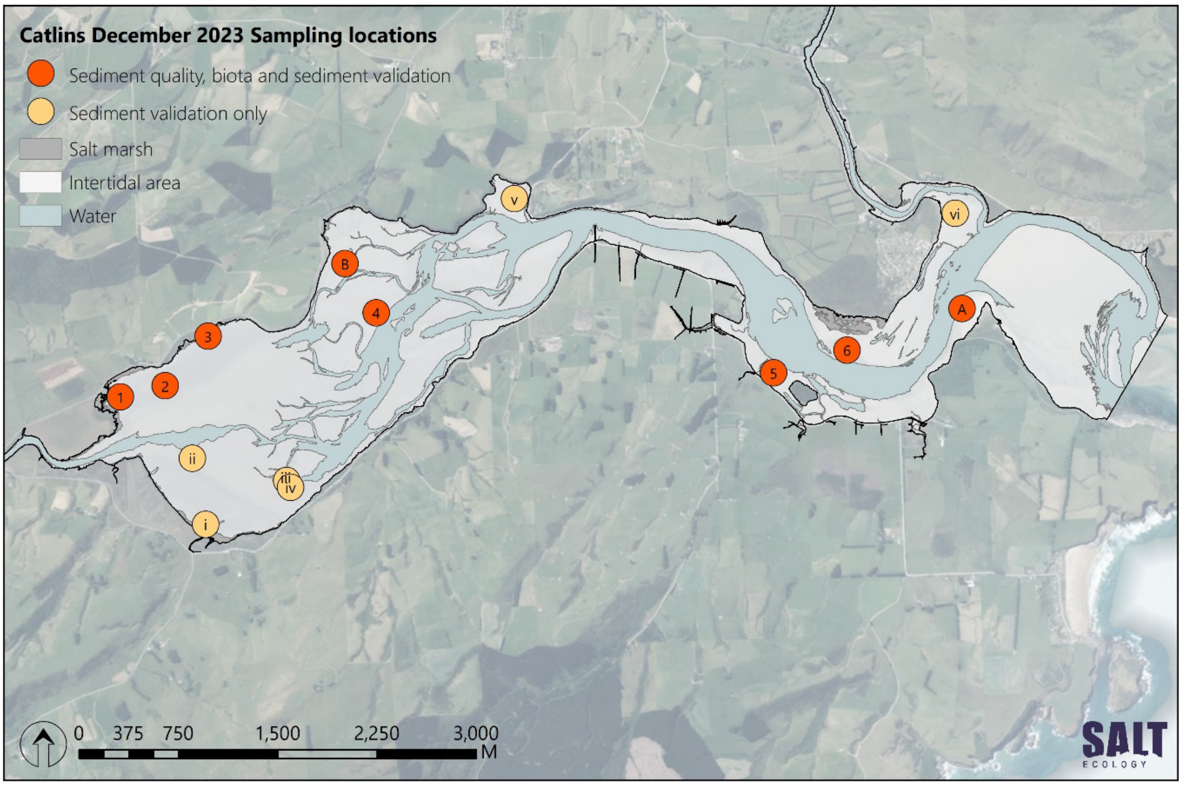
APPENDIX 6. SEDIMENT VALIDATION

Sampling was undertaken at twelve sites (see map below) to validate subjective field estimates of sediment type (with respect to mud content) against laboratory grain size analysis of mud content. For this method, an acceptance tolerance of '±5% mud' difference from the broad substrate class has been adopted, unless field notes specify the sample was taken because the substrate could not be accurately determined in the field (e.g., flood deposits overlying and/ or integrating into firm substrates). For any samples with differences >5%, photos of the sample site and field notes are revisited to assess the disparity and determine whether to change the field classification.

There was a match for ten of the fourteen samples (no shading), while three samples were within ±5% of the subjective classification (light green shading). The one difference >5% is shown in red (light yellow shading). Site 5 was adjusted down, with the likely cause for the difference due to the high-water content in the sediment.

Site	NZTM East	NZTM North	Sed firmness	Field code	Subjective % mud	Mud (%)	Sand (%)	Gravel (%)	aRPD (mm)	Updated classification[1]
A	1346643	4847645	firm	S0_10	<10%	3.5	96.5	<0.1	25	
B	1341980	4847983	soft	MS10_25	10 to <25%	28.1	71.9	<0.1	40	No change
1	1340283	4846979	very soft	SM50_90	50 to 90%	79.5	20.4	0.1	3	
2	1340622	4847062	soft	SM50_90	50 to 90%	70.9	28.7	0.3	2	
3	1340947	4847436	very soft	SM50_90	50 to 90%	76.1	23.7	0.2	1	
4	1342217	4847614	firm	S0_10	<10%	6.0	94	<0.1	50	
5	1345220	4847160	firm	MS10_25	10 to <25%	3.6	96.3	<0.1	20	Changed to <10%
6	1345776	4847332	firm	MS10_25	10 to <25%	21.3	78	0.7	5	
i	1340927	4846019	very soft	M90_100	90 to <100%	88.0	12	<0.1	1	No change
ii	1340828	4846517	soft	SM50_90	50 to 90%	47.8	52.1	<0.1	25	No change
iii	1341539	4846347	firm	MS10_25	10 to <25%	10.4	89.6	<0.1	45	
iv	1341571	4846298	firm	MS10_25	10 to <25%	17.3	82.7	<0.1	35	
v	1343262	4848474	firm	MS10_25	10 to <25%	17.5	82.5	<0.1	30	
vi	1346592	4848362	mobile	S0_10	<10%	2.0	98	<0.1	>50	

1. Updates to subjective mud classifications were made to the hard copy and digitised maps to reflect the measured grain size. Photos and notes were reviewed before changes were made. Indeterminate aRPD indicated by na.



Photos of sediment quality and biota sampling sites moving downstream from Catlins Lake to the entrance.

Site 1

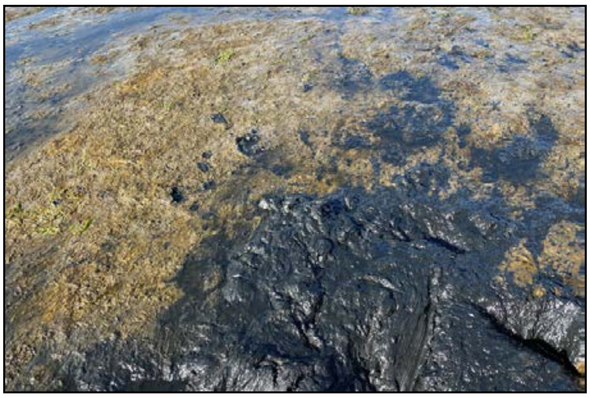
Site 1 - aRPD

Site 2

Site 2 - aRPD

Site 3

Site 3 - aRPD



Site 4

Site 4 - aRPD

Site B

Site B - aRPD

Site 5

Site 5 - aRPD

Site 6

Site 6 - aRPD

Site A

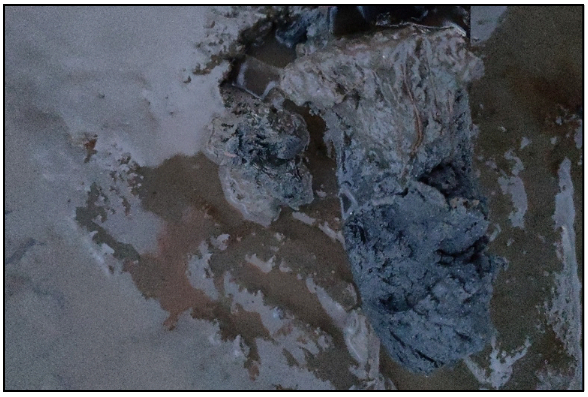
Site A - aRPD

Site (i)

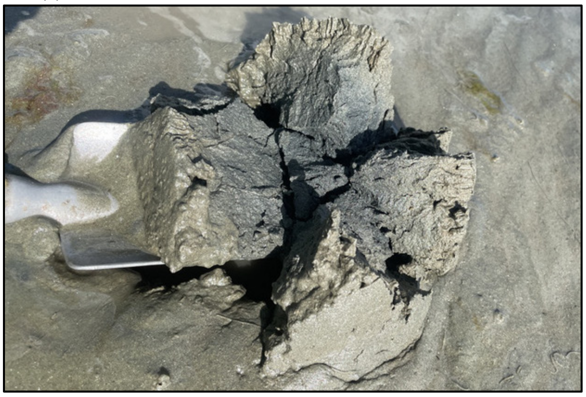
Site (ii)

Site (iii)

Site (iv)



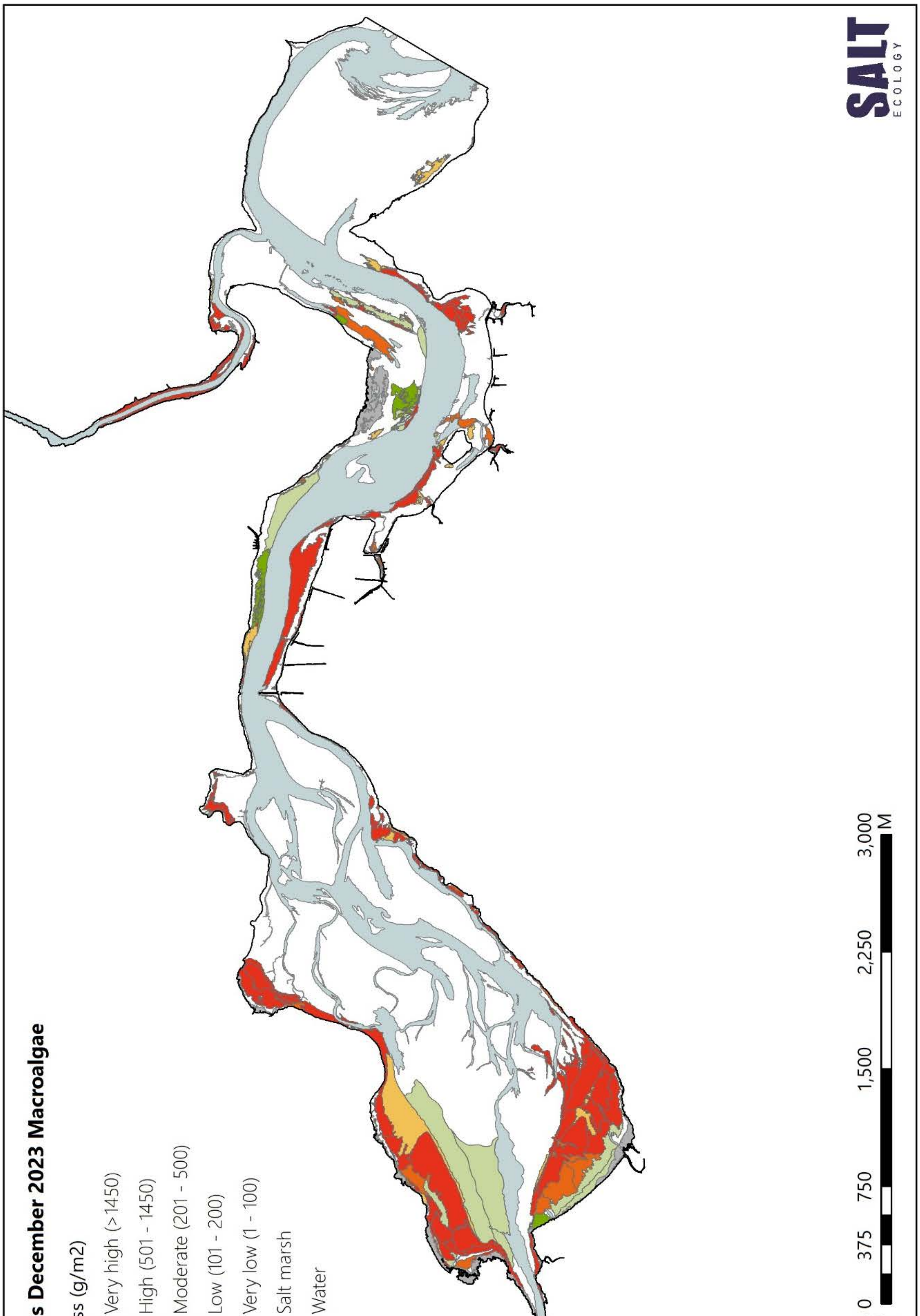
Site (v)



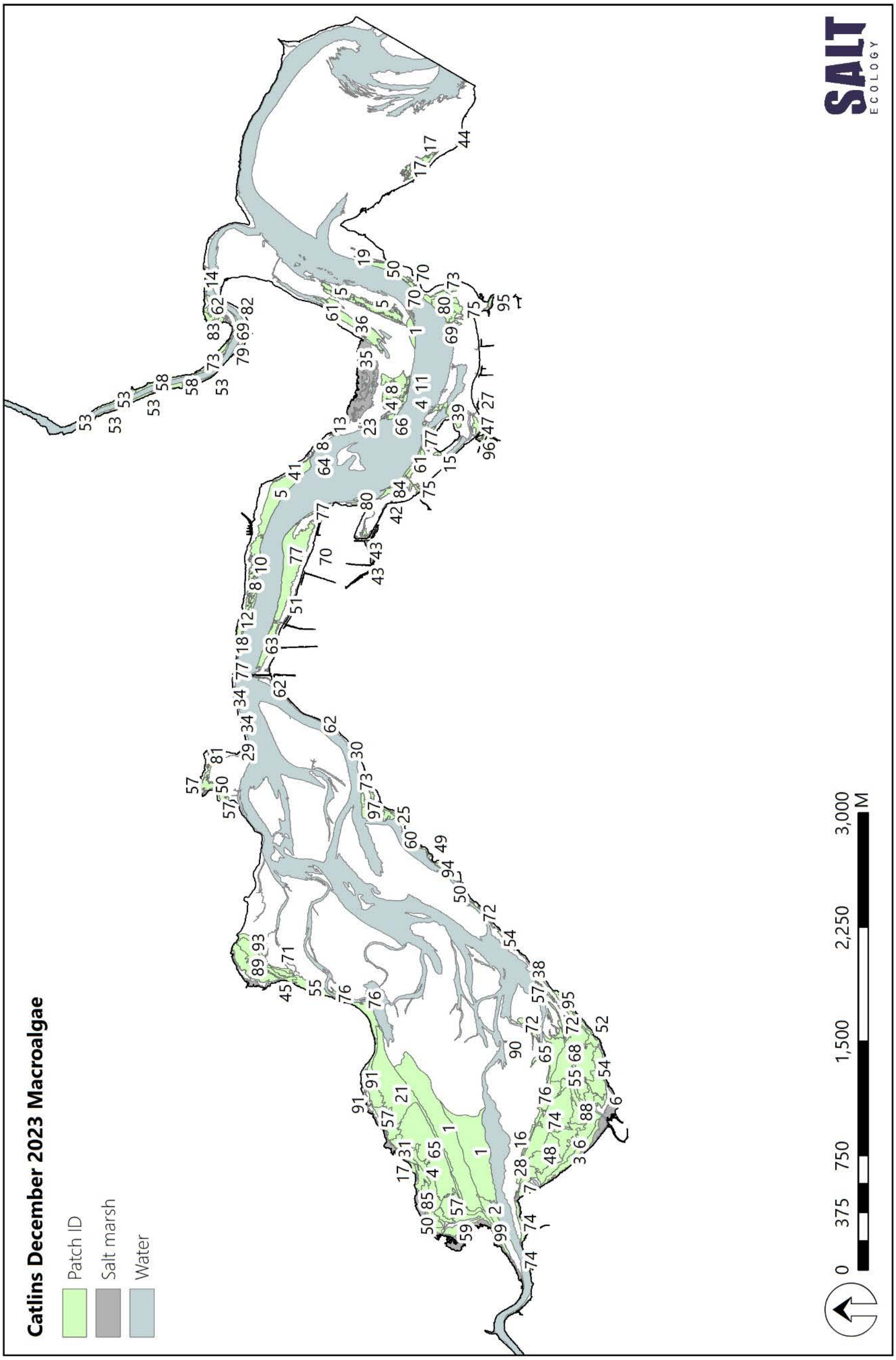
Site (vi)

APPENDIX 7. MACROALGAE BIOMASS AND PATCH INFORMATION

A. Biomass



B. Macroalgae patch ID information



C. Macroalgae Patch data and OMBT input data

Patch ID	Dominant Species	% Cover	Percent Cover Category	Biomass (g/m^2)	Biomass Category	Entrained*	Substrate	Area (ha)
1	*Gracilaria* spp.	10	Sparse (10 to <30%)	60	Very low (1 - 100)	0	sMS10	12.736
1	Filamentous brown algae	15	Sparse (10 to <30%)	50	Very low (1 - 100)	0	sMS25	9.345
1	*Ulva* spp.	5	Very sparse (1 to <10%)	50	Very low (1 - 100)	0	mS CKLE	0.683
2	*Vaucheria* sp.	50	High-Moderate (50 to <70%)	80	Very low (1 - 100)	0	vsSM	0.036
2	Filamentous brown algae	25	Sparse (10 to <30%)	80	Very low (1 - 100)	0	sMS25	1.154
3	*Gracilaria* spp.	5	Very sparse (1 to <10%)	80	Very low (1 - 100)	1	vsM90	1.810
4	Filamentous brown algae	15	Sparse (10 to <30%)	100	Very low (1 - 100)	0	vsSM	0.429
4	Filamentous brown algae	10	Sparse (10 to <30%)	100	Very low (1 - 100)	0	sMS25	1.196
4	Filamentous brown algae	10	Sparse (10 to <30%)	100	Very low (1 - 100)	0	fS	0.732
5	*Ulva* spp.	5	Very sparse (1 to <10%)	100	Very low (1 - 100)	0	mS	1.895
5	Filamentous brown algae	5	Very sparse (1 to <10%)	100	Very low (1 - 100)	0	mS	4.267
6	Filamentous brown algae	30	Low-Moderate (30 to <50%)	100	Very low (1 - 100)	1	vsSM	3.858
7	Filamentous green algae	30	Low-Moderate (30 to <50%)	150	Low (101 - 200)	0	vsSM	0.747
8	*Ulva* spp.	80	Dense (70 to <90%)	200	Low (101 - 200)	0	RF GF	0.077
8	Filamentous brown algae	30	Low-Moderate (30 to <50%)	200	Low (101 - 200)	0	fS	0.128
8	Filamentous brown algae	10	Sparse (10 to <30%)	200	Low (101 - 200)	0	fShS	0.834
8	Filamentous brown algae	10	Sparse (10 to <30%)	200	Low (101 - 200)	0	fS	1.514
9	Filamentous brown algae	30	Low-Moderate (30 to <50%)	200	Low (101 - 200)	0	fS	0.057
10	*Ulva* spp.	15	Sparse (10 to <30%)	200	Low (101 - 200)	0	fShS GF	0.282
10	*Ulva* spp.	20	Sparse (10 to <30%)	200	Low (101 - 200)	0	Shel	0.008
10	Filamentous brown algae	30	Low-Moderate (30 to <50%)	200	Low (101 - 200)	0	fShS	1.577
11	*Ulva* spp.	50	High-Moderate (50 to <70%)	200	Low (101 - 200)	0	mS CKLE	0.263
11	*Ulva* spp.	50	High-Moderate (50 to <70%)	200	Low (101 - 200)	0	mS	0.834
12	*Ulva* spp.	20	Sparse (10 to <30%)	300	Moderate (201 - 500)	0	fMS10	0.098
12	Filamentous green algae	11	Sparse (10 to <30%)	300	Moderate (201 - 500)	0	fShS	0.813
13	*Ulva* spp.	80	Dense (70 to <90%)	300	Moderate (201 - 500)	0	RF GF	0.057
14	*Ulva* spp.	50	High-Moderate (50 to <70%)	300	Moderate (201 - 500)	0	CF GF	0.082
14	*Ulva* spp.	50	High-Moderate (50 to <70%)	300	Moderate (201 - 500)	0	GF fMS10	0.044
15	*Ulva* spp.	70	Dense (70 to <90%)	300	Moderate (201 - 500)	0	fShS	0.083
16	*Gracilaria* spp.	15	Sparse (10 to <30%)	300	Moderate (201 - 500)	1	sSM	1.336
17	*Ulva* spp.	60	High-Moderate (50 to <70%)	400	Moderate (201 - 500)	0	GF	0.011
17	*Ulva* spp.	40	Low-Moderate (30 to <50%)	400	Moderate (201 - 500)	0	RF fS	1.136
17	Filamentous brown algae	60	High-Moderate (50 to <70%)	400	Moderate (201 - 500)	0	sSM	0.209
18	*Ulva* spp.	85	Dense (70 to <90%)	400	Moderate (201 - 500)	0	RF	0.030
18	*Ulva* spp.	85	Dense (70 to <90%)	400	Moderate (201 - 500)	0	fShS	0.114
19	*Ulva* spp.	5	Very sparse (1 to <10%)	400	Moderate (201 - 500)	0	fS GF	0.045
19	*Ulva* spp.	5	Very sparse (1 to <10%)	400	Moderate (201 - 500)	0	fS	0.479
20	*Ulva* spp.	5	Very sparse (1 to <10%)	400	Moderate (201 - 500)	0	fS	0.032
21	Filamentous brown algae	100	Complete (>=90%)	480	Moderate (201 - 500)	1	sSM	8.865
22	Filamentous green algae	30	Low-Moderate (30 to <50%)	500	Moderate (201 - 500)	0	fShS	0.230
23	*Ulva* spp.	70	Dense (70 to <90%)	500	Moderate (201 - 500)	0	Shel	0.242
24	Filamentous green algae	30	Low-Moderate (30 to <50%)	500	Moderate (201 - 500)	0	fShS	0.266
24	Filamentous green algae	20	Sparse (10 to <30%)	500	Moderate (201 - 500)	0	fShS	0.214
25	*Ulva* spp.	50	High-Moderate (50 to <70%)	500	Moderate (201 - 500)	0	GF RF	0.405
26	*Gracilaria* spp.	50	High-Moderate (50 to <70%)	500	Moderate (201 - 500)	1	sSM	0.008
27	*Gracilaria* spp.	80	Dense (70 to <90%)	500	Moderate (201 - 500)	1	sSM	0.020
28	Filamentous green algae	90	Complete (>=90%)	520	High (501 - 1450)	1	vsSM	0.868
29	*Ulva* spp.	60	High-Moderate (50 to <70%)	600	High (501 - 1450)	0	RF	0.120
30	*Ulva* spp.	80	Dense (70 to <90%)	600	High (501 - 1450)	0	RF CF fMS25	0.152
30	*Ulva* spp.	80	Dense (70 to <90%)	600	High (501 - 1450)	0	RF	0.010
31	Filamentous brown algae	80	Dense (70 to <90%)	640	High (501 - 1450)	0	sSM	1.424
32	Filamentous brown algae	70	Dense (70 to <90%)	640	High (501 - 1450)	1	sSM	1.959
32	*Gracilaria* spp.	80	Dense (70 to <90%)	700	High (501 - 1450)	1	vsSM	0.096
33	*Ulva* spp.	50	High-Moderate (50 to <70%)	700	High (501 - 1450)	0	sSM	0.036
34	*Ulva* spp.	80	Dense (70 to <90%)	800	High (501 - 1450)	0	GF	0.101
35	*Gracilaria* spp.	10	Sparse (10 to <30%)	800	High (501 - 1450)	1	sMS25	0.038
36	*Ulva* spp.	50	High-Moderate (50 to <70%)	800	High (501 - 1450)	0	fMS10	0.094
36	*Ulva* spp.	50	High-Moderate (50 to <70%)	800	High (501 - 1450)	0	fS	0.014
36	*Ulva* spp.	50	High-Moderate (50 to <70%)	800	High (501 - 1450)	0	mS	2.833
37	*Ulva* spp.	80	Dense (70 to <90%)	800	High (501 - 1450)	0	RF	0.042
38	Unspecified Macroalgae	50	High-Moderate (50 to <70%)	900	High (501 - 1450)	0	fMS10 BF	0.408
39	*Ulva* spp.	50	High-Moderate (50 to <70%)	1000	High (501 - 1450)	0	CKLE mS	0.103
39	*Ulva* spp.	50	High-Moderate (50 to <70%)	1000	High (501 - 1450)	0	fShS	0.606
39	*Ulva* spp.	50	High-Moderate (50 to <70%)	1000	High (501 - 1450)	0	CKLE fShS	0.080
40	Filamentous brown algae	25	Sparse (10 to <30%)	1000	High (501 - 1450)	0	vsSM	0.585
40	*Ulva* spp.	20	Sparse (10 to <30%)	1000	High (501 - 1450)	0	mS	0.102
41	Filamentous brown algae	80	Dense (70 to <90%)	1000	High (501 - 1450)	0	CF RF	0.169
42	*Ulva* spp.	90	Complete (>=90%)	1000	High (501 - 1450)	0	RF fS	0.007
42	*Ulva* spp.	90	Complete (>=90%)	1000	High (501 - 1450)	0	fMS10	0.022
42	*Vaucheria* sp.	90	Complete (>=90%)	1000	High (501 - 1450)	0	fMS10	0.010
43	*Ulva* spp.	80	Dense (70 to <90%)	1000	High (501 - 1450)	0	RF GF	0.037
43	*Gracilaria* spp.	80	Dense (70 to <90%)	1000	High (501 - 1450)	0	sSM	0.209
44	*Ulva* spp.	70	Dense (70 to <90%)	1000	High (501 - 1450)	0	GF CF	0.040
45	*Gracilaria* spp.	95	Complete (>=90%)	1200	High (501 - 1450)	1	vsSM	0.373
46	*Gracilaria* spp.	50	High-Moderate (50 to <70%)	1400	High (501 - 1450)	1	sSM	0.565
47	*Ulva* spp.	60	High-Moderate (50 to <70%)	1440	High (501 - 1450)	0	sMS10	0.356

Patch ID	Dominant Species	% Cover	Percent Cover Category	Biomass (g/m^2)	Biomass Category	Entrained*	Substrate	Area (ha)
48	Filamentous brown algae	100	Complete (>=90%)	1440	High (501 - 1450)	1	sSM	2.889
49	*Ulva* spp.	90	Complete (>=90%)	1500	Very high (>1450)	0	fMS10	0.061
49	*Ulva* spp.	90	Complete (>=90%)	1500	Very high (>1450)	0	RF	0.347
49	*Ulva* spp.	90	Complete (>=90%)	1500	Very high (>1450)	0	CF	0.115
50	*Ulva* spp.	80	Dense (70 to <90%)	1500	Very high (>1450)	0	RF	0.082
50	*Ulva* spp.	81	Dense (70 to <90%)	1520	Very high (>1450)	0	fMS10	0.841
50	*Ulva* spp.	80	Dense (70 to <90%)	1500	Very high (>1450)	0	fS	0.601
50	*Gracilaria* spp.	85	Dense (70 to <90%)	1500	Very high (>1450)	0	vsSM	1.073
51	Filamentous brown algae	50	High-Moderate (50 to <70%)	1500	Very high (>1450)	0	fS Shel	0.213
52	*Gracilaria* spp.	60	High-Moderate (50 to <70%)	1500	Very high (>1450)	0	sMS25	0.294
53	*Ulva* spp.	50	High-Moderate (50 to <70%)	1680	Very high (>1450)	0	sMS25	1.318
53	*Ulva* spp.	50	High-Moderate (50 to <70%)	1600	Very high (>1450)	0	Shel mS	0.171
54	*Gracilaria* spp.	75	Dense (70 to <90%)	1500	Very high (>1450)	1	sSM	4.195
54	*Gracilaria* spp.	80	Dense (70 to <90%)	1600	Very high (>1450)	1	fMS10 BF	0.260
55	Filamentous brown algae	100	Complete (>=90%)	1760	Very high (>1450)	1	sSM	2.180
55	*Gracilaria* spp.	90	Complete (>=90%)	1760	Very high (>1450)	1	vsSM	1.260
56	*Ulva* spp.	90	Complete (>=90%)	2000	Very high (>1450)	0	RF CF	0.124
56	Filamentous brown algae	65	High-Moderate (50 to <70%)	1960	Very high (>1450)	0	GF	0.052
57	*Gracilaria* spp.	90	Complete (>=90%)	2000	Very high (>1450)	1	sMS25	0.634
57	*Gracilaria* spp.	85	Dense (70 to <90%)	2000	Very high (>1450)	1	sSM	2.316
57	Filamentous brown algae	85	Dense (70 to <90%)	2000	Very high (>1450)	1	vsSM	2.005
57	*Gracilaria* spp.	81	Dense (70 to <90%)	1920	Very high (>1450)	1	sSM	0.635
58	*Gracilaria* spp.	80	Dense (70 to <90%)	2000	Very high (>1450)	1	sSM	0.448
58	*Gracilaria* spp.	80	Dense (70 to <90%)	2000	Very high (>1450)	1	sMS25	0.537
59	*Gracilaria* spp.	50	High-Moderate (50 to <70%)	2000	Very high (>1450)	1	vsSM	1.045
60	Filamentous brown algae	100	Complete (>=90%)	2000	Very high (>1450)	0	fS	0.058
60	*Ulva* spp.	100	Complete (>=90%)	2000	Very high (>1450)	0	fS	0.045
60	*Ulva* spp.	100	Complete (>=90%)	2000	Very high (>1450)	0	RF	0.164
61	Filamentous green algae	50	High-Moderate (50 to <70%)	2000	Very high (>1450)	0	fShS	0.526
61	Filamentous brown algae	65	High-Moderate (50 to <70%)	2000	Very high (>1450)	0	GF fMS10 Shel	0.113
61	Filamentous brown algae	50	High-Moderate (50 to <70%)	2000	Very high (>1450)	0	GF Shel fMS10	0.187
61	*Ulva* spp.	60	High-Moderate (50 to <70%)	2000	Very high (>1450)	0	mS	0.650
62	Filamentous green algae	70	Dense (70 to <90%)	2000	Very high (>1450)	0	fShS	0.106
62	Filamentous green algae	75	Dense (70 to <90%)	2000	Very high (>1450)	0	GF	0.258
62	*Ulva* spp.	75	Dense (70 to <90%)	2000	Very high (>1450)	0	sSM	0.541
63	Filamentous brown algae	20	Sparse (10 to <30%)	2000	Very high (>1450)	0	fMS10	1.244
64	Filamentous brown algae	100	Complete (>=90%)	10000	Very high (>1450)	0	RF GF	0.027
64	Filamentous brown algae	100	Complete (>=90%)	10000	Very high (>1450)	0	RF GF	0.051
65	*Gracilaria* spp.	100	Complete (>=90%)	10320	Very high (>1450)	1	sSM	9.434
65	*Gracilaria* spp.	100	Complete (>=90%)	11840	Very high (>1450)	1	vsSM	0.111
65	*Gracilaria* spp.	100	Complete (>=90%)	10000	Very high (>1450)	1	vsSM	1.731
66	Filamentous green algae	100	Complete (>=90%)	20000	Very high (>1450)	0	mS	0.334
67	Filamentous green algae	100	Complete (>=90%)	27040	Very high (>1450)	0	fS	0.075
68	*Gracilaria* spp.	100	Complete (>=90%)	9120	Very high (>1450)	1	vsSM	4.180
69	*Ulva* spp.	100	Complete (>=90%)	4000	Very high (>1450)	0	sMS25	0.217
69	Filamentous green algae	50	High-Moderate (50 to <70%)	4000	Very high (>1450)	0	fShS	0.582
70	Filamentous green algae	50	High-Moderate (50 to <70%)	4000	Very high (>1450)	0	fS	0.616
70	Filamentous green algae	50	High-Moderate (50 to <70%)	4000	Very high (>1450)	0	fShS	0.217
70	Filamentous green algae	50	High-Moderate (50 to <70%)	4000	Very high (>1450)	0	fShS	0.012
71	*Gracilaria* spp.	75	Dense (70 to <90%)	3000	Very high (>1450)	0	sMS25	0.779
71	Filamentous brown algae	90	Complete (>=90%)	4000	Very high (>1450)	0	fMS10 GF	0.058
72	*Gracilaria* spp.	100	Complete (>=90%)	4000	Very high (>1450)	1	fMS10	0.308
72	*Gracilaria* spp.	100	Complete (>=90%)	4000	Very high (>1450)	1	vsSM	1.572
73	*Gracilaria* spp.	100	Complete (>=90%)	3000	Very high (>1450)	0	sMS25	0.417
73	Filamentous brown algae	90	Complete (>=90%)	3000	Very high (>1450)	0	RF GF fS	0.203
73	Filamentous green algae	50	High-Moderate (50 to <70%)	3000	Very high (>1450)	0	fShS	0.188
74	Filamentous brown algae	100	Complete (>=90%)	2880	Very high (>1450)	1	sSM	5.681
74	Filamentous green algae	75	Dense (70 to <90%)	3000	Very high (>1450)	1	vsSM	0.786
75	Filamentous green algae	80	Dense (70 to <90%)	6000	Very high (>1450)	0	fShS	0.755
75	Filamentous green algae	90	Complete (>=90%)	6000	Very high (>1450)	0	fShS	0.436
76	*Gracilaria* spp.	80	Dense (70 to <90%)	5000	Very high (>1450)	1	sSM	1.645
76	*Gracilaria* spp.	98	Complete (>=90%)	5200	Very high (>1450)	1	vsSM	0.176
76	*Gracilaria* spp.	100	Complete (>=90%)	5000	Very high (>1450)	1	sSM	0.865
77	Filamentous brown algae	81	Dense (70 to <90%)	5000	Very high (>1450)	0	CF GF	0.112
77	Filamentous green algae	100	Complete (>=90%)	5000	Very high (>1450)	0	fS	0.305
77	Filamentous green algae	80	Dense (70 to <90%)	5000	Very high (>1450)	0	fShS	6.178
77	Filamentous green algae	100	Complete (>=90%)	5000	Very high (>1450)	0	RF	0.101
77	*Ulva* spp.	100	Complete (>=90%)	5000	Very high (>1450)	0	RF	0.418
78	*Gracilaria* spp.	100	Complete (>=90%)	6000	Very high (>1450)	1	vsSM	0.374
79	*Gracilaria* spp.	100	Complete (>=90%)	7000	Very high (>1450)	0	vsSM	0.257
80	Filamentous green algae	80	Dense (70 to <90%)	8000	Very high (>1450)	0	fShS	0.921
80	Filamentous green algae	90	Complete (>=90%)	8000	Very high (>1450)	0	sMS10	0.376
81	*Gracilaria* spp.	90	Complete (>=90%)	7520	Very high (>1450)	1	fMS10	0.080
82	*Gracilaria* spp.	95	Complete (>=90%)	6500	Very high (>1450)	1	vsSM	0.203
83	*Gracilaria* spp.	90	Complete (>=90%)	4160	Very high (>1450)	1	sSM	0.265
84	Filamentous green algae	75	Dense (70 to <90%)	4000	Very high (>1450)	0	fShS	0.901

Patch ID	Dominant Species	% Cover	Percent Cover Category	Biomass (g/m^2)	Biomass Category	Entrained*	Substrate	Area (ha)
85	*Gracilaria* spp.	80	Dense (70 to <90%)	2160	Very high (>1450)	0	sMS25	1.421
86	*Gracilaria* spp.	80	Dense (70 to <90%)	2500	Very high (>1450)	1	vsSM	0.485
87	*Gracilaria* spp.	90	Complete (>=90%)	2560	Very high (>1450)	1	sSM	0.106
88	Filamentous brown algae	100	Complete (>=90%)	2720	Very high (>1450)	1	sSM	2.270
89	*Gracilaria* spp.	95	Complete (>=90%)	2840	Very high (>1450)	1	vsSM	2.988
90	*Gracilaria* spp.	60	High-Moderate (50 to <70%)	3000	Very high (>1450)	1	sSM	0.088
91	*Gracilaria* spp.	97	Complete (>=90%)	3040	Very high (>1450)	1	sSM	3.337
92	*Gracilaria* spp.	95	Complete (>=90%)	3200	Very high (>1450)	1	vsSM	0.167
93	*Gracilaria* spp.	95	Complete (>=90%)	3440	Very high (>1450)	1	sSM	2.032
94	Filamentous brown algae	80	Dense (70 to <90%)	3500	Very high (>1450)	0	fMS25	0.231
95	*Gracilaria* spp.	100	Complete (>=90%)	2000	Very high (>1450)	1	sSM	0.389
95	*Gracilaria* spp.	100	Complete (>=90%)	2000	Very high (>1450)	1	vsSM	0.117
95	Filamentous brown algae	100	Complete (>=90%)	2080	Very high (>1450)	1	sSM	0.574
96	*Gracilaria* spp.	80	Dense (70 to <90%)	3600	Very high (>1450)	1	vsSM	0.245
97	Filamentous brown algae	100	Complete (>=90%)	3840	Very high (>1450)	0	RF	1.004
98	*Gracilaria* spp.	60	High-Moderate (50 to <70%)	4000	Very high (>1450)	1	sSM	0.603
98	*Gracilaria* spp.	55	High-Moderate (50 to <70%)	3600	Very high (>1450)	1	sMS25	0.049
99	*Gracilaria* spp.	80	Dense (70 to <90%)	4000	Very high (>1450)	0	sSM	0.649
100	*Gracilaria* spp.	95	Complete (>=90%)	4000	Very high (>1450)	1	sSM	0.220

December 2023 Metric	Face value	FEDS	Environmental Quality Class
% cover in AIH	17.4	0.552	Moderate
Average biomass (g/m^2) in AIH	78.8	0.842	High
Average biomass (g/m^2) in AA	288.6	0.541	Moderate
%entrained in AA	19.4	0.407	Moderate
Worst of AA (ha) and AA (% of AIH)		0.324	Poor
AA (ha)	157.3	0.324	Poor
AA (% of AIH)	27.3	0.530	Moderate
Survey EQR		0.533	'Fair'

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

December 2021 Metric	Face value	FEDS	Environmental Quality Class
% cover in AIH	15.3	0.594	Moderate
Average biomass (g/m^2) in AIH	333.3	0.511	Moderate
Average biomass (g/m^2) in AA	1560.9	0.198	Bad
%entrained in AA	38.8	0.275	Poor
Worst of AA (ha) and AA (% of AIH)		0.363	Poor
AA (ha)	127.7	0.363	Poor
AA (% of AIH)	21.4	0.564	Moderate
Survey EQR		0.388	'Poor'

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

December 2016 Metric	Face value	FEDS	Environmental Quality Class
% cover in AIH	5.0	0.801	High
Average biomass (g/m^2) in AIH	41.5	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	0.727	Good
Survey EQR		0.615	'Good'

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

APPENDIX 8. MACROFAUNA RAW DATA

Main group	Taxa	EG	1a	1b	2a	2b	3a	3b	Ba	Bb	4a	4b	5a	5b	6a	6b	Aa	Ab
Polychaeta	*Boccardia acus*	IV												9				
	Boccardia syrtis	II									2	2	3		1		64	15
	Boccardiella magniovata	III	4	6	1	1												
	Capitella cf. capitata	V	1	2	2	4			14	7	1	11					2	
	Exogoninae sp. 1	II												2				
	Heteromastus filiformis	IV													1	4		
	Lagis australis	III														1		
	Macroclymenella stewartensis	II											26	19	1	2	3	
	Magelona dakini	I												2				
	Microphthalmus riseri	II																1
	Microspio maori	I							7	3	132	144						1
	Paradoneis lyra	III											8	7				
	Perinereis vallata	III							1		4	1	3	2	2			
	Platynereis sp.	III														1	9	1
	Prionospio aucklandica	III											17	8	94	65	43	45
	Sabellidae	I	1															
	Scolecolepides benhami	IV									4	7			1	1		
	Scoloplos cylindrifer	I													2	2		
	Sphaerodoridae	II											4	3				1
Amphipoda	*Josephosella awa*	II	15	53	69	80	2		1						2			
	Paracalliope novizealandiae	I	15	9	118	162		1	30	30	2	4	20	21	60	208	12	17
	Paracorophium brisbanensis	IV		1	1	4												
	Paracorophium excavatum	IV	129	94	25	35	8	2	551	434	442	404			1		59	20
	Paracorophium lucasi	IV	3	4														
	Torridoharpinia hurleyi	I											11	11	2	9	5	9
	Waitangi brevirostris	II												1			17	1
Bivalvia	*Arthritica sp. 5*	III			15	10			14	7	15	15	17	3	5	10	3	
	Austrovenus stutchburyi	II										1		5	4	2	2	1
	Lasaea parengaensis	II											3	2			189	148
	Legrandina turneri	-										2		1			56	44
	Macomona liliana	II											1	2			1	
	Nucula nitidula	I											3	3				
	Paphies australis	II									2	2						
Gastropoda	*Cominella glandiformis*	III								2								
	Diloma subrostratum	II													1			
	Micrelenchus huttonii	I													4	3		
	Notoacmea scapha	II													11	5		
	Potamopyrgus estuarinus	IV		2	2		1											
	Turbonilla sp.	I													1			
Decapoda	*Halicarcinus whitei*	III													5			
	Hemiplax hirtipes	III	3												1	1		
Isopoda	*Exosphaeroma planulum*	V				1												
	Omonana sp.	-	1		2													
Anthozoa	*Edwardsia sp.*	II									9	20	12	8			12	6
Chironomidae	*Chironomidae*	III	28	36	59	84	8	36	1									
Copepoda	*Copepoda*	II			1		1							1		1		
Cumacea	*Colurostylis lemurum*	II									1		14	13			13	12
Mysida	*Mysida*	II	3	1	3	19	39	1										
Nemertea	*Nemertea sp. 2*	III	1	2							12	26						
Oligochaeta	*Oligochaeta*	V	372	729	156	286	217	40	26	20	8		108	70	1	49	3	1
Ostracoda	*Ostracoda*	I														1		
Stomatopoda	*Heterosquilla tricarinata*	II															1	

For the environment
Mō te taiao


SALT
ECOLOGY